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An evaluation of phosphorus export from four urban land uses during summer rainfall-runoff events in the Laurel Creek watershed

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AN EVALUATION OF PHOSPHORUS EXPORT FROM FOUR URBAN LAND USES DURING SUMMER RAINFALL-RUNOFF EVENTS IN THE LAUREL CREEK WATERSHED

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THESIS

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ABSTRACT

Cultural eutrophication, resulting from anthropogenic inputs of nutrients, such as phosphorus, can be detrimental to aquatic ecosystems. The effectiveness of recent phosphorus abatement programs, focused on point source inputs such as municipal and industrial effluent, has brought attention to the reduction of non-point sources, such as urban runoff.

Target phosphate loads for the Great Lakes, set by the International Joint Commission, are deemed unattainable, without phosphorus reduction from non-point sources (Yaksich and Rumer, 1980), and it is with this knowledge that this thesis is undertaken.

Analysis of phosphate export data from areas of different urban land uses, indicates that residential land contributes the greatest phosphate yield on a per unit area basis, and should therefore be the focus of urban abatement programs.

Comparison of urban and rural phosphate export data, illustrates the need to consider urban runoff a major polluting factor, for any watershed abatement programs. Similarly, comparison of baseflow and stormflow phosphate export, clearly shows the necessity of monitoring stormflow export for annual phosphate assessments.

ACKNOWLEDGEMENTS

Seven years of post-secondary education and my parents still love me. I guess that puts them on the top of my list for 'thank-you's'. Hopefully, in the future, I can return the favour, financially and emotionally.

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CHAPTER 1

INTRODUCTION

1.1 Statement of the Problem

The trophic state of a natural body of water is largely a result of nutrient availability to algae and other aquatic plants. Change in the trophic state of a lake is a natural occurrence. Anthropogenic inputs of nutrients, notably phosphorus (P), to aquatic systems are reported to accelerate the eutrophication process (Vollenweider, 1968; McGriff, 1972; Sager and Wiersma, 1975; Free and Mulamoottil, 1983). Cahill et al (1974), report that natural eutrophication in lakes may extend through hundreds of years, but subjected to unnaturally high inputs, this period of time could be reduced to only a few years. Accelerated eutrophication can cause increased aquatic growth, resulting in a general deterioration of a lake's ecosystem (Yaksich and Rumer, 1980).

Anthropogenic sources of phosphorus previously identified, include non-point sources such as runoff from ag 'cultural and urban land, and point source inputs such as munic:pal wastewater and industrial discharges (Sager and Wiersma, 1975). Most phosphorus reduction programs in the past have focused on point source inputs as they are easily monitored and controlled (Kleusener and Lee, 1974). However, with the success of these programs, the influence of diffuse pollution sources, such as urban runoff, must be investigated (Whipple et al., 1974). Much has been written about urban runoff as a source of phosphorus to receiving waters, however less is known about runoff quality with respect to differing urban land uses (Kleusener and Lee, 1974).

Conflicting results have arisen from previous investigations of phosphorus inputs in runoff from different urban land types. Miller and Mattraw (1982) found residential land contributed far more phosphorus (10.08g/ha/day) than commercial (1.90g/ha/day) or highway (1.79g/ha/day) land uses. Prior to this study, Sartor and Boyd (1972) found little difference in phosphorus contribution between residential and commercial land uses. Sartor and Boyd (1972) collected street contaminants from various land uses and found total phosphorus (TP) strengths of 0.113% for residential land and 0.103% for commercial land. Strength being defined as the amount of TP contained in the dry solids collected from the street surface; that is, 0.10% would be 1.0g of TP in 1 kg of sample. In order to improve cost-effective phosphorus abatement programs, a better understanding of phosphorus inputs from urban runoff is necessary.

This chapter reviews some of the literature pertaining to phosphorus inputs from urban runoff, including; phosphorus forms and bioavailability, point and non-point sources, urban sediment sources, urban runoff, land use, and previous studies.

1.2 Literature Review

Cultural eutrophication, which is the overproduction of aquatic plant life prompted by unnaturally high anthropogenic nutrient (phosphorus and nitrogen) inputs, has been recognized as a serious water quality problem for many years (International Joint Commission, 1980). The advanced trophic state of Lake Erie in the late 1960's is a prime example of man's ability to disrupt the natural environment by excessive nutrient loading.

Phosphorus is identified as the main cause of excessive algal growth because it is usually the limiting nutrient which controls the growth of plants in aquatic ecosystems (Bird, 1985). Most nutrients are available to plant growth in excess of the plant's need. Phosphorus is naturally present in quantities close to that required by plants for growth. Thus if phosphorus is used to the point of exhaustion for plant growth it will eventually limit this growth (Stoker and Seager, 1976). To reduce eutrophication rates in any aquatic system, phosphorus inputs must be reduced.

In 1972, the Great Lakes Water Quality Agreement recognized the need to control nutrient inputs to the Great Lakes and thus retard the overall rate of eutrophication. Much success has been achieved from phosphorus reduction programs incorporated since 1972 (International Joint Commission, 1980). However, phosphorus inputs to the Great Lakes are still greater than target loads, set by the

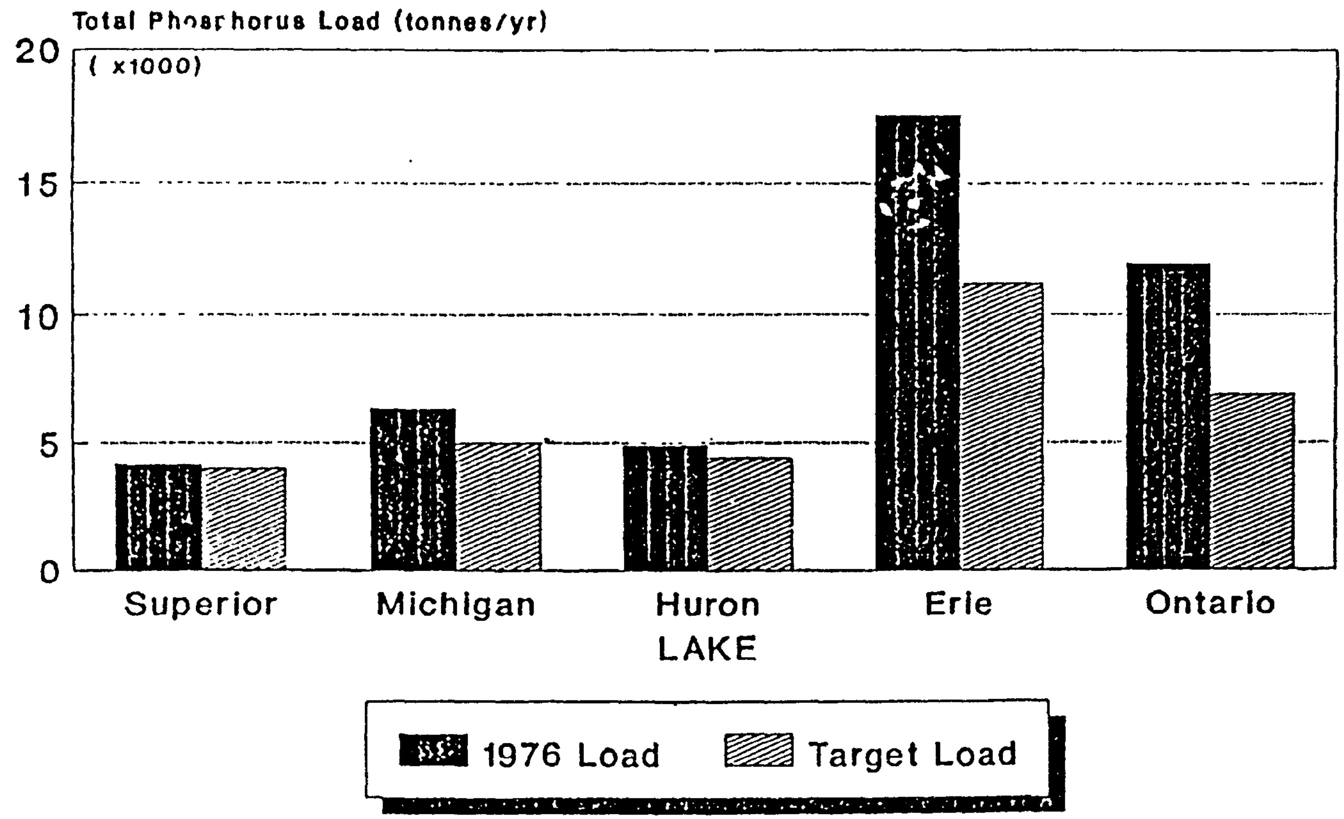
International Joint Commission, (IJC) considered necessary to rejuvenate the lakes (see Fig.1.1). The Pollution from Land Use Activities Reference Group (PLUARG) of the IJC estimate that about 50% of the Lake Erie total phosphorus input originates from diffuse (non-point) source tributary loads, (Dorich et al, 1984). In order to meet phosphorus target loads for the Great Lakes, this diffuse source must be reduced.

1.2.1 Phosphorus Forms and Bioavailability

In general, there are two important fractions of phosphorus found in natural waters; dissolved and particulate. These fractions can be further subdivided into: organic, inorganic and condensed fractions (see Table 1.1). Condensed phosphorus is not found naturally in minerals, it is found in all plants and animals where it is synthesized enzymatically and constitutes a part of the polyphosphate pool (Stumm, 1970). Pyrophosphates, tripolyphosphates and trimetaphosphates are some of the more common condensed phosphates. Dissolved phosphorus is defined as that fraction that is less than .45 um, and is considered biologically available, and particulate phosphorus is that fraction greater than .45 um, and is considered only partially bioavailable.

Biologically available phosphorus (BAP) is that portion of the total phosphorus that is available for uptake by aquatic life. The IJC (1980), suggest that bioavailability generally implies that the

Figure 1.1
1976 Phosphorus loads and recommended target loads



Source: (PLUARG, 1978)

TABLE 1.1

Summary of Phosphorus Forms
Present in Aquatic Systems

Particulate	Dissolved
Inorganic P: NAIP; P adsorbed on metal hydrous oxides (Fe,Al), Fe and Al-P minerals, non-apatite Ca-P AIP, Ca-P mineral	Inorganic P; DRP, $H_2PO_4^-$ and HPO_4^{-2}
Organic P: nucleic acids, phospholipids, inositol phosphates, other	Organic P: DOP, P-O-C bonds
Condensed P	Condensed P: DCP, P-O-P bonds

NAIP = Non-apatite inorganic phosphorus
AIP = Apatite inorganic phosphorus

SOURCE: Sonzogni et al (1982)

phosphorus can be incorporated by aquatic life with reasonable speed: usually considered a single growing season. Bird (1985) emphasizes that the process of eutrophication is not necessarily controlled by the amount of total phosphorus, but that amount which is bioavailable. Reports on the many forms of phosphorus and their respective bioavailabilities are at best incomplete (see Table 1.2) and a cause for some debate due to the complex physical, chemical and biological processes which govern phosphorus bioavailability (IJC, 1980).

Soluble or dissolved inorganic forms of phosphorus, including orthophosphates, those phosphates that are organically bound, are generally considered to be readily available for biotic uptake. Soluble organic P, particulate P and condensed P may become available through a conversion to soluble inorganic phosphorus. This conversion occurs through instream processes such as hydrolysis, biological mineralization, dissolution or desorption (Sonzogni et al, 1982). The rate of conversion is dependent on several factors including; temperature, concentration of dissolved reactive phosphorus (DRP) in the receiving water, hydrology and mixing dynamics, size and density of the particles, the forms of the phosphorus compounds, productivity of the ecosystem, and the sedimentation rate of the sediment-bound phosphorus (Bird, 1985).

In order to improve cost-effective management of phosphorous reductions to the Great Lakes, the bioavailable fraction of the

TABLE 1.2

INORGANIC AND ORGANIC FORMS OF PHOSPHORUS AND THEIR RELATIVE SOLUBILITIES

BIOLOGICALLY AVAILABLE INORGANIC FORMS OF PHOSPHORUS	SOLUBILITY
Soluble Orthophosphates	Very Soluble
Condensed Phosphates	
Pryophophate	6.70g/100cc at 25°C ($Na_4P_2O_7$)
Tripolyphospate	20g/100cc at 25°C ($Na_5P_3O_{10}$)
Trimetaphosphate	very soluble
Biologically Unavailable Mineral Forms of Phosphorus	
Hydroxyapatite	practically insoluble
Fluorapatite	no information
Carbonate Fluorapatite	no information
Phosphate Minerals With Varying Availability	
Brushite	0.0316g/100cc at 25°C
Bobierite	insoluble
Variscite, stringite	insoluble, slightly soluble
Wavelitte	practically insoluble
Clay-phosphate	no information
Organic Phosphates With Varying Availability	
Bacterial cell material	poor solubility
Plankton material	no information

Source: IJC (1980)

total phosphorus load should be the focus of future research. Identifying the source of this fraction of the total phosphorus load could assist decision makers as to what abatement measures would be most cost-effective. DePinto et al (1981), and Sonzogni et al (1982), state that since a large percentage of the phosphorus load to the Great Lakes may be in an unavailable form, phosphorus bioavailability is critical when considering cost-effectiveness of control methods.

1.2.2 Point and Non-Point Inputs

Water is transported to receiving waters by one of two routes; point and non-point inputs. Point sources include industrial effluent, municipal sewage treatment plant effluent and sewer overflows (Bird, 1985). Phosphorus loads in point source inputs are largely dissolved and are thus readily available for biotic uptake (IJC, 1983). Nutrient inputs from point sources are generally high in concentration and low in volume and are relatively constant throughout the year (Bird, 1985).

Conversely, non-point sources, such as surface runoff, agricultural inputs, forests and groundwater seepage, are often associated with high discharge events such as rainstorms and springmelt. Non-point sources, also referred to as diffuse sources, are generally high in particulate matter (Bryan, 1972), which may facilitate the transport of phosphorus. That particulate phosphorus is less bioavailable than soluble phosphorus, has created some controversy as to its relative importance (IJC, 1983). However, as noted above, elimination of all point source phosphorus loads would not reverse the eutrophication process in the Great Lakes, and this clearly demonstrates the importance of any non-point phosphorus source. Yaksich and Rumer (1980), found that a reduction in diffuse source loadings of total phosphorus is necessary to achieve the objective of 11,000 tonnes of total phosphorus per year, a reduction of approximately 9,000 tonnes per year for Lake Erie. Whipple et al, (1974), note that once secondary sewage treatment is widespread in developing urban and suburban areas, diffuse sources will account for more than half of a stream's pollution load.

1.2.3. Urban Sediment

In terms of water quality, urban runoff is dissimilar from the precipitation that produces it (Sartor, et al, 1974). This results from the addition of natural and anthropogenic inputs of organic and inorganic matter to the precipitation after it reaches the ground. As phosphorus has an affinity for particulate matter, urban sediment can transport pollutants in urban runoff, (Field, 1973). This sediment can collect on city streets for lengthy periods of time before being washed, swept or blown away by nature or humans. It is known that particulate organic and inorganic matter is a source of phosphorus to urban runoff. Kleusener and Lee (1974), note that there are many sources of urban sediment, some of which are leaves, atmospheric (dry) deposition or dustfall, lawn fertilizers, fossil fuel combustion products, animal faeces, and eroded soil. In Chicago, Heaney and Sullivan (1971), estimate that 70% of urban street dust and dirt can be attributed to dustfall.

Sediment that accumulates in urban areas may not become a factor in the contamination of receiving waters. A fraction of the urban sediment may not be transported to sewer inlets during precipitation events. Due to several possible conditions this sediment is not physically available. The runoff may not have sufficient energy to transport the particulate matter to receiving waters, the particulate matter may be removed by wind and deposited where it is not accessible to urban runoff, or it may be removed by street cleaning.

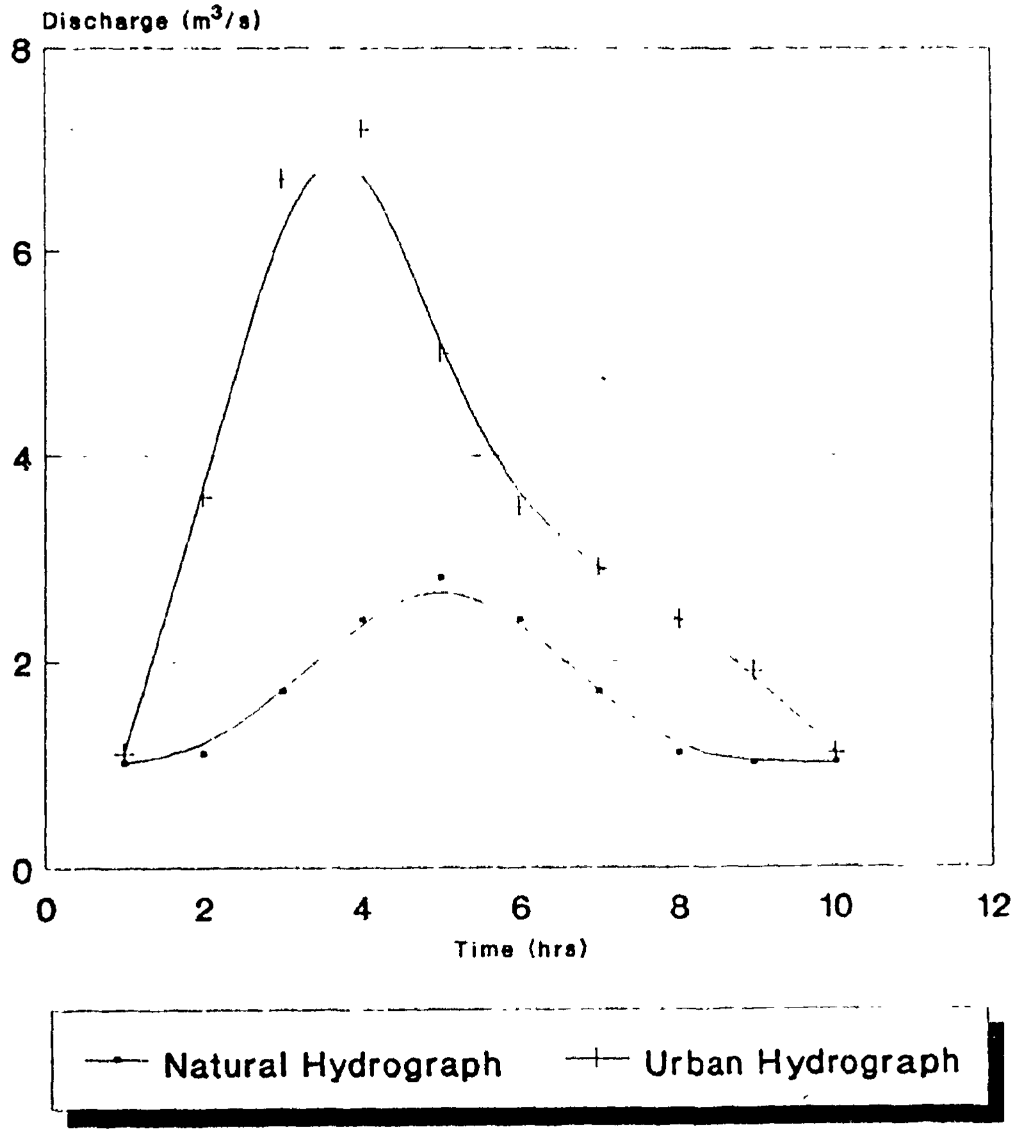
1.2.4. Urban Runoff

The effects of urbanization on stream hydrographs is well documented; (Graf, 1975; Okuda, 1975; Yoshino, 1975; and Douglas, 1985). Much of the study of urban hydrology has focused on the effects of urbanization on flooding. The importance of urban hydrology for this study, is the decrease in lag time and concomitant increase in peak discharge, which occurs with an increase in impermeable ground surface and routing through storm sewers. Lag time is defined here as the time from peak rainfall to the time of the corresponding peak on the urban runoff hydrograph (Ikuse, 1975). This runoff travels quickly through storm sewers to receiving waters, resulting in reduced lag times compared to natural lag times. Ikuse et al, (1975) state that the lag time in an urbanized watershed may be reduced to one quarter of that of non-urbanized watersheds. Similarily, Anderson (1970), found the reduction in lag time of an urbanized basin to be 10-25% of its natural basin value.

This reduction of lag time is important when considering phosphate export from urban areas. Rainwater runoff travelling over impervious areas transports particulate matter to receiving tributaries quite rapidly, resulting in a sudden input of water with a high concentration of phosphorus. The reduction in lag time, combined with an increase in peak discharge can create very high phosphate loads in a short period of time.

By comparing a hypothetical storm hydrograph of a natural watershed and a predominantly urban watershed, the resulting increase in phosphorus export can be explained, (Figure 1.2). With 100% of the area being permeable, the initial source of water to the surface water system is groundwater flow, if rainfall intensity exceeds infiltration and soil saturation occurs, a second source of water, overland flow, may become available. This hydrological situation brings about a slow rise in the hydrograph as compared to the urban hydrograph, (Figure 1.2). The phosphorus concentration of

Figure 1.2
Comparison of a Natural and an
Urban Watershed Storm Hydrograph



Source: Gray and Male (1981)

the groundwater is presumably at natural levels. the increase in phosphorus export during storms is therefore solely the result of increased discharge.

Figure 1.2 also shows a hypothetical urban storm hydrograph, with a rapidly increasing hydrograph. This runoff, contaminated by urban street dirt, does not undergo natural filtration in the soil system thereby resulting in high phosphorus concentrations in the urban runoff. Thus urban watersheds can be expected to export greater phosphate loads than natural watersheds.

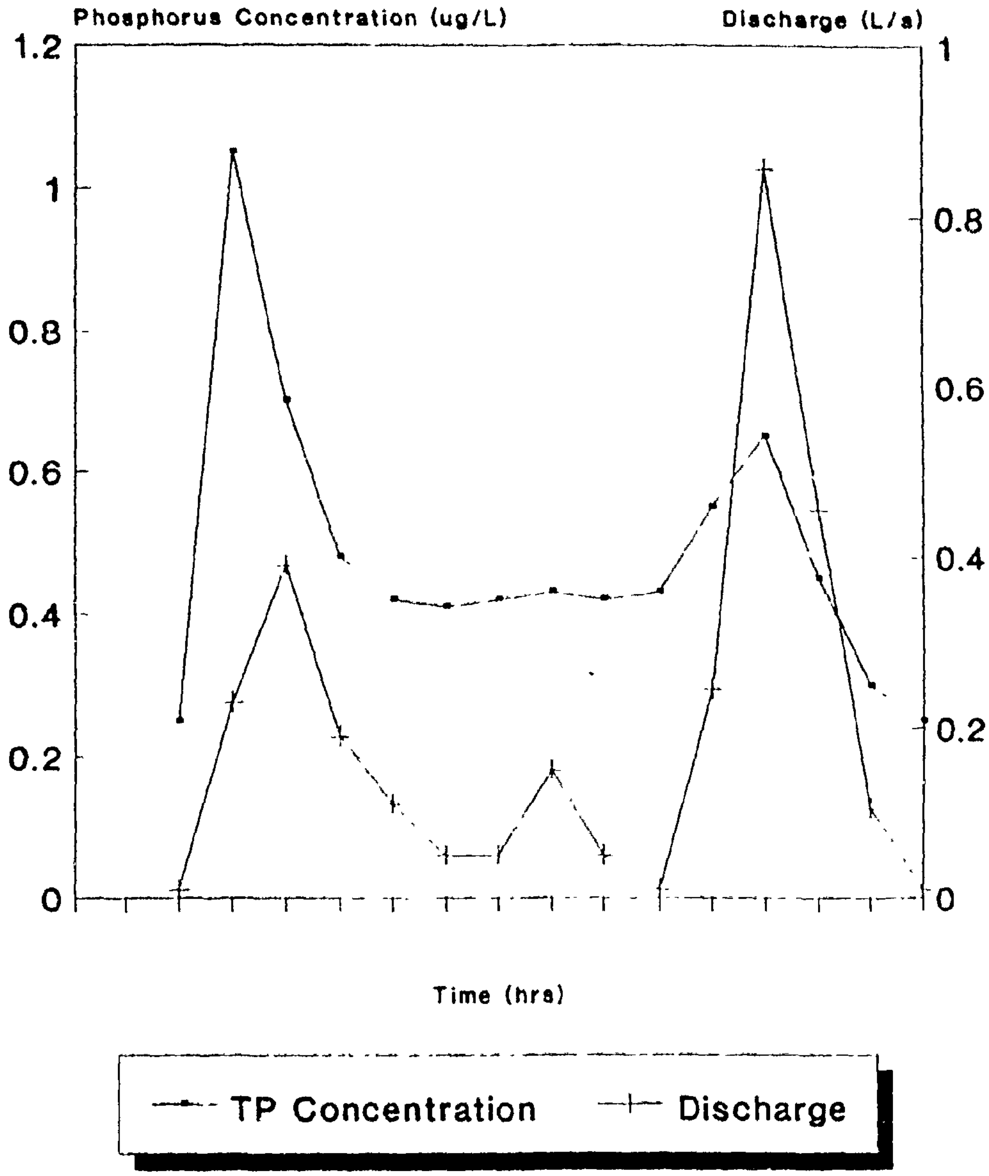
Government agencies, responsible for monitoring annual phosphorus export, are likely to sample on a regular basis (e.g., 1 sample every two weeks). This method may result in samples only being taken during baseflow, thereby missing urban runoff and stormflow contributions.

According to Whipple and Hunter (1977), phosphorus export is not adequately represented by monitoring of base flow conditions alone. The concentration of total phosphorus increases markedly during heavy rainfalls, and consequently, the storm loadings are extremely important. This is illustrated graphically in Fig. 1.3.

1.2.5. Land Use

In order to understand the nature of phosphorus from urban runoff, several authors have examined variations in phosphate export from different land uses. (Kleusener and Lee, 1974; Sager and

Figure 1.3
Phosphorus Concentration in Urban Runoff



Source: Kleusener and Lee (1974)

Wiersma, 1975; and Miller and Mattraw, 1982).

It appears that land use within any particular drainage basin is a determining factor in phosphorus loadings. Most previous studies which detail phosphorus and urban areas examine land use (i.e., commercial, residential, industrial) and their respective phosphorus export. Fewer studies have focused on the relationship between the degree of imperviousness of an area and phosphate export. McGriff (1972), states that the percentage of urban land that becomes impervious is a function of land use pattern. For example, commercial land may be more impervious than industrial land which may be more impervious than residential land. Consequently, this study will concentrate on phosphate export from areas of differing permeability.

1.2.6 Previous Studies

Weibel et al. (1964), carried out one of the first studies of pollution in urban runoff. They found dissolved reactive phosphorus (DRP), concentrations of urban runoff averaged 0.36mg/L. This is well above Sawyer's suggested level of 0.01mg/L of DRP for algal nuisance conditions in lakes, (Sawyer, 1947). The Ontario Ministry of the Environment has set a guideline for surface waters of 0.03 mg/L. Weibel et al (1964), concluded that urban storm runoff cannot be neglected in considering waste loadings from urban sources.

Whipple et al. (1974), reported urban stormwater quality ranging from 0.58mg/L to 1.7mg/L. Ellis (1977), concluded that urban storm water discharges are normally no better, and often worse, than secondary sewage treatment effluent. This statement suggests that reduction of phosphorus loads from urban runoff may be more useful than implimentation of tertiary treatment plants.

In order to achieve phosphorus target loads, for surface waters, reduction of biologically available phosphorus (BAP), from non-point sources is recognized as a necessity. Gregor and Johnson (1980), state that to reach the phosphorus target loads for the Great Lakes, non-point source controls will be required. The IJC (1983), reports that even with complete elimination of phosphorus from point sources, the target load reductions, set to be reviewed in 1988, would not be met. One diffuse source that requires further investigation is phosphorus export during storm events from different urban land uses.

1.3 Study Objectives

In order to attain a better understanding of phosphorus export from urban areas during summer rainfall events, the following research objectives were undertaken:

1. Determine the precipitation phosphate (DRP and TP) load to an urban area during summer rainfall events.

2. Determine and evaluate urban runoff phosphate export from areas of differing surface permeability.

3. Determine and compare summer stream base flow and high discharge event phosphorus export.

4. Compare phosphate runoff yields from urban areas to agricultural areas.

CHAPTER 2

METHODOLOGY

2.1 INTRODUCTION

Urban runoff has been identified as one source of phosphorus to aquatic ecosystems, which may result in excessive primary production. In order to improve our understanding of the spatial variation of phosphorus inputs from urban areas and their relative significance on water quality, the following sampling programs were carried out: 1. examination of base flow phosphorus export in an urban environment, and 2. examination of phosphorus inputs during storm events from four distinguishable diffuse sources which include: runoff from residential land, commercial land, a transportation route, and a parking lot.

2.2 Study Site

Laurel Creek, a small tributary of the Grand River, is located in Southwestern Ontario, in the City of Waterloo, (Fig. 2.1). The Grand River is a major source of phosphorus to Lake Erie, (Ostry, 1982).

