THE UNIVERSITY OF CALGARY

A Monitoring Programme to Assess the Use of a Natural Wetland for Stormwater Treatment in Calgary

by

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ABSTRACT

Urban stormwater runoff introduces many contaminants into aquatic systems, some of which are harmful to aquatic and human life. Conventional stormwater management practices are designed to drain the city of excess runoff as rapidly as possible to prevent flooding and are not designed to control water quality. Wetlands are effective in improving runoff water quality by various physical, chemical and biological processes. When introduced into a city storm drainage plan one of the major benefits is less contaminated receiving waters. The use of natural wetlands as stormwater treatment facilities is relatively new, therefore, long-term effects are not well known. Monitoring is essential, then, as a tool to document and assess the changes in water quality treatment and wetland integrity.

This study presents an initial assessment of stormwater quality treatment by a natural wetland in Rocky Ridge subdivision, northwest Calgary. The study is based on three years of data collection, the first two of which provide baseline wetland water quality data and the third which provides water quality data associated with the introduction of stormwater into the wetland. Initial analysis of the data indicates that Rocky Ridge wetland is effective in reducing stormwater pollutants. However, further monitoring over several additional years is required to provide sufficient data for a complete assessment of the long-term capability of a natural wetland for stormwater treatment.

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1. PROJECT RATIONALE AND BACKGROUND

Stormwater pollution is a problem that needs mitigation to protect receiving waters from deterioration of water quality and aquatic life. During storms, contaminants are washed from city surfaces and deposited into rivers and lakes at a rate higher than the assimilation capacity of the water. Aquatic systems in upstream areas are capable of filtering out pollutants, leaving less contaminated runoff to enter receiving waters.

Rocky Ridge Ranch is one of Calgary's newest subdivisions and one of the first in the city to incorporate a natural wetland into its stormwater drainage plan. A small basin with aquatic plants in the subdivision (2000m^2 in area) would have faced demise in past City developments. However, as an alternative to the City's current stormwater drainage practices, Rocky Ridge development plan retained the basin as is, complete with its wetland plants. The primary objective of the pond is to comply with a regulation to control water quantity. New subdivisions are required to design storm management facilities for a 100-year storm event (City of Calgary, 1981). The second objective, which exceeds City regulations, is to improve runoff water quality before it drains into the Bow River.

The Rocky Ridge stormwater treatment wetland is a pilot project in the City's master drainage plan. Its suitability as a stormwater facility is unknown. Long-term studies on the use of natural wetlands as an alternative to conventional stormwater practices are not available. To evaluate the successes and failures of the Rocky Ridge stormwater treatment wetland, an extensive monitoring programme is necessary. Documentation is provided here for three years of data collection at Rocky Ridge along with general monitoring recommendations for natural wetlands in stormwater treatment. Background information is provided on stormwater and wetland processes to assist in defining the system being monitored.

1.1 PURPOSE

The purpose of this study is to initiate the assessment of a natural aquatic system (with edge modification) being used as a stormwater treatment facility in the Calgary area. Recommendations on monitoring are made based on information collected from three years of sampling at Rocky Ridge stormwater treatment wetland and related literature.

The information collected from the monitoring programme should allow evaluation of:

1. the long-term capability of a naturally occurring wetland to remove contaminants from urban stormwater
2. the sustainability of the wetland in terms of its biological communities, water quality and aesthetics after prolonged exposure to stormwater
3. management strategies that may be needed to improve facility operations.

1.2 OBJECTIVES

The study objectives were carried out by collecting water quality information for three seasons of open water at Rocky Ridge wetland. The first two years of data (1994 and 1995) consist of in-pond water quality samples prior to the introduction of stormwater, while the later year (1996) consists of stormwater samples for the first year of operation of Rocky Ridge stormwater treatment wetland. These data were compiled and summarized for reference in future analyses.

1.3 BACKGROUND

1.3.1 Urban Stormwater

Water pollution is the presence of impurities at such a level that it impairs the use of water for its designated purpose (Peavy *et al.*, 1985). Urban stormwater runoff contributes to water pollution by elevating levels of sediment, chemicals and microbes in receiving water bodies (Makepeace *et al.*, 1995; Marsalek *et al.*, 1992). Urban areas have a higher rate and volume of runoff than rural areas because of decreased infiltration to the soil, reduced detention of water in natural swales and greater efficiency of conveyance through the use of artificial conduits (Dunne and Leopold, 1978). Pollutants that accumulate on streets, parking lots and other surfaces are rapidly flushed into streams after the start of a rainfall event. The highest concentration of pollutants occurs at the beginning of the event, often causing a serious shock loading to aquatic life (Lazaro, 1979). This phenomenon is referred to as the *first-flush* effect. Pollutants in stormwater that require mitigation to prevent severe degradation of receiving waters are generally included under the headings of solids, nutrients, metals, hydrocarbons, bacteria and toxicants (Watt and Marsalek, 1994).

Sediment load is a natural attribute of streams; however, in abundance, sediments can have a detrimental effect on aquatic life by covering streambed habitat, clogging fish gills and reducing light penetration which reduces the rate of photosynthesis (Dunne and Leopold, 1978). This in turn reduces the amount of dissolved oxygen in the water body because greater plant production will generate more oxygen during daylight hours. A lower oxygen supply can impede the growth of fish and other oxygen-dependent organisms. Also, excess sediment in a drinking water source will increase treatment costs. Sources of sediment in urban areas are construction sites, poorly vegetated land, stream channel erosion, slumping from steep slopes (Stockdale, 1991) and winter sanding on streets and parking lots.

Nutrients, especially phosphorus and nitrogen, may also affect receiving water bodies by causing eutrophication leading to explosive plant growth, in turn reducing water clarity and depleting dissolved oxygen levels (plant decomposition consumes oxygen). There are many sources of nutrients in urban areas including sediments, fertilizers, petroleum products, domestic animal excrement, septic systems and vegetation (Stockdale; 1991).

Metals, oil, grease and other organic chemicals are sources of toxicity in aquatic systems and can be harmful in raw drinking water. They also have the potential to accumulate in the food chain. Petroleum products are a source of persistent toxic substances (PTS) which have no assimilative capacity in a natural system and must be removed by sinks, such as landfill sites, or even wetlands (Thompson, 1994).

Microorganisms in the form of bacteria carry water-borne diseases that can be passed on to humans during contact recreation.

In an extensive summary of individual contaminants found in stormwater Makepeace *et al.* (1995) identify those that are a major concern to human and aquatic life. With respect to drinking water, the most critical contaminants affecting humans are total suspended solids, aluminium, chloride, chromium, iron, lead, manganese, mercury, total polycyclic aromatic hydrocarbons, benzo(*a*)pyrene, tetrachloroethylene, fecal coliforms, fecal streptococci, and enterococci. The contaminants identified as most critically affecting aquatic life are total solids, total suspended solids, aluminium, beryllium, cadmium, chloride, chromium, copper, iron, lead, mercury, nitrogen, silver, zinc, dissolved oxygen (which tends to decline greatly during a storm and can stay that way for up to five days) ,polychlorinated biphenyl, *bis*(2-ethylhexyl) phthalate, γ-BHC, chlordane, heptachlor and heptachlor epoxide. Makepeace *et al.* (1995) include in their summary the concentration ranges that are acceptable for stormwater contaminants and the most common sources.

1.3.2 Stormwater Drainage in Calgary

Traditionally, Calgary has collected excess runoff in gutters and underground conduits and directed it into the Bow River system. With its extremes in topographic relief and the advantage of gravity, this system has worked fairly well to drain the city rapidly and to prevent flooding (City of Calgary, 1981). As Calgary grows, however, so does the area of impermeable surfaces and the amount of runoff. The result is often overtaxed storm sewers and increased flooding (Dunne and Leopold, 1978). More recent regulations (since 1981) call for each new subdivision in Calgary to include water detention facilities in their stormwater drainage plan to detain water for a short period and attenuate downstream flooding (City of Calgary, 1981). The most common means of detaining runoff has been construction of stormwater ponds or *dry ponds*. These basins are dry most of the time but fill up during periods of excess rain. They are designed to hold water temporarily then gradually release it to city storm trunk lines and into receiving waters. They often double as recreation facilities such as baseball diamonds (*Ibid.*). Retention basins, on the other hand, such as McCall Lake in northeast Calgary, are designed to retain water all year round.

Stormwater management in Calgary is concerned with the attenuation of floods and the reduction of peak flows that overload underground drainage systems (*Ibid.*). This system does little to reduce pollution. Storm sewers around Calgary have been found to contain high levels of coliform bacteria, nutrients, some metals, salts, suspended solids and other pollutants (BRWQTF, 1991). Recent studies show stormwater to be the greatest source of suspended solids in the Bow River and a significant source of coliform bacteria and phosphorus (*Ibid.*). These pollutants lead to a deterioration in water quality, destruction of fish spawning grounds, reduction in water use for contact recreation (*Ibid.*) and, in some cases, increased costs for drinking water treatment.

It is agreed by water pollution managers that the most effective treatment of stormwater pollution is to develop control measures in upstream communities before contaminants enter receiving waters (BRWQC, 1994; Makepeace *et al.*, 1995). A method that is proven effective is the use of wetlands (Hammer, 1992) which modify water quality through physical and biochemical processes to assimilate or transform contaminants.

2. WETLANDS AND WATER QUALITY

2.1 Wetlands Definition

Wetlands are extremely diverse in both form and function and, consequently, are difficult to define. Zoltai (1979) defines them as "...areas where wet soils are prevalent, having a water table near or above the mineral soil for the most part of the thawed season, supporting a hydrophylic vegetation." The wet extreme of this definition is shallow open waters, generally less than two metres deep. On the basis of this definition, the stormwater facility at Rocky Ridge subdivision (Figure 1) can be referred to as a wetland.

Figure 1: Rocky Ridge stormwater wetland in complete operation (July 1996)

The study of wetlands involves a variety of disciplines not just ecology. The wetland specialist should be knowledgeable in surface and groundwater hydrology, chemistry (especially in the area of water and sediment interaction), microbial biochemistry to understand the processes of anaerobic environments and botanical and zoological studies (Mitsch and Gosselink, 1993). Engineering skills are also needed in wetland management as constructed wetlands are being used increasingly for pollution abatement and environmental protection.

2.2 Wetland Processes

A wetland such as that at Rocky Ridge can act as a sink or accumulator of nutrients and as a chemical transformer. Municipal wastewater treatment uses wetland processes to successfully lower concentrations of nitrogen and phosphorus and to reduce biological oxygen demand (BOD). The Saskatchewan Research Council has been using plants in the town of Humbolt (population 5500) for over 15 years to provide viable and economical sewage treatment (Sinclair, 1981). According to Sinclair (1981), *Scirpus* and *Typha* are responsible for consuming one year's supply of sewage in just six months. Nitrates, ammonia and soluble phosphates are taken up by plants and microbes and incorporated into organic matter (Horne and Goldman, 1994).

According to Dunbabin and Bowmer (1992), one of the first known applications of an engineered wetland was in Buick Mine, Missouri at a lead and zinc mine (reported in 1979). They describe the operation as a long, meandering channel, complete with plants such as *Typha* and *Potomogeton,* that increase the residence time of wastewater in the channel before it reaches the final destination of a natural stream. They conclude that the process is effective in reducing particulate matter and metals. Studies have shown that metals are retained in sediments by means of ion exchange and precipitation. In less significant amounts metals are taken up by emergent vegetation and stored in the pore spaces of stems and roots (*Ibid.*).

2.2.1 Sedimentation

Sedimentation is one of the most important processes for removing pollutants from water entering a wetland (Bingham, 1994; Stockdale, 1991). The current of inflowing water slows as it enters the wetland because of plant friction and a decrease in gradient. Heavier particles fall out of suspension and are deposited on the wetland floor. The efficiency of removing suspended solids from wetlands is dependent on many factors including water inflow rate, particle settling velocity (which is related to particulate size, shape and density), detention time, depth and temperature (Urbonas, 1995; Badakhshan, 1996).

