Chapter 14

Quality of Stormwater From Residential Areas

Z. John Licsko, Graduate Student
H.R. Whiteley, Associate Professor
R.L. Corsi, Assistant Professor
School of Engineering
University of Guelph
Guelph, Ontario
N1G 2W1

14.1 Introduction

Stormwater from urban residential areas has been found in several studies to contain a variety of pollutants. These include solids, nutrients, chlorides, bacteria, trace organics and heavy metals. The impact of these substances on a receiving environment is controlled by such factors as concentration, duration of discharge, time of discharge and the sensitivity of the receiving environment to a particular pollutant. As point sources of wastewater, residential stormwater can be, for brief durations, substantially in excess of existing water quality standards. Research using biological indicators of environmental impact has also shown that intermittent stormwater discharge can have a measurable impact on the receiving water downstream of storm sewer outfalls

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(Garrie 1986, Payne 1990, Willemsen 1990, Gast 1990).

Control of pollutants carried in stormwater from residential areas has not, however, usually been of sufficient concern to warrant specific control measures, although some American municipalities and states have in the last decade implemented substantive stormwater quality programs (Bissonette 1986, Zeno 1986, Livingston 1986, Shaver 1986).

Strategies for improving the quality of residential stormwater can range from elimination of polluting substances to end-of-pipe control. One strategy involves adding quality requirements for structures which are already required for the control of stormwater quantity. These structures include wet and dry detention ponds, wetlands, grassed swales, and groundwater recharge devices. The improvement in stormwater quality produced by these control structures is usually associated with a reduction in the suspended solids concentration in the stormwater. Pollutants such as BOD₅, heavy metals and nutrients are removed to a varying extent by the removal of suspended solids. Nutrients and metals may also be removed from sediment and from water by plant growth in these structures.

Careful design and management of structures used for stormwater quality improvement is needed. Pollutants initially removed may eventually be discharged through re-suspension or re-solubilization unless this is prevented through specific features of the design and operation of the facility.

The research reported here was undertaken to help establish whether low density residential areas and/or commercial development in residential areas warrant stormwater treatment beyond that which currently exists. Specifically, the objectives of this research were to:

1. Characterize the quality of stormwater from two residential catchments and from a commercial catchment typical of those located in residential areas. The focus was on obtaining data on the maximum, and the "steady state" or clean concentration of several stormwater quality parameters.

2. Assess the impact of existing water quantity control structures on the quality of stormwater from two residential catchments.

14.2 Literature Review

Numerous sampling programs have been undertaken in the last three decades to characterize the quality of stormwater from urban areas. In Canada, research undertaken by the International Joint Commission under the Canada-US Great Lakes Water Quality Agreement of 1972 represents the largest single source of information on urban runoff quality. A summary of the pollutants measured, their magnitude, their sources and transport, was presented by O'Neill (1979). Pollutant loadings from urban areas on a $\text{kg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ basis and an analysis of stormwater abatement methods can be found in Marsalek (1978). Additionally, several studies undertaken through joint efforts between municipalities, provincial and federal governments have characterized aspects of stormwater quality and stormwater treatment structures (Ontario Ministry of the Environment 1977, 1982, 1983, & 1991, Canadian Mortgage and Housing Corporation 1980a, 1980b & 1981, Marsalek 1986).

In the United States from 1979-83 the U.S. Geological Survey (USGS) and the Nationwide Urban Runoff Program (NURP) jointly and separately conducted stormwater quantity and quality monitoring in 28 urban catchments (EPA, 1983). Thirteen detention basins were also monitored in the NURP sampling program, nine of which were wet basins or ponds (EPA, 1986). Several earlier research projects also characterized and quantified urban street contaminants in the United States (Wanielista, 1979, Sartor, 1974).

Past studies have highlighted the variability and site-specific characteristics of stormwater quality and of stormwater treatment facilities. As noted in the introduction, the pollutants commonly assessed in these studies included: solids, BOD_5 , nutrients, chloride, organics, heavy metals and micro-organisms.

14.3 Description of Sampling Sites

The Fieldstone residential catchment is located in the southern portion of Guelph and is 14.2 ha in area with a density of 12 single family detached houses/ha (gross catchment area). Housing was constructed in about two thirds of the catchment in 1986, with the remaining third of the housing constructed in 1987. A grass-surfaced park with an area of about 1.5 ha forms part of the catchment. Roof downpipes drain directly onto lawns in most instances. Streets, backyards and the park area are all drained by catch basins. The entire catchment drains into a stormwater detention wet pond which was designed to control water flow rates in the catchment to pre-development rates.