The Laurel Creek watershed drains an area of 76.7 km^2 and empties into the Grand River at the Village of Bridgeport, $80^0 30'$ W - $43^0 30'$ N. Approximately 48% of the basin is rural and the remaining

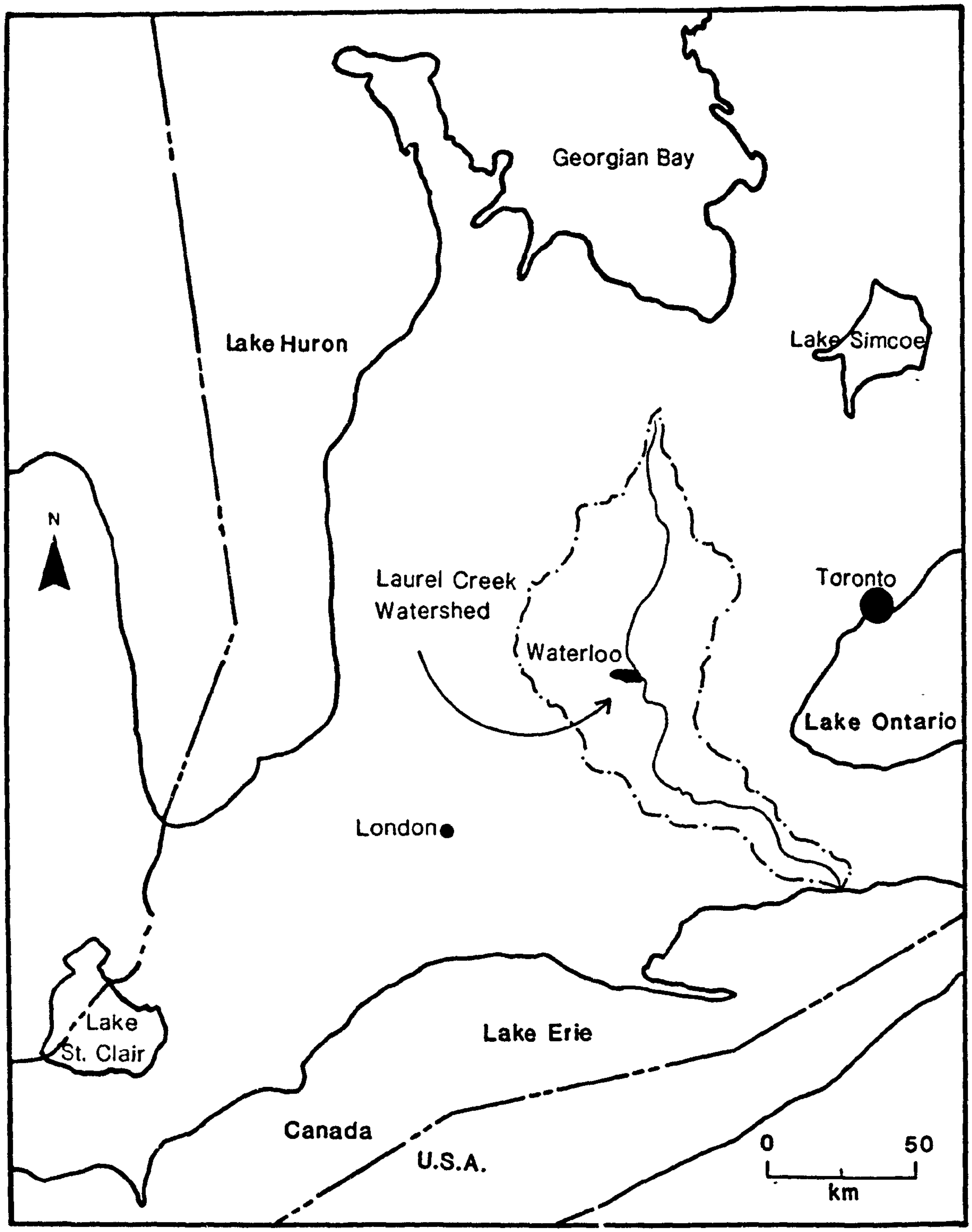


FIGURE 2.1 Location Map of the Laurel Creek Watershed

52% is urban. The Laurel Creek watershed contains ten sub-watersheds and two tributaries: Forewell and Clair, (Fig. 2.2). The Clair Creek watershed is 13.5 km^2, and consists largely of new residential land. The catchment area is partially agricultural at the western edge which is continuously being replaced by new residential subdivisions. Presently 20% of the watershed is rural and the rest urban, predominantly residential.

Forwell Creek drains 8.9 km^2 of predominantly new residential land, (40%), and industrial land, (40%), and a small area of commercial land, (5%). Openland in the east of the Forewell Creek watershed has steadily been replaced by new commercial and residential development in the last fifteen years, leaving about 15% of the watershed undeveloped.

Laurel Creek runs west to east, starting in a rural environment in the upper reaches and then enters and crosses the City of Waterloo in the lower reaches. The drainage area west of the Laurel Creek Reservoir (Fig. 2.3), is approximately 36 km^2 and consists of mostly rural land, the majority of which is used for agriculture. The soils in this area are generally sandy and well drained, (Grand River Conservation Authority, 1987).

The middle portion of the drainage basin, 23 km^2, between the Laurel Creek Reservoir and Silver Lake, and including the Clair Creek watershed, drains a large amount of institutional land, including the University of Waterloo and Wilfrid Laurier University,

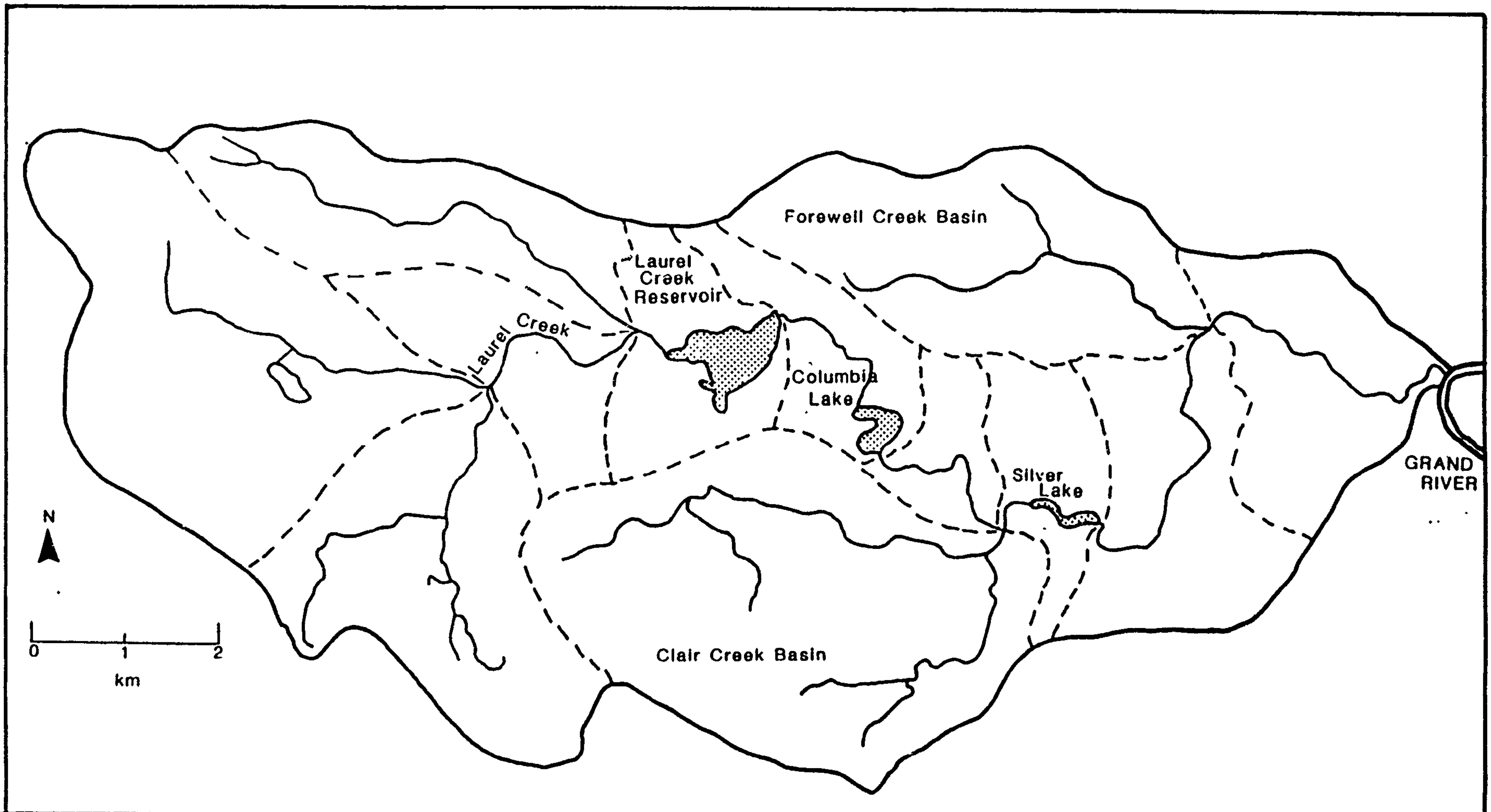


FIGURE 2.2 Laurel · Creek Watershed

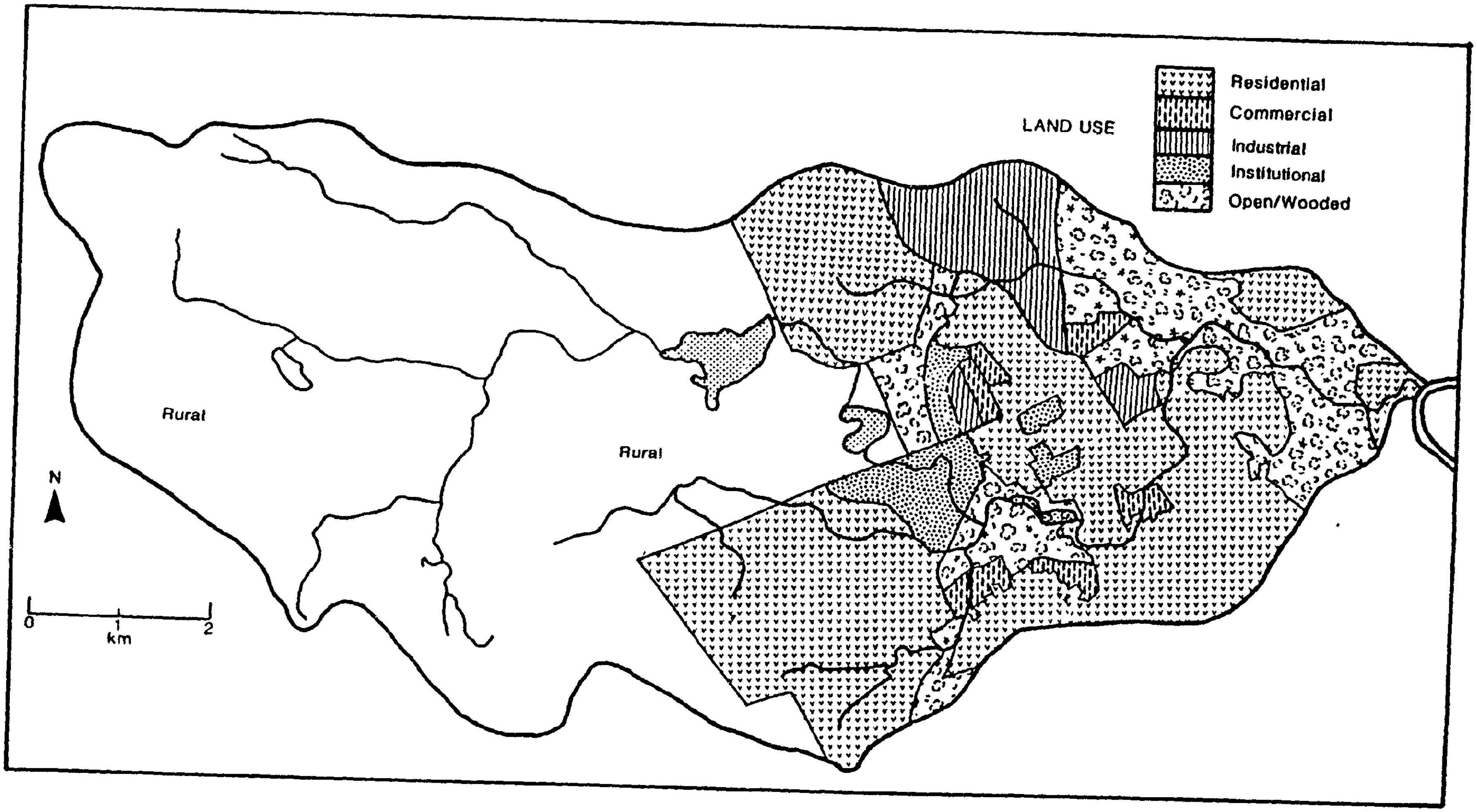


FIGURE 2.3 Land Use in the Laurel Creek Watershed

and residential land. The lower reaches of the Laurel Creek basin, from Silver lake to the mouth, 17 km^2, and including the Forwell Creek watershed are comprised of residential land (50%), open land (25%), industrial land (15%), and commercial land (5%), (Fig. 2.3).

Laurel Creek was chosen as a study area because of accessibility and a wide variety of land uses, found within the basin, typical of Southern Ontario drainage basins.

2.3 Sample Collection (Base Flow)

In order to complete the study objectives, two separate sampling programs were employed, one during base flow and one during high discharge events. Base flow samples were collected on fifteen occasions between June 10th and October 6th, 1988. Eleven sites along Laurel Creek were chosen for their accessibility and to include areas of hydrologic change in the creek system. Figure 2.4 illustrates the location of the eleven sites on Laurel Creek.

Site 1 was chosen to represent the creek upstream of the urban area, thus providing data on the phosphorus regime without any urban runoff affecting the creek. The phosphorus levels at this site are not considered to be natural as runoff from the agricultural land would alter the natural levels.

Site 2 is located 100m downstream of the Laurel Creek Reservoir. This site marks the start of the urban area of the Laurel Creek basin. This site was chosen to monitor the change in

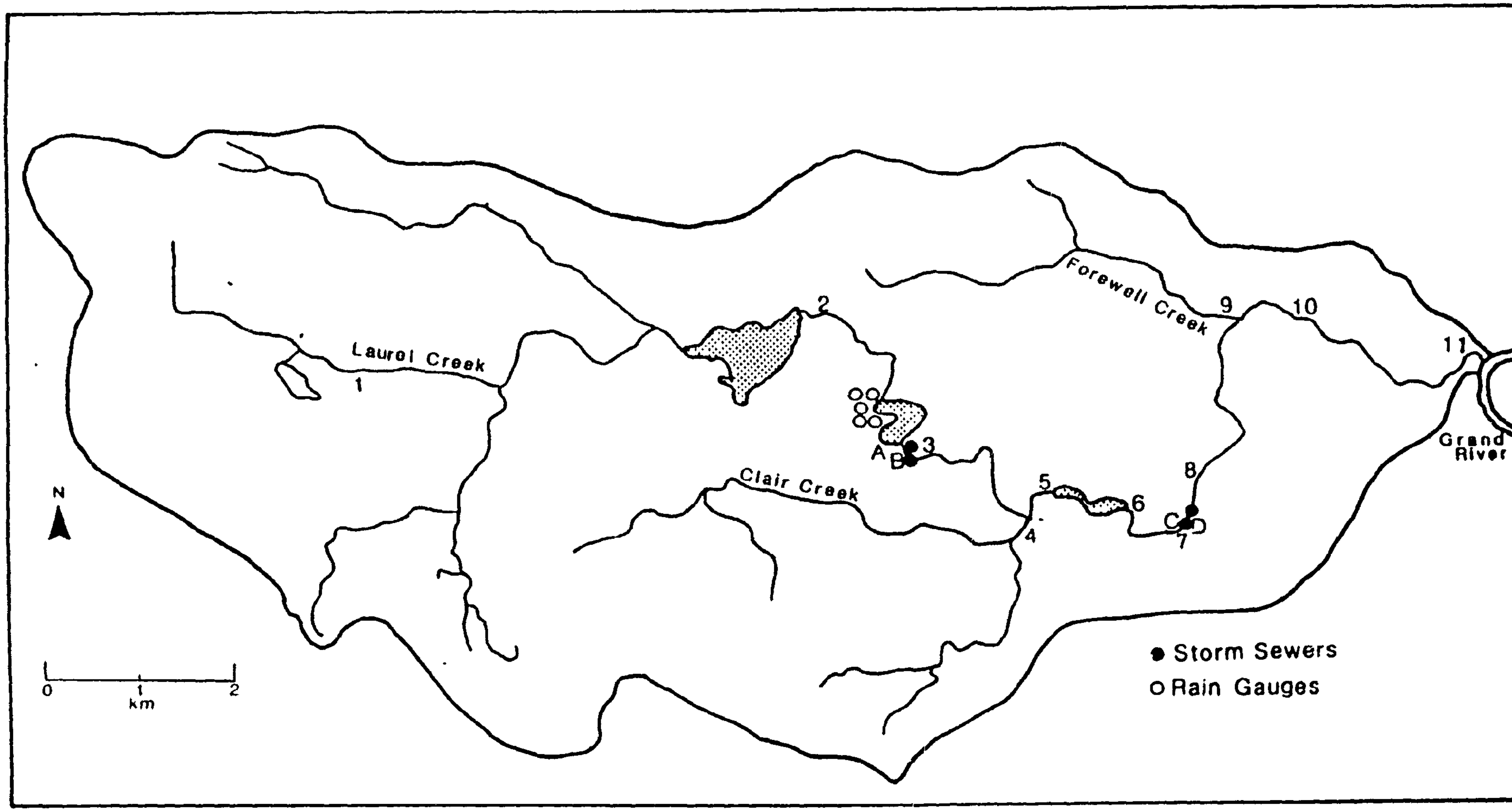


FIGURE 2.4 Sample Collection Sites

phosphorus levels below the reservoir. A bridge crossing the creek at this location allowed for an accessible stage board to be set up for discharge measurements.

Site 3 is located 30m downstream of the Columbia Lake dam. This site was chosen to monitor the effect of this reservoir on phosphorus concentrations.

Site 4 is located on Clair Creek, 20m upstream of the confluence with Laurel Creek. This site was sampled to calculate the phosphorus export to Laurel Creek from the Clair Creek watershed.

Site 5 is located 100m upstream of Silver Lake and Site 6 is located at the downstream end of Silver Lake. These sites were sampled to monitor change in phosphate concentration in the stream, resulting from this impoundment.

Silver Lake, at site 6, drains over a dam into an underground culvert, which resurfaces 1 km downstream at site 7. Legally no industries discharge into Laurel Creek while it runs underground. Samples were collected at site 7 to determine if in fact phosphate concentration increased as the stream runs through this culvert.

Site 8 is located at the Weber Street bridge which is also the location of a permanent stage/discharge recorder operated by the Water Survey of Canada (Station #02GA024).

Site 9 is located on Forewell Creek about 50m upstream from the confluence with Laurel Creek. This tributary was sampled to calculate the phosphorus export to Laurel Creek from the Forewell Creek watershed.

Site 10 is located on Laurel Creek 100m downstream of Waterloo's sewage treatment plant. Although the plant discharges directly to the Grand River, and not Laurel Creek, site 10 was sampled to monitor possible seepage from the treatment plant.

The final site, 11, is located 100m upstream from the confluence of Laurel Creek with the Grand River. The best place for measuring discharge is at this site, as the river starts to mix with the creek below this point.

2.3.1 Water Samples

At each of the eleven sample sites, (Fig. 2.4), a DH-48 depth integrating suspended sediment sampler was used for sample collection. Samples were collected in 500 ml Nalgene bottles. From each sample, 100 ml was immediately transferred into a 125 ml pre-acidified (with 1 ml H_2SO_4), glass bottle for total phosphorus analysis. Another 25 ml was transferred into a 25 ml acid washed (rinsed with distilled water) glass bottle, for dissolved reactive phosphorus (DRP) analysis. The samples for DRP analysis were stored in a cooler at approximately $2\,^{\circ}C$ to reduce ingestion by aquatic organisms before analysis. Dissolved reactive phosphorus determination was carried out within 24 hours of sample collection.

This sampling program was carried out to determine the average daily phosphorus export for the five month period (June 1 - Oct. 31).

2.3.2 Phosphate Export

To obtain a phosphorus export value, two variables, discharge and phosphorus concentration, are needed. Stage boards were set up at sites 2,4,9 and 11 (Fig. 2.4), and a stream discharge rating curve was established for each site before the chemistry sampling program was initiated. Discharge was calculated by measuring velocity, with a Marsh-McBirney model 201D portable water current meter, and multiplying it by the cross-sectional area of flow determined by on site measurements (see Equation 2.1.). Velocity was measured at 15, 30, or 50 cm intervals across the creek, the frequency of measurement being a function of the width of the stream. At each interval, velocity was measured at 0.6 depth, from the surface. According to Gregory and Walling (1973), with depths of less than 60 cm, the velocity at 0.6 depth is used to represent the mean velocity:

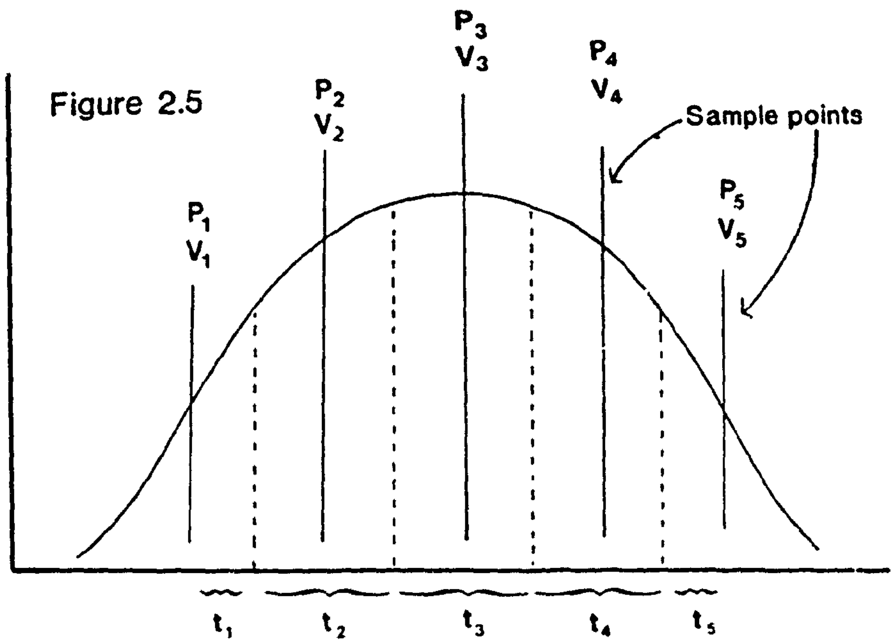
$$Q = V \cdot A \tag{2.1}$$

where: Q = discharge (m^3/s)

V = velocity (m/s)

A = cross-sectional area of flow (m^2).

For each site, approximately 15 discharge values were plotted on graph paper using linear coordinates against their respective stage values to create a rating curve for each site. Thus, stage readings taken during sample collection were later converted to discharge. Phosphorus export was then calculated as follows:



$$V = Q * t \tag{2.2a}$$

$$Ptp = \sum_{i=1}^{n}(V_i\,[TP]_i) \tag{2.2b}$$

$$Pdrp = \sum_{i=1}^{n}(V_i\,[DRP]_i) \tag{2.2c}$$

where:
- V = volume (m^3)
- Q = discharge (m^3/s)
- t = time (s)
- Ptp = total phosphorus load (mg)
- Pdrp = dissolved reactive phosphorus load (mg)
- [TP] = TP concentration (mg/m^3)
- [DRP] = DRP concentration (mg/m^3)

For each time segment of the hydrograph (Figure 2.5), the discharge and phosphorus concentration samples were used to calculate a load. If five samples were taken throughout the hydrograph, five separate loads were calculated. These loads were then summed (eq. 2.2b and 2.2c) to give a total phosphorus load for each hydrograph.

Measurements of discharge during storm hydrographs were non-continuous. According to a study by Scheider et al. (1979), this method has a 12% mean absolute error. This error is defined as the absolute percent difference between the results of a given calculation and the results of discharge calculated from continuous stage records. This error will vary with the number of discrete measurements taken during the high discharge event. However, according to Scheider et al. (1979), this method, as far as accuracy is concerned, is second only to continuous stage records, which were not feasible for this study.

2.3.3 Sample Analysis

All phosphorus samples were analyzed using the stannous chloride method, (NAQUADAT No.15413, Env. Can., 1974) with a Technicon Autoanalyzer. (The autoanalyzer's detection limit is .001mg/L). To analyze total phosphorus with this method, 25 ml of sample were initially digested and evaporated to 3-5 ml with 0.3 ml of potassium persulfate and rediluted to 25 ml with deionized water. This digestion is done to convert filterable and particulate organically-bound phosphorus, inorganic and condensed phosphorus into orthophosphate. Total phosphorus, as orthophosphate, is then determined by the stannous chloride method (Cahill et al, 1974). These were then filtered through 0.45 um filters and analyzed using the aforementioned method. It is important to note that several researchers, (Syers et al, 1975; Cowen and Lee, 1976; Logan et al, 1979) have found that persulfate digestion may not recover as much phosphorus as perchloric acid digestion. This should be considered for future studies.

2.4 Sample Collection (Storm Flow)

A similar sampling program was employed during rainfall-runoff events to allow for comparison of high discharge event phosphorus export with base flow phosphorus export. This sampling program included examination of phosphorus inputs from four urban land types: 1) residential (Sewer A), 2) transportation corridor (Sewer B), 3) commercial (Sewer C), and 4) parking lot (Sewer D).

Ten sites, A,B,C,D,2,3,4,7,9,11, (Fig. 2.4) along Laurel Creek were sampled during rainfall-runoff events for total and dissolved reactive phosphorus. These sites included one storm sewer outfall from each of the four land uses, the tributary inputs, Forewell and Clair Creeks, the mouth of Laurel Creek, site 11, and site 2, where the creek enters the urban area. Two more sites, 3 and 7, were sampled to monitor the phosphorus flux in the creek during high discharge events. Discharge was measured at sites 2,4,9 and 11, and storm sewers A,B,C and D.

2.4.1 STORM SEWERS

During high discharge events, runoff from the four land use areas was sampled for phosphorus concentrations and discharge. Sewer A drains residential land, sewer B drains a transportation corridor, (Columbia St.), sewer C drains a commercial area and sewer D drains a parking lot in the downtown Waterloo area.

Storm sewer A drains water from a residential area west of Westmount road (Fig. 2.4). This is an area of 18.0 hectares, of which 5.1 hectares (28.8%) is paved and considered impervious. Forty-six street inlets collect runoff and deliver it to Laurel Creek at storm sewer A.

Storm sewer B drains runoff from a portion of Columbia Street, encompassing a total area of 2.93 hectares. Of this area 0.38 hectares is a grass median, leaving 2.55 hectares (87.1%) of the total area impervious. Twelve street inlets collect runoff and deliver it to the outlet at Laurel Creek.

Storm sewer C drains a commercial area of land in downtown Waterloo. This drainage basin is 2.5 hectares, of which 1.2 hectares (48.0%) is impervious. The catchment is drained by ten street inlets which drain into Laurel Creek at outlet C.

Storm sewer D drains a parking lot in the downtown section of

Waterloo. The parking lot is 0.3 hectares, all of which drains into one outlet which drains into Laurel Creek at outlet D.

Samples were collected using the same sampling sequence until discharge returned to pre-rainfall levels. At the onset of precipitation a sample was collected at the first upstream site. Samples were collected in the order they appeared downstream. Driving from the first to the last site, collecting samples at each, lasted approximately fifty minutes.

All samples from storm events were analyzed as described in section 2.3.3.

2.4.2 PRECIPITATION

In order to determine the phosphorus load from precipitation during the storm events, rain gauges were employed at five sites in the catchment (Fig. 2.4). The five rain gauges were plastic containers, 10 centimeters in diameter, mounted on wooden rods approximately one metre above the ground surface. When rain was forecast, sterile plastic bags were put in each rain gauge to collect the precipitation. The plastic bags were removed and replaced if precipitation did not occur within twelve hours of being set up. This helped to reduce phosphorus contamination from dry fallout.

Immediately following a rainfall event, the amount of precipitation in millimeters was measured in a clean graduated cylinder, then half of the samples were transferred to clean glass bottles for DRP analysis (section 2.3.3) and the other half were transferred to acidified glass bottles for TP analysis. By calculating the area of the opening of the rain gauges, the volume was converted to a depth using equation 2.3:

$$Pd = Pv/Ag \qquad (2.3)$$

where: Pd = precipitation depth (cm)

Pv = precipitation volume (cm^3)

Ag = Area of gauge opening (cm^2)

Volumes from the five sites were averaged and converted to millimeters to obtain a mean value for each rainfall event.

2.4.3 Storm Sewer Discharge

Four city storm sewers, (sites A,B,C, and D), that drain into Laurel Creek, were sampled during rainfall events, (Fig. 2.4). Two of these sewer outlets, A and B are concrete; the other two, C and D are corrugated steel. Water samples for TP and DRP were collected by holding sample bottles under the storm sewer outfalls.