2.2.2 Filtration

Suspended solids are filtered when water flows through dense stands of submerged vegetation and roots. Filtration engages other processes to further remove contaminants such as: *adhesion* - as water passes through a wetland, suspended particles adhere to vegetation or other filtration media; *flocculation* - particles are brought together at constricted flow areas to form larger-sized particles known as flocs; *straining* - takes place when large particles will not pass through the filtration medium (Badakhshan, 1996).

2.2.3 Adsorption

Adsorption is a physical process that requires large adsorbent surface areas (such as clay particles). Dissolved particles affix themselves to surface areas due to an imbalance of forces that prevent the solute from remaining in suspension (Badakhshan, 1996). Contaminants adhere to clay soils and plant material. The process is enhanced by extended contact with the adsorbent medium and is dependent on adsorbent type, surface area, electric charge and percent of free ions available (Stockdale, 1991).

2.2.4 Precipitation

Precipitation is one of the principal methods of phosphorus removal in wetlands. Inorganic phosphate can form precipitates with dissolved aluminium, iron, calcium and clay minerals (Nichols, 1983) that are stored in the wetland soil.

2.2.5 Biochemical Transformation

Biochemical reactions in a wetland, *oxidation* and *reduction*, require biological mediation often supplied by microorganisms that utilize organic compounds as food. The result is a transformation of compounds to different species of the same element (Peavy *et al.*, 1985).

Nitrogen exists in many different forms and is converted from one form to another by ammonification, denitrification and nitrification. Ammonification is the oxidation of organic nitrogen to ammonia (NH_3) by bacteria. Denitrification is an oxidation reaction and occurs in anaerobic environments and involves the conversion of nitrate (NO_3^-) to nitrite (NO_2^-) to nitrogen gas (N_2) by bacteria. Nitrification is the oxidation of ammonium (NH_4^+) to nitrate. This process requires oxygen and occurs in the thin aerobic layer on the surface of the wetland soil. Nitrate then permeates into the water or to the lower anaerobic layer where denitrification occurs (Horne and Goldman, 1994). The resulting nitrogen gas is removed from the wetland by diffusion to the atmosphere.

2.3 Wetland Hydrology

The hydrology of a wetland consists of all inputs and outputs of water. It refers to pathways by which water can enter a wetland (such as precipitation, surface runoff and groundwater), water depth, flow pattern, flood duration and frequency) and exit pathways such as evapotranspiration (Mitsch and Gosselink, 1993). Mitsch and Gosselink (1993) advocate that hydrology is the single most important determinant for the establishment and maintenance of all wetland processes. The importance lies in its control over water availability, nutrient availability, aerobic and anaerobic activity, soil particle size and composition, water chemistry and velocity (Hammer, 1992).

Although productivity will vary between wetland types, the vegetation structure of a wetland is controlled by the inundation of water. Through physical transport, hydrology controls nutrient cycling and availability, nutrient import and export and decomposition rates. Wetlands are more vulnerable to interference than any other habitat because small changes in water level can destroy plant communities that exist only at specific levels of water (Etherington, 1983). A small change from drainage or civil engineering works that affect hydrology may have enormous biological consequences (*Ibid.*).

2.4 Water Budget

The balance of inflows and outflows of water is referred to as the water budget (Eastlick, 1994). A *mass balances* approach in studying the fate of pollutants through a stormwater treatment system considers all the components as an integrated unit measuring all inputs and outputs. Mass loadings of constituents are determined by the storage capacity of a wetland. The amount of time water stays in the wetland (known as *residence time*) is a factor in physical and biochemical processes which remove constituents from inflowing water (Eastlick, 1994). The water budget of a treatment wetland can be calculated to determine the annual pollutant removal ability of the wetland. What the wetland is storing can be determined by knowing the constituent concentration in the inflow and the outflow. This should be done as an annual calculation to balance out seasonal fluctuations. Mitsch and Gosselink (1993) describe the balance between water storage and inflows and outflows by the following equation:

$$\Delta V/\Delta t = Pn + Si + Gi - ET - So - Go$$

where,

ΔV = volume of water storage in wetlands

$\Delta V/\Delta t$ = change in volume of water storage in wetland per unit time, t

P_n = net precipitation

S_i = surface inflows, including flooding streams

G_i = groundwater inflows

ET = evapotranspiration

S_o = surface outflows

G_o = groundwater outflows

2.4.1 Volume

The volume of a wetland basin is determined by a detailed hydrographic map that shows depth contours of the basin. Hydraulic residence time is the time it takes an empty basin to refill with its natural inflow. It is calculated by dividing the volume by the inflow (or outflow) rate. Long residence times in wetlands increase the opportunity for dissolved substances to come in contact with particulate matter (Bingham, 1994). Therefore, residence time is an important function of pollutant removal rates (Horne and Goldman, 1994).

2.4.2 Precipitation

Precipitation can be measured at any point in a watershed using a rain gauge. A non-recording rain gauge allows measurement of only the amount of precipitation during a given interval. A recording rain gauge records the amount of precipitation as well as the timing and intensity. Measurement of precipitation over the area of the wetland is estimated using the point data multiplied by the area of the wetland surface, representing direct precipitation to the wetland (Dunne and Leopold, 1978). Similarly, precipitation can be determined for the drainage basin by knowing the catchment area.

Some of the precipitation that falls does not reach the ground but is intercepted by vegetation or other surface cover and evaporated back to the atmosphere. It is not considered to be a large amount but a significant part of the budget calculation. Mitsch and Gosselink (1993) use net precipitation, P_n, in their water budget equation which is the amount of precipitation that reaches the water surface. It is determined by total precipitation (P) minus interception (I):

$$P_n = P - I$$

If equipment for measuring precipitation is not available, rainfall can be estimated from local meteorological records. These data are often collected at airports which may be a great distance from the study site and may provide an inaccurate estimate of precipitation.

2.4.3 Surface Inflows and Outflows

Surface inflows refer to *overland flow*, a non-channelized sheet flow (runoff) that occurs directly after a rainfall event, and *streamflow*, a channelized flow (Dunne and Leopold, 1978) that may enter the wetland continuously or at any time of year.

2.4.4 Groundwater

Groundwater inflows and outflows could be a significant factor in the hydrology of a wetland depending on where it is situated with respect to the water table. Mitsch and Gosselink (1993) describe several ways wetlands can lose or gain water through groundwater flow; however, they report the prairie pothole to be little influenced by groundwater. Wetlands of the Prairie region generally occur in silty and clayey till and on lake sediments that prevent rapid infiltration (Winter, 1989). Non-coastal wetlands that are influenced by groundwater are found in one of the following situations summarized from Mitsch and Gosselink (1993): i) if the water surface of a wetland is hydrologically above the water table but still in contact with the groundwater it will experience losses through groundwater outflow; ii) alternatively, if the water table is above the wetland water surface then groundwater will flow into the wetland - this represents a gain in wetland hydrology, nutrients and dissolved minerals; iii) a wetland can have inflows and outflows if it intercepts the water table on a slope (groundwater will flow in at the high end and out at the low end); iv) if a wetland is perched above the water table and not in contact with the groundwater it can lose water through infiltration.

Groundwater movement is calculated using Darcy's Law, an equation that considers the slope of the water table and the permeability of the substrate (Mitsch and Gosselink, 1993):

$$G = k\,a\,s$$

where,

G = flow rate of groundwater

k = permeability or hydraulic conductivity

a = groundwater cross-Sectional area perpendicular to the direction of flow
s = slope of water table or hydraulic gradient

Groundwater measurements are not as simple as those for surface water because they involve more than dipping a sample bottle into water. Wells must be drilled to the top of the water table in several places to measure the hydraulic gradient and to analyze the soil for substrate permeability. Ideally, a treatment wetland would be sealed to avoid interaction with groundwater. Darcy's Law can also apply to the movement of water through wetland soils of a treatment wetland (Kadlec, 1989)

2.4.5 Evapotranspiration

Evapotranspiration refers to atmospheric losses through transpiration from plants above the water surface and evaporation from water and soil (Kadlec, 1989). Evaporation represents a significant water loss and its estimated value should be incorporated into the water budget of a wetland treatment system especially in dry climates (Dunne and Leopold, 1978; Mitsch and Gosselink, 1993; Kadlec, 1989).

2.5 Hydroperiod

The water budget is a description of the balance of all inflows and outflows of a particular system and can be extrapolated over several years (Dunne and Leopold, 1978). The *hydroperiod* is the seasonal pattern of water level, a measure of flood duration and frequency (Mitsch and Gosselink, 1993). Whereas the water budget of the hydrologic cycle is used at a planning level to assess economical and ecological feasibility of a project, the hydroperiod characterizes the seasonal variation of the wetland. It is a function of surrounding geomorphology, soil, geology and groundwater conditions and it determines the internal structure of biological communities (Mitsch and Gosselink, 1993).

Nutrients enter a prairie wetland through precipitation, river flooding, direct runoff and groundwater inflow (Mitsch and Gosselink, 1993). The hydroperiod, therefore, determines the productivity of a wetland. A steady or frequent inflow of water provides a continual supply of nutrients for wetland plants and encourages high productivity. Periodic drying recirculates nutrients that are unavailable during flooded conditions. Wetlands in stagnant or continuously-deep water have low productivity because nutrients remain immobilized in the soil and on plants. Nutrients that are bound to sediments or adsorbed as ions can get trapped in the anaerobic soil layer (*Ibid.*). The cycle is then closed with no exchange of nutrients across the soil-water boundary and nutrients are unavailable to plants (National Wetlands Working Group, 1988). Productivity will increase once the dry-out cycle begins because nutrients are recycled through the system. Elements that have been adsorbed to sediments will be released or oxidized.

2.6 Wetlands as Stormwater Management Facilities

Natural wetlands have been used for decades in waste assimilation with varying degrees of success (Nichols, 1983). Livingston (1989) advocates the use of natural wetlands as an opportunity to use, not abuse, a natural system to mitigate the effects of urban runoff. Authors such as Hammer and Bastian (1989) and Stockdale (1991) discourage the use of natural wetlands, claiming there is not enough information available on wetland assimilation capacity to increased pollutant loadings. They concur that natural wetlands are a valuable resource and, because much is unknown of the long-term effects of stormwater pollutants, it is not worth the risk of destroying an already disappearing resource.

Artificial or constructed wetlands are used for wastewater treatment (secondary treated sewage) and less commonly for stormwater treatment in many parts of the United States, especially Florida, Oregon, California and Maryland. There is some documentation on the use of natural systems and natural channel design for stormwater control but not many examples were found in the literature similar to the Rocky Ridge wetland.

A similar situation to Rocky Ridge might be that of a small lake receiving stormwater in the Chicago area. Striegl (1987) reports on pollutant removal by a lake slightly larger than the pond in Rocky Ridge subdivision. His study shows the lake as highly effective in removing suspended sediments and metals from urban runoff but there is no mention of other pollutants such as nutrients and pathogens. Striegl also comments that sedimentation rate on the lake bottom is 20mm per year and the effect of accumulated pollutants on flora and fauna is unknown.

2.6.1 Artificial Wetlands

Constructed or artificial wetlands have been found to be successful for the treatment of all types of wastewater including stormwater (Hammer and Bastian, 1989; Stockdale, 1991). Hammer and Bastian (1989) suggest they are an economical alternative to conventional water treatment systems and easy to construct, operate and maintain. However, they caution that because of recent application of the technology, their long-term reliability is yet to be known. Design manuals were published years ago in the late 1980s to provide specific construction guidelines in Maryland (Smith *et al.*, 1993) and for the United States in general (U.S. EPA, 1988) but the wetlands have not been in operation long enough to provide sufficient data. In western Canada, Eastlick (1994) has developed a design manual for the Prairie Provinces and in 1996 the City of Calgary constructed a stormwater management wetland as a pilot project for which water quality and vegetation data are being collected (see Bell, 1998 for more information).