The Brandt catchment is located in the northeast corner of Guelph. This catchment covers 18 ha in area and has a single family detached housing density of 11 single detached houses/ha (gross catchment area). The area was developed in 1971. A school and park area, mostly grassed, encompass approximately four hectares of the catchment. Roof downpipes are connected to the stormwater sewer drainage system directly. The catchment drains into a dry storm water detention pond. Each residential catchments had total curb lengths of approximately 3600 m.

The commercial catchment is 1.25 ha and has thirteen retail stores and a gasoline station on the site. Drainage from the parking lot area and the roofs are conveyed to a storm sewer directly into a wetland.

14.3.1 Wet and Dry Pond Characteristics

The surface area of the wet pond at Fieldstone is 0.16 ha (1.1 percent of the catchment area) with an average depth of about 30 cm giving the pond a total volume of approximately 500 m³. Measured pond overflow rates during storms ranged from a maximum of 20 cm/hr (24.2 mm storm with a two hour duration) to a minimum of 1 cm/hr (8.6 mm storm with a four hour duration).

The dry pond at Brandt encompassed 1.1 ha (6.1 percent of the catchment area). The pond makes use of a naturally occurring grassed wetland. A field on the south and east sides of the pond and a wooded area on the pond's west side sometimes contribute runoff that is in addition to the inflow of stormwater from the catchment. Overflow rates were not monitored for this pond.

14.4 Sampling Procedures

Stormwater quality depends on site and weather conditions which can be highly variable. Consequently, a consistent program of field sampling is important (Huber, 1986). Moreover, a field sampling program for stormwater quality is an expensive endeavour both in terms of the actual sampling and subsequent water quality analyses.

Various sampling methods have been employed in the field to collect data on stormwater quality. Procedures range from street vacuuming and flushing, to pollutant measurements in streams or rivers upstream and downstream of stormwater outfalls. Results are expressed as: mean event concentrations, area unit loadings of pollutants on an annual basis ($\text{kg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$), or mass loadings of pollutants per curb length.

In some instances the actual concentrations of pollutants are not as important as is the environmental impact of stormwater and as a result, in situ toxicity testing has been advocated. Both the effect of the intermittent nature of stormwater pollution and of the biological availability of stormwater pollutants can then be assessed by in situ tests (Bascombe, 1990).

Stormwater quality impacts are, however, short term for some water quality parameters (e.g., bacteria and temperature) and long term for others (e.g., nutrient loads). EPA sampling procedures under the National Pollutant Discharge Elimination System (NPDES), for instance require stormwater grab sampling within the first 30 minutes of an event as well as the collection of an event-mean concentration sample. The first sample gives an indication of the maximum concentrations, which is important for

some aquatic life, and which, in stormwater toxic management programs, form the basis for acute toxicity testing requirements (Collins, 1991). The event-mean concentration provides information on the longer-term impacts of stormwater pollution such as sediment and nutrient loading.

The choice of sampling procedures, including type of sample collection and list of parameters to be tested, involves balancing cost and effort against expected benefits in defining impacts. In this study, the variability associated with seasonal changes was included by conducting stormwater sampling from March, 1991 to November of 1991. Grab samples were collected at least twice during each event from four or five different locations in the two urban catchments and from one location at the commercial site. At each location, one grab sample was collected as close as possible to the start of each rain event investigated while the second was collected as close as possible to the end of the storm event. Sampling was conducted in this manner to obtain a maximum range of water quality values and a "steady state" value associated with the end-of-event sample. Since both residential sites had sampling completed at both the inlet and outlet of stormwater quantity control ponds this method of sampling also provided a measure of each pond's effectiveness for removing several pollutants.

Water quality parameters tested for in this study included temperature and dissolved oxygen at the time of sample collection, conductivity, pH, biochemical oxygen demand (BOD_5), conductivity, turbidity, fecal and total coliform (MPN/100 ml), sodium, chloride, nitrate, ammonia, total phosphorus, total lead, total solids, suspended solids and dissolved solids. The volatile content of total, suspended and dissolved solids tests were also obtained. This provided a wide range of information on pollutants likely to be included in legislation on stormwater quality.

Also, these test results provide for a comparison of relatively inexpensive tests such as water temperature, dissolved oxygen, pH, conductivity, and turbidity with more expensive and complicated water quality tests. Such a comparison might

provide justification for the use of inexpensive surrogate indicators for stormwater quality monitoring.