Immediately after sample collection, the depth of the water in the sewer outfalls was measured. To calculate discharge for each sewer, these depth measurements were used with the Manning Equation for flow in an open channel (Grant, 1981).

$$\text{Manning Equation: } Q = (1/n)\, R^{2/3} S^{1/2} \qquad (2.4)$$

where: Q = discharge (m^3/s)

n = roughness coefficient

R = hydraulic radius (m)

S = slope of hydraulic gradient (%)

This empirical equation depends significantly on the value of 'n' which is an index of frictional resistance to flow offered by the conduit. (Grant, 1981). The 'n' coefficient can be found for various conduit types in the literature (Chow, 1959), or assessed in the field as described below. In order to achieve an accurate 'n' value, discharge was measured at each sewer by calculating the time (seconds), necessary to fill a ten litre pail, thus giving a discharge reading in L/s. Knowing all variables in Manning's Equation, excepting 'n' , but including 'Q', the equation was solved for 'n' for each sewer. Thus simple depth measurements during sewer runoff allowed for calculation of discharge at a later date.

By plotting various depths, and therefore different cross-sectional areas of flow, a rating curve was produced for each sewer, thus necessitating only depth measurements to be taken during sample periods.

With discharge measurements and phosphorus concentrations for each sample, phosphorus export was calculated, using equation 2.2, for each sewer outlet for each storm event.

CHAPTER 3

RESULTS

3.1 INTRODUCTION

This chapter reports the data collected during the summer field program, between May and October, 1988, to examine baseflow and stormflow phosphorus export in Laurel Creek.

3.2 PRECIPITATION

Precipitation samples were collected during seven storm events throughout the summer to evaluate the precipitation phosphate load to each of the four urban areas. Samples were measured for depth and phosphate concentration. For each storm a composite rainfall sample was collected from the five precipitation gauges. In order to calculate rainfall volume for each area it was assumed that the sample results from the five rain gauges were applicable to the entire study area. For the five rain gauges used, the average variation about the mean sample depth was 6.1%.

Precipitation falling on paved areas undergoes little if any infiltration (Kibler, 1982). However, considering the areal extent of paved areas in urban environments, a large volume of water may not run off due to depression storage. Depression storage is that amount of precipitation which pools or puddles, without either infiltrating or running off (Kibler, 1982).

Wright-McLaughlin Engineers, (1969) suggest that the depression storage of a paved area is 2.54mm. Therefore, for each storm, 2.54mm of precipitation was subtracted from the measured precipitation, to calculate the runoff volumes from impervious areas.

Table 3.1 shows the amount of precipitation and the calculated runoff volume for each storm event from each of the four land uses. The calculated runoff in Table 3.1 does not include overland flow from pervious areas as it is assumed that little or no overland flow occurred with these amounts of precipitation. Kelling (1971), indicates that runoff from established lawns in Madison, Wisconsin, would only occur under unusually heavy (12.7mm/hr) rainfall. As infiltration is a function of soil type, permeability and depth to the water table, infiltration rates reported in Kelling (1971), pertain to the areas examined in that study.

To evaluate precipitation phosphate loads to each urban area, total and dissolved reactive phosphorus concentrations of each precipitation sample were analyzed. Figure 3.1 shows the phosphorus concentrations of the precipitation samples from each of the seven storm events.

Precipitation phosphate loads for each land use area were

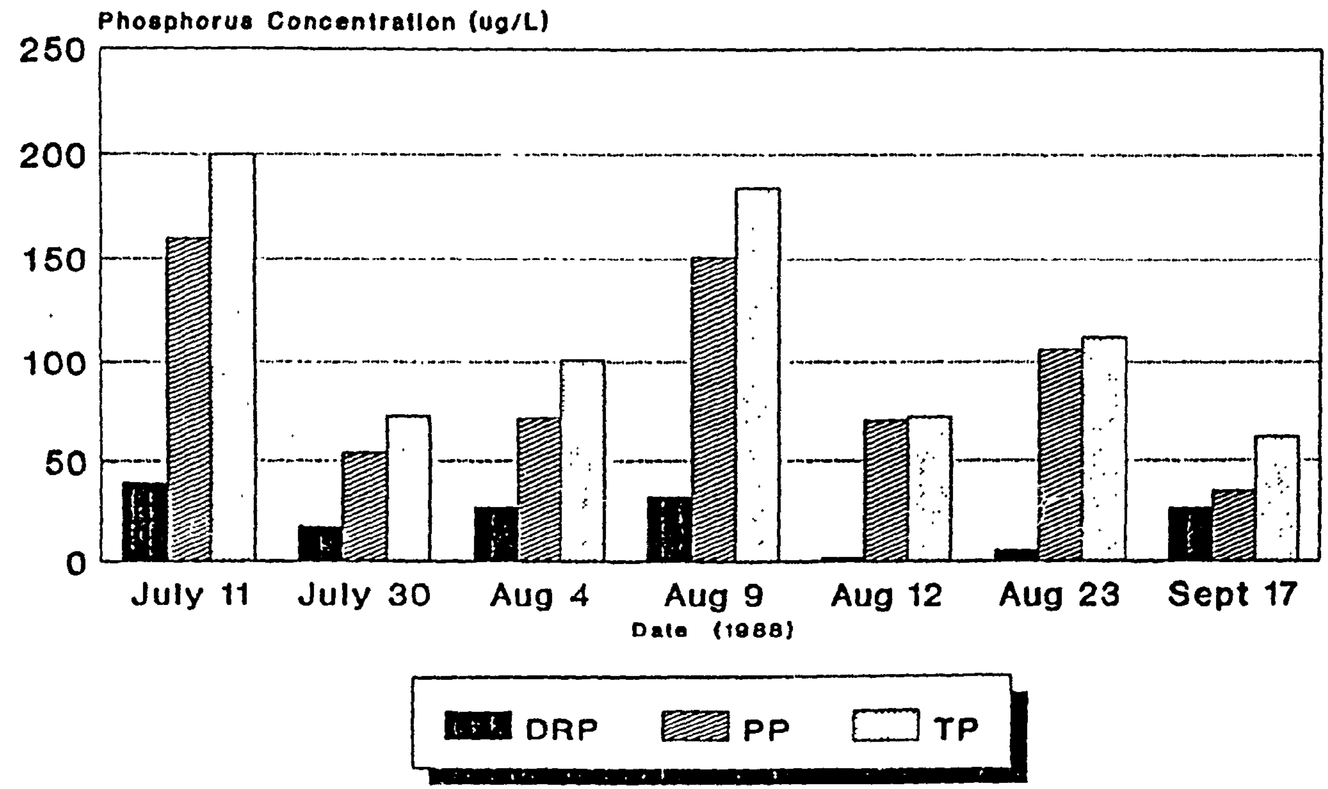
TABLE 3.1

Precipitation and Associated Runoff from Impervious Areas of Each Catchment

	Precipitation	Runoff Volume in Cubic Meters*			
	(mm)	Sewer A	Sewer B	Sewer C	Sewer D
July 11	4.6	107.1	52.5	25.2	6.3
July 30	7.2	239.7	117.5	56.4	14.1
Aug 4	8.9	326.4	160.0	76.8	19.2
Aug 9	4.2	86.7	42.5	20.4	5.1
Aug 12	9.9	377.4	185.0	88.8	22.2
Aug 23	8.1	285.6	140.0	67.2	16.8
Sept 17	9.8	372.3	182.5	87.6	21.9

* Total Calculated Runoff Volume for Each Catchment
For calculation of runoff volume, 2.54mm of precipitation was assumed not to runoff.

Figure 3.1
Precipitation Phosphorus Concentration
of Events Sampled



calculated to ascertain the phosphate load that would runoff from the impervious areas to Laurel Creek without contamination from street dirt. These loads were calculated assuming 2.54mm of precipitation would be retained by depression storage and runoff would only originate from impervious areas. Precipitation phosphate loads were calculated using equations 3.1 - 3.3.

$$Pptp = V_p * [TP] \tag{3.1}$$
$$Ppdrp = V_p * [DRP] \tag{3.2}$$
$$Ppp = Ptp - Pdrp \tag{3.3}$$

where: V_p = volume of precipitation (m^3)
[TP] = TP concentration (mg/m^3)
[DRP] = DRP concentration (mg/m^3)
Pptp = precipitation TP load (mg)
Ppdrp = precipitation DRP load (mg)
Ppp = precipitation PP load (mg)

These calculated loads are reported in Table 3.2.

3.3 URBAN RUNOFF

To evaluate urban phosphorus export during storm events, storm sewer outfalls from the residential, transportation, commercial and parking land use areas, were sampled for discharge and phosphate concentration. Table 3.3 reports the mean stormflow discharge for the four storm sewers during each of the seven storm events, and Table 3.4 reports the mean phosphate concentrations of the discharge of each storm event. Sewer C, draining the commercial area, was not accessible during the August 4 storm, resulting in missing data for

TABLE 3.2

Precipitation Phosphorus Loading to Each Storm Sewer

DATE	Sewer A Residential (g)	Sewer B Transportation (g)	Sewer C Commercial (g)	Sewer D Parking Lot (g)	
July 11	21.4	10.5	5.0	1.3	(TP)
	17.1	8.4	4.0	1.0	(PP)
	4.3	2.1	1.0	0.3	(DRP)
July 30	17.3	8.5	4.1	1.0	(TP)
	13.0	6.4	3.1	0.7	(PP)
	4.3	2.1	1.0	0.3	(DRP)
Aug 4	32.9	16.2	7.8	1.9	(TP)
	23.8	11.7	5.6	1.4	(PP)
	9.1	4.5	2.2	0.5	(DRP)
Aug 9	15.9	7.8	3.8	0.9	(TP)
	13.0	6.4	3.1	0.7	(PP)
	2.9	1.4	0.7	0.2	(DRP)
Aug 12	27.2	13.3	6.4	1.6	(TP)
	26.4	12.9	6.2	1.56	(PP)
	0.8	0.4	0.2	0.04	(DRP)
Aug 23	31.9	15.7	7.5	1.9	(TP)
	30.2	14.9	7.1	1.8	(PP)
	1.7	0.8	0.4	0.1	(DRP)
Sept 17	23.1	11.3	5.4	1.4	(TP)
	13.0	6.4	3.0	0.8	(PP)
	10.1	4.9	2.4	0.6	(DRP)

TABLE 3.3

Mean Stormflow Discharge for Storm Sewer Outfalls

DATE	Sewer A	Sewer B	Sewer C	Sewer D
July 11	0.41	0.08	0.75	0.15
July 30	1.97	0.39	0.99	0.13
Aug 4	1.96	0.25	--	0.21
Aug 9	24.29	2.74	1.16	0.21
Aug 12	24.77	1.05	0.70	0.21
Aug 23	6.94	1.28	2.23	0.18
Sept 17	3.03	0.81	1.16	0.89

* Values in the table should be multiplied by 10^{-3} to get discharge in cubic meters per second.

TABLE 3.4

Average TP, PP and DRP Concentrations for the Four Storm Sewers During Storm Events (mg/m^3)

DATE	Sewer A	Sewer B	Sewer C	Sewer D	
July 11	316	300	2567	835	(TP)
	12	141	744	101	(PP)
	304	159	1823	734	(DRP)
July 30	254	156	440	403	(TP)
	187	133	398	391	(PP)
	67	23	42	12	(DRP)
Aug 4	166	160	--	400	(TP)
	77	128	--	387	(PP)
	89	32	--	13	(DRP)
Aug 9	565	319	368	90	(TP)
	258	259	220	42	(PP)
	307	60	148	48	(DRP)
Aug 12	199	275	210	75	(TP)
	169	268	203	72	(PP)
	30	7	7	3	(DRP)
Aug 23	197	396	461	97	(TP)
	148	386	293	89	(PP)
	49	10	168	8	(DRP)
Sept 17	286	213	410	95	(TP)
	225	191	405	94	(PP)
	61	22	5	1	(DRP)

that sewer.

In order to evaluate the role of urban runoff as a source of phosphorus to Laurel Creek, phosphate export was calculated for the storm sewer of each land use. Table 3.5 shows the TP, PP and DRP export of the storm sewers of each land use for each storm.

Due to the difference in the impervious area of the four urban catchments, the values in Table 3.5 were converted to a unit area load value (Table 3.6) to allow for comparison between land uses.

In order to evaluate the significance of these reported phosphate yields, the total seven storm export for each land use area was calculated (Table 3.7). When compared to the total seven storm export at site 11, the results indicate that 0.31% of the Laurel Creek drainage basin (the four land uses sampled), exported 1.71% of the TP load, 1.34% of the PP load and 4.78% of the DRP load. This illustrates the importance of urban runoff phosphate export.

3.4 LAUREL CREEK

Discharge and phosphate concentration in Laurel Creek was sampled during baseflow and stormflow events to evaluate the significance of stormflow phosphate export and examine phosphorus movement in the creek during baseflow and stormflow. Discharge was measured at site 2 and 11 on Laurel Creek as well as at the tributary inputs, sites 4 and 9.

TABLE 3.5

Storm Sewer Phosphorus Loads During Storm Events

DATE	Sewer A Residential (g)	Sewer B Transportation (g)	Sewer C Commercial (g)	Sewer D Parking Lot (g)	
July 11	3.75	0.14	37.22	1.04	(TP)
	0.20	0.06	25.45	0.09	(PP)
	3.55	0.08	11.77	0.95	(DRP)
July 30	8.75	0.18	1.21	0.95	(TP)
	7.42	0.15	1.14	0.94	(PP)
	1.33	0.03	0.07	0.01	(DRP)
Aug 4	3.66	0.57	--	0.25	(TP)
	1.61	0.43	--	0.24	(PP)
	2.05	0.14	--	0.01	(DRP)
Aug 9	114.61	4.16	1.28	0.06	(TP)
	66.48	3.55	0.76	0.03	(PP)
	48.13	0.61	0.52	0.03	(DRP)
Aug 12	37.22	2.37	0.44	0.05	(TP)
	35.30	2.32	0.42	0.047	(PP)
	1.92	0.05	0.02	0.003	(DRP)
Aug 23	38.80	6.92	4.70	0.28	(TP)
	30.35	6.71	3.64	0.27	(PP)
	8.45	0.21	1.06	0.01	(DRP)
Sept 17	6.72	2.11	1.43	0.26	(TP)
	5.08	1.99	1.41	0.257	(PP)
	1.64	0.12	0.02	0.003	(DRP)

TABLE 3.6

Normalized Values for Storm Sewer Phosphorus Loads During Storm Events

DATE	Sewer A Residential (g/ha)	Sewer B Transportation (g/ha)	Sewer C Commercial (g/ha)	Sewer D Parking Lot (g/ha)	
July 11	0.74	0.05	31.02	3.45	(TP)
	0.04	0.02	21.21	0.30	(PP)
	0.69	0.03	9.81	3.15	(DRP)
July 30	1.72	0.07	1.01	3.17	(TP)
	1.46	0.06	0.95	3.13	(PP)
	0.26	0.01	0.06	0.04	(DRP)
Aug 4	0.72	0.22	--	0.83	(TP)
	0.32	0.05	--	0.80	(PP)
	0.40	0.05	--	0.03	(DRP)
Aug 9	22.47	1.63	1.07	0.19	(TP)
	13.04	1.39	0.63	0.10	(PP)
	9.44	0.24	0.44	0.09	(DRP)
Aug 12	7.29	0.93	0.37	0.17	(TP)
	6.92	0.91	0.35	0.16	(PP)
	0.38	0.02	0.02	0.01	(DRP)
Aug 23	7.61	2.72	3.92	0.93	(TP)
	5.95	2.63	3.03	0.90	(PP)
	1.66	0.09	0.89	0.03	(DRP)
Sept 17	1.32	0.83	1.19	0.87	(TP)
	0.99	0.78	1.17	0.86	(PP)
	0.33	0.05	0.02	0.01	(DRP)

TABLE 3.7

Phosphorus Loads For Each Land Use and Site 11
for the Seven Sampled Storm Events

Land Use	Load (g)	
Residential	213.5	(TP)
	146.4	(PP)
	67.1	(DRP)
Transportation Corridor	16.45	(TP)
	15.21	(PP)
	1.24	(DRP)
Commercial	46.28	(TP)
	32.82	(PP)
	13.46	(DRP)
Parking Lot	2.89	(TP)
	1.87	(PP)
	1.02	(DRP)
Site 11	16 340	(TP)
	14 620	(PP)
	1 730	(DRP)

3.4.1 Discharge

Table 3.8a reports the mean discharge for the four sites during baseflow, calculated from the fifteen measurements taken over the five month sampling period.

It is important to note that there is a difference in the discharge at the mouth of the creek and the sum of the tributary sites, 4 and 9, and the upstream site 2, for baseflow. The sum of these three sites, 0.082 m^3/s is approximately half of the discharge at site 11 which is 0.156 m^3/s. This suggests additional inputs of water between sites 2 and 11, some of which may include:

i) groundwater flow

ii) reservoir discharge (Silver or Columbia Lake)

iii) lawn watering, car washing

Table 3.8b shows the average discharge for these four sites during the seven storm events. As well as the three suggested inputs mentioned above, that contribute to the increased discharge at site 11, overland flow between sites 2 and 11 becomes an important factor during rainfall-runoff events.

3.4.2 Phosphate Concentration

Phosphorus samples, TP and DRP were taken at all eleven sites on Laurel Creek during baseflow sampling periods. Figure 3.2 shows

TABLE 3.8a

Mean Baseflow Discharge for Laurel Creek

(June-October)

Site 2	0.031 m^3/s
Site 4	0.017 m^3/s
Site 9	0.034 m^3/s
Site 11	0.156 m^3/s

TABLE 3.8b

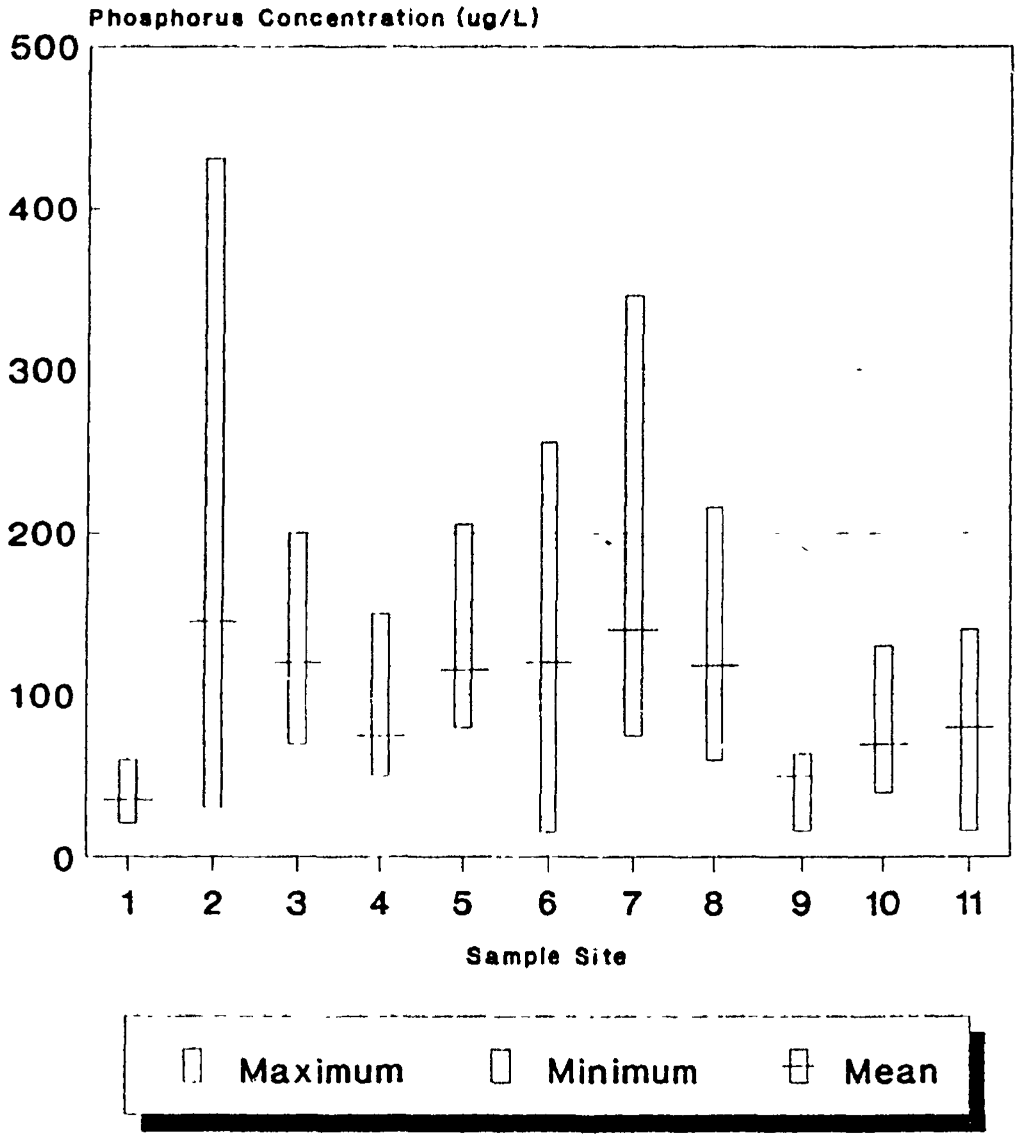
Mean Stormflow Discharge for Laurel

Creek at Sites 2,4,9 and 11

DATE	Site 2	Site 4	Site 9	Site 11
July 11	0.019	0.047	0.073	0.317
July 30	0.036	0.018	0.236	0.783
Aug 4	0.295	0.019	0.346	1.090
Aug 9	0.043	0.012	0.175	0.429
Aug 12	0.076	0.144	0.775	0.709
Aug 23	0.021	0.016	0.079	0.198
Sept 17	0.026	0.037	0.228	0.502

* Discharge measured in m^3/s.

Figure 3.2
Mean, Minimum and Maximum Total Phosphorus Concentration in Laurel Creek



(June 10th-Oct6th)

the average TP concentration for these eleven sites calculated from the fifteen baseflow samples. It is interesting to note that in the case of both tributary inputs, the TP concentration is lower than their respective upstream sites, this would suggest a dilution effect is occuring at the respective downstream sites as is evident in Figure 3.2. Figure 3.3 shows the average DRP concentration for the same samples.

Table 3.9 reports the average TP and DRP concentrations of the samples taken during the storm events for sites 2,4,9 and 11 on Laurel Creek.

3.4.3 Phosphate Export

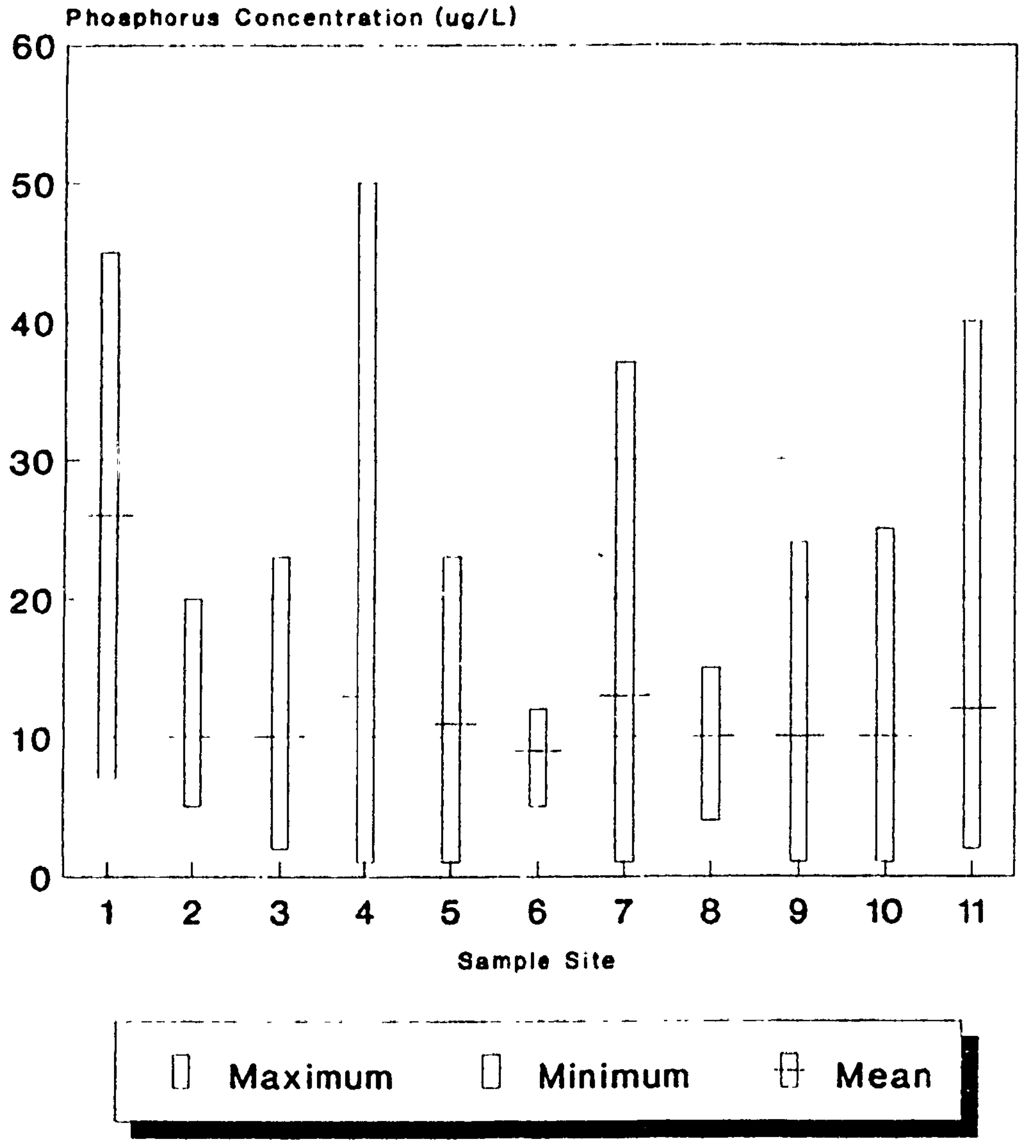
Using fifteen sample days, a total phosphorus export of 166.2 kg, consisting of 143.8 kg of particulate phosphorus and 22.4 kg of dissolved reactive phosphorus from Laurel Creek to the Grand River was calculated for the five month period. Equation 3.4 demonstrates how export was determined.

$$\text{Five Month Load} = \bar{x}\ \text{g/hr} * 24\ (\text{hrs}) * 153\ (\text{days}) \qquad (3.4)$$

where: $\bar{x}$ g/hr = average grams per hour

Discharge and phosphorus concentration measurements were taken during seven storm events over the five months. During these seven events, the phosphate export from Laurel Creek was 16.3 kg of TP,

Figure 3.3
Mean, Minimun and Maximum DRP Concentrations in Laurel Creek



(June 10th-Oct 6th)

TABLE 3.9

Average TP, PP and DRP Concentrations for Laurel Creek During Storm Events (mg/m^3)

DATE	Site 2	Site 4	Site 9	Site 11	
July 11	180	227	139	131	(TP)
	171	166	93	105	(PP)
	7	61	46	26	(DRP)
July 30	131	194	94	92	(TP)
	121	175	86	71	(PP)
	10	19	8	21	(DRP)
Aug 4	87	99	110	177	(TP)
	77	86	86	162	(PP)
	10	15	24	15	(DRP)
Aug 9	103	164	122	100	(TP)
	98	71	90	91	(PP)
	5	93	32	9	(DRP)
Aug 12	115	406	172	126	(TP)
	112	382	147	117	(PP)
	3	24	25	9	(DRP)
Aug 23	88	93	79	124	(TP)
	82	86	61	104	(PP)
	6	7	18	20	(DRP)
Sept 17	72	143	160	148	(TP)
	70	116	89	134	(PP)
	2	27	71	14	(DRP)

consisting of 14.6 kg of PP and 1.7 kg of DRP.

Table 3.10 illustrates the TP export for sites, 2,4,9 and 11 along Laurel Creek for the five months of baseflow and also for the seven storm events. As each of the four sites vary in areal extent, for comparative purposes, TP, PP and DRP export are expressed in g/ha.

Comparison of the upstream site, 2 and the sample site at the mouth of the creek, 11, indicates that a large amount of phosphorus enters Laurel Creek from the urban area during storm events, as illustrated by the ratio column in Table 3.10. These ratios show that during baseflow, for every 2.7kg of TP exported at site 11, site 2 accounts for 1 kg, whereas during storm events for every 19.0 kg exported at site 11, site 2 accounts for 1kg, meaning large amounts of phosphorus must enter the system within the urban area.

The five month total baseflow load for TP, PP, and DRP was calculated as 166.2 kg, 143.7 kg, and 22.5 kg, respectively, while the seven recorded storms produced a total of 16.3 kg of TP, 14.6kg of PP and 1.7 kg of DRP (baseflow is subtracted from stormflow). For the total calculated summer TP, PP and DRP export, including baseflow and stormflow, the seven storm events accounted for 8.9% of the TP export, 9.2% of the PP export and 7.1% of the DRP export, but accounting for only 4.5% of the time, suggesting the importance of stormflow phosphorus export.