2.6.2 Natural Channel Design

Smith *et al.* (1993) describe a successful natural channel design in the town of Oakville, Ontario where existing woodlots and natural valleys have been preserved. In the subdivision of Glen Abbey the developers used a 7.5m buffer zone extending from the top of a stream bank to the rear lot lines in which no development takes place. The stream was left in its natural state with the addition of detention basins on the flood plain to double as playing fields. The floodway is now a park with walking paths following the stream channel and is used for recreation and education by the community.

The Beechwood and Lakeshore Village developments in Kitchener-Waterloo, Ontario are similar to the Glen Abbey design. Smith *et al.* (1993) report that Beechwood attempted to retain natural valleys and woodlots while Lakeshore did not attempt to save trees and even converted a stream into a straight-sided ditch for stormwater drainage. Although the development costs per acre were higher for Beechwood, the developer realized an 85% return on the initial investment and Lakeshore gained only a 58% return.

2.7 Rocky Ridge Stormwater Treatment Wetland

The concept of Rocky Ridge was derived from literature that suggests retrofitting stormwater ponds for water quality control (Marsalek *et al.*, 1992). Stormwater ponds became common in the 1980s to control flooding within upstream developments and to reduce drainage infrastructure costs but they have proved ineffective for controlling water quality and protecting receiving waterbodies from pollutants (*Ibid.*).

The introduction of this new approach to stormwater management can be less expensive than conventional methods due to the elimination of in-pond piping and excavation (van Duin *et al.*, 1995). However, the addition of civil engineering works and a monitoring programme raises the cost above conventional systems (*Ibid.*).

The wetland at Rocky Ridge Ranch is a naturally occurring feature that was included into the subdivision drainage plan. The development was not designed around the natural drainage but rather, the wetland was incorporated into the development plan. There was no allowance for a land buffer zone or drainage enhancement features such as greenways, swales or sedimentation pond for upland pollution management. As a result, the construction phase left some impact on the pond which may have adversely affected wetland processes.

It was the intent of the developers to leave the pond undisturbed to take advantage of existing wetland processes for stormwater treatment. However, the pond did not remain undisturbed during construction. Heavy rainstorms washed sediments from stripped land into the pond and drainage of the sediment vault in summer 1996 took place directly into the pond resulting in additional sediments on the pond bottom. This can affect wetland ecology by smothering benthic organisms.

Although Rocky Ridge wetland is primarily a stormwater facility it must be accepted by residents as an aesthetically pleasing natural amenity to ensure its success. Surveys conducted in Ontario by Carlisle and Mulamoottil (1991) and Adams *et al.* (1984) demonstrate that public acceptance is key to the success of stormwater management projects like this. In fact, Adams *et al.* (1984) suggest that due to concerns and perceived problems by the public on issues such as mosquitoes, wetlands for stormwater control are not likely to be common in the near future. Studies have been done on mosquito management and remedies range from wetland hydrological controls to biological controls, such as fish that feed on mosquito larvae or administration of bacterial insecticides (Mitsch and Gosselink, 1993).

The use of natural wetlands for stormwater management is new in Calgary. Hence, the City will not take responsibility of Rocky Ridge stormwater wetland until it has proven itself a successful facility and an acceptable natural amenity. The developer was asked by the City to monitor the wetland for a period of five years (beginning in 1996) before it will be assumed under the Engineering and Environmental Services Department. If the wetland is not successful for any reason after this period it will be converted to a more suitable stormwater management facility. If the project is a success, the sprawling boundaries of Calgary could see more urban stormwater treatment wetlands.

2.7.1 Description of Area

Rocky Ridge Ranch is located at 114°14′07″W, 51°08′50″N (SE 1/4 Sec 20 Tp 25 R2 W5) in northwest Calgary along Rocky Ridge Road north of highway 1A (Figure 2). The land prior to development was characterized as hummocky terrain with several depressions that hold water most of the year (van Duin *et al.*, 1995). These depressions, or wetlands, found throughout the Prairies, provide important habitat for wildlife such as deer and waterfowl (Usher and Scarth, 1990) and they are aesthetically pleasing in Calgary's dry landscape.

The wetland in the subdivision of Rocky Ridge Ranch, northwest Calgary, existed as a natural feature prior to development. Some edge modifications were made to incorporate the pond into the City's master drainage plan (Figure 3). The alternative was to drain the wetland and replace it with a more conventional facility such as a stormwater dry pond. A sedimentation

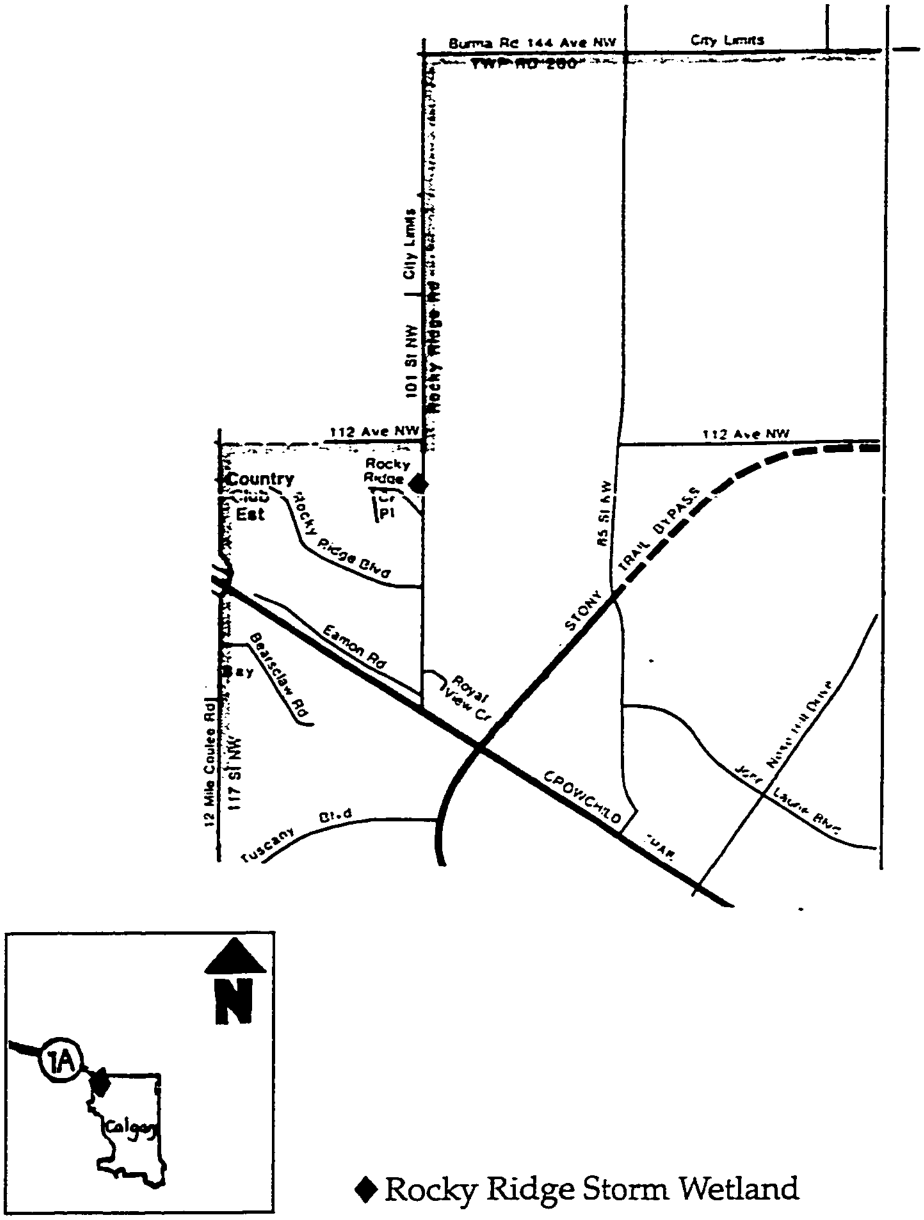

Figure 2: Location of Rocky Ridge Ranch in northwest Calgary (adapted from Ideal Street Maps, 1998).

vault was constructed to link the underground drainage network of part of the subdivision and to trap sediment from stormwater before it drains into the pond (Figures 4 & 5). An outlet structure was added along the pond edge to link to the City drainage system that leads to the Bow River (Figures 6 & 7). Stormwater from approximately 15 hectares of the subdivision began flowing into the pond during the first runoff in 1996.

Residential development for single family homes began in Rocky Ridge Ranch in 1994 at the south end of the subdivision. By spring 1995, construction had begun in the lots adjacent to the pond. By summer 1997 the entire pond was surrounded by homes with the exception of the east side which is Rocky Ridge Road. A recreational pathway, covered in part by asphalt paving and crushed rock, circles the pond.

2.7.2 Climate

The climate in Calgary is described by the Calgary Economic Development Association (C.E.D.A., 1998) as moderate with warm summers and mild winters. Mean daily temperature for July and August is 22.7°C and mean daily winter temperature is -8.9°C. Average annual precipitation is 425mm with 70% of that falling as rain from May to September. Figure 8 is a climatograph of annual monthly precipitation and temperatures for Calgary.

2.7.3 Geography

Rocky Ridge Ranch is located in the Aspen Parkland ecoregion of Alberta and is characterized by chernozemic soils (black and dark brown) and aspen and

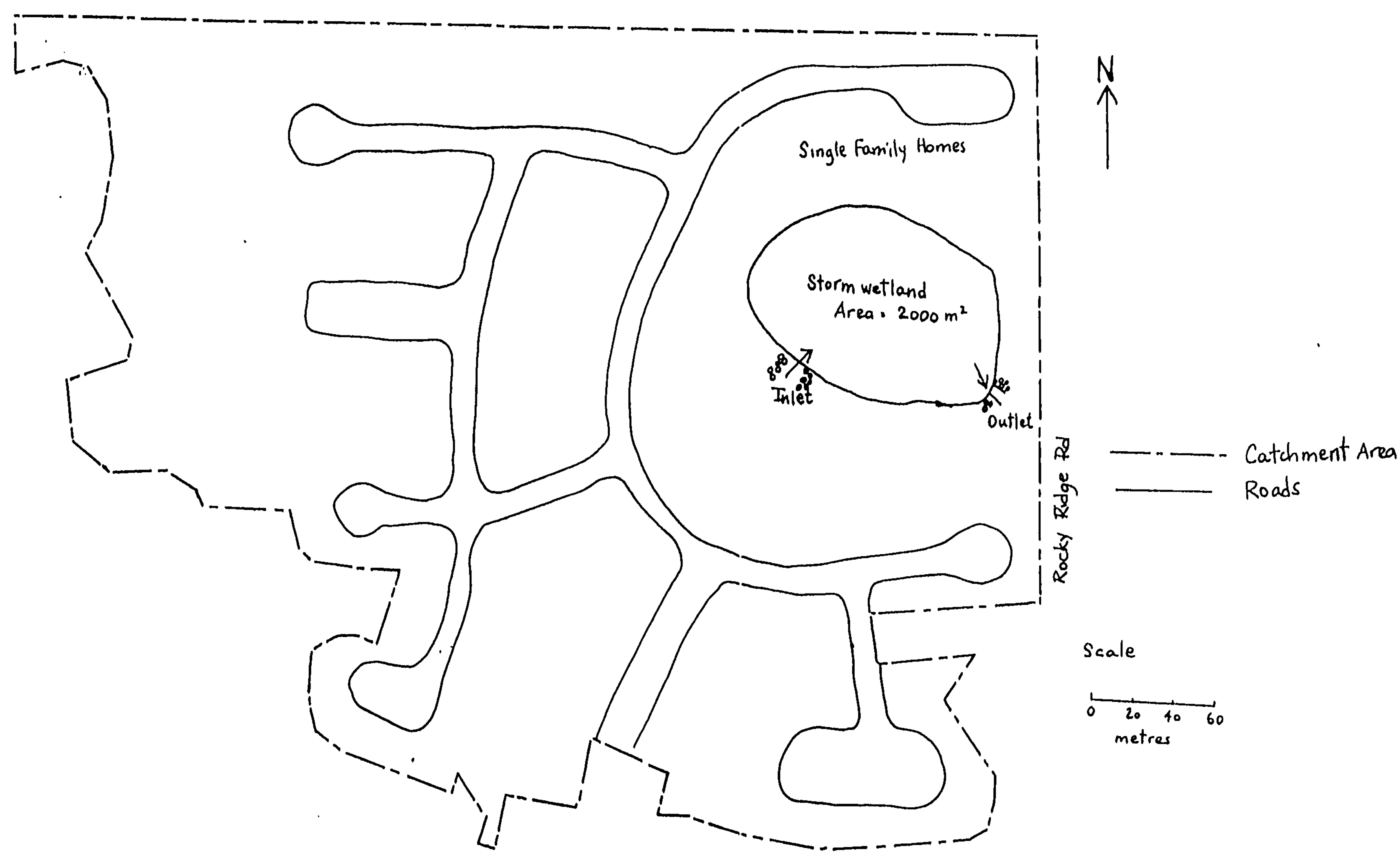

Figure 3: Rocky Ridge storm wetland catchment area showing roads, pond/wetland, and 100-year storm elevation contour (adapted from W.E.R. Agra, 1993; pond survey by M. Dietrich 23/07/96)