14.4.1 Sample Analysis

Most sample analyses were completed as outlined in Standard Methods (1985). Exceptions to the procedures outlined in Standard Methods occurred for the analysis of sodium, chloride, total lead and total phosphorus. Sodium and chloride ions were analyzed with the use of Orion ion selective electrodes and analyses were performed as outlined in the supporting documentation for these probes. Total phosphorus and total lead analyses were completed at the Land Resources Water Quality Laboratory (University of Guelph). For both the determination of total lead and of total phosphorus a 25 ml sample was first evaporated. The residue was then digested with sulphuric and nitric acid until the nitric acid had dissipated. The sample was then, with the addition of distilled, deionized water, brought back to the original sample volume of 25 ml. An atomic adsorption spectrophotometer (Varian 300) was then used for the total lead determination, while a spectra-photometer (Technocan auto analyzer) was used in the total phosphorus determination.

14.5 Results

A number of water quality parameters were measured, as mentioned earlier in the stormwater samples collected during this study. Space restrictions, however, permit the discussion of only some of the results obtained. An attempt has been to include those parameters commonly reported for urban stormwater as well as some where interesting trends were observed. Included for discussion were: suspended solids, dissolved solids, BOD₅, fecal coliform, total phosphorus, sodium and chloride.

Similarities in the measured water quality parameters in the two residential catchments resulted in the presentation of an

Figure 14.1: Variations in suspended sediment concentration by location.

overall average for data collected in each of these areas. This includes all four sample locations in each of the two residential catchments: roof, street gutter, pond inlet and pond outlet. Exceptions to this method of analysis were noted were applicable.

14.5.1 Suspended Solids

Average concentrations of total suspended solids (tss) from samples collected were 238 mg/L (street gutter), 212 mg/L (pond inlets) and (240 mg/L) for the commercial site. The concentrations were similar for the various seasons over the sampling period. Waller (1980) reported an annual mean concentration of suspended solids from the surface runoff in

urban areas in Ontario of 170 mg/L.

The concentration of suspended solids at the pond inlets showed a larger range than did the street gutter flow, presumably due to deposition and re-suspension of sediment in the sewer system as shown in Figure 14.1.

Suspended solids concentrations in roof runoff exhibited a high first flush concentration, but this quickly diminished. Based on the time of sampling in terms of an estimated accumulation of rainfall the quality of roof water approached that of rainwater after 2-3 mm of rainfall.

The concentration of tss in the street gutter and pond inlet did not approach that of rainwater until between 10-15 mm of rainfall had accumulated. This is consistent with research by Wanielista (1977) that indicates that up to 95% of pollutants are washed off in the first 12.7 mm of rainfall for watersheds less than 40 ha in size. For watersheds over 40 ha the percentage of pollutants washed off in the first 12.7 mm of rainfall reduces with increased watershed area. At the commercial site, which has an area of 1.25 ha, for two of the four storms for which data were collected, the suspended solids concentration dropped by an average of 95% after 6.5 mm of rainfall.

Suspended solids at both the dry and wet ponds were effectively removed by detention with an average removal proportion for the two ponds of 94 percent. Seasonal effects, however, were apparent in the functioning of both ponds. In late winter and early spring the wet pond can be frozen and flows from the inlet pass over and under the ice sheet to the outlet. The pond outlets may also be partially blocked by ice and snow accumulation and outflow vs storage height relations are altered. Frozen outlets can result in either complete retention, or in the case where outflows bypass the outlet, a shorter retention time for the incoming stormwater.

The dry pond appeared to retain ability to detain stormwater and to allow the effective settling of sediment even in the winter and spring. Apparently it retains a substantial effectiveness as a grassed filter.

Unit loadings on an annual basis were calculated for

comparison with previous research. The calculations were based on an 830 mm annual average rainfall for Guelph, a runoff coefficient of 0.45 for the residential areas and 0.85 for the commercial area. Mass loadings of tss were based on the average concentration measured at the pond inlets.

A comparison of the estimated annual loading of suspended solids from the two residential and the commercial catchments showed an estimated annual loading similar to research previously completed in Ontario for residential areas as shown in Table 14.1. Calculations of the ss loading from the commercial area were found to be substantially higher than that previously measured while calculations for the residential area resulted in loadings similar to previously reported values.

A grid survey of the wet pond's sediment found an average accumulated sediment depth of 5.7 cm. Using the above unit area loading for this study, a measured specific gravity of 1.23 and 5 1/2 years of pond use resulted in an estimated sediment accumulation of 3.4 cm. Development of individual lots during the course of 5 1/2 years are the likely sources of the balance of sediment accumulation.