TABLE 3.10

Areal Contribution of Phosphorus Loads for Four Sites on Laurel Creek

	Five Month Baseflow Load (kg)	Total Load from Storm Events (kg)	Five Month Baseflow Load (g/ha/day)	Total Load from Storm Events (g/ha/day)	
SITE 2	60.53	0.86	0.109	0.076	(TP)
	57.17	0.79	0.104	0.070	(PP)
Rural portion of basin	3.36	0.07	0.005	0.006	(DRP)
SITE 4	15.96	4.26	0.076	1.053	(TP)
	10.42	4.03	0.050	0.996	(PP)
Clair Cr. basin	5.54	0.23	0.026	0.057	(DRP)
SITE 9	21.51	8.15	0.157	3.053	(TP)
	15.92	5.21	0.116	1.953	(PP)
Forewell Cr. basin	5.59	2.94	0.041	1.100	(DRP)
SITE 11	166.20	16.34	0.141	0.850	(TP)
	143.72	14.61	0.122	0.756	(PP)
Laurel Cr. basin	22.48	1.73	0.019	0.094	(DRP)
Ratio of	2.7 : 1	19.0 : 1			(TP)
Site 11	2.5 : 1	17.8 : 1			(PP)
to Site 2	6.7 : 1	24.7 : 1			(DRP)

CHAPTER 4

DISCUSSION

4.1 INTRODUCTION

The purpose of this chapter is to interpret and discuss the results presented in Chapter Three. Phosphate export during baseflow and stormflow in Laurel Creek will be compared, phosphorus inputs from four different urban land uses are discussed, and a linear regression model will be created to estimate storm event phosphorus export for Laurel Creek.

4.2 STUDY OBJECTIVES

The results reported in Chapter 3 will be used to comment on the four study objectives outlined in section 1.3. These objectives are:

1. to determine the precipitation phosphate load for summer rainfall.

2. evaluate urban runoff phosphate export.

3. compare base flow and high flow phosphorus export.

4. compare phosphorus runoff yields from urban and agricultural areas.

4.2.1 Precipitation Phosphate Load

The first study objective was to determine the precipitation phosphate (TP and DRP) load to an urban area during summer rainfall events. To evaluate phosphate export in Laurel Creek, it is necessary to know the phosphate load entering the system through precipitation. By subtracting the phosphorus load in the precipitation from phosphorus export in urban drainage it is possible to determine what phosphate inputs to urban runoff originate from urban street dirt. Urban street dirt is considered here to be comprised of anthropogenic pollution; atmospheric dry deposition, industrial pollution, automobile exhaust products, fertilizers, and natural sources of pollution; leaves, animal faeces, and eroded soil.

The phosphate concentrations recorded from rain samples gathered during the seven rainfall events of this study, range from .062-.200mg/L, ($\bar{x}$=115) of total phosphorus and .002-.040mg/L, ($\bar{x}$=22) of dissolved reactive phosphorus.

These values are similar to precipitation phosphate concentration data collected at the Waterloo-Wellington Airport by the Ministry of Environment, (MOE), between 1983 - 1986, which gives a TP range of .001-.222mg/L with an average of .024mg/L. The MOE data gives mean monthly precipitation phosphate concentration data, which means that the value of .222mg/L is an average phosphate concentration for one month, and not a maximum concentration.

Other studies have noted similar values. Sanderson and LaValle (1979), report precipitation TP concentrations in Southern Ontario, as less than 1 mg/L. Murphy and Doskey (1976) report precipitation phosphate concentrations on and around Lake Michigan, of .020-.036mgTP/L and .006-.014mgTP/L. The precipitation phosphate concentrations of this study are slightly higher in value than these two previous studies, possibly due to contamination from a farmers field upwind of the precipitation gauges.

This region is dominated by the prevailing westerly winds. The rain gauges for this study were located downwind of a farmers field, (Fig 2.4). The prevailing westerly winds may pick up particulate matter, containing phosphorus, from the agricultural land and deposit it in the rain gauges resulting in contamination of the samples. This may account for the slightly higher phosphorus values than those recorded by Murphy and Doskey (1976) and Sanderson and LaValle (1979). These two studies were done at different sites, 11 and 8 years ago, respectively. Spatial variation and increased atmospheric pollution over this time may also be partly responsible for the higher concentrations of this study.

It is necessary to explain why such a large range occurs in precipitation phosphate concentration over time, in one place. There are two mechanisms for removal of atmospheric pollutants; wet and dry deposition (Seinfield, 1986). Wet deposition involves adsorption of a pollutant to precipitation droplets and subsequent deposition by precipitation. Dry deposition is the result of gravitational forces attracting airborne pollutants to the earth's surface. As dry deposition was reduced by the use of plastic bags, only wet deposition was measured, and therefore the great range in phosphate concentration is found in the precipitation alone.

It is suggested that the longer the dry period before a rainstorm the higher the precipitation phosphate concentration will be. For example, after a 4 week drought the precipitation phosphate concentration would be higher than after a 4 day drought. This is the result of atmospheric scouring that takes place during wet deposition.

Wet deposition involves two methods of atmospheric scouring; rainout and washout, (Seager and Stokes, 1976). Rainout occurs when particulate matter serves as nuclei on which water condenses and raindrops are formed. Washout involves rainfall or snowfall colliding with and collecting particulates during precipitation. If a drought has preceeded a rainfall, the atmosphere will be relatively dirty and there is a large potential source of pollution for the precipitation. If a rainstorm has occurred recently, the atmosphere will be relatively clean, meaning less chance of particulates acting as nuclei, or precipitation intercepting airborne particulates. Therefore, the longer the antecedent dry period, the higher the precipitation phosphate concentration.

A simple regression analysis between precipitation phosphate concentration and the antecedent dry days for the seven storms was performed to determine the effect of atmospheric scouring on the large variation in phosphate concentration.

The correlation coefficient (r) for TP concentration and antecedent dry days was .92 (significant at 99%) and the coefficient of determination (r^2) was .84. For DRP, the 'r' value was .84 (significant at 95%) and the 'r^2' value was .70. Although only seven sample events were regressed, the strong values of the correlation coefficient suggest that the antecedent dry period and subsequent scouring of the atmosphere results in a large range in precipitation phosphate concentration. Knowing the precipitation phosphate concentration, and the precipitation volume for each storm, precipitation phosphate loads to each land use were calculated.

Table 3.2 reports the calculated phosphate loads for runoff from each land use from precipitation alone. That is, if all of the precipitation that fell over one land use were collected, without the addition of urban dirt, it would potentially produce the phosphorus runoff export tabulated in Table 3.2. Table 3.5 shows the measured P loads from runoff of each urban area. Using a simple mass balance equation (4.1), the net urban phosphorus input was determined, by subtracting the calculated precipitation phosphorus load from the measured runoff phosphorus export:

$$RPout - PPin = UPin \tag{4.1}$$

where: RPout = runoff phosphorus output (mg)

PPin = precipitation phosphorus input (mg)

UPin = urban phosphorus input (mg)

The measured runoff phosphate load, in most cases, is less than that calculated from the precipitation inputs, suggesting a loss or retention of P between initial contact with the ground and runoff from the land use in question. There are several factors that may cause this phosphorus reduction;

i) particulate and dissolved phosphorus may collect in small surface craters and cracks (DRP by adsorbing to sediment in the craters) in the pavement and not be physically available to runoff.

As well, infiltration through cracks in the concrete may remove surface water from the streets. removing phosphorus from urban export.

ii) catchbasins in sewer inlets may trap sediment on which P is adsorbed, preventing it from entering sewer outlets.

iii) precipitation data, both mean depth and phosphate concentration, were assumed to be uniform throughout the basin. This may not be true.

iv) If the precipitation samples were contaminated by particulate matter from the farmers field (Fig. 2.4) the precipitation phosphorus values calculated in Table 3.2 would be higher than expected.

On several occasions, storm sewers A,C, and D measured greater phosphorus loads in the runoff than their respective calculated precipitation phosphate loads, indicating an additional source of phosphorus to the runoff from urban street contamination. Table 4.1 illustrates that on four occasions the urban TP export load is greater than the TP load of the precipitation, and on six occasions the DRP export is greater than the DRP load of the precipitation. It is suggested that phosphorus in urban street dirt is the source of this additional phosphate load.

In order to determine why retention occurred during some storms for some land uses, and not for others, the calculated export/retention values were analyzed in consideration of those factors that might influence whether P would be retained or exported, (Table 4.2). These factors are; precipitation phosphate concentration, depth and intensity of precipitation and the antecedent dry period. It is possible that high intensity storms occurring after a long dry period might lead to an export of P over and above that contributed by precipitation, and a low intensity storm occurring shortly after another storm, may lead to P

TABLE 4.1

MASS BALANCE CALCULATIONS

Land Use (Sewer)	Storm Date	Precipitation P Input (g) DRP / TP	Runoff P Output (g) DRP / TP	Urban Contribution (g/ha) More than precip input DRP/TP	Urban Contribution (g/ha) Less than precip input DRP/TP
A (Res)	July 11	4.3 / 21.4	3.6 / 3.8		0.1/3.5
A	July 30	4.3 / 17.3	1.3 / 8.8		0.6/1.7
A	Aug 4	9.1 / 32.9	2.1 / 3.7		1.4/5.7
A	Aug 9	2.9 / 15.9	48.1 / 114.6	8.9/19.4	
A	Aug 12	0.8 / 27.2	1.9 / 37.2	0.2/1.9	
A	Aug 23	1.7 / 31.9	8.5 / 38.8	1.3/1.4	
A	Sept 17	10.1 / 23.1	1.6 / 6.7		1.8/3.2
B(Tran)	July 11	2.1 / 10.5	0.1 / 0.1		0.8/4.2
B	July 30	2.1 / 8.5	0.03 / 0.2		0.8/3.3
B	Aug 4	4.5 / 16.2	0.1 / 0.6		1.8/6.2
B	Aug 9	1.4 / 7.8	0.6 / 4.2		0.3/1.4
B	Aug 12	0.4 / 13.3	0.1 / 2.4		0.1/4.4
B	Aug 23	0.8 / 15.7	0.2 / 6.9		0.2/3.5
B	Sept 17	4.9 / 11.3	0.1 / 2.1		1.9/3.7
C (Com)	July 11	1.0 / 5.0	11.8 / 37.2	9.0/26.8	
C	July 30	1.0 / 4.1	0.1 / 1.2		0.8/2.4
C	Aug 4	2.2 / 7.8	-- / --		-----
C	Aug 9	0.7 / 3.8	0.5 / 1.3		0.2/2.1
C	Aug 12	0.2 / 6.4	0.02 / 0.4		0.2/5.0
C	Aug 23	0.4 / 7.5	1.1 / 4.7	0.6	2.3
C	Sept 17	2.4 / 5.4	0.02 / 1.4		1.9/3.3
D(Park)	July 11	0.3 / 1.3	0.9 / 1.0	2.0	1.0
D	July 30	0.3 / 1.0	0.01 / 0.9		0.9/0.3
D	Aug 4	0.5 / 1.9	0.01 / 0.3		1.6/5.3
D	Aug 9	0.2 / 0.9	0.03 / 0.06		0.6/2.8
D	Aug 12	0.04 / 1.6	0.003 / 0.05		0.1/5.2
D	Aug 23	0.1 / 1.9	0.01 / 0.28		0.3/5.3
D	Sept 17	0.6 / 1.4	0.003 / 0.26		1.9/3.8

TABLE 4.2

INCIDENTS OF URBAN PHOSPHORUS EXPORT
AND RESPECTIVE PRECIPITATION DATA

Date	Precipitation Intensity	/ Depth	Antecedent Dry Days	Precip P Concen-tration	Urban Input	Land Use
	(mm/hr)	(mm)	(days)	(ug/l)	(g)	(Sewer)
July 11	3.0	4.6	13	40 / 200	10.08/32.2 0.06	C D
July 30	4.1	7.2	5	18 / 72	(n.a.)	
Aug 4	7.1	8.9	3	28 / 101	(n.a.)	
Aug 9	3.4	4.2	5	33 / 184	45.2/98.7	A
Aug 12	9.9	9.9	1	2 / 72	1.1/10.0	A
Aug 23	2.3	8.1	6	6 / 112	6.8/ 6.9 0.7	A C
Sept 17	3.9	9.9	1	27 / 62	(n.a.)	

retention. By comparing the data for sewers A and C during storms when export occurred, with the precipitation data, the above hypothesis is supported.

Sewer C, draining the commercial area, exported DRP on July 11, (9.0 g/ha) and Aug 23, (0.6 g/ha). The rainfall intensity of the two storms were similar, although nearly twice as much rain fell during the August 23 storm. This alone would suggest greater export during the Aug 23 storm. However, the antecedent dry period of the July 11 storm, 13 days, was approximately twice that of the Aug 23 storm, 6 days. Likewise, the precipitation DRP concentration on July 11 was .040mg/L, seven times greater than the precipitation DRP concentration (.006mg/L) recorded for August 23. As the July 11 storm exported more phosphorus, it is assumed that the long antecedent dry period and the high DRP concentration were the responsible factors.

Sewer A, which drains the residential land, exported TP on three occasions; August 9, (19.4 g/ha), August 12, (1.9 g/ha), and August 23, (1.4 g/ha). On Aug 9 the rainfall intensity was the third lowest recorded, the antecedent dry period of 5 days, the median of the seven storms, and the precipitation TP concentration, .184mg/L, the second highest. The Aug 12 storm, while having the highest rainfall intensity, had only one antecedent dry day, and the second lowest precipitation phosphate concentration, .072mg/L. August 23 had the lowest rainfall intensity, this occurred after 6 dry days and with the precipitation TP concentration,

A larger data base would be needed to more accurately explain why export or retention occurs in the study area. However the data presented here, although limited, suggests that precipitation intensity, antecedent dry days, and the precipitation phosphate concentration in conjunction with each other create conditions amenable to export or retention.

This urban source of phosphorus is introduced to Laurel Creek during rainfall-runoff events, the following section discusses the significance of stormflow phosphorus export, with respect to baseflow export.

4.2.2 Baseflow vs. Stormflow Phosphate Export

The second objective of this study is to determine the relative significance of high discharge event phosphate export with respect to summer baseflow phosphorus export. In order to assess annual phosphate export accurately, it is important to have an understanding of the magnitude of stormflow phosphate export. For all comparisons, the baseflow load has been subtracted from the stormflow load. One method of comparing baseflow and stormflow phosphorus loads is to examine their respective phosphorus export rates, (Table 4.3).

TABLE 4.3

Rate of Phosphorus Export at Site 11, During Baseflow and Stormflow

	TP	PP	DRP
Baseflow	45.3 g/hr	39.2 g/hr	6.1 g/hr
Stormflow	230.1 g/hr	205.9 g/hr	24.4 g/hr
% Increase of stormflow over baseflow	507.9	525.3	400.0

Baseflow and stormflow export rates are shown as the average rate for the five months for baseflow, and the average rate of the seven storm events studied.

Table 4.3 illustrates that there is a 500% increase in TP transport during high discharge events over baseflow. For stormflow in Laurel Creek during the summer of 1988, phosphate export rates were five times greater for TP and PP, and four times greater for DRP, than baseflow export rates. For the five months of this study, measurement of baseflow alone, would have underestimated the phosphorus export by 41% for TP and 44% for DRP. These values are similar to that of Yaksich and Verhoff (1983), who determined that phosphate export would be underestimated by up to 30% without incorporating high discharge flows.

Another method of comparing the stormflow and baseflow phosphate export is by collating their respective phosphate export with the time in which they were exported. Summing the baseflow and stormflow phosphate export at the mouth of Laurel Creek for the five months, a total of 197.8 kg TP, consisting of 173.8 kg PP and 24.0 kg DRP was calculated. For this total TP load, 44% (the stormflow load) was exported in 17.2% of the total study time. For the total DRP load, 30% (the stormflow load) was exported in the same 17.2% of the time. For the total PP load, 46% (the stormflow load) was exported in 17.2% of the time. This illustrates that large amounts of phosphorus can potentially be exported in short periods of time during high discharge events.

In a study of annual phosphorus loss from a rural watershed, Johnson et al., (1976), state that 50% of the DRP was lost during 10% of the time (stormflow and springmelt) and 80% of the TP was lost in the same time period. The results of this study reflect those of Johnson et al., (1976), both suggesting that storm event phosphorus export is, on a time basis, proportionately more important than baseflow export. Also, that in calculating watershed mass balances, the stormflow phosphate contribution can be significant. In order to illustrate the large quantities of P exported during stormflow, as compared to baseflow, a predicted P export for the 31 storms not sampled during the summer of 1988, was calculated using equation 4.2:

$$\text{Stormload} = \text{Pl}/7 * 38 \qquad (4.2)$$

where: stormload = P export for 38 storms (kg)

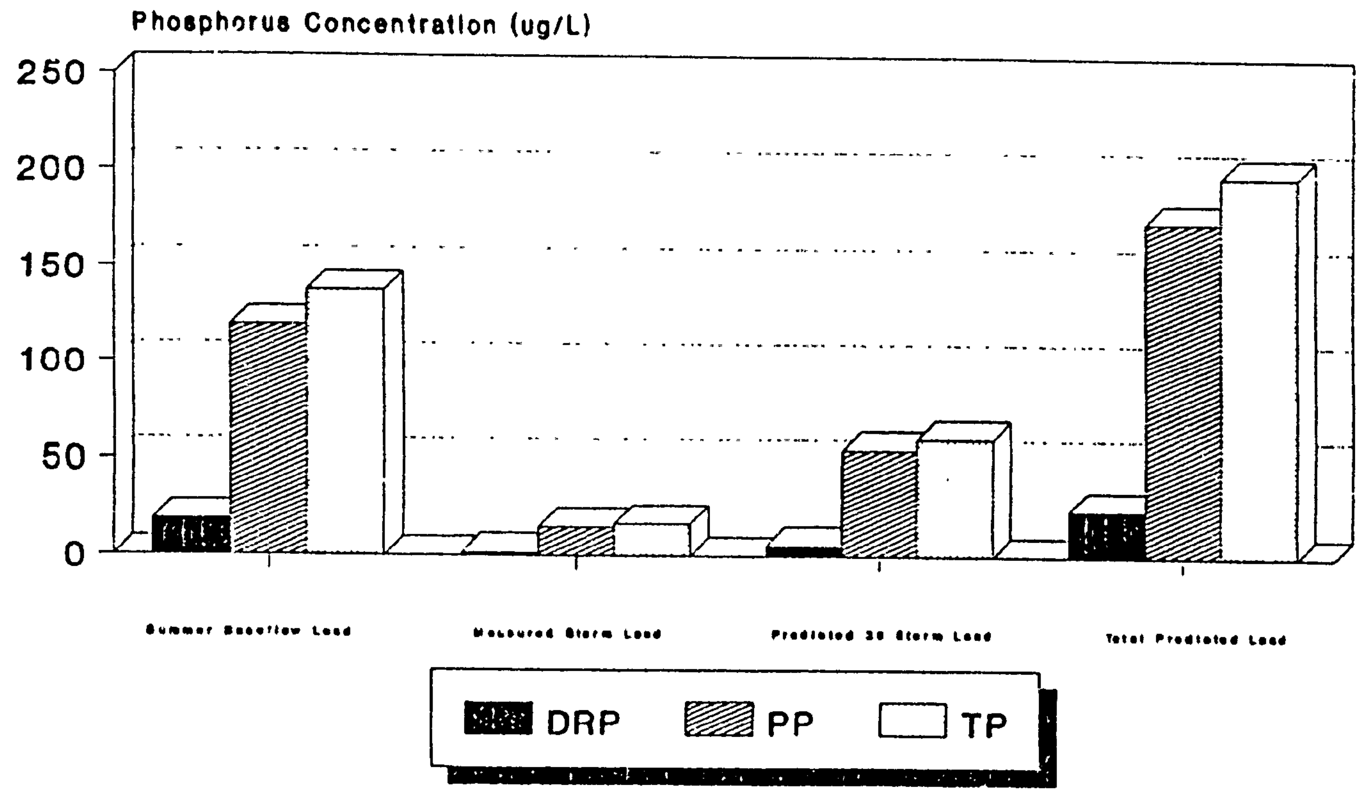
Pl = P export for the seven sampled storms (kg)

This is an estimate used only to show the potential magnitude of phosphate export from 38 events (Figure 4.1). By comparing these loads with the baseflow values in Figure 4.1 the significance of stormflow monitoring becomes evident.

It is important at this point to determine whether or not the source of phosphorus, that creates high phosphorus export during rainfall-runoff events, is from urban runoff. Table 4.4 shows the difference in TP, PP and DRP loads between Laurel Creek, at the beginning of the urban area: site 2, and at the end of the urban area; site 11, for stormflow and baseflow events. During baseflow, site 2 accounted for 43.9% of the TP, 47.9% of the PP and 18.2% of the DRP export, at site 11. During stormflow events, site 2 accounted for 5.3% of the TP, 5.4% of the PP and 4.0% of the DRP, load at site 11, which is significantly less than during baseflow. That less phosphorus, as a percentage, originates from site 2 during stormflow than during baseflow indicates that during stormflow much of the phosphorus originates downstream of site 2, which is the urban area.

Although not contradicting research by Keup (1968) and Harms et al (1978), who suggest that the increase in phosphorus concentration during high discharge events is a result of resuspension of bed

Figure 4.1
Predicted Phosphorus Loads at Site 11 During Baseflow and Stormflow



The total predicted load is the sum of the baseflow load and the predicted load for the 38 storms.

TABLE 4.4

PHOSPHORUS LOADS FROM MAY TO OCTOBER AT SITE 2
AS A PERCENTAGE OF SITE 11 LOADS

		Site 2 (Before urban input) (kg)	Site 11 (After urban input) (kg)	%
BASEFLOW	TP	60.53	137.71	43.9
	DRP	3.36	18.5	18.2
	PP	57.17	119.23	47.9
STORMFLOW	TP	0.86	16.34	5.9
FOR 7	DRP	0.07	1.73	4.0
STORMS	PP	0.79	14.62	6.7

material already enriched with phosphorus, the data in Table 4.4 does suggest that urban stormwater runoff may contribute a significant phosphorus load during rainfall-runoff events, to Laurel Creek.

During baseflow conditions, the mean TP concentration decreases from 150 ug PL^{-1} at site 2, to 80 ug PL^{-1}at site 11. This decrease in concentration may be a result of a diluting influence of the tributary creeks, sedimentation in Columbia and Silver Lakes, and phosphorus uptake by aquatic life in the lakes and the stream. Mean discharge, during baseflow increased from 31 L/s at site 2, to 156 L/s at site 11. This increase being the result of the two tributaries and possibly inflow from groundwater.

Phosphorus concentration actually decreases in Laurel Creek within the urban area during baseflow conditions, although mass export at site 11 is still greater as is illustrated by multiplying the mean phosphate concentration and the mean discharge at each site, 2 and 11. This calculation gives a mean total phosphorus export rate of 4.7 mg/s at site 2 and 12.5 mg/s at site 11. Thus, site 11, while less concentrated with phosphorus than site 2, exports 2.7 times the mass of P.

During stormflow events, there are two possible reasons why site 2 accounts for only 5.3% of the TP export at site 11 as oppcsed to 44% during baseflow. Between the two sites, either discharge increases while maintaining it's phosphate concentration, or the phosphate concentration increases resulting in an increase in mass export. Increase in discharge during stormflow is expected due to urban runoff and increased groundwater flow. Increased phosphorus concentration is the result of one or two processes. Keup (1968), suggests increase in phosphorus concentration during stormflow is due to resuspension of bedload already rich in phosphorus. The other source is highly concentrated urban runoff. Which process is responsible for increasing the phosphorus concentration during any given storm is not known for this study. However, analysis of Figure 4.2 shows clearly that the TP concentration of the urban runoff is higher than the TP concentration of Laurel Creek, meaning the urban input does increase the Laurel Creek TP concentration. It is assumed that both processes play a vital role in the phosphorus dynamics during stormflow. Analysis of Figure 4.2 shows that urban runoff is supplying Laurel Creek with water high in TP concentration. As discharge subsides in Laurel Creek the sediment-bound phosphorus is deposited on the creek bed until the next high flow period. It is then resuspended and transported downstream eventually being replaced by sediment phosphorus from urban runoff further upstream. Obviously this process will overlap spatially and temporally, as illustrated in Fig. 4.3:

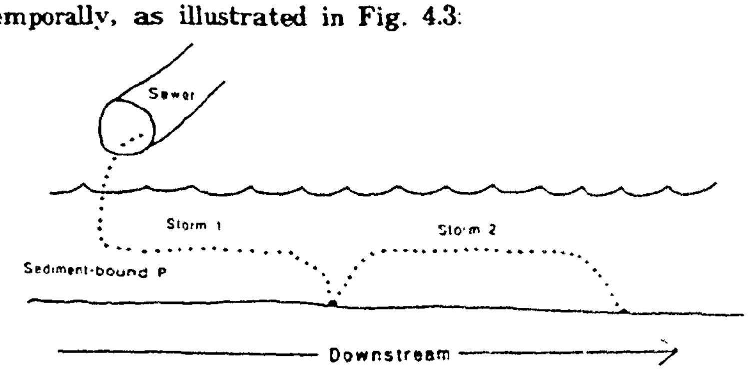
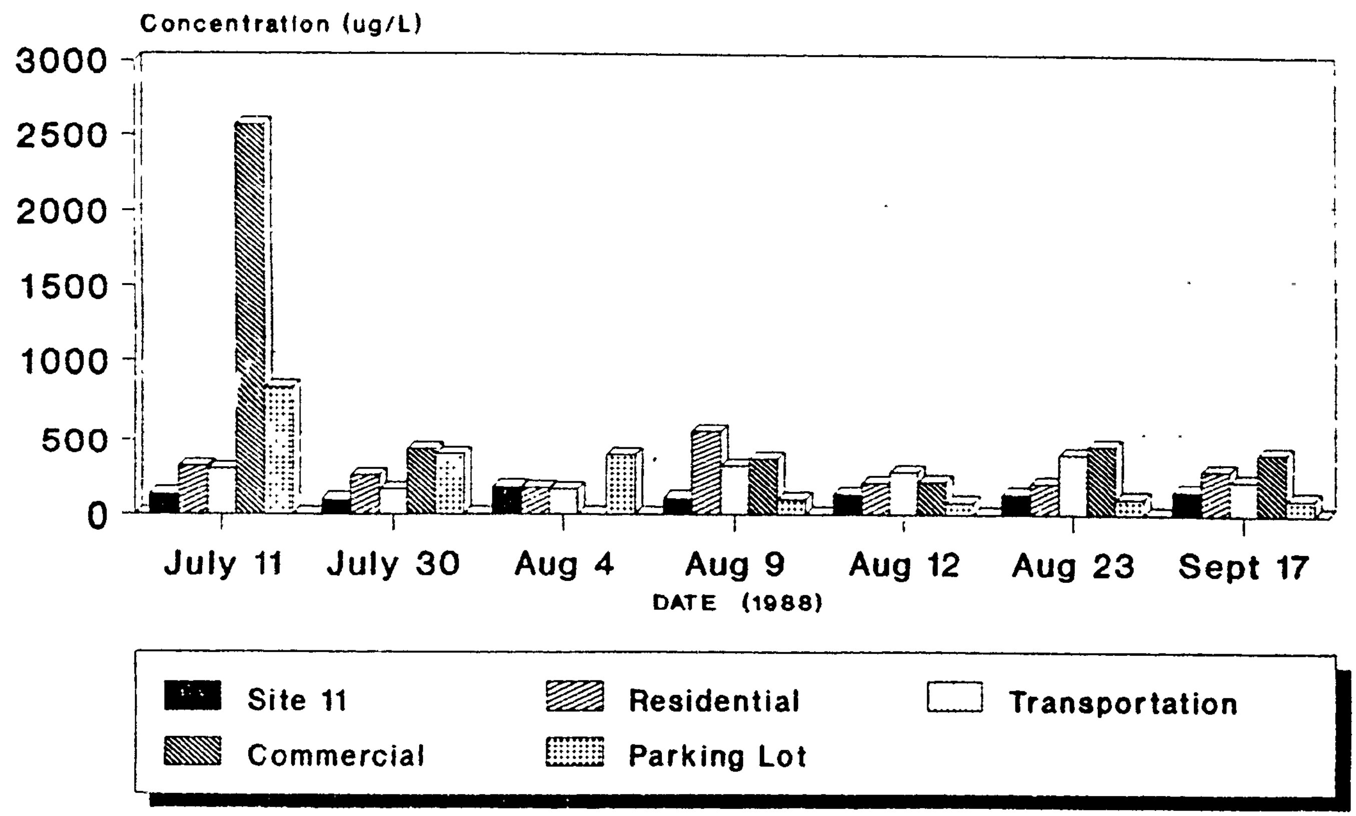


Figure 4.2
Average TP Concentrations For Each Land Use and Site 11 During Storm Events



* Using data from Tables 3.4 & 3.9.

4.2.3 Urban Runoff Phosphate Loads

The third objective of this thesis is to determine the contribution of phosphorus from urban land, and to then determine if land use or the percent of impervious surface of a land use, is responsible for the varying P contributions in urban runoff.