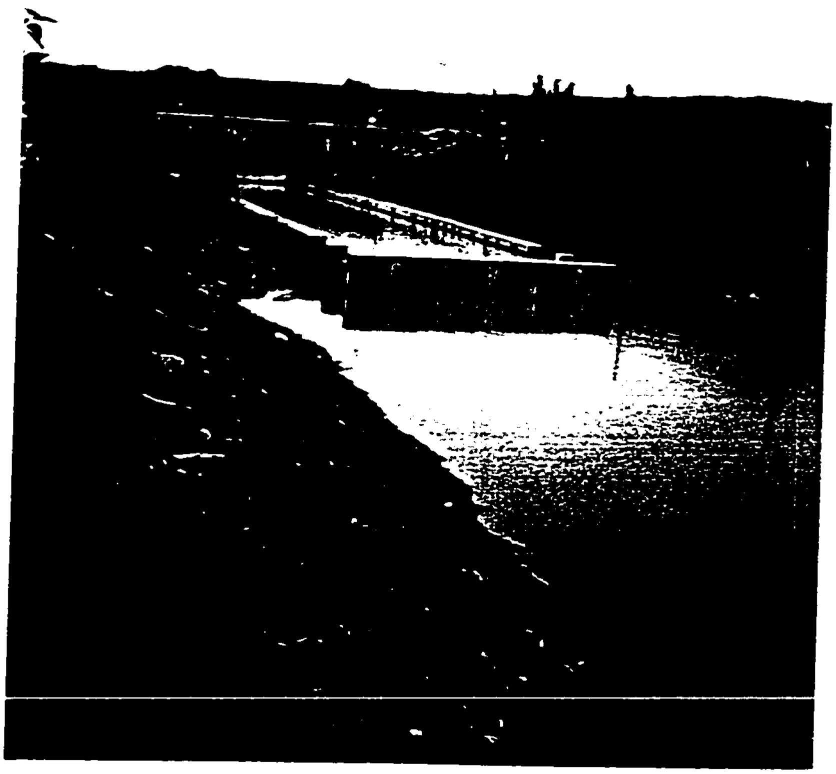

Figure 4: Construction of sediment vault (Spring 1995)

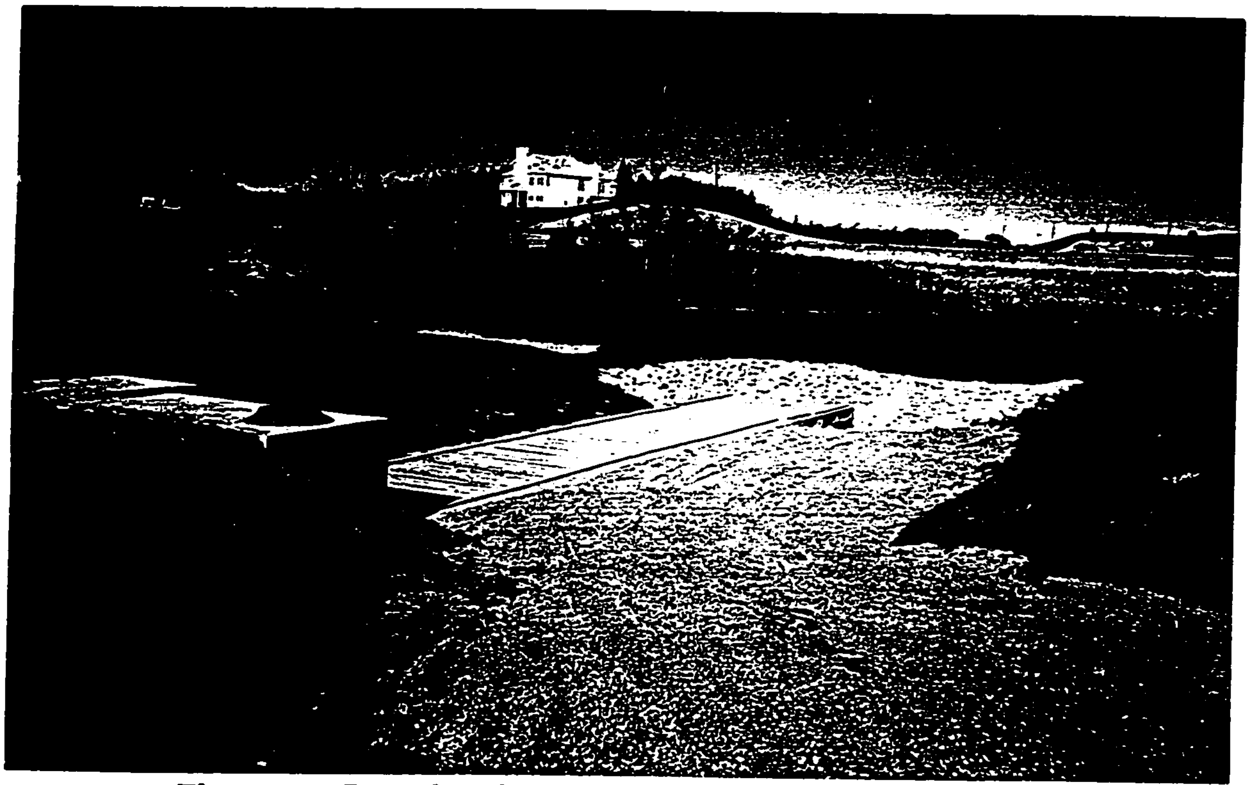

Figure 5: Completed sedimentation vault (October 1995)

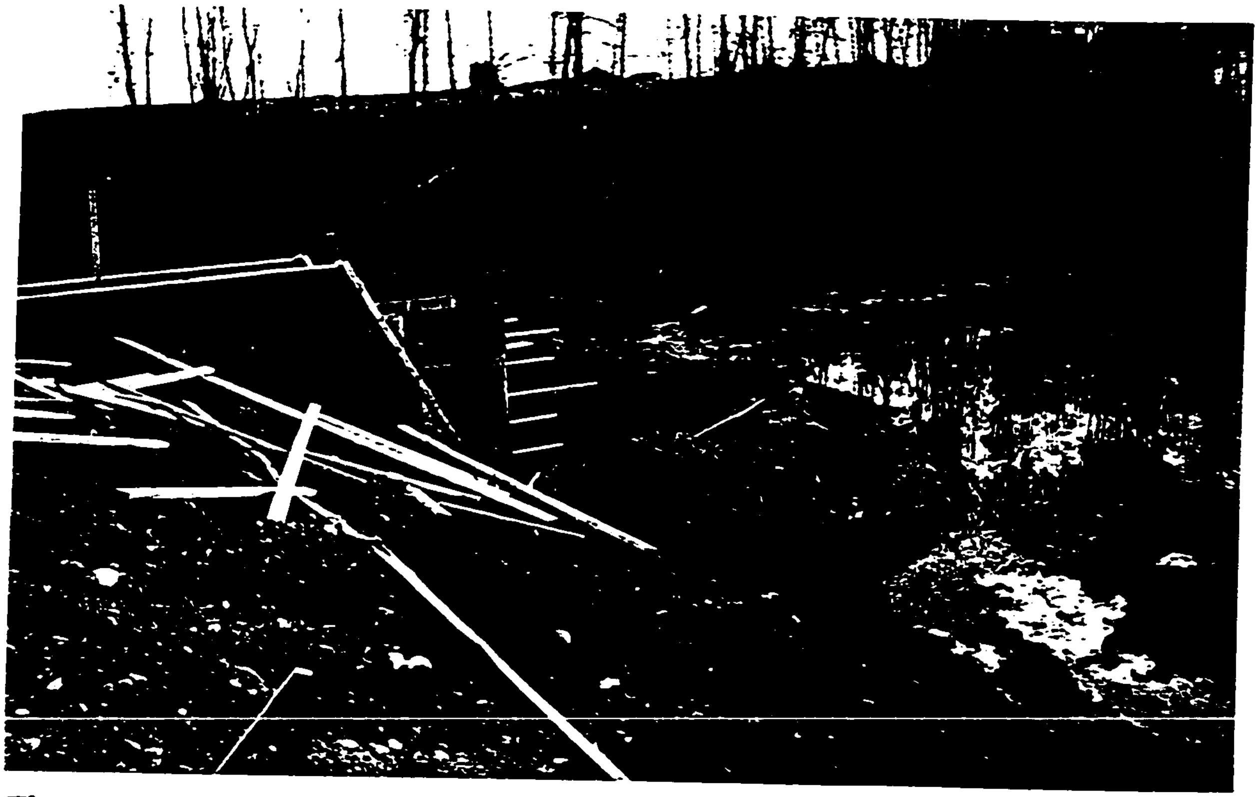

Figure 6: Construction of outlet structure draining to Bow River (Spring 1995)

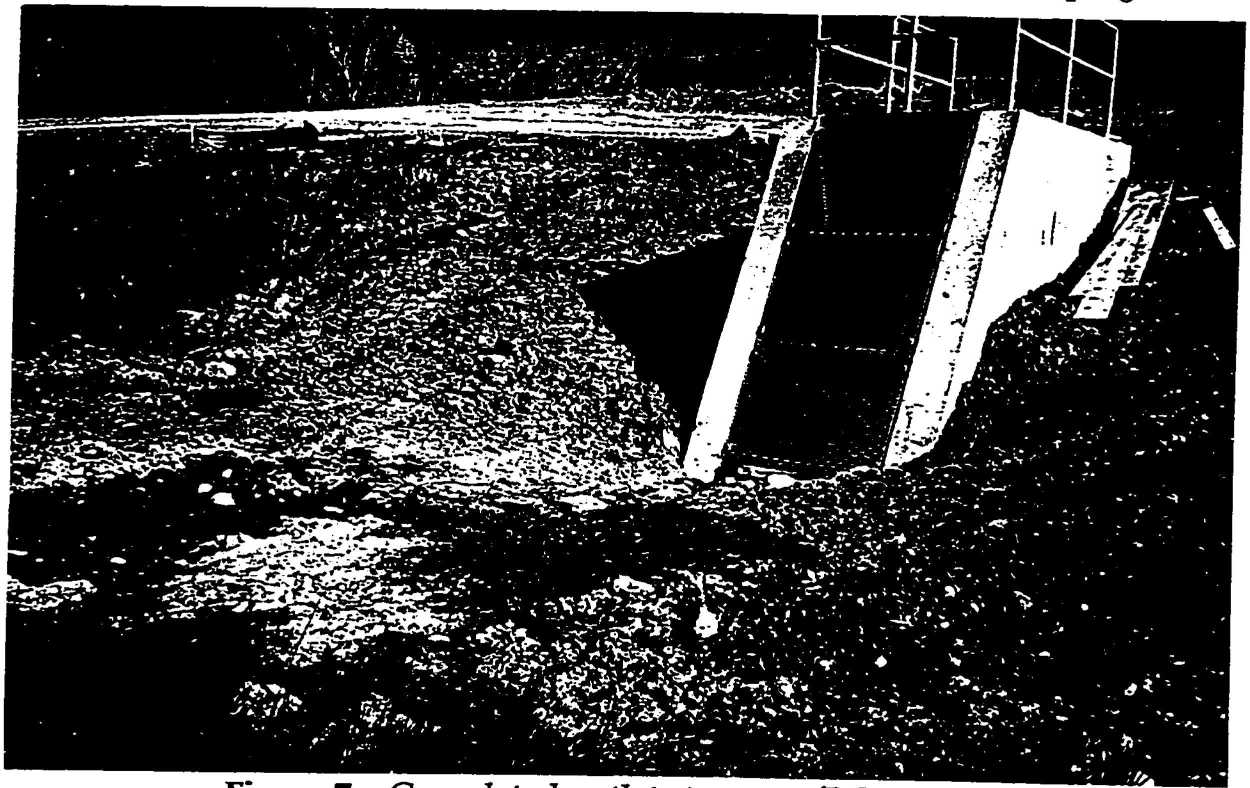

Figure 7 : Completed outlet structure (July 1996)

grassland vegetation (Strong and Leggat, 1980).