Table 14.1: Unit area loads of suspended solids.

Study	Annual Unit Loads (kg·ha ⁻¹ ·yr ⁻¹)	
	Residential	Commercial
Singer (1977)	619	825
Marsalek (1978)	388	233
This Study	840	1993

Measurements of volatile suspended solids (vss) at the street gutter and pond inlets averaged 34 mg/L or 15% of total suspended solids while 5 mg/L (42% of tss) of vss was measured at the pond outlets as shown in Figure 14.2. Reduction of volatile suspended solids during retention for the two ponds averaged 86%. However, the dissolved volatile solids after retention increased by 58%, on average for the two ponds, resulting in only a 12% overall reduction in total volatile solids during detention in the ponds.

Figure 14.2: Variation in volatile suspended solids concentration by location.

Volatile suspended solid concentrations measured at the commercial site were 2.3 times higher than those measured in the residential catchments at the inlets to the ponds and at the street gutter. A possible explanation for this is that oil and grease concentrations are associated with the suspended solids and contribute much of the volatile portion. Three studies cited in Stenstrom (1984) found between 81-96 % of oil and grease was adsorbed or otherwise attached to suspended solids and that this oil and grease was three times higher in runoff from commercial

and parking lot areas than from runoff in residential areas (Stenstrom, 1984).

14.5.2 Dissolved Solids

There was a consistent increase in the concentration of dissolved solids, from the street gutter (63 mg/L) to the pond inlets (104 mg/L) and finally the pond outlet (252 mg/L). Between the pond inlet and pond outlet there was on average a 60% increase in volatile dissolved solids and a 142% increase in non-volatile dissolved solids. This increase is unexplained at this time and is likely due either to a sampling effect created from outlet samples bearing pre-event concentrations of pond water or the presence of undetected groundwater inflow between events. Evaporation rates of up to 12.5 mm/day were measured at the wet pond and are responsible for a portion of the increased concentrations of dissolved solids in the ponds.

14.5.3 Total Phosphorus

Total phosphorus concentrations were highest at the pond inlets, averaging 0.29 mg/L, 38% higher on average than those phosphorus values measured at the street gutter (0.18 mg/L) (Figure 14.3). The likely explanation for this is a first flush effect of catch basin sumps which tend to accumulate organic matter during periods of low flow. Septic conditions often occur in the sump with an accompanying release of nutrients from the vegetation. A mean annual concentration of 0.35 mg/L of total phosphorus was reported by Waller (1980) for surface runoff from urban areas in Ontario. The median event-mean concentration measured during the NURP (EPA, 1983) study was 0.33 mg/L.

Since phosphorus is often chemically bound to sediment and colloidal material, the removal of suspended solids in detention ponds should also remove some phosphorus. The average percent reduction of phosphorus levels across the two ponds was

Figure 14.3: Variation in total phosphorus concentration by location.

approximately 70 percent. Average removal rates for total phosphorus from wet detention ponds monitored by US EPA (1986) ranged from 3% to 79%. Monitoring data from detention ponds monitored in Ontario cited phosphorus removal efficiencies from between 25% to 86% (Ontario, MOE 1991).

Whether the phosphorus removal during pond detention obtained in this study and in others is real or apparent is not, however, clear. The availability of phosphorus for biological growth is normally associated with the dissolved or orthophosphate fraction of the total phosphate, which is unlikely to be affected by a short pond retention time. Additionally, algae which often grow in wet ponds are quite capable of extracting and using the phosphorus deposited with sediment (G. van Eck, 1982). This phosphorus could later be released as dissolved phosphorus during decay of the algae. Additionally, conditions in a wet pond such as low oxygen levels and elevated

temperatures may also enhance the release of dissolved phosphorus from the sediment for use in biological processes.

Comparison of the data on an annual unit load basis using the method of calculation described earlier for suspended solids shows good agreement for the phosphorus loading rates from the residential areas as shown in Table 14.2. Phosphorus loadings from the commercial area were less than half of that found in previous research.

Table 14.2: Unit area loads of total phosphorus.

Study	Annual Unit Loads (kg·ha ⁻¹ ·yr ⁻¹)	
	Residential	Commercial
Marsalek (1978)	1.5	3.5
Waller (1980)	1.1 ¹	
This Study	1.1	1.5

¹ Urban area in total.

Total phosphorus was one of two parameters which exhibited different concentrations between the two residential catchments. The newer catchment had substantially higher concentrations of total phosphorus, almost three times more than the older area at both the street gutter and at the pond inlet.