As discussed in the previous section, urban runoff is a source of phosphorus to Laurel Creek. The mean basin stormflow phosphate yield, for Laurel Creek, during storm events measured at the mouth of the creek is 0.36 g/ha TP and 0.04 g/ha DRP. These figures compare to;

TABLE 4.5

Phosphate Yields From Each Land Use

Land Use	TP (g/ha)	DRP (g/ha)
Residential	5.98	1.88
Commercial	6.43	1.87
Parking Lot	1.38	0.48
Transportation	0.92	0.07

These figures, are calculated using the impervious areas only. There is a large amount of precipitation falling on each land use that does not contribute to overland flow. This water is also a source of P to Laurel Creek, and should be included in calculating phosphate yields for each land use. Natural phosphate concentration levels were determined by sampling water from a groundwater pumping station, groundwater seepage into sewer A, and an artesian well near Columbia Street. Groundwater phosphate concentration values from these three sites were averaged, resulting in 0.019mgTP/L and .007mgDRP/L . This gives a groundwater yield of 1.43 g/ha TP and 0.53 g/ha DRP.

Table 4.6 shows the calculated groundwater phosphate input to Laurel Creek for each storm sampled during the summer of 1988. These values are the product of the volume of water landing on the pervious area of the basin and the groundwater phosphate concentration. flow varying due to many factors, such as soil porosity and soil moisture the P load may not enter the creek for a long time after the storm and is not likely accounted for in each storm's phosphate export at site 11. However it will eventually enter the creek system and should be accounted for.

As Table 4.5 shows the phosphate yields from the sampled land uses are greater than the yield from the Laurel Creek basin as a whole. Residential and commercial land produce greater P yields than transportation corridors and parking lots, yet these latter two contribute greater phosphate yields than the mean basin yield.

There are two reasons why transportation corridors produce less

TABLE 4.6

CALCULATED GROUNDWATER PHOSPHORUS INPUT

DATE	GROUNDWATER INPUT DRP (g)	TP (g)
July 11	577	1567
July 30	904	2453
Aug 4	1117	3032
Aug 9	527	1431
Aug 12	1243	3373
Aug 23	1017	2760
Sept 17	1230	3339

These values were calculated by multiplying the mean groundwater phosphate concentration by the volume of water landing on the pervious areas.

P than parking lots, despite having the same source of P (lead halophosphate from automobile exhaust) and despite handling larger volumes of traffic. First, vehicles travelling, on average, 60 km/h in the transportation corridor, will redistribute settled street dust, to pervious surfaces, such as medians, reducing the phosphate load on the street. Second, cars being started in a parking lot will often sit and run for a few minutes before leaving, allowing a build-up of lead-halophosphate in one area, (Laxen and Harrison, 1977).

Larger phosphate loads in the residential and commercial areas may be a result of phosphorus sources such as lawn fertilizers, automobile combustion products and animal faeces.

To examine urban phosphate inputs to Laurel Creek during stormflow, comparison of the predicted urban runoff phosphate export and the phosphate export at site 11 was undertaken for each storm. If the urban P input is less than the amount exported at site 11 for each storm, then Laurel Creek is acting as a source of P during storm events, supporting Keup's (1968), suggestion of resuspended bedload. Likewise, if the urban P input is greater than the export at site 11, Laurel Creek is acting as a sink. To calculate the predicted urban P input for each storm, the data from the four land uses was extrapolated to the entire basin. For each storm the measured yield for each land use was applied to the entire area of the respective land use.

Analysis of the data in Table 4.7 shows that for TP, Laurel Creek acted as a sink during 3 of the 7 storms, and as a sink for DRP during 6 of the 7 storms. If larger quantities of phosphorus are entering Laurel Creek during rainfall events than are being exported, at site 11, the phosphorus must be undergoing removal from the creek system at some point. There are three possible explanations for this removal:

i) Sedimentation: sediment-bound phosphorus may settle out in Columbia or Silver Lake, rather than remaining suspended until reaching site 11.

ii) Phosphorus Uptake: aquatic life may uptake phosphorus removing it from the creek.

iii) Settling: it is possible that during the recessional limb of the hydrograph, large quantities of PP will settle before reaching site 11.

4.2.3.1 Phosphate Sources

To examine the origin of phosphorus sources in the study area, the relationship between phosphate yields (TP, PP, and DRP) for each land use and the percent impervious of each land use are evaluated.

In order to determine if the variation in phosphorus yields among land uses are due to different sources, or different

TABLE 4.7

Predicted Urban Phosphorus Input
and Corresponding Export as Site 11

DATE	EXPORT AT SITE 11 DRP / TP (g)	URBAN INPUT (PREDICTED) DRP / TP (g)	SINK OR SOURCE DRP / TP
July 11	315 / 1305	603 / 1049	sink / source
July 30	211 / 841	218 / 1666	sink / sink
Aug 4	268 / 4571	355 / 874	sink / source
Aug 9	273 / 3299	637 / 3018	sink / source
Aug 12	316 / 4613	301 / 5768	source / sink
Aug 23	587 / 1678	1490 / 7353	sink / sink
Sept 17	99 / 1995	257 / 1590	sink / source

quantities of the same source, phosphate yields were regressed linearly with the percent of impervious land from which they originated. The regression was undertaken to show if any general trends among storms were obvious. Figures 4.4 - 4.6 show the best fit regression lines for the TP, PP and DRP phosphorus yields, versus the percent of impervious surface of the land from which they originated. These figures illustrate that for most of the seven storms, there is an inverse relationship between impervious area and phosphate export. For DRP there was an inverse relationship for all seven storms, and for PP, 5 out of the 7 storms had inverse relationships, July 30 and August 4 being the exceptions.

These relationships are controlled by anthropogenic influences, phosphorus accumulation from anthropogenic sources, as well as natural accumulations. As the July 30 and August 4 storm do not differ significantly from the other storms, with respect to precipitation, antecedent dry days and precipitation phosphate concentration, the fact that positive relationships occurred on these two days for PP is believed to be a result of anthropogenic variations, which were not monitored.

The general trend of the regression lines suggests that as the impervious area increases, the unit area export of phosphorus decreases. (The export is also dependent on the antecedent dry period as is discussed below). This suggests that the phosphorus sources in areas less impervious (residential and commercial), are

FIGURE 4.4

Total Phosphorous Export vs. % of Impervious Land

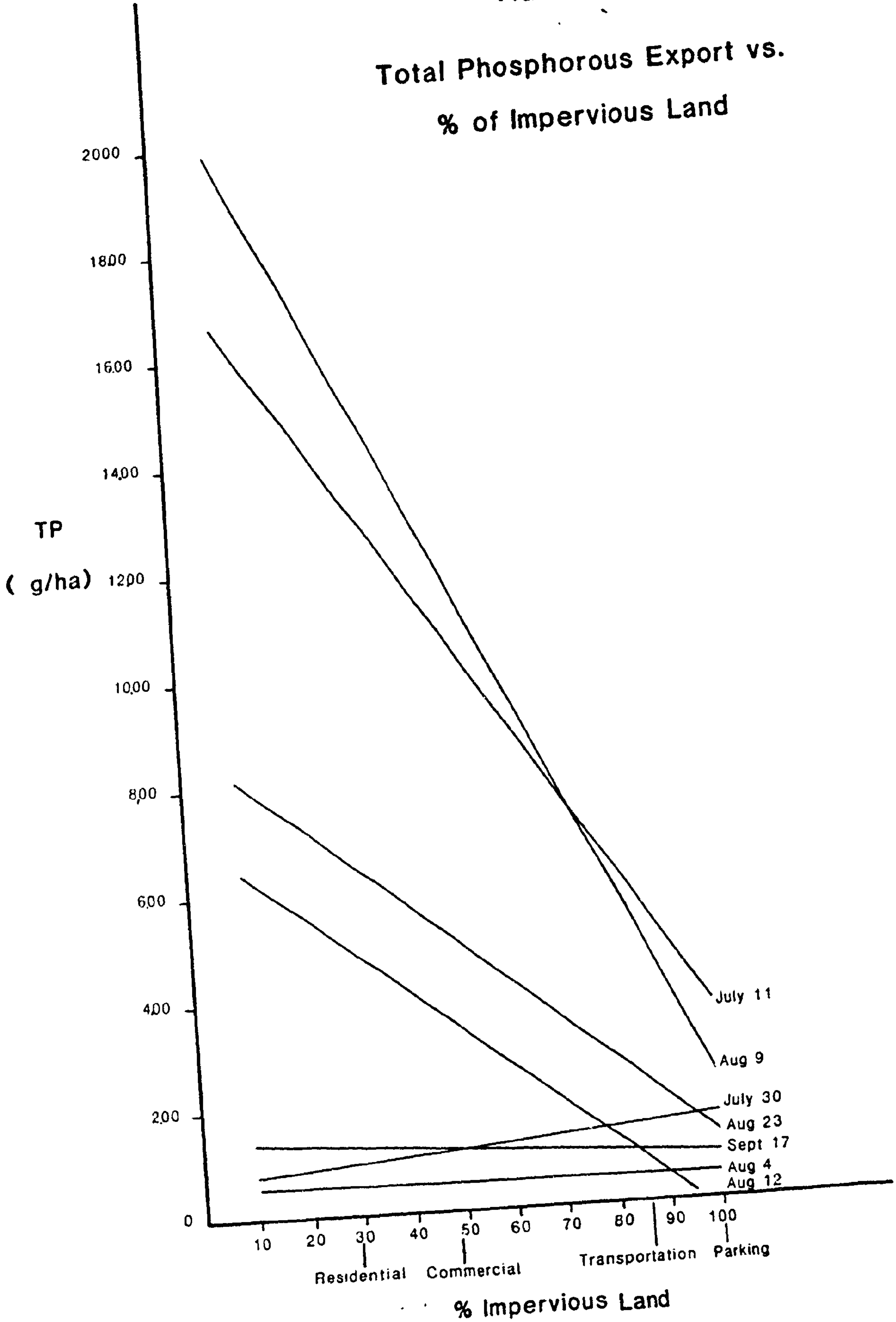


FIGURE 4.5
Particulate Phosphorous vs.
% of Impervious Land

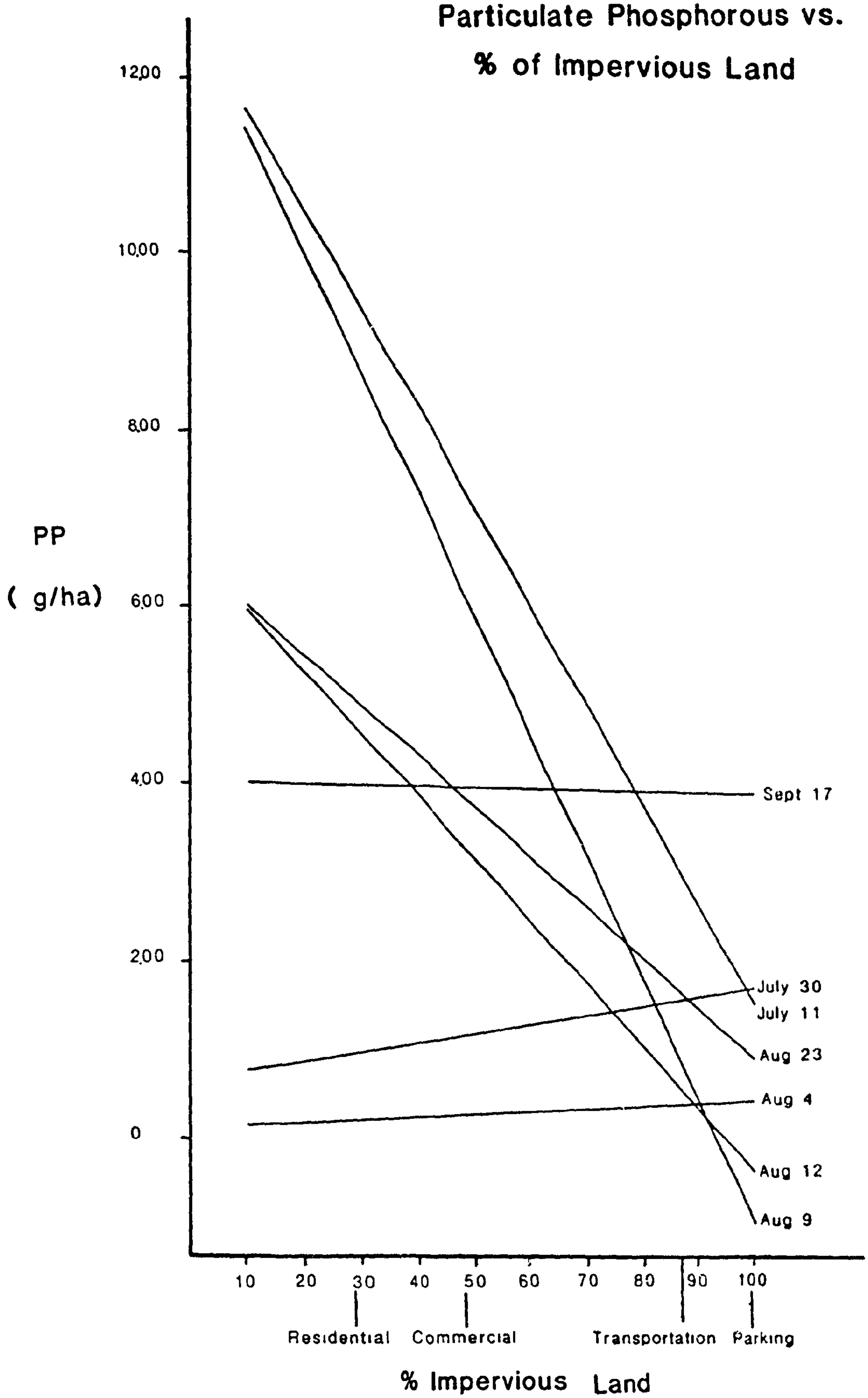
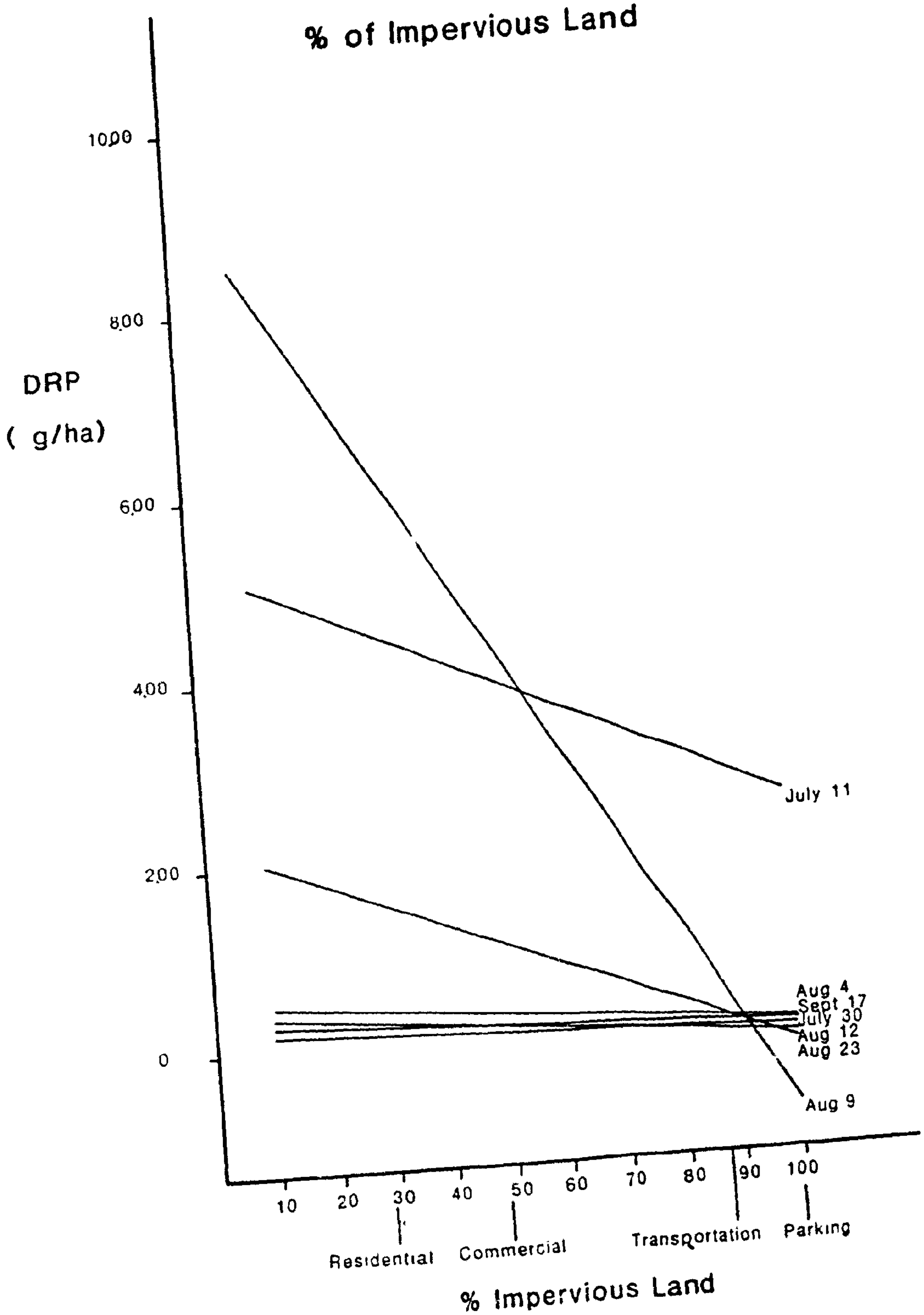


FIGURE 4.6

Dissolved Reactive Phosphorous vs.
% of Impervious Land



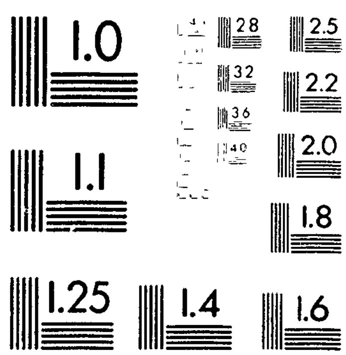
greater than those of areas with a high percentage of impervious area.

Figure 4.5 shows that on three occasions, July 30, August 4 and September 17, the 'best fit' regression lines were close to horizontal, whereas the other four storms were inverse. Examination of the precipitation data shows that these three storms had three of the four shortest antecedent dry periods. Similarly, Figure 4.6 shows four regression lines for DRP close to horizontal, occurring on July 30, August 4, August 12 and September 17. These four storms also have the four shortest antecedent dry periods. It is possible that with little time for P build-up on the streets, little variation occurs in the accumulation rate, creating an equal unit area yield for each land use. For storms with inverse regression lines, and likewise, long antecedent dry periods, it is possible that additional sources such as fertilizers accumulate, creating larger yields in the areas where these additional sources are likely to be found. (ie; residential land).

The fact that the horizontal regression lines occurred simultaneously for PP and DRP, three out of four storms, also suggests that the P on these occasions originated from the same source, and on the days of inverse regression lines, additional sources came into play.

Because the PP and DRP relationships are generally inverse, there is a possibility that they originate from the same source.

2 OF/DE 2



although at different rates for each land use. The fact that the sources of phosphorus are at least partially a result of anthropogenic inputs, suggests that it is not the imperviousness of an area that controls runoff phosphorus yields. Rather, it is the land use, and human interactions related to each specific land use. These sources will be further discussed in Section 4.4.

4.2.4 Comparative Studies

In order to assess the data collected in this study, it is important to compare the data to other studies that have examined phosphorus in urban runoff. Likewise, in order to determine the relative importance of phosphorus export from urban runoff, this section will examine phosphorus export from agricultural and forested land, based on information from previous research.

4.2.4.1 Urban Phosphorus Export

Table 4.8 lists the results of this study and previous studies that have examined phosphate export from urban land runoff. The average and range of phosphate concentrations of this study are comparable to the other reported studies for both total phosphorus and dissolved reactive phosphorus.

Table 4.9 compares the unit area exports of phosphorus reported in this and previous studies; all results have been converted to g/ha/day for comparative purposes.

TABLE 4.8

URBAN PHOSPHORUS CONCENTRATIONS REPORTED IN LITERATURE

DATE	AUTHOR	PLACE	LAND USE	Reported Urban Runoff Export TP(mg/l)	DRP(mg/l)
1943	Sawyer et al	Wisconsin	Urban	0.56	0.22
1959	Sylvester	Washington	Urban	1.4	0.78
1963	Weibel et al	Ohio	Residential		0.7 - 4.3
1972	Bryan	N. Carolina	Urban	0.15 - 2.5	0.08 -0.47
1974	Kleusener	Wisconsin	Residential	0.3 - 4.0	0.2 - 1.8
1989	This Study	Ontario	Residential	0.1 - 1.1	0.01 -0.47
			Commercial	0.21 - 5.3	0.01 - 3.1
			Transport	0.05 -0.76	0.01 -0.16
			Parking	0.05 -0.96	0.01 -0.88

TABLE 4.9

URBAN PHOSPHORUS YIELDS REPORTED IN LITERATURE

DATE	AUTHOR	PLACE	LAND USE	UNIT AREA EXPORT (g/ha/day)	
				TP	DRP
1969	Weibel	Ohio	Urban	2.88	
1971	Kleusener	Wisconsin	Urban	3.01	1.70
1972	Bryan	N. Carolina	Urban	4.50	
1973	Emery et al	Washington	Urban	0.41	
1978	Sonzogni and Lee	Wisconsin	Urban	3.01	
1982	Miller and Mattraw	Florida	Residential	10.08	
			Commercial	1.90	
			Highway	1.79	
1988	This Study	Ontario	Residential	2.40	1.13
			Commercial	3.60	1.09
			Transportion	0.23	0.03
			Parking Lot	0.45	0.39

Miller and Mattraw (1982), report that urban TP concentrations in runoff from commercial, residential and highway land uses in Florida, U.S.A. are 1.90 g/ha/day, 10.08 g/ha/day and 1.79 g/ha/day respectively. Marsalek (1988), reports TP exports of 3.4 - 4.4 g/ha/day for residential areas and 4.6 - 9.3 g/ha/day for commercial areas in various studies in Canada and the United States. Only the study by Kleusener (1971), gave comparable DRP unit area exports. He reports a DRP yield of 1.7 g/ha/day from an urban area, which is comparable to the DRP unit area exports for the commercial and residential land uses in this study (see Table 4.9).

Considering the spatial and temporal variation among these studies, and the large number of variables that differ between time and place, it is not possible to compare the values of this study to those studies cited in Table 4.9, except to say that the concentration ranges are comparable.

4.2.4.2 Agricultural Phosphorus Export

Initial phosphorus abatement programs focused on point sources, such as industrial effluent and treatment plants, as they were easily monitored (Weibel et al. 1964). Due to the affinity phosphorus has for particulate matter, abatement measures also focused on agricultural land runoff (Weidner et al, 1969). The significance of urban runoff phosphorus export was recognized over 25 years ago (Weibel et al., 1964). However, phosphorus abatement measures in urban areas seemed inappropriate due to the small percentage of urban land, compared to the vast amount of agricultural land. As agricultural land dominates the Great Lakes basin, it would not be cost effectiv to focus phosphate abatement programs on urban runoff, unless urban phosphorus yields are considerably greater than agricultural phosphate yields. Thus, a comparison of urban and agricultural phosphate yields is undertaken.

Phosphorus input from agricultural land runoff in the Great Lakes basin, has four main sources: 1) surface runoff from cropland, 2) runoff from livestock operations, 3) streambank erosion and 4) runoff from unimproved land, (land that has more than 70% of its area in perennial cover), (Miller and Spires, 1978). Miller et al (1982) in a study of Southern Ontario, calculate that approximately 70% of the agricultural phosphorus load, comes from cropland runoff, 20% from livestock operations, and 10% from a combination of unimproved land and streambank erosion.

Kunishi et al (1972), state that the P concentration of agricultural runoff is a function of soil quantity, chemical characteristics, (P sorption capacity), and origin (streambank, subsoil, topsoil), from which the runoff originates.

To assess phosphorus export from agricultural and rural land, it is first necessary to understand what controlling factors influence phosphorus export. Four important factors controlling rural P export are land management, crop type, geology and soil type.

As phosphorus has an affinity for particulate matter, soil management on farmland can have a great effect on phosphorus export. If erosion from agricultural and rural land can be reduced, there is great potential for reducing phosphorus export. For example, contour tilling (tilling the earth parallel to natural contours), as opposed to straight-row tilling (tilling across contours), reduces soil loss and is therefore capable of reducing phosphorus export (Weidner et al., 1969).

The role of crop type on phosphorus export has also been examined (Buchman and Brady, 1961; Johnson et al, 1965; and Holt, 1969). Timmins et al (1968) found that rotation hay plots (plots where crops are rotated seasonally with hay) lost three times as much phosphorus as plots in continuous corn.

Dillon and Kirchner (1975), found significant differences in P export among areas of differing geology. They found the average annual TP export of forested igneous watersheds (0.13 g/ha/day) to be significantly different than forested sedimentary watershed TP export (0.30 g/ha/day). Likewise, they found a significant difference between igneous watersheds with forest and pasture (0.32 g/ha/day), and sedimentary watersheds with forest and pasture (0.79 g/ha/day).

Due to the many variables affecting phosphorus export from a watershed, there is a possibility of a large range in P export, within and among watersheds. Table 4.10 lists agricultural and rural phosphate export values from other studies and the P export value for the agricultural portion of the Laurel Creek basin.

The lowest TP yield from agricultural or rural land runoff (Table 4.10), is 0.16 g/ha/day, coming from agricultural land with sedimentary geology corresponding to the TP value of this study, 0.19 g/ha/day. The range of DRP runoff yields for the previous studies is 0.15 - 0.60 g/ha/day, compared with 0.02 g/ha/day for this study.

The low agricultural P export values for this study may be attributable to the sampling period. Phosphorus loss from agricultural areas during summer months is minimal compared to springmelt phosphorus loss. Owen and Johnson (1966), in a study in Southern Ontario found 73 - 80% of the annual phosphorus loss occurred during February, March and April, as compared to 11% for May through September. Likewise, Engelbrecht and Morgan (1961), found 6% of the annual TP loss occurred between April and September, in Illinois surface waters. As the sample period for this study was May through October, it is understandable that the calculated phosphate export would be less than those of studies incorporating twelve month sampling periods.

The mean urban P export from the literature (Table 4.9), is 3.45 g/ha/day TP and 1.7 g/ha/day DRP. These values compare respectively to 0.34 g/ha/day and 0.25 g/ha/day for agricultural and

TABLE 4.10

RURAL PHOSPHORUS EXPORT REPORTED IN LITERATURE

DATE	AUTHOR	PLACE	LAND USE	UNIT AREA EXPORT (g/ha/day) TP	DRP
1966	Owen and Johnson	Ontario	(A) Sedimentary	0.47	
1967	Missingham	S.W. Ont	(A) Sedimentary	0.16	
1971	Cywirn et al		(A) Corn	0.63	
			Alfalfa	0.33	
1972	Schuman et al	Iowa	(A) Corn		0.30
			Bromegrass	0.76	0.60
1975	Singer and Rust	Minnesota	(A) Agricultural	0.25	0.16
1988	This Study	S.W. Ont	(A) Agricultural Sedimentary	0.19	0.02
1970	Schindler et al	Ontario	(R) Forest Igneous	0.24	
1975	Dillon et al	S. Ont	(R) Forest Igneous	0.13	
			Pasture & Forest	0.30	
1978	Miller et al	S.W. Ont	(R) Unimproved Land	0.21	
			Streambed Erosion	0.08	

(A) - Agricultural Land
(R) - Rural Land

rural land. These values show that on average, urban TP export is ten times, and DRP export seven times greater, than export from agricultural and rural land. Owen and Johnson, (1966), found that urban annual TP export in Toronto, Ontario, was seven times greater than three nearby agricultural watersheds.

By multiplying the agricultural P export value cited by Owen and Johnson, (1966), by a factor of seven, a predicted urban yield of 3.3 g/ha/day is calculated. This is extremely close to the average urban phosphate export (3.45 g/ha/day), calculated from the previous literature.