The Rocky Ridge wetland is a "kettle" (topographical depression) in the upper unit of "knob and kettle" ablation glacial till of the Spy Hill Formation. The till is silty to clayey with a grain-size composition of 10 to 20 percent sand, 45 to 55 percent silt, and 20 to 45 percent clay (Moran, 1986). Land use in the area prior to development was primarily ranching.

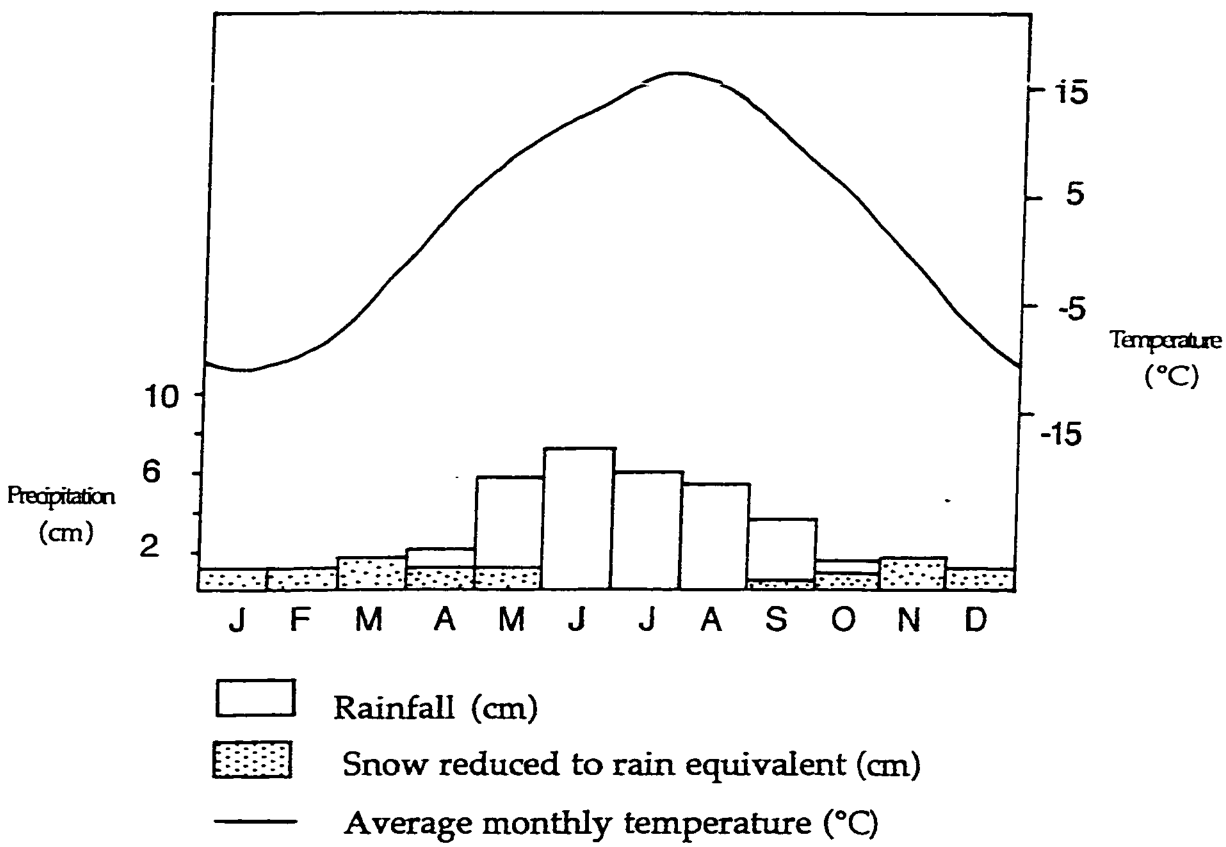

Figure 8: Climatic graph of Calgary showing mean monthly temperature and mean monthly precipitation (Energy Mines and Resources, 1969).

A vegetation survey was completed by Agra Earth & Environmental (the consulting firm retained to design Rocky Ridge Ranch stormwater plan) in 1993 before development began; the resulting map is shown in Figure 9. A list of dominant species obtained from that survey is provided in Table 1.

Table 1: Dominant wetland plant species found at Rocky Ridge Stormwater Wetland on July 22 and 26, 1993 (adapted from W.E.R. Agra, 1993).

OPEN WATER ZONE	
Emergent vegetation -	
spike rush	*Eleocharis spp.*
beaked sedge	*Carex rostrata*
tall manna grass	*Glyceria grandis*
slough grass	*Beckmania syzigachne*
hardstem bulrush	*Scirpus acutus*
mare's tail	*Hippurus vulgaris*
Submergent and Floating-leaved Vegetation -	
sago pondweed	*Potamogeton pectinatus*
water smartweed	*Polygonum natans*
naiad	*Najas sp.*
SHALLOW MARSH ZONE	
Kentucky blue grass	*Poa pratensis*
foxtail barley	*Hordeum jubatum*
baltic rush	*Juncus balticus*
spike rush	*Eleocharis sp.*
silverweed	*Potentilla anserina*
alkali grass	*Pucinella distans*
tufted hair grass	*Deschampsia caespitosa*
slender wheat grass	*Agropyron trachycaulum*

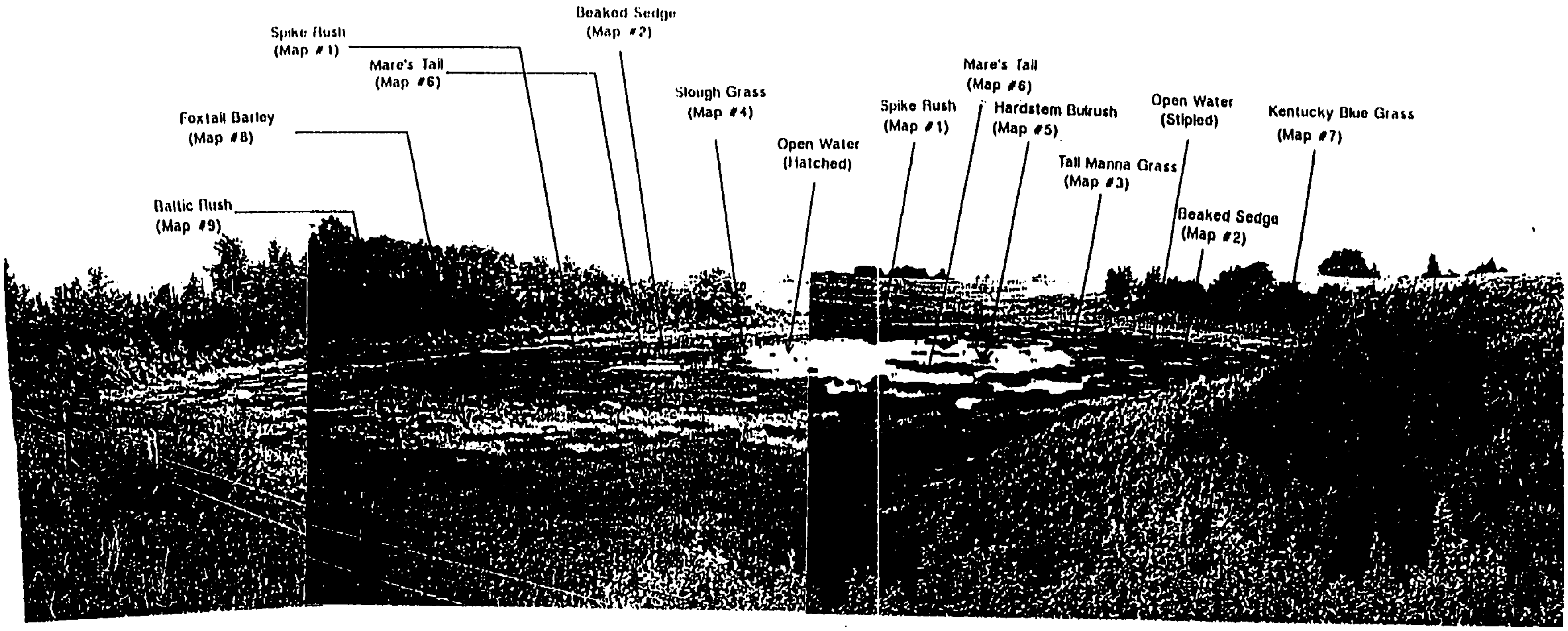

Figure 9: Vegetation structure of Rocky Ridge wetland prior to development in 1993 (W.E.R. Agra, 1993)

3. CHARACTERISTICS OF A MONITORING PROGRAMME

To determine the effectiveness of a treatment wetland, that is, the efficiency of pollutant removal and effect of pollutants on wetland ecology, a monitoring programme is required (Watt and Marsalek, 1994). Ward *et al.* (1990) recommend routine monitoring (instead of special surveys) with a well designed programme and clear objectives as the best tool to assess background variability, seasonality and long-term trends. Wren *et al.* (1997) recommend standardized programmes to provide guidance for future projects. Landers and Knuth (1991) report that most projects lack adequate monitoring to determine adverse ecological effects. Monitoring should focus on water, sediment and pollutant mass balances with identification of sources, sinks, and transport and transformation processes (Watt and Marsalek, 1994). Environmental baseline conditions should also be documented (Wren *et al.*, 1997). Urbonas *et al.* (1995) suggest a standard list of parameters be used to compare data amoung various studies; however, they do not suggest which parameters should be used.

Landers and Knuth (1991) describe a treatment wetland with optimal management practices as having all of the following components fulfilled:

1. Wetland protection mechanisms in place to encourage preservation of wetlands to maintain their value in water quality improvement and natural ecosystems.
2. Decentralization of management to a moderate degree to involve all the expertise needed for diverse wetland studies.

3. Water level and retention control to provide optimal pollutant removal capability by obtaining the appropriate depth and retention time.
4. Sheet flow rather than channelized flow to slow inflowing water and ensure more uniform distribution over the surface of the wetland.
5. Nutrient removal by means of harvesting of vegetation or flushing so that accumulation does not occur in the wetland.
6. Chemical treatment, although controversial because of possible negative ecological impacts, to enhance pollutant removal.
7. Ecological monitoring to test for the accumulation of pollutants in flora, fauna and sediments.
8. Effectiveness monitoring in the form of mass balance studies to measure amount of pollutants being removed by the wetland.
9. Resource enhancements to provide wildlife habitats, aesthetics and recreational opportunities.