14.5.4 Biochemical Oxygen Demand (BOD₅)

Pond inlets and roof downspouts were both characterized by high first-flush BOD₅ values which quickly diminished. The commercial catchment had the highest concentrations of BOD₅ as shown in Figure 14.4.

Reductions in BOD₅ concentrations in the detention ponds were due to the settling of suspended organic material as indicated by the measured reduction of volatile suspended solids (86%) between the pond inlet and outlet.

The average BOD₅ reduction in the two ponds was about 30%

Figure 14.4: Variation in BOD₅ concentration by location.

This represented a BOD₅ reduction from 10.4 mg/L to 6.1 mg/L. The average reduction of BOD₅ across the dry pond was substantially higher than that for wet pond: 50% vs 10 %.

For this study, an annual unit BOD₅ load of 38.8 kg·ha⁻¹·yr⁻¹ was calculated. Unit load data reported by Marsalek (1978) for urban test catchments in Ontario ranged from 18.9 to 35.3 kg·ha⁻¹·yr⁻¹.

Data on BOD₅ obtained from measurements in storm sewers in the United States indicated loadings ranging from 28 to 43 kg·ha⁻¹·yr⁻¹ (Heaney et al., 1977). An annual unit loading for the commercial catchment was calculated to be 184 kg/ha⁻¹·yr⁻¹.

14.5.5 Fecal Coliform

Fecal and total coliform are indicators of the presence of pathogenic organisms in water. For water bodies which receive

stormwater and have a recreational use that involves body contact this is a concern. Discharges from all three catchments sampled in this study went directly to a wetland and micro-biological constituents would not be expected to have an adverse impact in this environment.

Figure 14.5: Variation in fecal coliform count by location.

The lowest average counts (an arithmetic mean was used in expressing the counts for coliform) recorded for fecal coliform were from the roof downspout samples (59 MPN/100 mL) and the samples collected from the commercial catchment (1880 MPN/100 mL). Highest coliform values were recorded from the street gutter and the inlet to the ponds. Both of these locations had similar average counts for coliform (46,000 MPN/100 mL). Although the outlets from the ponds showed a reduced coliform count the absolute magnitude of coliform counts in water leaving the ponds remained high.

Typical concentrations of fecal coliform counts in street gutters and from rooftops reported previously found fecal

coliform counts for these sample locations of 10,000 and 100 MPN/100 mL respectively (Ontario Ministry of the Environment, 1983).

Sediment and catch basin sump water were found in the same study to have low fecal coliform counts, 20/g solids and 20 MPN/100 ml respectively. Catch basin sumps, in particular, would not be expected to contribute significant amount of coliform to the stormwater.

14.5.6 Sodium and Chloride

Pond inlet and outlet sampling, as would be expected, resulted in a similar average concentration for both measurements of chloride and sodium. The normal ratio of Cl/Na (obtained from solution of NaCl) was observed. A lower average for both sodium and chloride at the street gutter as compared to the pond inlets was due to the sampling point for gutter flow being on a minor road that did not receive as much salt as did the main road. Higher concentrations of sodium and chloride would likely have been recorded had sampling been completed immediately after road salt application which was not the case for most of sampling done.

The highest concentration of chloride recorded during this study was from the wet pond outlet (493 mg/L). Concentrations of chloride from residential areas have been recorded at concentrations as high as 786 mg/L (Waller, 1986).

14.6 Conclusions

The following conclusions can be drawn:

1. Results of the sampling program in Guelph indicated that the concentrations and mass loadings of BOD₅, suspended solids, total phosphorus, and fecal coliform were similar in magnitude to previous studies. Published annual loadings are a reasonable base for the design of quality control structures.

2. The concentration and mass loading of BOD₅, and the mass loading of suspended solids from the commercial area differed substantially from that found in previous research and warrants further investigation.
3. Most pollutants were washed off the rooftops within the first 2-3 mm of rainfall, within 6-7 mm of rainfall for the commercial area and within 10-15 mm for the residential areas.
4. Both the wet and dry quantity control structures can be effective at reducing suspended solids and associated pollutants. Reductions of 95% for suspended solids, 70% percent for total phosphorus and 30% for BOD₅ were measured for the wet and dry ponds in this study.
5. Although reductions of fecal coliform and BOD₅ were observed, neither were effectively removed by pond detention.
6. Incorporating a grassed-swale type filter into wet ponds could be an effective method of improving the performance of these structures during winter and spring seasons.

14.7 References

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