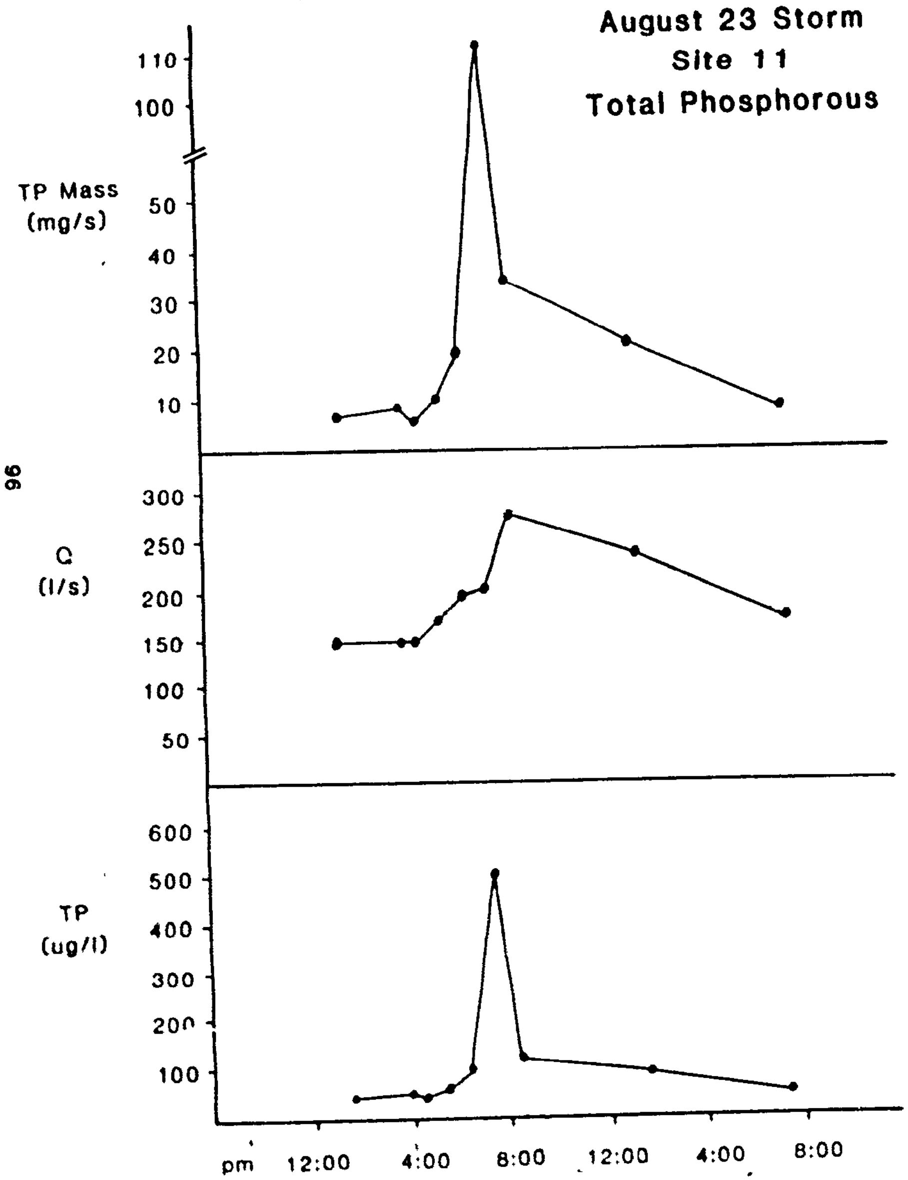
4.3 HYDROGRAPHS AND CHEMOGRAPHS

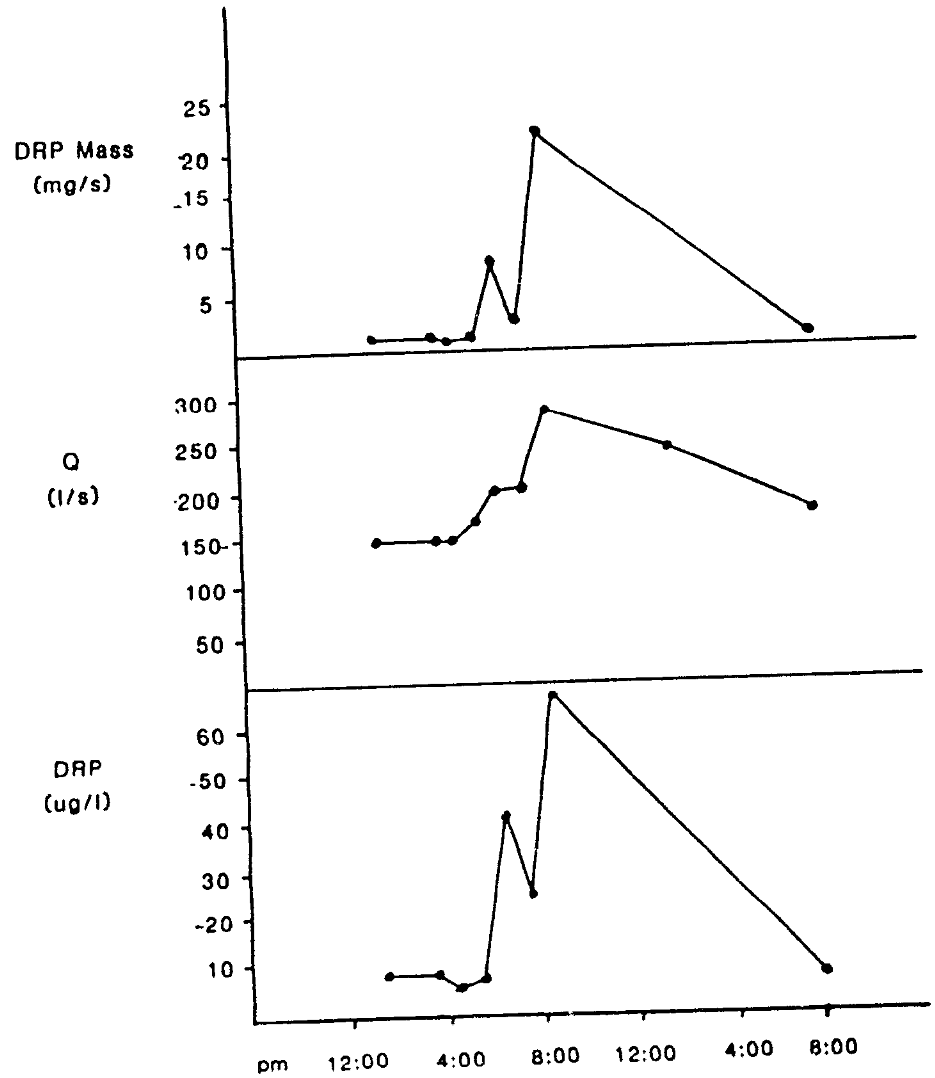
For this study, it is important to compare the phosphorus flux of streamflow during high discharge to the phosphorus flux of urban runoff to determine any differences between the two types of flow. Researchers have examined phosphorus transport in rivers during stormflow and meltwater events, (Keup, 1968; Cahill et al, 1974; Verhoff et al, 1979,1980,1982; Yaksich et al, 1980). As a result of these investigations, several conclusions about the changes in phosphorus concentration over time, during high discharge events have been reached. First, rivers are classified as stable or event response. Total phosphorus transport in event response rivers is dominated by runoff events, while stable response rivers, characterized by watersheds with soils of course texture and high permeability, are not dominated by runoff events (Yaksich et al, 1980). Laurel Creek TP transport is dominated by runoff events resulting from the large amount of runoff from impermeable areas, thereby classifying it as an event response creek. Second, for event response rivers, the TP concentrations increase with an increase in discharge, while DRP concentration decreases as discharge increases (Cahill et al, 1974). Third, for event response rivers, the peak of TP concentration occurs slightly before the peak in discharge (Verhoff et al, 1982).

4.3.1 Phosphorus Transport in Laurel Creek

Figure 4.7 shows the hydrograph and chemographs for site 11 on Laurel Creek for the August 23 storm. The graphs for the August 23 storm are used here as they best illustrate the relationships discussed below. As noted in the literature, (Verhoff et al, 1980) and as can be seen in the chemograph, the TP concentration increases with increasing discharge, and decreases with decreasing discharge. Discharge at site 11 was regressed on TP concentration to determine the relationship between these two variables. The correlation coefficient calculated is .42 which is significant at the 95% level, illustrating a positive correlation between discharge and TP concentration. This phenomenon is thought to be the result of two processes: the addition of highly concentrated surface runoff, and resuspension of phosphorus rich streambed sediments (Harms et al,

Figure 4.7


August 23 Storm
Site 11
Total Phosphorous
TP Mass
(mg/s)
110
100
50
40
30
20
10
Q
(l/s)
300
250
200
150
100
50
TP
(ug/l)
600
500
400
300
200
100
pm
12:00
4:00
8:00
12:00
4:00
8:00


August 23 Storm
Site 11
Dissolved Reactive Phosphorous
DRP Mass
(mg/s)
25
20
15
10
5
Q
(l/s)
300
250
200
150
100
50
DRP
(ug/l)
60
50
40
30
20
10
pm
12:00
4:00
8:00
12:00
4:00
8:00

1975).

A contradiction between the findings of previous researchers and this study, occurs in the change in DRP concentrations over time. Wang and Evans (1970), and Cahill et al (1974), report that as discharge increases, the DRP concentration decreases. This change in DRP concentration is attributed to a dilution effect. This is believed to be the result of stormwater with low DRP concentration, diluting highly concentrated point sources (Cahill et al, 1974). During four of the seven storms of this study, DRP concentrations increased with increasing discharge. During one storm, the dilution effect was observed, and the DRP concentration remained constant for the two remaining storms. Discharge at site 11 was regressed on DRP concentration at site 11 to determine the relationship between these two variables. The calculated correlation coefficient is .07 which is not significant, suggesting there is no relationship between these two variables. Figure 4.7 shows this increase in DRP concentration for the August 23 storm. The discrepency between this study and what has been observed in other phosphorus studies is presumably the result of different baseflow DRP concentrations for Laurel Creek and other surface waters, such as the Brandywine River in Southern Pennsylvania, which was studied by Cahill et al (1974). The Brandywine River has six point sources contributing large amounts of DRP to the baseflow, resulting in extremely high DRP baseflow concentrations (.915mg/L).

The addition of stormwater runoff in the Brandywine River system caused a dilution effect, whereas in the present study, addition of stormflow tended to increase the DRP concentration in Laurel Creek. Low DRP concentrations in Laurel Creek, averaging .015mg/L are not diluted, rather they are enriched by added stormwater.

Based on the above explanation, rivers that receive highly concentrated point source effluent, are likely to observe the diluting effect for DRP, while smaller tributaries, such as Laurel Creek, which have low baseflow DRP concentrations, are likely to undergo an increase in DRP concentration during high discharge events.

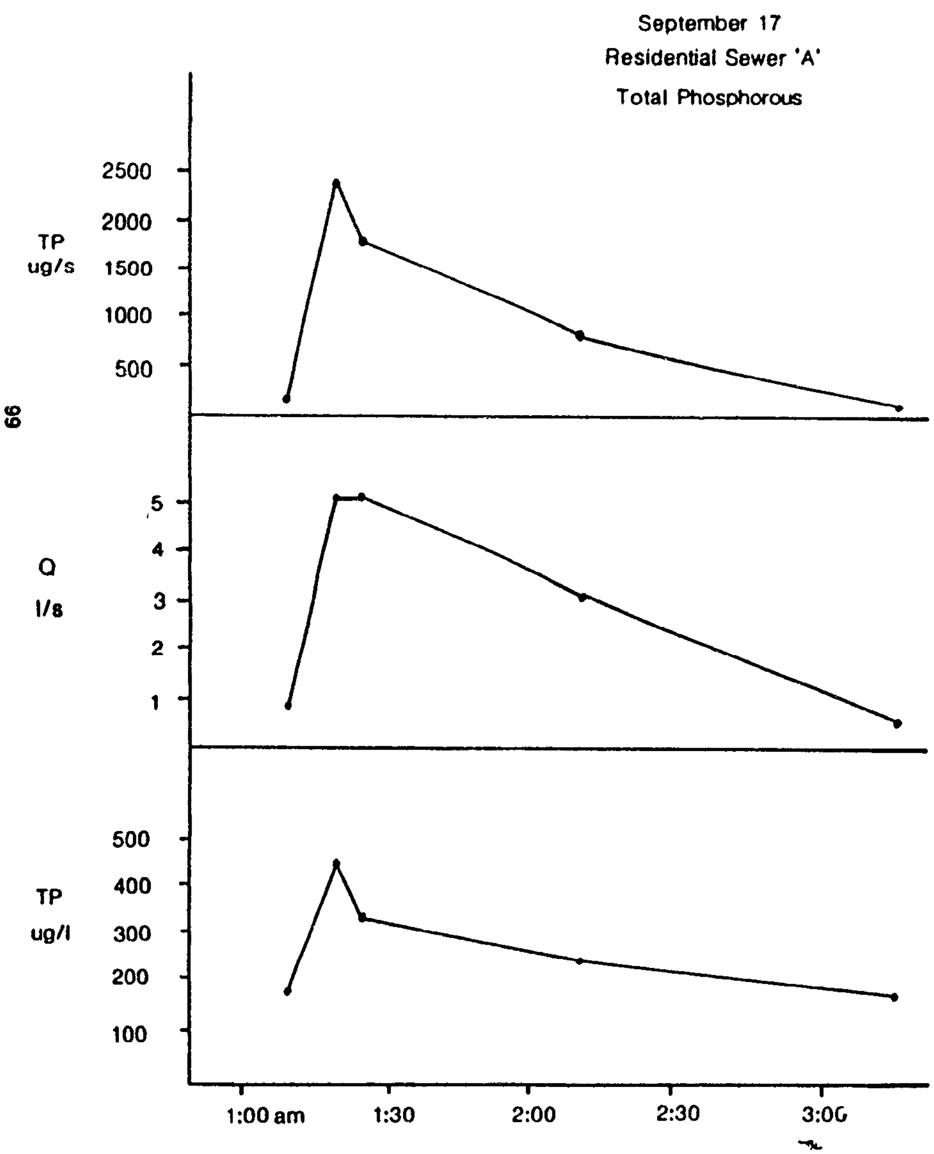
Figure 4.7 shows that the peak in TP concentration occurs slightly before the peak in discharge, which is consistent with previous studies of event response rivers.

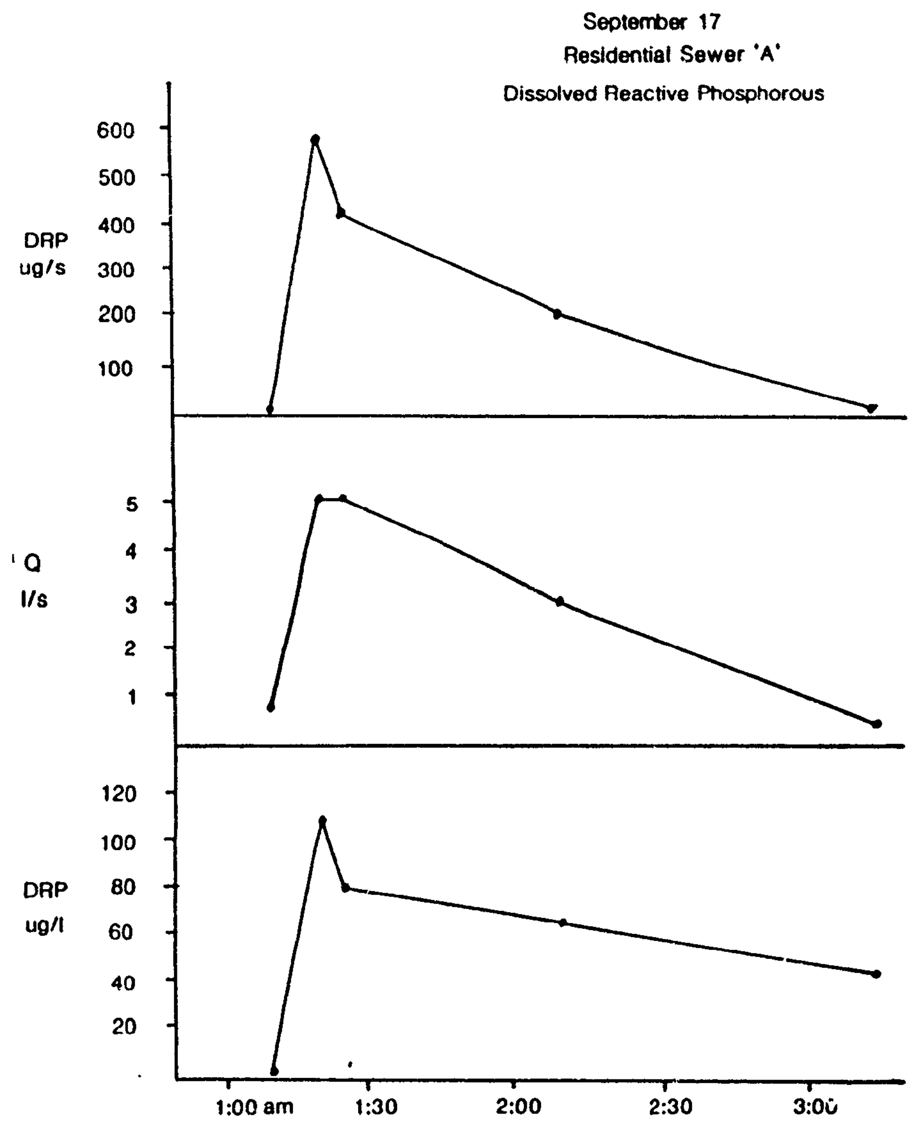
Analysis of Figure 4.7 shows that phosphorus transport in Laurel Creek is consistent with event response rivers in other studies. The exception being the increase in DRP concentration, as discharge increases, a result of the difference in background DRP levels.

4.3.2 Phosphorus Transport in Urban Runoff

Figure 4.8 shows the hydrograph and chemographs for the residential land use, Sewer A, for the September 17 storm. The graphs for the September 17 storm are used here as they best

FIGURE 4.8


September 17
Residential Sewer 'A'
Total Phosphorous
TP ug/s
2500
2000
1500
1000
500
Q l/s
5
4
3
2
1
TP ug/l
500
400
300
200
100
1:00 am
1:30
2:00
2:30
3:00


September 17
Residential Sewer 'A'
Dissolved Reactive Phosphorous
DRP ug/s
600
500
400
300
200
100
Q l/s
5
4
3
2
1
DRP ug/l
120
100
80
60
40
20
1:00 am
1:30
2:00
2:30
3:00

illustrate the relationships discussed below. In this section, these graphs will be analyzed to determine similarities and differences of phosphorus transport between residential land runoff and Laurel Creëk flow.

Total phosphorus concentration increased as discharge increased for urban runoff during this storm. This results from the suspension of urban sediment produced by urban runoff. The characteristics of DRP concentration in urban runoff appears to act similarly to the TP concentration, (Figure 4.8). No dilution is observed or expected as precipitation is the primary source of water to urban runoff. The increase in DRP results from the leaching of organic matter from the urban land, as well as other sources discussed in Section 4.2.3.1. During four of the seven storms, DRP concentration continued to increase while discharge decreased, and during the three remaining storms, the DRP concentration decreased as discharge decreased. This increase or decrease may be a result of the the accumulation period of urban sediment, although this is not supported by the data in this study. Unlike the timing of the peak in TP concentration in event response rivers, the timing of the peak in TP concentration is simultaneous with the peak in discharge for the seven storms, for the residential land.

Figure 4.8 shows that the phosphorus transport in urban runoff is dissimilar to that of event response streams and rivers. While TP concentration increases with increasing discharge, the DRP concentration also increases with increasing discharge, and the peak in TP concentration occurs at the same time as the peak in discharge, not before, as is reported for event response rivers.

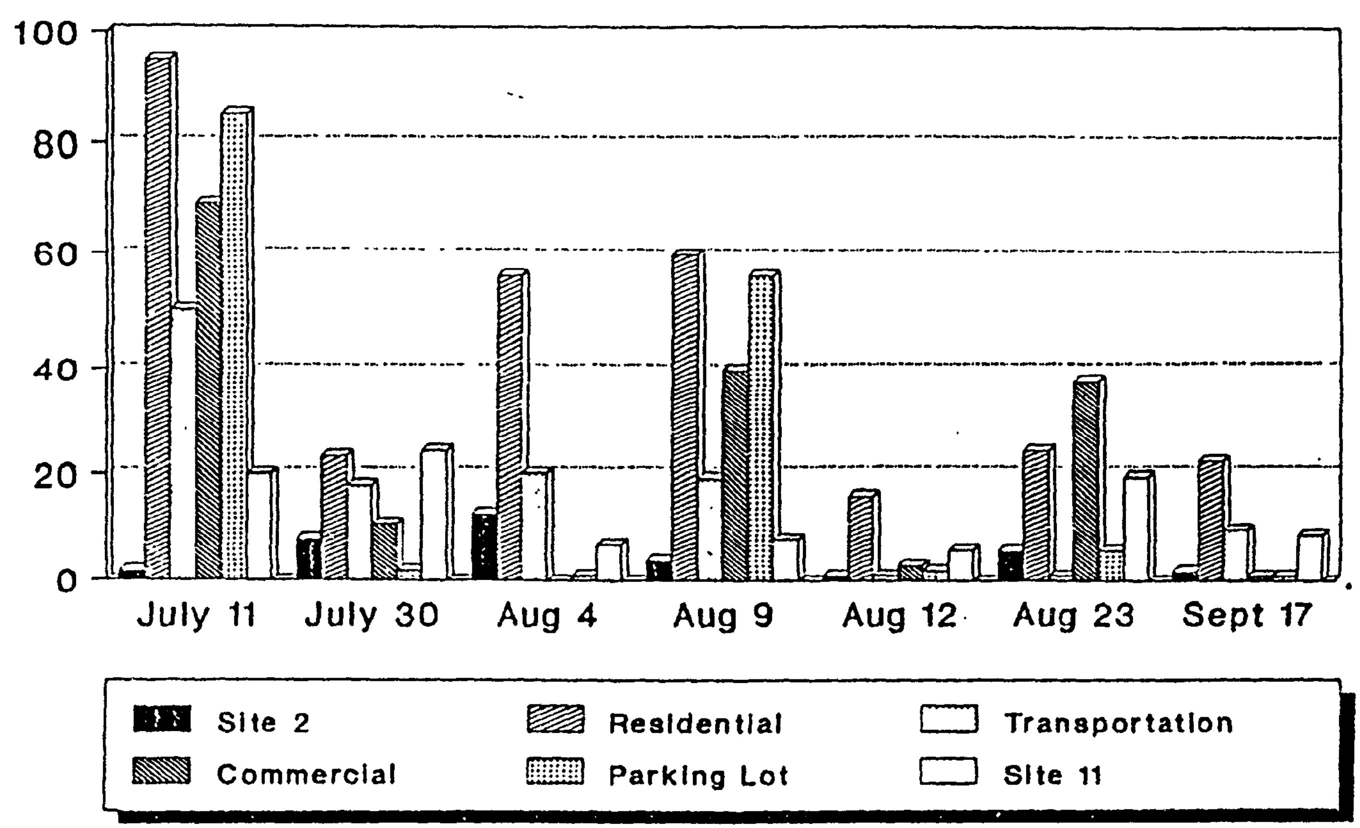
4.4 DISSOLVED REACTIVE / TOTAL PHOSPHORUS CONCENTRATION RATIOS

In this section dissolved reactive / total phosphorus concentration ratios will be used to examine the sources of DRP and TP in Laurel Creek. Dissolved reactive phosphorus as a percent of TP was plotted for each of the sampled storm sewers and sample sites 2 and 11, to determine the spatial variation of DRP inputs and outputs as well as explain potential sources of DRP, (Figure 4.9).

A series of quantitative observations can be made regarding the stream phosphorus composition during baseflow and stormflow events. Between site 1 (before the urban area), and site 2 (start of the urban area), the DRP concentration decreases, on average, from two sites increases from .038mg/l at site 1 to .145mg/l at site 2. The change in phosphorus composition between these two sites may be the result of adsorption / desorption processes or additional P sources such as the resuspension of sediment, occurring in the Laurel Creek Reservoir immediately upstream of site 2.

At the downstream site 11, DRP made up more of the TP load, than at sample site 2, although most of the TP is still particulate. Site 2 averaged 94% PP during stormflow, and site 11 averaged 87%. This increase in DRP between sites 2 and 11 suggests instream

Figure 4.9
DRP Concentration as a Percent of TP



transformation processes such as desorption or sedimentation are taking place or the addition of DRP during storm events.

Dissolved reactive phosphorus in urban runoff, often makes up the greater percentage of the TP concentration, (Figure 4.9). This shows up dramatically in the July 11 storm where the average runoff phosphorus concentration from the four sampled land uses contained 75% DRP. Table 4.11a shows the average DRP / TP for sites 2 and 11, as well as the four sampled land use areas during the seven storm events. There is an increase of 7% in DRP concentration between sites 2 and 11.

A t-test undertaken to compare mean DRP / TP concentration ratios between site 2 and 11 shows the difference between these two sites is significant at the 95% confidence level. This difference may be the result of urban runoff with higher DRP / TP concentration ratios. A t-test was also undertaken to compare the mean DRP / TP concentration ratios of sites 2 and 11 to the mean DRP / TP concentration ratio of urban runoff. The results of the t-test show that while site 2 differed significantly from the urban runoff (at 95%), site 11 did not differ significantly (at 95%). Analysis of the t-test results suggests that prior to the addition of urban runoff, Laurel Creek DRP / TP concentration ratios are significantly different than those of urban runoff, and after the addition of urban runoff, Laurel Creek DRP / TP concentration ratios do not differ significantly from urban runoff.

TABLE 4.11a

DISSOLVED REACTIVE PHOSPHORUS AS A PERCENT OF TOTAL PHOSPHOROUS FOR SITES 2 AND 11 AND THE FOUR LAND USES

	%DRP Concentration	DRP MASS (kg)
Site 2	6	0.07
Residential	42	3.86(predicted)
Commercial	27	
Parking Lot	23	
Transportation	17	
Site 11	13	2.16

Average of the seven sampled storms.
Total DRP mass for the seven sampled storms.

TABLE 4.11a

SPEARMAN RANK CORRELATION BETWEEN DRP / TP CONCENTRATION RATIOS OF URBAN RUNOFF AND ANTECEDENT DRY PERIOD AND THE PRECIPITATION PHOSPHATE CONCENTRATION

	Antecedent Period (r)		DRP Concentration (r)	
Residential	0.63	(90%)	0.88	(99%)
Transportation	0.52	(-)	0.91	(99%)
Commercial	0.93	(99%)	0.75	(95%)
Parking Lot	0.80	(95%)	0.45	(-)

Values in brackets give level of significance.

Table 4.11a also reports the total DRP export for sites 2 and 11 during the seven storm events, as well as the predicted (section 4.2.2) urban DRP export for these seven storms. These values show that the urban DRP input is sufficient to create the increase in DRP export between sites 2 and 11. The fact that more DRP entered Laurel Creek from the urban area, than was exported at site 11, suggests that Laurel Creek acts as a sink for DRP during storm events, (see Table 4.7). It is also possible that the DRP from the urban runoff is converted to TP upon entering Laurel Creek, resulting in an increase in TP concentration and moderating the increase of DRP in the creek.

Combining the fact that urban runoff is enriched in DRP relative to Laurel Creek, (as shown by the t-test), and the fact that urban runoff contributed more than enough DRP to explain the DRP increase between sites 2 and 11, illustrates that urban runoff is responsible for increasing DRP export at site 11 during storm events and lowering the ratio of DRP to TP at site 11.

The average DRP ratios reported in Table 4.11a show a large range among the various urban land uses. Likewise, each land use area varies in percentage of DRP among the seven storm events. Dissolved reactive phosphorus concentration as a percent of TP concentration for the land uses ranged considerably for the seven storms;

Table 4.12

Range of DRP / TP Ratios for Each Land Use

Land Use	Range
Residential	15-96%
Commercial	1-71%
Parking Lot	1-88%
Transportation	3-53%

To examine the changes in ratios among storms, they were regressed with the storm precipitation data (Table 4.2) using Spearman's Rank Correlation. The results of this regression for each land use shows a significant positive correlation between DRP / TP concentration ratios and antecedent dry period, and DRP / TP concentration ratios with the precipitation DRP concentration (Table 4.11b). The ratios of DRP to TP in urban runoff are a function of the antecedent dry period and the DRP concentration of the precipitation. The results of the regression analysis suggest that the range in DRP / TP concentration ratios for any one land use is partially a function of these variables. The residential area is used to illustrate this point. The July 11 storm, which had the longest antecedent dry period (13 days), and the highest precipitation DRP concentration (40 ug/l), created urban runoff with

96% DRP. The August 12 storm, which had the shortest antecedent dry period (1 day), and the lowest DRP concentration (2 ug/l), produced urban runoff with 15% DRP. A statistical regression using the Spearman rank correlation test between runoff DRP / TP concentration ratios and the DRP / TP ratios of the precipitation did not produce significant correlations.

The variation in DRP ratios among land uses would presumably be nonexistent if accumulated sources of phosphorus were identical for the different land uses. It is possible that poorly applied lawn fertilizer, accumulated animal faeces, cut grass, and automobile combustion products, which are more prominent in residential areas, are the source of DRP to the residential runoff, accounting for the highest, low end value (15%) of the range, for all four land uses.

Cowen and Lee (1973), discuss the leaching of dissolved phosphorus from fallen leaves by urban runoff and conclude that this process may contribute enough phosphorus to 'fertilize' runoff water above critical concentrations often suggested as causing algal growth. It is suggested that dead grass, animal faeces, lawn fertilizers, and automobile combustion products act in a similar fashion, contributing to the residential DRP runoff export. Presumably, with fewer potential sources of DRP, the other three land areas, do not accumulate DRP as rapidly as the residential area, resulting in urban runoff with little DRP (eg. 1%).

4.5 PHOSPHORUS LOAD MODEL

This section examines the possibility of using a multiple regression model to predict phosphorus export at site 11 on Laurel Creek for individual storm events. Calculation of phosphate export for storms not sampled this summer could be made possible by employing a regression model. Multiple regression equations were employed to predict P export for those storms not sampled during the study period. The variables considered in these equations are; precipitation (mm), phosphate concentration of precipitation (ug/l), antecedent dry period (days), and peak discharge (m^3/s) for each storm event. For each variable n=7.