3.1 Description of Site

A basic requirement of a monitoring programme for an aquatic system is a detailed map of the watershed area showing impervious surfaces, vegetation cover, morphology (Urbonas, 1995) and land use. Sampling locations are indicated on the site map to ensure sampling takes place at the same place each time, as well as civil engineering works and installed instrumentation (Watt and Marsalek, 1994). A hydrographic map of the basin can be constructed using a transit and plane table triangulation survey. This method is appropriate for small lakes and ponds and requires the use of a small boat, alidade, stadia rod, and, preferably, two portable plane tables. A map of the pond area and underwater morphology can be produced in the field allowing calculation of surface area and water volume (see Welch, 1948 for more on this procedure).

Flow characteristics and retention time are critical in the function of a treatment wetland because they largely affect pollutant removal rates. Inflow and outflow rates, volume and water chemistry should be reported to determine removal efficiencies (Urbonas, 1995). Local climatic conditions (such as precipitation, temperature and evaporation) and land use in the watershed will affect the wetland operation and should also be reported during monitoring (Eastlick, 1994).

3.2 Water Quality

A list of parameters that are commonly used to describe water quality is provided here. The values obtained through sampling are compared to water quality guidelines that are provided by provincial and federal agencies for the protection of human and aquatic life (Environment Canada, 1998).

3.2.1 Physical parameters

Natural purification processes involve complex relationships with many variables affecting their efficiency (National Wetlands Working Group, 1988). The physical characteristics of water, most importantly, sediment load, hydrology and temperature, determine many of the environmental conditions of an aquatic system such as the rate of wetland processes (Peavy *et al.*, 1985; Mitsch and Gosselink, 1993).

Suspended solids may consist of inorganic particles (clay, soils) and organic particles (plant fibres, algal cells, bacteria). This parameter is measured as *Total Suspended Solids* (TSS) and turbidity.

Turbidity is an optical property that causes light to scatter through a water sample (Dunne and Leopold, 1978). It is caused by suspended matter and affects the clarity of the water. Increased turbidity will impede aquatic productivity by reducing the depth to which light can penetrate. Measurements can be taken *in situ* using a portable turbidity meter (measuring nephelometric turbidity units, NTU).

Temperature of surface waters, to a large extent, determines the rate of chemical and biological processes that occur in aquatic systems as well as the species present (Peavy *et al.*, 1985). Temperature affects chemical reactions, the solubility of gases and the rate of biological activity (*Ibid.*).

3.2.2 Chemical parameters

Total Dissolved Solids (TDS) is a measure of the material that remains in the sample water after filtration in the analysis of suspended solids. The two measurements (TDS and TSS) make up total solids. Dissolved substances, consisting of minerals, gases or organic constituents, can cause aesthetically displeasing odours or toxicity (*Ibid.*).

Conductivity is an expression of the ability of water to conduct an electric current. It is an indication of TDS but can be measured at the sampling site with a portable meter. Conductivity is temperature dependent, therefore, these two measurements should be noted together (Water Quality Branch, 1983).

Salinity is the amount of dissolved salts in a water sample. It is a smaller value than total dissolved solids because organic matter is not included in the measurement. It can have an effect on chemical and physical properties and wetland processes (*Ibid.*).

Alkalinity and hardness are measures of carbonate, bicarbonate and hydroxide concentrations in the water. They affect the solubility and toxicity of metals and other constituents (Urbonas, 1995).

Biological Oxygen Demand (BOD) is the amount of oxygen consumed by living matter (bacteria) in a water body. To measure BOD, a sample of water must be kept in a laboratory and left at constant temperature with a fixed supply of oxygen. Oxygen depletion is measured over a period of time (commonly five days, although chemically resistant substances may need 20 days because they take longer to break down). A high BOD indicates the presence of large amounts of biodegradable organic material that can lead to a depletion of dissolved oxygen which is vital to plants and other organisms in the water. Some organic material is not degradable by microorganisms but chemical oxidation of them consumes oxygen. Chemical Oxygen Demand (COD) is a measure of these non-biodegradable organics (Peavy *et al.*, 1985). Total Organic Carbon (TOC) is a direct measure of the organic chemical content in the water body rather than the oxygen demand placed on the water (American Public Health Association, 1976).

pH is a measure of the hydrogen ion concentration (acidity or alkalinity) of a waterbody and is measured in the field with a portable pH meter. Canadian freshwater aquatic life guidelines gives an acceptable pH range between 6.5 and 9.0 for surface water (Makepeace *et al.*, 1995). Aquatic life could suffer outside of this range (Horne and Goldman, 1994).

Dissolved Oxygen (DO) is needed at moderately high levels to maintain a healthy aquatic ecosystem. Alberta's surface water quality objective is ≥5.0mg/l (Makepeace *et al.*, 1995). DO can be measured in the field or in the laboratory by titration. Fluctuations occur on a daily basis and with water flow changes. The instrument used to measure DO must be calibrated according to local environmental conditions i.e. air pressure and temperature.

Metals and Oil & Grease can cause toxicity in aquatic systems. Toxic metals (e.g. arsenic, barium, cadmium, chromium, lead, mercury and silver) and compounds associated with petroleum hydrocarbons can be particularly harmful as they accumulate and become concentrated in organisms at the top of the food chain (Peavy *et al.*, 1985).

Nitrogen cycles between ammonia (NH_3), nitrite (NO_2-) and nitrate (NO_3-) compounds (Horne and Goldman, 1994). Phosphorus is found as phosphate

(PO_4^{3-}) in aquatic systems in either soluble or particulate forms of orthophosphate, condensed phosphates and organically bound phosphates (*Ibid.*). Both elements are cycled through photosynthesis and decomposition.

3.3 Water Quality Sampling

Water quality sampling was conducted in the wetland at Rocky Ridge during open water season in 1994 and 1995 prior to the introduction of storm runoff. In 1996 sampling took place at the inlet and outlet to quantify pollutants entering and leaving the pond.

The following parameters were measured during the monitoring period:

- total suspended solids (TSS)
- conductivity
- temperature
- salinity
- total metals scan
- pH
- chemical oxygen demand (COD)
- total and dissolved phosphorus (TP&DP)
- biochemical oxygen demand (BOD)
- turbidity
- total and fecal coliforms
- oil and grease
- total hydrocarbons (TPH-IR)
- ammonia nitrogen (NH_3N)
- dissolved oxygen (DO)
- total Kjeldahl nitrogen (TKN)
- nitrate and nitrite
- total organic carbon (TOC)

(van Duin *et al.*, 1995).

The list is consistent with the City's recommended water quality analysis for similar projects. That is, wetland grab samples of TOC, BOD, conductivity, DO, turbidity, salinity, fecal coliform and; wetland and inlet/outlet samples of pH, COD, TKN, metals scan, TSS, major ions and nitrate (City of Calgary, 1996b).

Water samples were collected by the author for TOC, COD, BOD, ammonia, nitrogen and phosphorus in sterilized bottles and, in some cases, treated with preservative, then sent to Chemex Labs in northeast Calgary for analysis. Other samples including temperature, pH, turbidity, conductivity, salinity, dissolved oxygen and water depth were measured directly on site by portable meters. General observations were also noted on wildlife, vegetation and anthropogenic disturbances. The information provides baseline data for a water quality profile of the pond which may be used in the future to assess the wetland as a stormwater facility.

Management issues that may be of concern and require further investigation are: pollutant accumulation in wetland sediments and the possibility of re-release into the aquatic system, maintenance of the sedimentation vault, removal and disposal of contaminated plants and nuisances such as mosquitoes and algal blooms.

3.3.1 Field Observations during Non-Storm Events (1994 & 1995 Sampling)

Sampling took place during non-storm events between noon and 2:00 PM as often as funding would allow (ten times in 1994, six in 1995). In 1995 the author used a small inflatable boat to collect samples near the centre of the pond (Figure 10) which differs from 1994 when sampling was done by wading to the centre. Depth was read from a stadia rod that was erected at the centre of the pond and sampling was done around this rod. All sampling days were non-storm events on arbitrary days throughout the open water season. The results from bottled samples and the data obtained on-site are supplied in Tables 2 & 3. Several photographs were taken by the author throughout the season to assist in documenting changes during subdivision construction.

The frames of two homes had been erected by mid-spring southwest of the pond and road grading continued to the west. Evidence that silt fences on the west side of the pond were working was the pile of dirt behind the fence (Figure 11). Construction waste was abundant in and around the pond throughout the season.

Water level in the pond was high until early July (stadia measurement of 0.93m). Heavy rainfall in early June raised water levels substantially (by 20cm in one week). Manual draw down was necessary to keep water depth low enough in the event of a large storm.

3.3.2 Field Observations after the Introduction of Storm Runoff (1996 Sampling)

Sampling in 1996 focused only on stormwater entering the pond and water leaving the pond. Budget limitations did not allow for sampling in the wetland. Samples at the inlet were taken from water flowing out of the sediment vault (Figure 12) and samples at the outlet were taken in standing water at the entrance of the outlet structure (Figure 13).

Chemical analyses were done by Chemex Labs and these data are supplied in Tables 8 (in Section 3.5). *In situ* measurements were done by the author using equipment from the University of Calgary and Agra Earth & Environmental.

A rain gauge and hygrothermograph were set up on June 26 to record precipitation, temperature and humidity. Measurements were recorded until October 27 at which time total precipitation was 257.75mm (Figure 14).

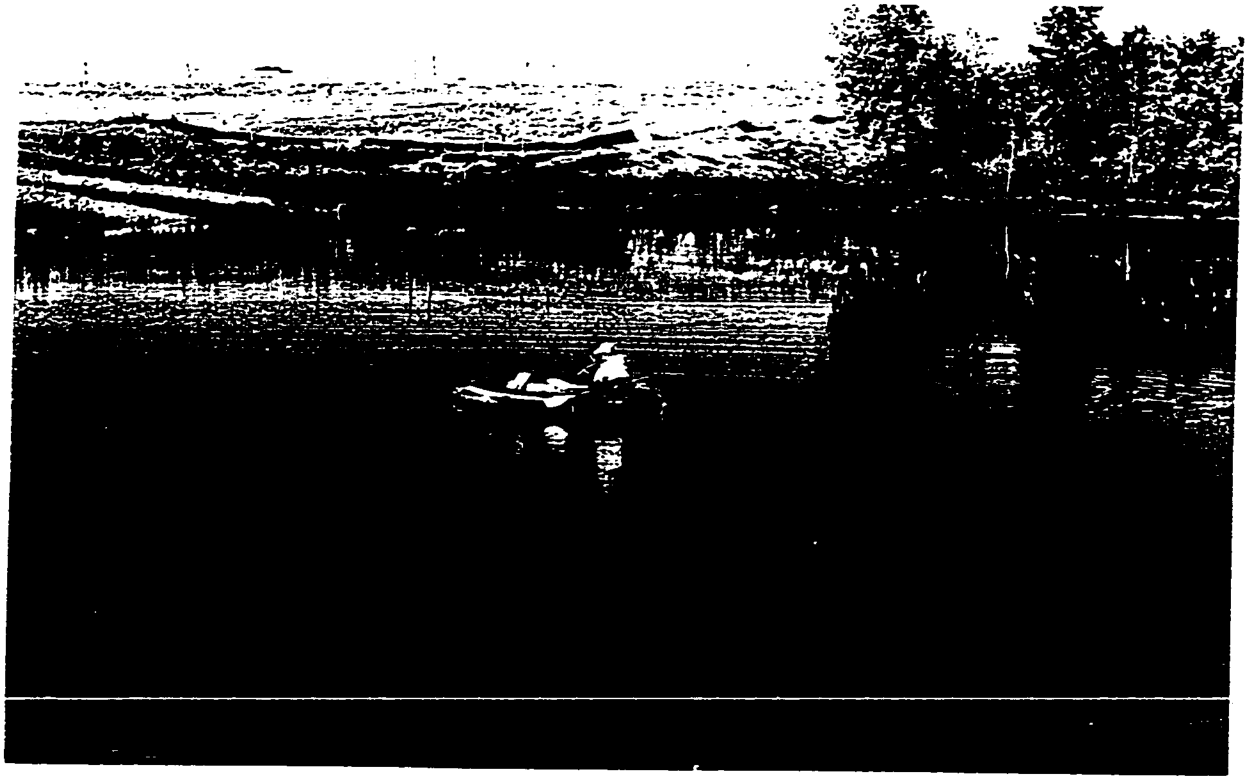

Figure 10: Sampling at Rocky Ridge wetland during construction phase (September 1995)