Table 4.13 shows the regression equations developed for predicting TP and DRP export from the four land uses, and for site 11 at the mouth of Laurel Creek. The combination of all four variables produced the highest correlation coefficients.

Predicted loads, using equation 'MouthTP' in Table 4.13, for site 11 are shown in Table 4.15 for the seven storms that were sampled, with the measured loads, the residuals, and the percent error between the predicted and measured export. Analysis was undertaken to determine if antecedent conditions correlated with the error involved for each storm. The data did not suggest any correlation.

To calculate phosphate export for the storms that were not

TABLE 4.13

MULTIPLE REGRESSION EQUATIONS WITH FOUR VARIABLES

Equation Name	Equation	r	r^2
MouthTP	$y=-9641.7 + 804.8x_1 + 55.6x_2 - 350.9x_3 + 1491.4x_4$	.968	.937
ResTP	$y=102.0 - 10.7x_1 + 0.11x_2 - 5.14x_3 + 0.86x_4$	.979	.959
TransTP	$y=-11.1 + 1.08x_1 - 0.03x_2 + 0.89x_3 + 2.09x_4$	.987	.974
ComTP	$y=-59.3 + 5.16x_1 + 0.11x_2 + 4.29x_3 - 3.07x_4$	.997	.994
ParkTP	$y=1.87 - 0.13x_1 - 0.01x_2 + 0.14x_3 + 0.19x_4$	.959	.921
MouthDRP	$y=492.5 - 7.63x_1 - 8.76x_2 + 20.54x_3 - 29.59x_4$	.769	.591
ResDRP	$y=57.4 - 6.45x_1 + 0.26x_2 - 2.49x_3 + 0.28x_4$	.967	.934
TransDRP	$y=0.19 - 0.03x_1 + 0.01x_2 - 0.01x_3 + 0.09x_4$	.986	.971
ComDRP	$y=-11.6 + 1.03x_1 + 0.04x_2 + 1.43x_3 - 0.92x_4$	.982	.964
ParkDRP	$y=-0.96 + 0.06x_1 + 0.01x_2 + 0.09x_3 + 0.06x_4$	.931	.868

TABLE 4.14

MULTIPLE REGRESSION EQUATIONS USED TO PREDICT UNSAMPLED STORM EVENTS

Equation Name	Equation	Predicted Load (g)	r	r^2
MouthTP	$y=5050.8 - 121.9x_1 - 275.3x_3 \pm 734.7$	97,367 TP	.548	.301
ResTP	$y=252.2 - 22.5x_1 - 10.8x_3$	3,598 "	.845	.714
TransTP	$y=4.9 - 0.22x_1 - 0.18x_3$	84 "	.196	.038
ComTP	$y=-26.9 + 2.03x_1 + 3.84x_3$	392 "	.927	.859
ParkTP	$y=-0.55 + 0.06x_1 + 0.09x_3$	14 "	.758	.575
MouthDRP	$y=40.9 + 22.1x_1 + 20.7x_3 \pm 165.6$	10,326 DRP	.372	.138
ResDRP	$y=110.9 - 10.6x_1 - 4.4x_3$	1,452 "	.929	.859
TransDRP	$y=1.28 - 0.11x_1 - 0.05x_3$	18 "	.858	.736
ComTP	$y=-7.93 + 0.55x_1 + 1.19x_3$	105 "	.920	.847
ParkTP	$y=-0.61 + 0.04x_1 + 0.09x_3$	7 "	.899	.808

where: x_1 = precipitation (mm)
x_2 = precipitation phosphate concentration (ug/l)
x_3 = antecedent dry period (days)
x_4 = peak discharge (m^3/s)

TABLE 4.15

MEASURED, PREDICTED AND RESIDUAL EXPORT AT SITE 11 AS CALCULATED BY USING REGRESSION EQUATIONS FROM TABLE 4.14

Date	Measured Load (g)	Predicted Load (g)	Residual	%Error
TOTAL P				
July 11	1379.6	1524.4	-144.7	10.5
July 30	892.6	834.4	58.2	6.5
Aug 4	5002.2	5231.6	-229.4	4.6
Aug 9	3495.4	3464.2	31.2	0.9
Aug 12	4937.3	4321.9	615.4	12.5
Aug 23	1799.4	1431.7	367.7	20.4
Sept 17	2053.8	2752.1	-698.3	34.0
DRP				
July 11	317.9	355.6	-37.8	11.8
July 30	214.9	334.1	-119.2	55.5
Aug 4	319.9	178.2	141.8	44.3
Aug 9	283.5	248.9	34.6	12.2
Aug 12	325.2	373.3	-48.1	14.8
Aug 23	594.1	492.5	101.6	17.1
Sept 17	101.4	174.3	-72.9	72.0

sampled during the summer of 1988, the variables: precipitation phosphate concentration and peak discharge, are not available; as such the two remaining variables, antecedent dry period and precipitation depth, were used to develop a separate set of regression equations, (Table 4.14).

Using the regression equation 'Mouth TP' for site 11, in Table 4.14, total phosphorus export for storms not sampled are shown. The total phosphorus exported during all summer storm events is the sum of the seven measured storms plus the predicted export calculated using this regression equation. In addition to the 16.3kg of TP measured in the seven storms, 97.4kg of TP was calculated for the 31 rainfall events not sampled. The calculated TP export for the 38 rainfall events in the summer of 1988 is 113.7 kg. Comparing this to the calculated baseflow TP export, 137.7 kg, the importance of monitoring TP in stormflow is recognized. For future storms, if the other two variables (precipitation phosphate concentration and peak stream discharge) are available, the equation 'MouthTP' in Table 4.13 could be used to predict phosphate export.

To predict DRP export for the storms not sampled during the summer of 1988, equation 'MouthDRP' in Table 4.14 is used. This regression equation predicted that 10.3 kg of DRP was exported for the 31 storms not sampled. Summing this with the 1.7 kg of DRP exported during the seven measured storms, a total of 12.0 kg is calculated as export during the summer storm events of 1988. Again, comparing the storm flow DRP export to the summer baseflow export (18.5 kg), it becomes evident that storm flow monitoring is essential to accurately assess annual phosphorus export. For future predictions, if all four variables are available, equation 'MouthDRP' in Table 4.13 is potentially the best predictor of DRP export in the study area.

Analysis of the correlation coefficients in Tables 4.13 and 4.12 show a poor coefficient for 'TransTP' in Table 4.12 and a good coefficient in Table 4.13. The variables used for Table 4.14, precipitation (mm), and antecedent dry days produced poor correlation coefficients, 0.02 and 0.14 respectively, combining to produce an 'r' value of 0.19. The addition of the two other variables, precipitation phosphate concentration and peak discharge with respective 'r' values of 0.06 and 0.77 create a combined 'r' value of 0.987. It is possible the poor correlation with the combination of precipitation depth and antecedent dry days is a result of the volume and speed of traffic on the transportation corridor. Cars travelling on Columbia Street, average 60 km/h, this may remove accumulated P to surrounding permeable surfaces, creating a poor relationship between P export and antecedent dry days and precipitation.

For DRP export prediction at site 11, the variables used in Table 4.14, antecedent dry period and precipitation have 'r' values of 0.29 and 0.37 respectively, combining for an 'r' value of 0.37.

Use of all four variables produces a correlation coefficient of 0.76. These two examples show the necessity of including all four variables when they are available.

A similar study by Miller and Mattraw (1982), found that the variables peak discharge, rainfall (mm), and antecedent dry period (number of hours prior to the storm in which 1.3mm of rain was not exceeded), created the best predictive equations. They also found the cross-product of two variables, rainfall and antecedent dry period (rainfall*antecedent dry period) to be a useful predictive variable. Table 4.16 lists the variables used for the Miller and Mattraw (1982) study, as well as the variables used for this study.

Table 4.16 lists the three best predictive variables for both studies. In both studies, precipitation phosphorus concentration was used as a predictive variable, but in both cases it was not considered very effective, possibly due to error in measurement. The fact that two studies, in two different geographical regions, would come up with the same three variables for predicting phosphate loads, does suggest that these may be the three most important variables.

4.6 ABATEMENT MEASURES

Due to several chemical and physical transformation processes, phosphorus has an affinity for sediment. As a result, several abatement measures are feasible. Shapiro (1974), determined that

TABLE 4.16

VARIABLES USED IN
MULTIPLE REGRESSION EQUATIONS

Miller and Mattraw (1982) - for TP only

Land Use	Variable(s)
Residential	Peak, Antecedent
Commercial	Peak, Rain
Highway	Rain

This Study (1988)

Residential	Peak, Rain, Antecedent
Commercial	Rain, Antecedent, Peak
Transportation	Peak, Rain, Antecedent

* the independent variables are listed in order of their 'r' values, from highest to lowest

** it appears that in most cases, peak discharge is the best predictive independent variable.

*** Peak = peak discharge (m^3/s)
Rain = depth of rainfall (mm)
Antecedent = length of dry period before storm (days)

weekly street sweeping could reduce phosphorus in urban runoff by up to 43%.

The predicted urban P input for the seven sampled storms is 21.3 kg of TP. Applying the 43% reduction of P resulting from street sweeping as stated by Shapiro, the mean urban P input could be reduced by 9.2 kg. Cost-effective street sweeping programs should consider the possibilities of pollutant removal as an added benefit, in addition to aesthetics.

Another measure to reduce P loadings, is discussed by Rausch and Schreiber (1981), and Free and Mulamoottil (1983). Storm-water impoundments can improve water quality as suspended sediment settles out and uptake and retention of nutrients, such as phosphorus, by plant life and sediment occurs. Rausch and Schreiber (1981) found that 77% of the total sediment phosphorus and 35% of the soluble phosphorous input to a flood detention reservoir in central Missouri was retained.

Field et al., (1982) discuss porous pavement as an abatement measure. Porous pavement helps reduce storm water runoff volume and pollution. By using latticed concrete, a fraction of the rainfall infiltrates into the soil and less water runs off directly into the sewer systems. Rather than flooding receiving streams, groundwater is recharged. This reduces discharge and sediment loads to receiving streams and as such also results in reduced phosphate loadings.

4.6.1 Cost-Effective Abatement Measures

Comparison of data from previous studies (Section 4.2.4.2) suggest that urban total phosphate and dissolved reactive phosphate export is approximately ten times, and seven times greater, respectively, than the phosphate export from agricultural and rural land on a per unit area basis.

This information is important to consider when examining cost-effective abatement measures. Abatement measures in the Laurel Creek basin should be directed towards urban areas. With 52% of the basin being urban and phosphate yields being seven and ten times greater (DRP and TP respectively) than agricultural and rural export, it would be more cost-effective to implement P abatement programs in urban areas.

The best cost-effective phosphorus abatement measures may vary among basins, as the percentage of urban and agricultural land, as well as reduction goals, may be different for each basin. For example, the Grand River basin, is approximately 5% urban; assuming the TP and DRP export from this urban land is ten and seven times greater than their respective agricultural P export throughout the Grand River basin, 5% of the entire basin would be producing 34% of the TP and 27% of the DRP basin non-point phosphorus yield. When considering cost-effective phosphate abatement measures and the phosphate reduction goals for the Grand River, it may be more effective to concentrate efforts on the agricultural areas. However, by projecting urban expansion to 6 and 7% of the area of the Grand River basin, new values are calculated. If 6% of the basin were urbanized this area would account for 39% of the TP and 31% of the DRP basin non-point phosphorus export. If 7% of the basin were urbanized, 43% of the TP and 35% of the DRP basin non-point phosphorus export should originate from 7% of the area.

With the continuing trend of urbanization in this area, it follows that the percentage of urban land will increase, coupled with the disproportionately large P export from urban land, increasing urbanization will result in increased P export to receiving waters.

4.7 REPRESENTATIVENESS OF THE DATA

In this study, 7 of 38 storms in the summer of 1988 were sampled. The question arises whether or not the sampled storms are representative of the unsampled storms. To determine whether or not they are representative, data from the seven storms must be compared to data from the unsampled storms. Two sets of data are available for such a comparison; precipitation depth and discharge at site 11. Discharge at site 11 was not directly available as there is not a permanent discharge recorder at this site. However, by regressing the discharge at site 7 (measured by the Water Survey of Canada, Station #02GA024) with the measured discharge at site 11, discharge at site 11 was predicted for the unsampled storms.

A t-test was performed on the means of the two sets of data between the sampled and unsampled storms. For the precipitation data for the sampled storms, $\bar{x}$ = 7.5mm, (n=7) and for the unsampled storms, $\bar{x}$ = 11.4mm, (n=31). The calculated t-value is -4.57 and the critical t-value is 2.75. It is concluded that there is a significant difference between the two sets of data. For the discharge data, for the sampled storms, $\bar{x}$ = 12713 m^3, (n=7) and for the unsampled storms $\bar{x}$ = 40352 m^3, (n=31). The calculated t-value is -9.47 and the critical t-value is 2.75. Again the two data sets differ significantly. The overall conclusion is that the sampled storms are not representative of the unsampled storms.

In both cases, the sampled data underestimates the unsampled data. Since increased precipitation increases discharge and increased discharge increases TP concentration (section 4.3.1) in Laurel Creek, it follows that the phosphorus load at site 11 during storm events would be underestimated for unsampled storm events. In conclusion, although the data used is not statistically representative, when comparing the sampled to unsampled storms, it produces conservative rather than extreme estimates of the unsampled data.

CHAPTER 5

CONCLUSION

5.1 CONCLUSIONS

The following is a list of conclusions based on the evidence produced from the data analysis.

i) Precipitation is a major source of phosphorous to urban runoff (see Table 3.2).

ii) For decision-making purposes, and cost-effective management, abatement measures should focus on residential areas, where large DRP, and therefore bioavailable phosphorous, loads originate.

iii) This study suggests that greater phosphate yields, both PP and DRP originate from areas of lesser impermeability in the urban area. However, it must be noted that this conclusion is based on only four different areas, and data from one summer. Since it is assumed that the phosphorus source depends on the land use, it would seem reasonable to suggest that land use and not the imperviousness of an area be the subject of further study with respect to phosphate loads.

iv) Urban phosphorous yields (3.45 g/ha/day TP and 1.7 g/ha/day DRP) are ten and seven times greater than agricultural phosphorous yields (0.34 g/ha/day TP and 0.25 g/ha/day DRP) for TP and DRP respectively.

v) It is extremely important that high discharge events are monitored for phosphorous export to calculate accurate annual assessments.

vi) Enforcement of so-called 'poop and scoop' laws, weekly leaf pick up and taking greater care in fertilizer application, all three of which can be managed by municipalities, could result in a substantial reduction of urban runoff DRP loads.

5.2 FUTURE RESEARCH

Only after completing this study was it possible to realize where improvements in data collection and analysis might be made. The following is a list of suggestions which might improve data collection and analysis for similar studies.

i) Although five rain gauges were used, the · were concentrated in one area of the basin. This increases the error involved in extrapolating precipitation data to the entire basin, as was done in this study. Unfortunately, urban structures create great error in precipitation gauges and sometimes adequate sites may not be found.

ii) Automated stage recorders and water samplers, such as those used by Weibel et al., (1964), would allow for greater monitoring capabilities. These machines can sample in intervals of one minute, whereas manual sampling for this study created an average sampling interval of fifty minutes. Continuous stage readings and more frequent water samples would allow for a more accurate assessment of P export.

iii) Include analysis of the snowmelt phosphate export for annual assessments, as phosphorous levels can be high (Oberts, 1986). Differences in P export from various land uses may also be apparent in snow melt runoff.

As always, in geography, similar studies differing spatially and temporally, often shed light on certain variations or consistencies. In order to improve our understanding of the role of phosphorous in urban runoff, the following research topics are suggested.

i) Analysis of biologically available phosphorous in urban runoff, through chemical extraction or algal bioassay techniques, might assist in cost-effective abatement measures.

ii) A study of wet and dry phosphorous deposition may shed some light on sources of phosphorous to urban street dust and dirt.

iii) Other pollutants, eg. lead, could be examined using a similar methodology to the one used in this study.

iv) Analysis of future storms in Laurel Creek and other basins to determine the accuracy of the predictive models presented in this study.

v) Calculate the trophic state of a hypothetical impoundment on the Grand River immediately downstream of Kitchener-Waterloo.

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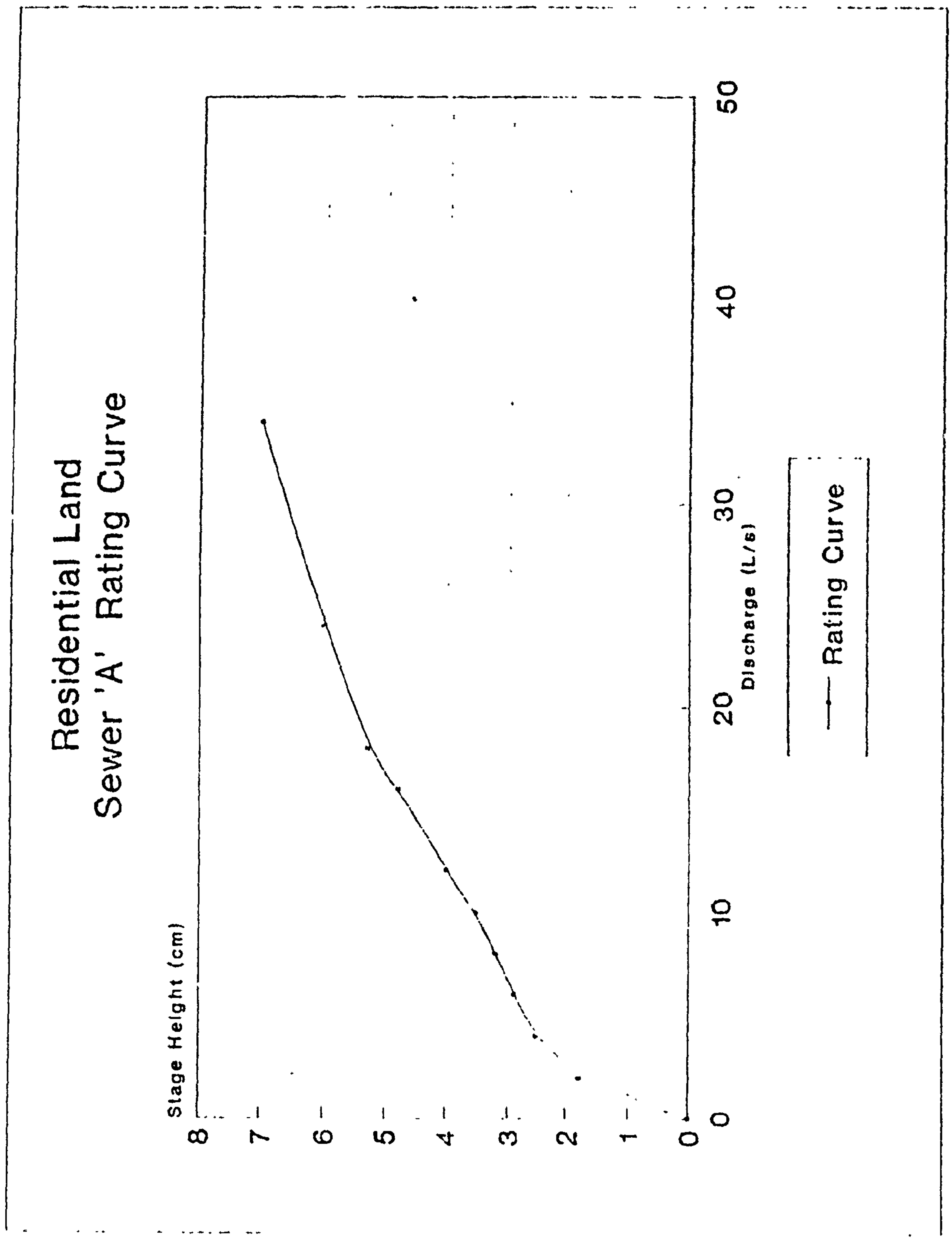
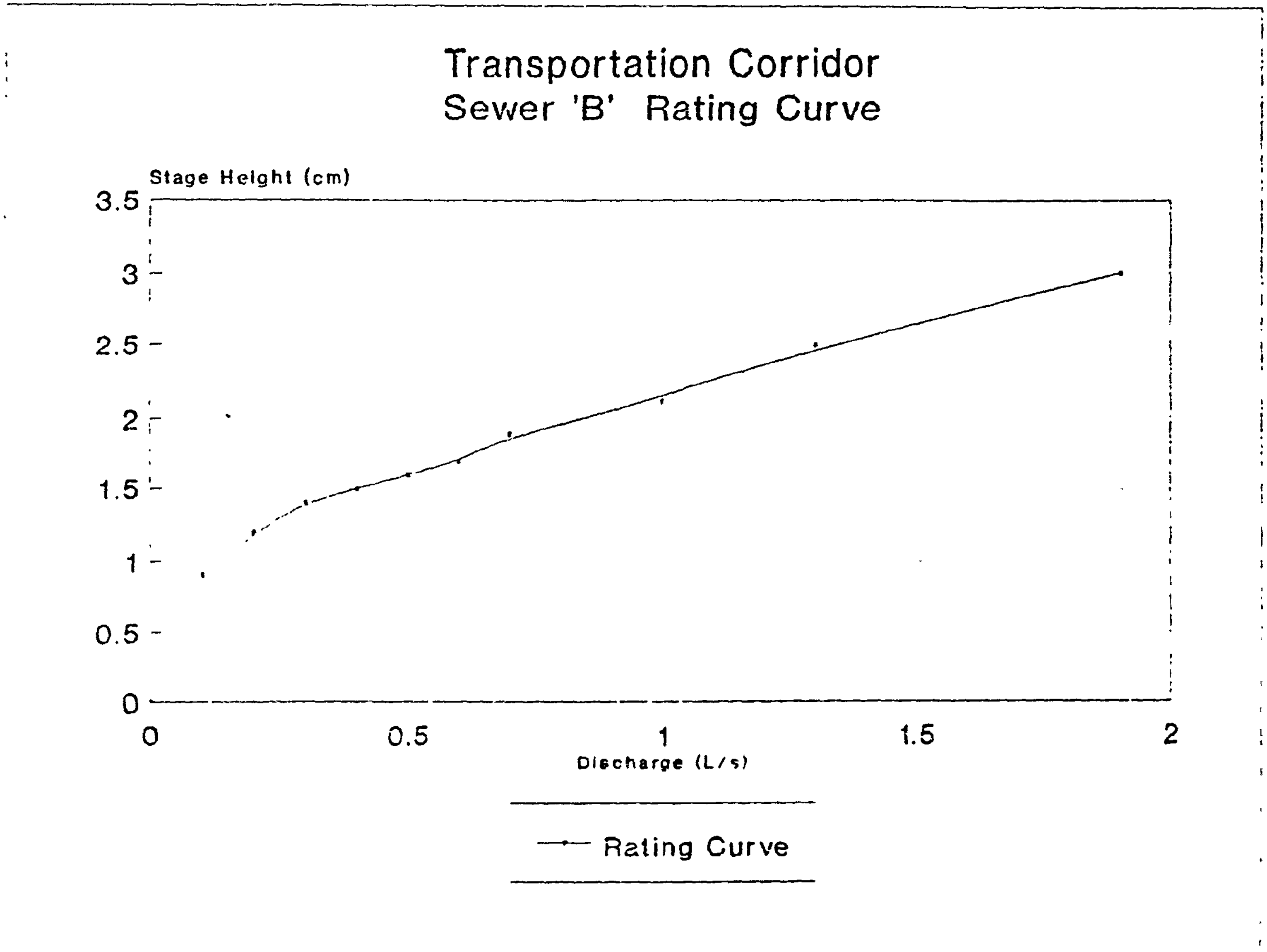
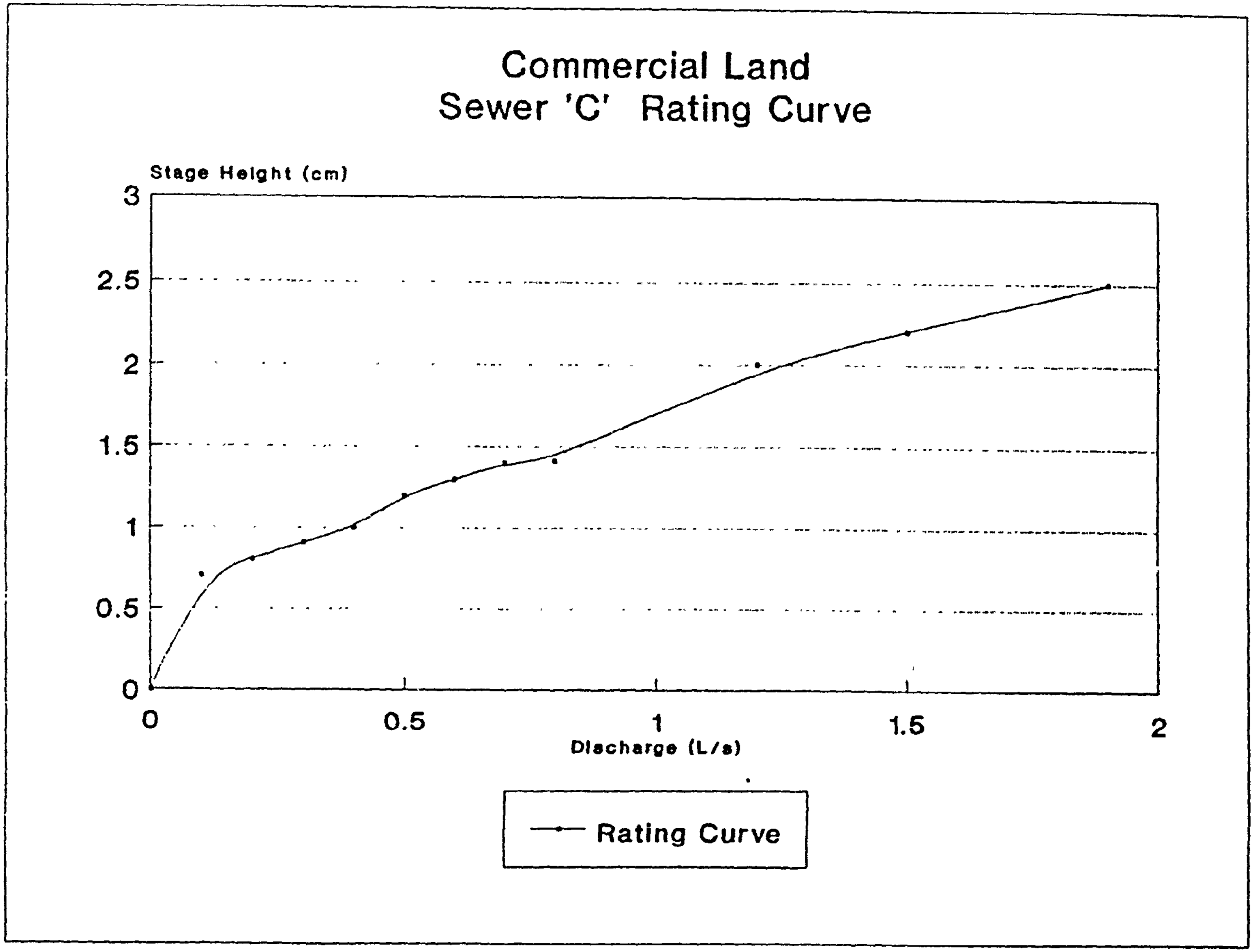
APPENDIX A