Figure 11: Silt fences installed as erosion control measures (Spring 1995)

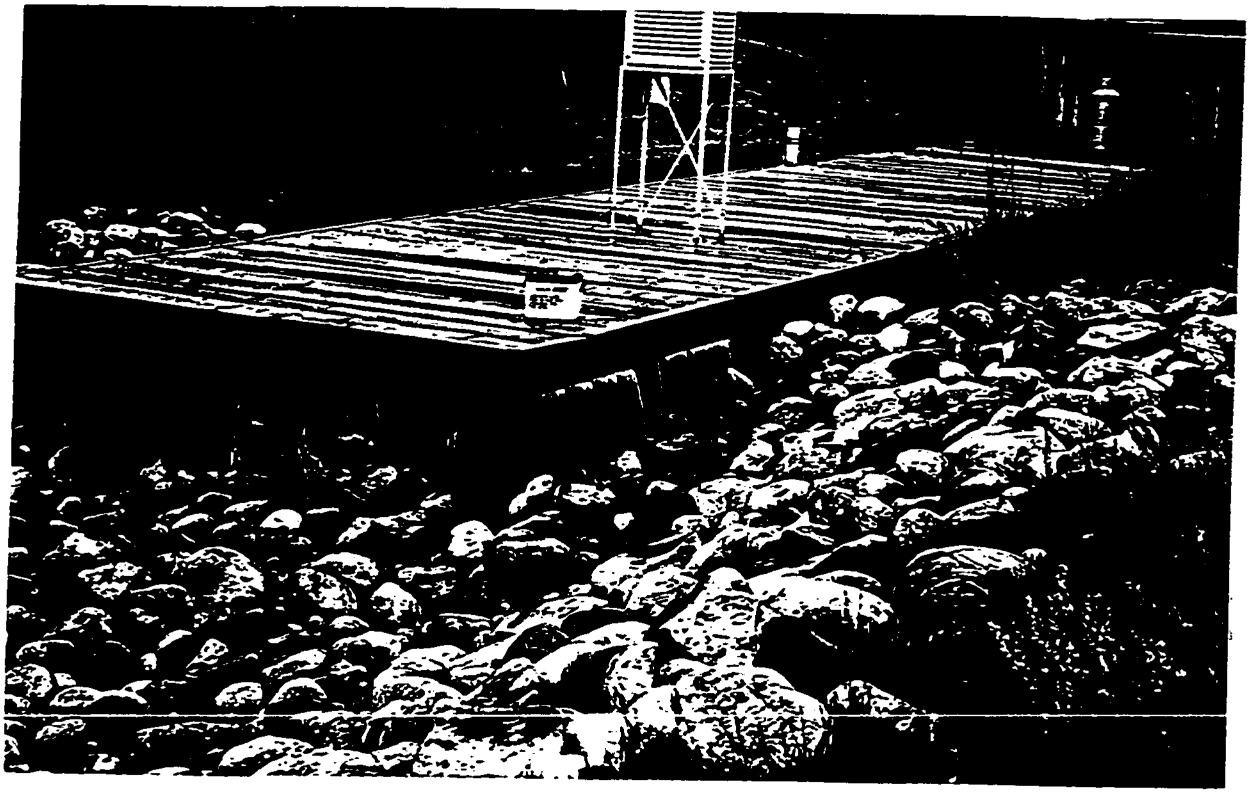

Figure 12: Outflow from sediment vault to pond (July 1996)

Figure 13: Outlet structure where storm outflow was sampled (July 1996)

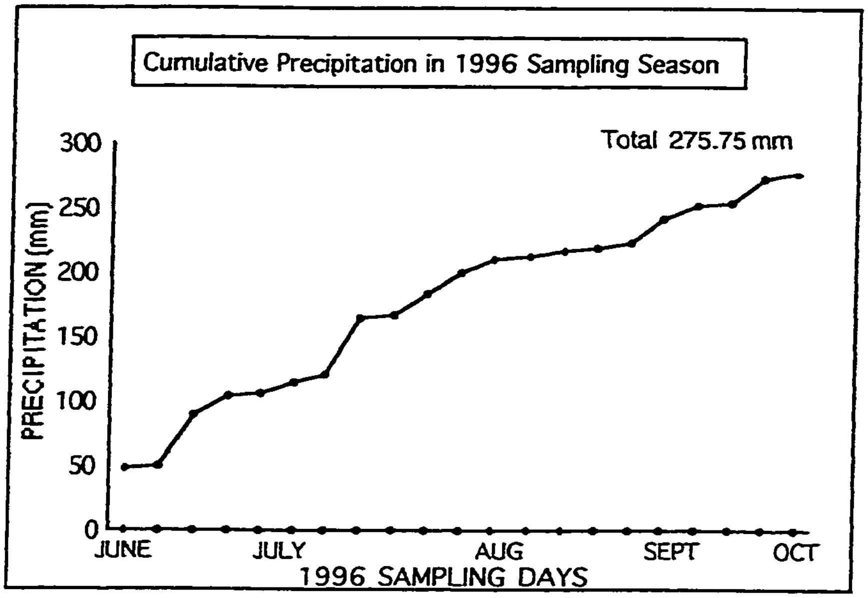

Figure 14: Total precipitation at Rocky Ridge storm wetland during 1996 sampling season (June to October).

In early June, pond depths were at 0.86m and algae were thick around the perimeter extending approximately three to nine metres into the pond. Water depth remained near this level until the last days of July when heavy rainstorms raised the level by over 20cm. Water levels did not go below 1.0m for the rest of summer and autumn. Rainstorms caused extensive erosion and washout of sediment into the pond (Figure 15). The crushed rock pathway around the perimeter washed out in several places and the silt fence to the west was no longer standing.

On July 10 a contracting company (hired by the developer) began pumping water out of the sediment vault into the pond. This was done to remove sediment from the vault. The author was told by the contractor that water was being pumped from the top of the column and mud from the bottom would be shovelled out and hauled away by truck. Rainstorms kept pumping operations going for two weeks before the job was complete. Fine sediment was deposited on the floor of the wetland as a result of this operation.

Figure 15: Erosion of pathway caused by heavy rainstorm (July 1996)

3.4 Water Quality Analysis

Water quality analysis is expensive. Of the list of parameters that were measured at Rocky Ridge, one third are attainable by means of portable water quality meters at the field site, the others must be sent for laboratory analysis, this being the greatest expense of the monitoring programme. To lower high analytical costs, an attempt was made to develop a model which could be used to predict the variables that are expensive to obtain from the set of variables that are easy to obtain.

3.4.1 Methods

Many of the variables collected from 1994 and 1995 sampling of non-storm events were compiled in tabular form (Tables 2 & 3) and entered into a spreadsheet program then into SPSS for Macintosh and all analyses were carried out on this program. The data table, or *matrix*, was set up with water quality variables in columns (15 in total) and sampling days in rows. For 1994 the data matrix has fifteen columns and ten rows and for 1995 the matrix has fifteen columns and six rows.

Correlation analysis was performed on the 1994 data set to quantify relationships that may exist. This was followed by time-series plots for each variable to obtain a graphical view of any trends that may be apparent from the sampling period. Principal components analysis (PCA) was performed to further investigate intercorrelations in the data set and to group overall variability according to similarity. This technique is commonly used on large data sets to simplify and condense information into related groups. The groups, or components, are geometrically arranged to visually portray relationships and the variability associated with them (Rummel, 1970). Linear and multiple regression were also performed on each of the variables especially on those that correlated well with each other. Regression explores relationships farther than correlation by implying dependence by one variable on one or many others (Ebdon, 1985). With this technique, interactions were explored in the data set.

Table 2: Results from Water Quality Sampling at Rocky Ridge Wetland-1994 (AGRA Earth & Environmental, undated)

Parameter	Staff Gauge	Air Temperature & Weather	Water Temperature Surface	Water Temperature Bottom	Conductivity	Salinity	pH	Turbidity	Dissolved Oxygen Meter[1]	Dissolved Oxygen Titration
Units		°C	°C		umhos	ppt		NTU	mg/L	mg/L
Date										
July 13/94	0.84	(scattered cloud/breeze)	19 - 23	15	1100	0.75	9.16	2.7	2.1 - 14.8 (8.8)	6.28
July 21/94	0.82	29 (thin cloud/breeze)	23 - 25	19 - 22	1150	0.75	9.32	3.5	1.7 - 13.59 (>15)	11.36
July 28/94	0.8	28 (clear)	22 - 25	18 - 20	1270	0.8	9.63	6.5	0.2 - >15 (11)	11
Aug. 4/94	0.74	24 (slight haze/breeze)	22 - 26	20 - 22	1250	0.75	10.28	5	4.3 - 11.4 (12.8)	14.32
Aug. 11/94	0.85	27 (sunny w/ clouds)	21 - 23	17 - 18	1100	0.5	9.65	4.4	7.7 - >15 (12)	10.4
Aug. 18/94	>1.6	22 (sunny w/ clouds)	19 - 20	16 - 17	710	0.3	7.82	10	3.9 - 5.6 (3.6)	3.32
Sept. 1/94	1.3	19 (partly sunny/windy)	14 - 15	13 - 15	1300	0.9	8.65	8	3.5 - 7.4 (6.2)	5.2
Sept. 8/94	1.28	(partly sunny/ high clouds/calm)	17 - 18	14 - 16	650	0.4	8.19	11	2.8 - 12	6.08
Sept. 21/94	1.29	(thin cloud/breeze)	13	12	600	0.6	7.69	8.2	2.4 - 5.3 (4.8)	3.2
Oct.5/94	1.26	20 (thin cloud/breeze)	6.1 - 6.5	6	490	0.2	8.34	3.8	10 - >15 (10.5)	10.83

[1] Reported ranges represent dissolved oxygen concentrations measured at various locations and depths in the wetland, including pockets of filamentous algae and the wetland bottom. Values shown in brackets are those concentrations measured in surface water collected for Winkler titrations.