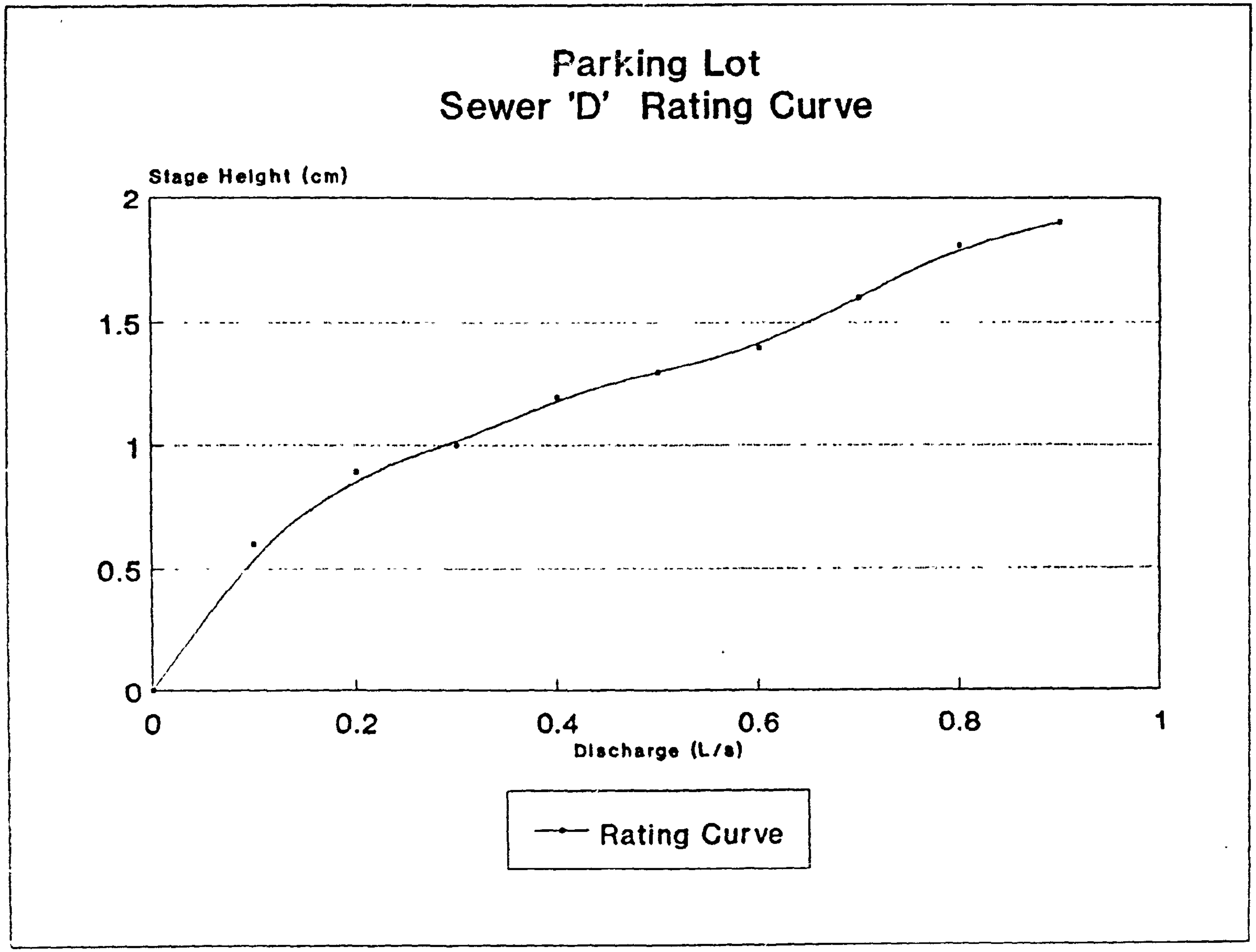
DISCHARGE RATING CURVES

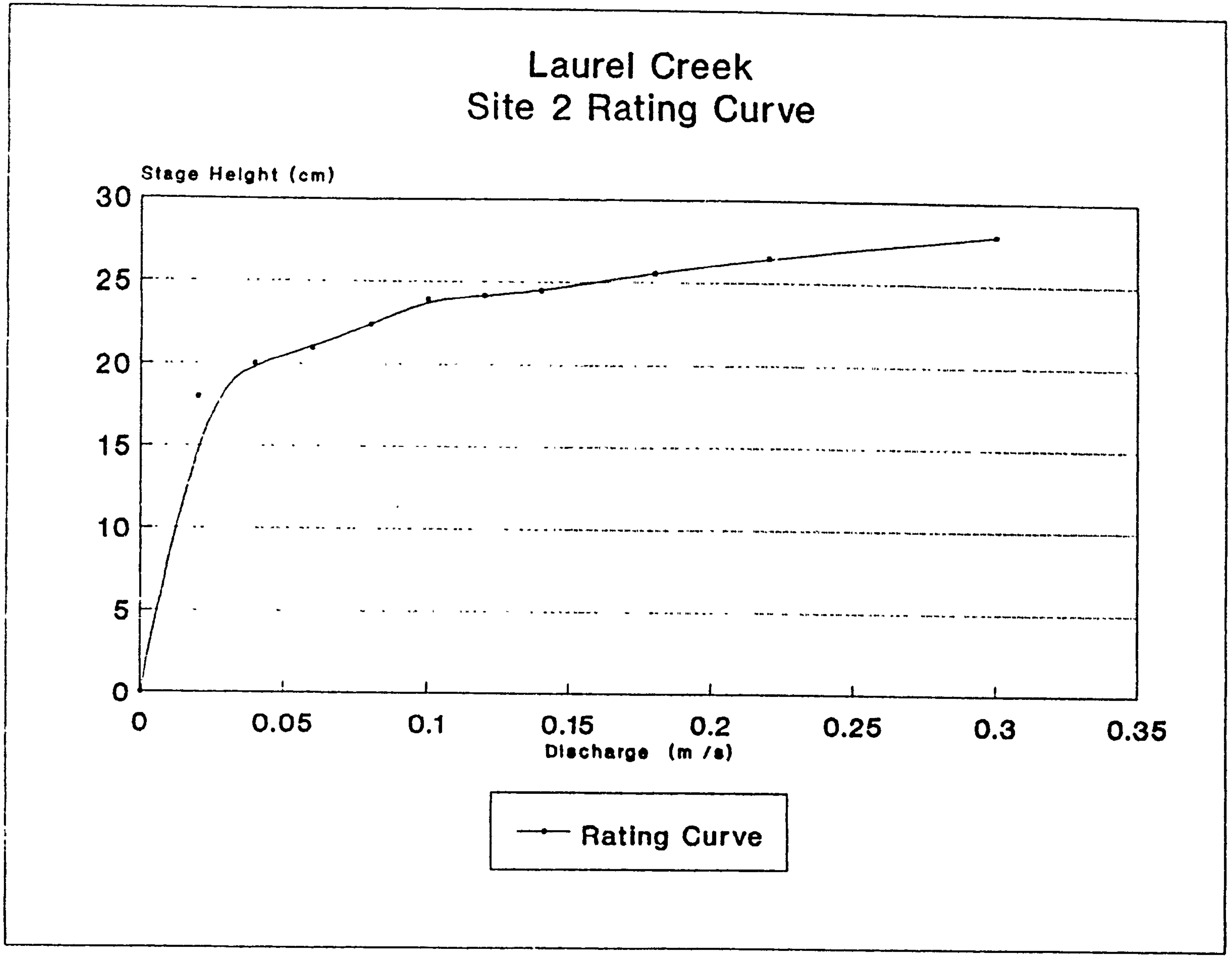


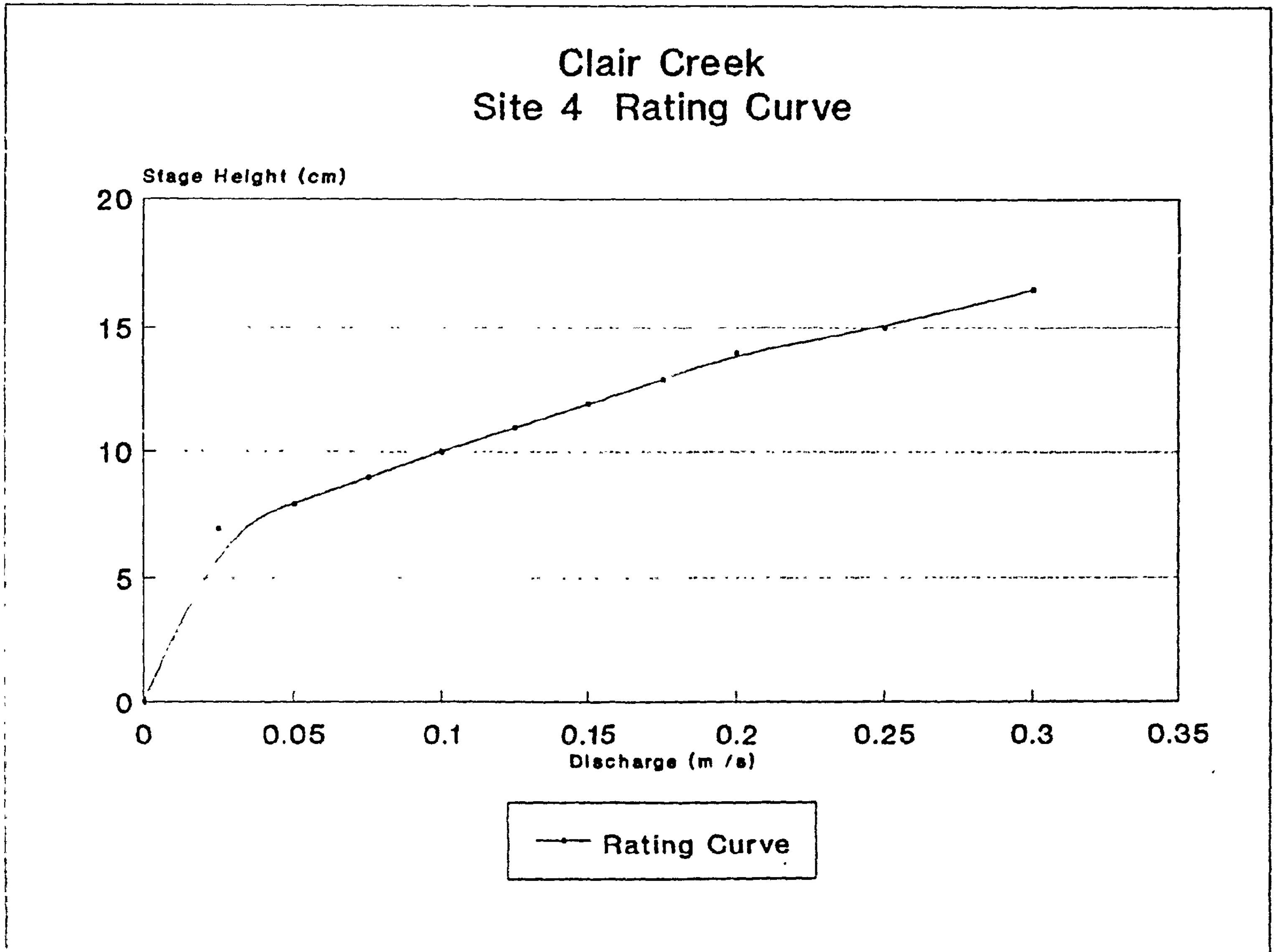
Residential Land
Sewer 'A' Rating Curve
Stage Height (cm)
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
Discharge (L/s)
Rating Curve

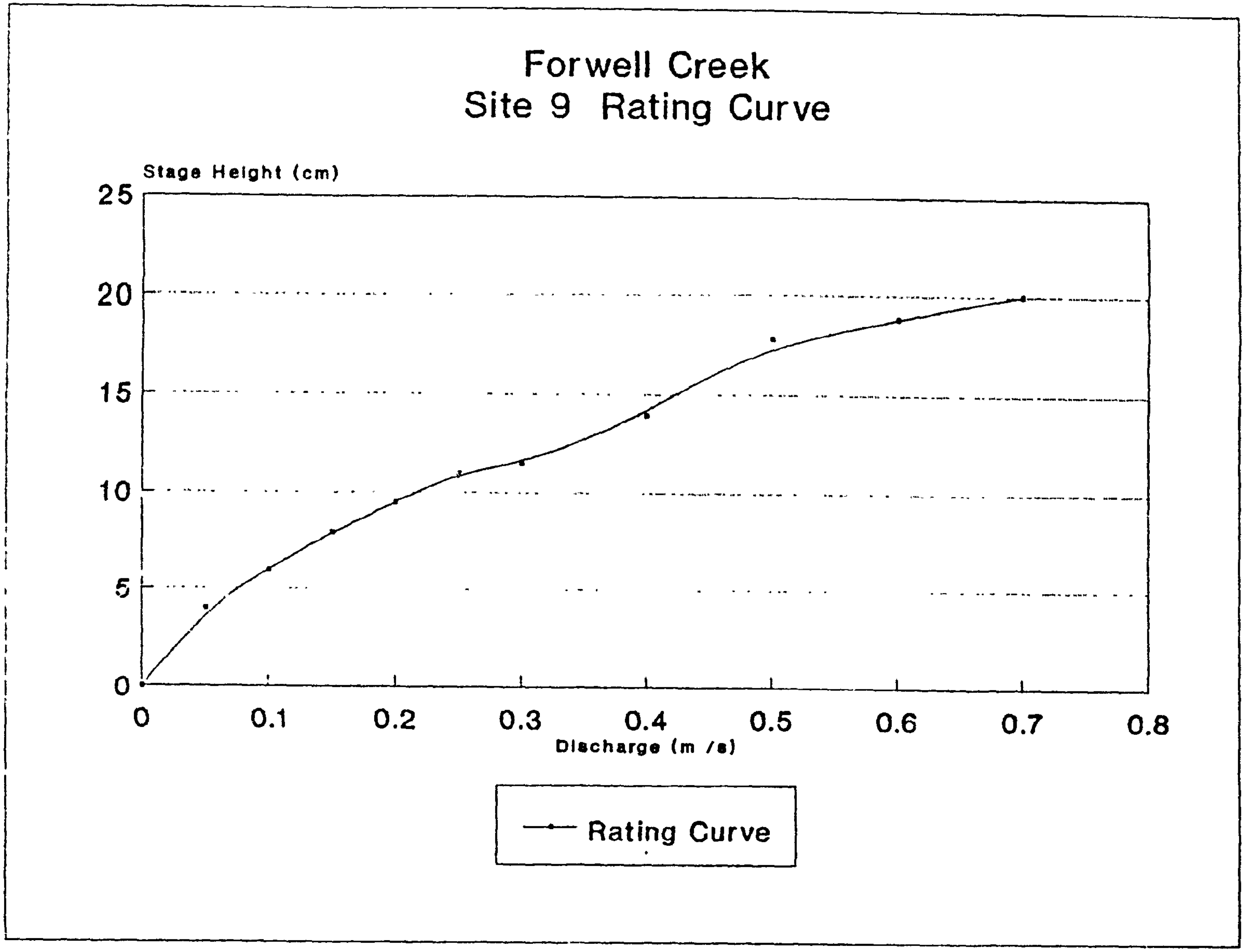

Transportation Corridor
Sewer 'B' Rating Curve
Stage Height (cm)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
Discharge (L/s)
Rating Curve

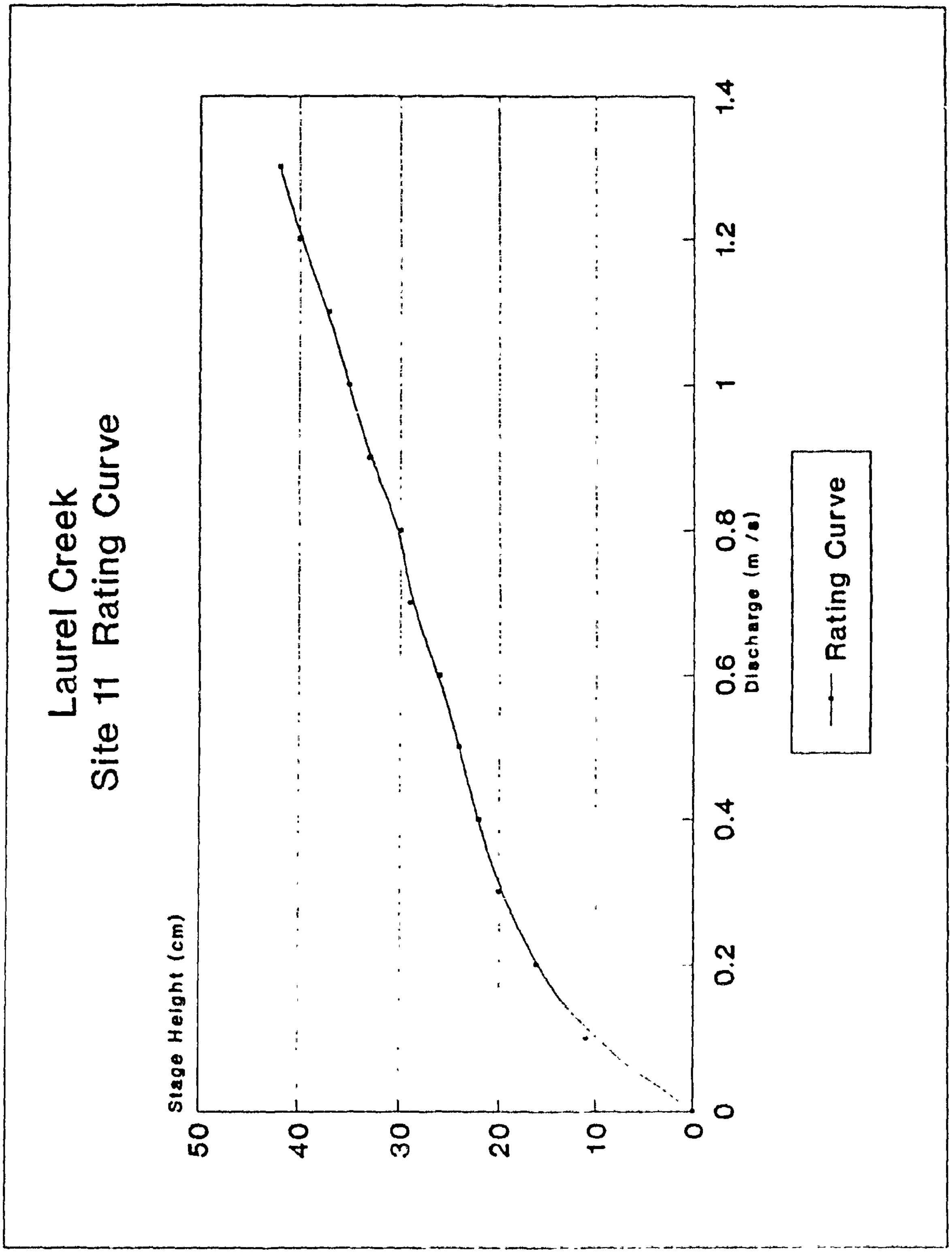

Commercial Land
Sewer 'C' Rating Curve
Stage Height (cm)
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
Discharge (L/s)
Rating Curve


Parking Lot
Sewer 'D' Rating Curve
Stage Height (cm)
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
Discharge (L/s)
Rating Curve


Laurel Creek
Site 2 Rating Curve
Stage Height (cm)
30
25
20
15
10
5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Discharge (m /s)
Rating Curve


Clair Creek
Site 4 Rating Curve
Stage Height (cm)
20
15
10
5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Discharge (m /s)
Rating Curve


Forwell Creek
Site 9 Rating Curve
Stage Height (cm)
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Discharge (m /s)
Rating Curve



Laurel Creek
Site 11 Rating Curve
Stage Height (cm)
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Discharge (m /s)
Rating Curve

APPENDIX B

DATA

PRECIPITATION DATA

Storm Date	Precipitation (mm)	[TP] (ug/L)	[DRP] (ug/L)
July 11	4.6	200	40
July 30	7.2	72	18
Aug 4	8.9	101	28
Aug 9	4.2	184	33
Aug 12	9.9	72	2
Aug 23	8.1	112	6
Sept 17	9.9	62	27

BASEFLOW DISCHARGE MEASUREMENTS

(m^3/s)

Date	Site#	2	4	9	11
June	10	0.030	-	-	0.140
	16	0.030	-	-	0.150
	21	0.014	-	-	0.110
	28	0.020	0.037	0.070	0.165
July	[illegible]	0.020	0.035	0.040	0.160
	8	0.018	0.027	0.045	0.150
	18	0.028	0.002	0.020	0.095
	25	0.034	0.005	0.020	0.140
	29	0.036	0.003	0.020	0.125
Aug	2	0.650	0.017	0.027	0.750
	5	0.288	0.075	0.040	0.445
	8	0.060	0.005	0.020	0.160
	11	0.034	0.005	0.035	0.140
	16	0.040	0.003	0.045	0.160
	19	0.030	0.005	0.035	0.160
	22	0.020	0.005	0.020	0.120
Oct	6	0.050	0.010	0.045	0.360

BASEFLOW TOTAL PHOSPHORUS CONCENTRATIONS

(ug/L)

Date / Site#		1	2	3	4	5	6	7	8	9	10	11
June	10	-	33	-	-	-	-	-	-	-	-	16
	16	34	120	105	120	-	-	345	-	55	-	110
	21	40	90	110	67	-	-	123	-	35	-	67
	28	35	100	140	50	-	-	160	-	50	-	107
July	2	33	115	120	60	-	-	215	-	45	-	145
	8	39	220	119	100	-	16	73	61	54	63	180
	18	42	425	200	152	204	166	200	208	65	119	115
	25	36	165	122	72	100	90	125	115	53	52	53
	29	56	123	116	50	112	82	84	103	56	54	55
Aug	2	38	105	118	108	140	-	118	118	58	130	107
	5	40	95	100	65	95	252	210	210	48	115	100
	8	36	103	123	39	103	118	108	109	45	72	68
	11	39	413	112	50	101	120	100	81	39	56	53
	16	37	137	141	126	134	140	122	64	47	50	64
	19	46	88	168	108	126	129	119	94	37	47	50
	22	34	71	144	29	127	126	98	87	40	40	60
Oct	6	-	62	77	120	81	-	80	80	337	73	71

BASEFLOW DRP CONCENTRATIONS

(ug/L)

Date / Site#		1	2	3	4	5	6	7	8	9	10	11
June	10	-	9	-	-	-	-	-	-	-	-	11
	16	16	4	3	2	-	-	6	-	5	-	6
	21	35	20	15	10	-	-	35	-	12	-	38
	28	25	10	13	5	-	-	10	-	22	-	5
July	2	20	10	10	50	-	-	10	-	15	-	15
	8	29	15	10	6	11	9	22	11	17	10	7
	18	7	8	7	135	23	12	27	7	13	15	13
	25	20	10	12	48	7	6	10	16	12	10	9
	29	33	9	9	15	11	9	15	13	9	15	17
Aug	2	26	10	10	70	23	-	10	10	10	22	14
	5	28	7	10	21	10	10	15	15	15	12	7
	8	24	3	5	12	4	6	6	4	8	5	13
	11	37	13	7	22	7	8	13	15	8	7	15
	16	23	6	5	20	7	6	12	11	6	6	6
	19	44	14	23	22	5	4	20	8	9	15	17
	22	18	11	8	15	2	8	8	5	1	1	11
Oct	6	-	2	2	4	2	-	2	3	63	2	2

LAUREL CREEK STORMFLOW DISCHARGE AND PHOSPHORUS CONCENTRATION

Storm / Site #	2		4		9		11	
	Q	[TP]	Q	[TP]	Q	[TP]	Q	[TP]
	(m /s)	(ug/l)	(m /s)	(ug/l)	(m /s)	(ug/l)	(m/s)	(ug/l)
July 10	.018	250	.030	364	.130	160	.140	92
	.023	170	.035	354	.035	117	.165	123
	.020	160	.090	234	.040	72	.170	91
	.018	156	.050	95	.090	234	.620	308
	.018	164	.030	87	.070	110	.485	93
							.320	76
July 30	.034	135	.005	220	.115	156	.170	64
	.042	136	.008	285	.035	86	.320	130
	.034	127	.045	148	.026	64	1.640	84
	.034	124	.013	122	.060	71	1.000	92
Aug 4	.288	87	.008	68	.200	112	.320	86
	.330	83	.012	139	.450	190	.360	88
	.288	84	.040	126	.480	100	2.120	410
	.288	84	.021	94	.410	96	1.580	240
	.288	90	.018	90	.330	93	1.200	130
Aug 9	.040	100	.008	112	.070	280	.170	74
	.050	125	.008	270	.130	80	.170	58
	.040	83	.018	200	.375	100	.270	94
			.013	74	.240	84	.850	110
					.145	110	.660	122
					.090	78		
Aug 12	.060	111	.010	156	.645	412	.170	57
	.115	121	.010	188	1.445	256	.170	71
	.070	114	.650	976	1.580	205	1.000	112
	.060	115	.450	864	1.230	176	1.310	138
			.075	561	.725	148	1.580	210
			.040	460	.565	118	.900	128
			.030	196	.480	95	.220	190
			.010	110	.240	80		

con't...

Aug 23	.020	95	.019	150	.040	28	.160	42
	.020	88	.019	115	.068	77	.160	54
	.020	85	.005	63	.080	120	.160	44
	.028	85	.013	80	.080	76	.180	57
	.020	80	.040	105	.135	162	.210	104
			.015	121	.115	85	.220	516
					.068	40	.300	125
Sept 17	.025	63	.033	44	.045	83	.200	64
	.034	68	.025	57	.405	311	.290	263
	.025	81	.075	2	.370	178	.900	173
	.020	75	.013	5	.090	67	.770	110

LAUREL CREEK STORMFLOW DISCHARGE AND
DRP CONCENTRATION

Storm / Site #	2		4		9		11	
	Q	[TP]	Q	[TP]	Q	[TP]	Q	[TP]
	(m /s)	(ug/l)	(m /s)	(ug/l)	(m /s)	(ug/l)	(m /s)	(ug/l)
July 11	.018	7	.030	123	.130	65	.140	15
	.023	10	.035	136	.035	80	.165	17
	.020	7	.090	37	.040	7	.170	23
	.018	6	.050	4	.090	72	.620	85
	.018	6	.030	4	.070	4	.485	10
							.320	4
July 30	.034	7	.005	6	.115	8	.170	7
	.042	15	.008	38	.035	7	.320	38
	.034	10	.045	5	.026	8	1.640	20
	.034	7	.013	26	.060	7	1.000	20
Aug 4	.288	11	.008	15	.200	7	.320	13
	.330	14	.012	24	.450	35	.360	11
	.288	7	.040	13	.480	24	2.120	17
	.288	18	.021	17	.410	41	1.580	7
	.288	7	.018	11	.330	17	1.200	27
							.960	12
Aug 9	.040	6	.008	17	.070	142	.170	10
	.050	4	.008	200	.130	20	.170	8
	.040	6	.018	137	.375	8	.270	10
			.013	18	.240	7	.850	6
					.145	6	.660	8
					.090	11		
Aug 12	.060	3	.010	10	.645	48	.170	8
	.115	4	.010	4	1.445	6	.170	6
	.070	3	.650	24	1.580	17	1.000	6
	.060	2	.450	38	1.230	27	1.310	6
			.075	58	.725	43	1.580	7
			.040	40	.565	33	.900	6
			.030	17	.480	24	.320	24
			.010	14	.240	14		

con't..

Aug 23	.020	3	.019	8	.040	5	.160	8
	.020	13	.019	10	.068	7	.160	8
	.020	4	.005	5	.080	13	.160	5
	.028	2	.013	5	.080	7	.180	7
	.020	5	.040	6	.135	80	.210	42
			.015	10	.115	14	.220	13
					.068	7	.300	73
					.045	11		
Sept 17	.025	1	.033	44	.045	1	.200	1
	.034	1	.025	57	.405	182	.290	57
	.025	1	.075	2	.370	78	.900	8
	.020	5	.013	5	.090	21	.770	2
							.350	1

LAND USE STORMFLOW DISCHARGE AND TP CONCENTRATION

Storm / Site Sewer	Res. A Q (l/s)	Res. A [TP] (ug/l)	Trans. B Q (l/s)	Trans. B [TP] (ug/l)	Com. C Q (l/s)	Com. C [TP] (ug/l)	Park. D Q (l/s)	Park. D [TP] (ug/l)
July 11	.51	10	.04	320	.27	1260	.04	660
	2.09	456	.12	280	.04	1140	.21	945
	.51	483			1.95	5300	.21	900
July 30	5.31	432	.39	156	1.95	430	.21	285
	.51	260			.04	450	.04	120
Aug 4	5.31	275	.02	100	-	-	.21	400
	.07	22	.71	330				
	.51	200	.02	50				
Aug 9	71.50	1080	5.36	523	1.16	368	.21	90
	.86	364	.12	115				
	.51	250						
Aug 12	57.60	312	1.87	425	.70	210	.21	75
	16.20	171	.02	117				
	.51	114	1.27	282				
Aug 23	.07	145	.71	300	5.26	370	.21	70
	.07	15	.02	70	1.16	734	.21	264
	2.09	264	.04	760	.28	280	.21	52
	16.20	200	1.87	290			.04	46
	.07	19	.02	116			.21	54
	2.09	264	3.14	705				
	2.09	320	3.14	532				
	32.90	345						
Sept 17	.86	189	.71	220	1.16	410	.89	95
	5.30	456	.71	228				
	5.30	346	.71	177				
	3.16	260	1.87	290				
	.51	180	.04	148				

LAND USE STORMFLOW DISCHARGE AND DRP CONCENTRATION

Storm / Site Sewer	Res. A Q (l/s)	Res. A [TP] (ug/l)	Trans. B Q (l/s)	Trans. B [TP] (ug/l)	Com. C Q (l/s)	Com. C [TP] (ug/l)	Park. D Q (l/s)	Park. D [TP] (ug/l)
July 11	.51	8	.04	156	.27	1250	.04	506
	2.09	430	.12	162	.04	1120	.21	886
	.51	474			1.95	3100	.21	810
July 30	5.31	65	.39	23	1.95	23	.21	15
	.51	77	.12	12	.04	60	.04	9
Aug 4	5.31	115	.02	12	-	-	.21	13
	.07	15	.71	80				
	.51	99	.02	8				
Aug 9	71.50	450	5.36	76	1.16	148	.21	48
	.86	277	.12	43				
	.51	193						
Aug 12	57.60	3	1.87	3	.70	7	.21	3
	16.20	32	.02	8				
	.51	56	1.27	11				
Aug 23	.07	110	.71	18	5.26	18	.21	1
	.07	3	.02	3	1.16	440	.21	10
	2.09	7	.04	5	.28	45	.21	2
	16.20	53	1.87	13			.04	25
	.07	5	.02	13			.21	1
	2.09	145	3.14	11				
	2.09	10	3.14	8				
	32.90	56						
Sept 17	.86	1	.71	1	1.16	5	.89	1
	5.30	110	.71	67				
	5.30	81	.71	1				
	3.16	67	1.87	15				
	.51	45	.04	24				