Parameter	NO3-N	NO2-N	NH3-N	TKN	Diss. P (Ortho)	Total P	BOD (5-day)	COD	TOC	TSS	TPH	O&G	Total Coliforms	Fecal Coliforms
Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100 mL	CFU/100 mL
Det. Lim.	0.05	0.05			0.01	0.05		1	1	2	0.1	0.1		
Date														
July 13/94	<0.05	<0.05	0.102	4.53	0.04	0.2	34	129	53	8	0.8	2.5	26	20
July 21/94	<0.05	<0.05	0.120	3.52	0.03	0.2	90	133	53	2	1.1	4.2	18	4
July 28/94	<0.05	<0.05	0.120	3.33	0.03	0.13	21	136	58	<2	<0.1	<0.1	8	2
Aug. 4/94	<0.05	<0.05	0.117	3.78	0.04	0.13	58	146	58	2	<0.1	<0.1	<1	<1
Aug. 11/94	<0.05	<0.05	0.161	3.46	0.02		34	120	61	1	<0.1	<0.1	38	4
Aug. 18/94	--	--	0.097	2.58	0.05	0.13	280	81	38	5	<0.1	<0.1	11	<1
Sept. 1/94	<0.05	<0.05	0.078	2.12	0.01	0.058	72	72	27	3	<0.1	0.2	8	2
Sept. 8/94	--	--	0.053	2.1	<0.01	0.037/0.048	430	75	29	<2	<0.1	0.2	24	8
Sept. 21/94	<0.05	<0.05	0.046/0.053/0.068	1.62/1.69/1.68	0.01/0.01/0.02	0.05/0.05/0.06	13/17/33/38	65/70/75	24/26/26	<2/2/2	0.1/0.1/0.2	<0.1/0.1/0.4	<1/<1/<1	<1/<1/<1
Oct. 5/94	--	--	0.054	2.17	<0.01/<0.01 TD	0.045	6	70	23	4	0.2	0.3	8	2

Table 2: Results from Water Quality Sampling at Rocky Ridge Wetland-1994 (cont'd) (AGRA Earth & Environmental, undated)

Parameter	Al	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg
Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Det. Lim.												
Date												
July 13/94	<0.06	0.170	<0.001	0.06	<0.003	24.8	0.03	<0.01	<0.01	0.14	<0.04	92.6
July 21/94	0.16	0.177	<0.001	0.02	<0.003	25.6	0.02	<0.01	<0.01	0.08	<0.04	97.8
July 28/94	<0.05	0.2	<0.001		<0.005	26	<0.01	<0.05	<0.01	0.07	<0.05	116
Aug. 4/94	<0.05	0.2	<0.001		<0.005	28	<0.01	<0.05	<0.01	0.06	0.05	114
Aug. 11/94	0.07	0.28	<0.001		<0.005	28	<0.01	<0.05	<0.01	0.08	<0.05	98
Aug. 18/94	0.1	0.25	<0.001		<0.005	21	<0.01	<0.05	<0.01	0.14	<0.05	58
Sept. 1/94	0.08	0.25	<0.001		<0.0005	24	<0.005	<0.005	<0.005	0.2	<0.01	54
Sept. 8/94	0.12	0.25/0.28	<0.001		<0.0005/0.0007	26/28	<0.005	<0.005	<0.005	0.18	<0.01	60/61
Sept. 21/94	0.07/0.07/0.08	0.24/0.24/0.25	<0.001		<0.0005	18/19/19	<0.005	<0.005	<0.005	0.21/0.24/0.29	<0.01	40/44/44
Oct.5/94	0.14	0.21	<0.001		<0.0005	13.3	<0.005	<0.005	0.008	0.15	0.01	29.5

Parameter	Mn	Mo	Ni	K	Ag	Si	Na	Tl	Th	V	Zn
Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Det. Lim.											
Date											
July 13/94	0.045	<0.02	<0.02	19	<0.05	0.92	110	<0.003	<0.10	<0.003	0.049
July 21/94	0.028	<0.02	<0.02	21	<0.05	0.55	119	<0.003	<0.10	0.012	0.015
July 28/94	<0.05	<0.05	<0.05	34	<0.05		210		0.1	<0.05	<0.01
Aug. 4/94	<0.05	<0.05	<0.05	37	<0.05		230		<0.10	<0.05	<0.01
Aug. 11/94	<0.05	<0.05	<0.05	29	<0.05		187		<0.10	<0.05	<0.01
Aug. 18/94	<0.05	<0.05	<0.05	13	<0.05		76		<0.10	<0.05	0.02
Sept. 1/94	0.034	<0.005	<0.005	13	<0.005		68		<0.10	<0.05	0.07
Sept. 8/94	0.041/0.042	<0.005	<0.005	12/13	<0.005		63/69		<0.10	<0.005	<0.005
Sept. 21/94	0.020/0.021/0.022	<0.005	<0.005	14	<0.005		94/101/102		<0.10	<0.005	<0.005
Oct.5/94	0.005	<0.005	0.008	21.1	<0.005		109		<0.10	<0.005	0.008

Table 3: Results from Water Quality Sampling at Rocky Ridge Wetland-1995

PARAMETER	Water Temperature	pH	Conductivity	Salinity	DO	Turbidity	Water Depth	Ca	Mg	Na	K	Si	TotalColiforms	FecalColiforms
UNITS	C		µSiemens	ppm	mg/L	NTU	metres	mg/L	mg/L	mg/L	mg/L	mg/L	col/100mL	col/100mL
Det. limits								0.01	0.01	0.01	0.02	0.02	1	1
DATE Y/M/D														
June 28	16.5	8.69	407	0.21	8.3	4	0.96	20.1	50	52.9	9.8	0.68		
July 17	23	5.62	337	0.17	8.1	5.6	0.78	21.5	32.9	34.3	5.8	0.21	2	2
August 12	18.8	5.39	282	0.14	11.2	8.7	0.74	13.6	31.7	39.4	6.9	0.38	10	1
August 27	17	5.54	298	0.15	9.4	4.7	0.74	11.1	27.4	33.9	6.1	0.56	1	1
September 24	11	5.41	203	0.1	9.4	4.8	0.75	14.3	27.2	29.6	6.1	0.28	1	1
October 9	6.1	5.23	207	0.1	7.7	10	0.74	16.4	33.2	34.6	7.3	1.24	1	1
October 9								20.4	34.7	33	6.8	33.3	1	1
October 9								19.4	33.6	32	6.7	36.6	20	1
													17	3

PARAMETER	BOD	COD	TPH-IR	TOC	NH3-N	TKN	NO3-N	NO2-N	DissP	TotalP	S	TSS	Al	As	Ba	Be	B	Cd	Cr	Co
UNITS	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Det. limits	0.1	5	0.2	0.2	0.01	0.05	0.003	0.003	0.003	0.003	0.2	0.4	0.01	0.2	0.01	0.001	0.01	0.003	0.002	0.003
DATE Y/M/D																				
June 28	1.9	46	0.4	17.3	0.01	1.47	0.003	0.003	0.044	0.054	3.9	0.4	0.06		0.16	0.002	0.01	0.003	0.002	0.005
July 17	2.1	43	0.2	13.1	0.05	0.13	0.004	0.004	0.036	0.058	3.5	0.4	0.04		0.14	0.001	0.02	0.003	0.002	0.003
August 12	1.3	24	0.2	17	0.02	1.34	0.003	0.003	0.053	0.058	2.6	5	0.06	0.2	0.13	0.001	0.03	0.003	0.007	0.003
August 27	4.2	52	0.2	18.1	0.04	1.26	0.003	0.003	0.052	0.07	2.6	12	0.07	0.2	0.09	0.002	0.04	0.003	0.006	0.003
September 24	1.4	38	0.2	14.9	0.01	1.17	0.003	0.003	0.064	0.045	4.5	1	0.1	0.2	0.12	0.001	0.01	0.003	0.002	0.011
October 9	1.6	44	0.2	15.2	0.02	1.18	0.003	0.047	0.058	4.3	1	0.08	0.2	0.14	0.001	0.06	0.003	0.002	0.003	0.001
October 9	1.7	47	0.2	15.8	0.06	1.19	0.003	0.003	0.027	0.038	5.1	3	0.11	0.2	0.19	0.002	0.19	0.003	0.013	0.005
October 9	2.2	40	0.2	18.2	0.07	1.19	0.008	0.008	0.027	0.041	4.6	1	0.08	0.2	0.18	0.002	0.16	0.003	0.006	0.003

PARAMETER	Cu	Fe	Pb	Li	Mn	Mo	Ni	Se	Ag	Sr	Tl	U	V	Zn
UNITS	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Det. limits	0.001	0.01	0.02	0.001	0.001	0.003	0.005	0.04	0.002	0.002	0.003	0.5	0.002	0.001
DATE Y/M/D														
June 28	0.004	0.09	0.02	0.013	0.023	0.009	0.005	0.1	0.002	0.173	0.003	0.5	0.003	0.017
July 17	0.004	0.1	0.02	0.007	0.013	0.004	0.005		0.002	0.142	0.003	0.5	0.002	0.083
August 12	0.001	0.03	0.02	0.009	0.008	0.003	0.012	0.04	0.002	0.135	0.008	0.5	0.002	0.028
August 27	0.003	0.15	0.02	0.006	0.001	0.003	0.005	0.04	0.003	0.105	0.003	0.5	0.002	0.009
September 24	0.001	0.13	0.02	0.006	0.011	0.009	0.005	0.04	0.002	0.124	0.011	0.5	0.002	0.015
October 9	0.11	0.02	0.007	0.009	0.007	0.007	0.005	0.04	0.002	0.14	0.003	0.5	0.002	0.04
October 9	0.002	0.22	0.02	0.006	0.091	0.004	0.011	0.04	0.002	0.158	0.003	0.5	0.007	0.226
October 9	0.002	0.19	0.02	0.006	0.019	0.003	0.006	0.04	0.002	0.15	0.003	0.5	0.005	0.104

3.4.2 Results

The first step in the statistical analysis was to obtain descriptive statistics about each variable. Table 4 provides a summary of the 1994 data set.

Through correlation analysis, the degree of association between variables was determined. The resulting new matrix shows relationships between variables, strength of association and orientation (Table 5). Values range between -1.0 and 1.0, zero being no relationship.

Table 4: Descriptive statistics of some of the 1994 variables showing mean, standard deviation and range.

	Mean	Std dev	Minimum	Maximum
TEMP	19.450	6.335	6.500	26.000
PH	8.873	0.866	7.690	10.280
CONDUCT	962.000	312.723	490.000	1300.000
SALINITY	0.595	0.235	0.200	0.900
DO	8.199	3.845	3.200	14.320
TURBID	6.310	2.880	2.700	11.000
DEPTH	1.118	0.390	0.740	2.000
BOD	106.025	140.104	6.000	430.000
COD	104.200	31.368	70.000	146.000
TPH	0.223	0.396	0.000	1.100
TOC	42.633	15.609	23.000	61.000
NH3N	0.096	0.036	0.053	0.161
TKN	2.926	0.925	1.670	4.530
DP	0.023	0.017	0.000	0.050
TP	0.110	0.060	0.043	0.200

Many of the variables from the 1994 data set show significant correlation, both negatively and positively, suggesting there may be an overall interaction occurring in the data set. The variables may be inter-related through physical, biological and chemical processes that occur in wetlands. For example,

Table 5: Correlation matrix of 1994 data showing significant relationships with one asterisks and very significant relationships with two asterisks.

	TEMP	PH	CONDUCT	SALINITY	DO	TURBID	DEPTH	BOD	COD	TPH	TOC	NH3N	TKN	DP	TP
TEMP		0.7213*	0.7221*	0.5277	0.3927	-0.2113	-0.5100+	0.0266	0.8924**	0.2445	0.9041**	0.7892**	0.7811**	0.7108*	0.7663*
PH	0.7213*		0.8011**	0.5425	0.8368**	-0.6166	-0.8400**	-0.4344	0.8790**	0.1495	0.8645**	0.7672**	0.7830**	0.3616	0.5327
CONDUCT	0.7221*	0.8011**		0.8587**	0.4347	-0.3614	-0.6184	-0.3687	0.7128*	0.1578	0.7063**	0.6904*	0.6379*	0.4226	0.5412
SALINITY	0.5277	0.5425	0.8587**		0.1697	-0.2403	-0.5807	-0.4062	0.4959	0.2582	0.4264	0.3407	0.4163	0.2618	0.4105
DO	0.3927	0.8368**	0.4347	0.1697		-0.6292	-0.7322*	-0.4011	0.6698*	0.1328	0.6105	0.5141	0.5148	0.0862	0.2929
TURBID	-0.2113	-0.6166	-0.3614	-0.2403	-0.6292		0.7001*	0.7513*	-0.5758	-0.6078	-0.5215	-0.4714	-0.6884*	-0.1937	-0.5652
DEPTH	-0.5100+	-0.8400+	-0.6184	-0.5807	-0.7322*	0.7001*		0.5485	-0.7138*	-0.3595	-0.6730*	-0.5126	-0.6548*	-0.0314	-0.4174
BOD	0.0266	-0.4344	-0.3687	-0.4062	-0.4011	0.7513*	0.5485		-0.3213	-0.2119	-0.2898	-0.3177	-0.3134	-0.0666	-0.2110+
COD	0.8924**	0.8790**	0.7128*	0.4959	0.6698*	-0.5758	-0.7138*	-0.3213		0.3601	0.9632**	0.8099**	0.9086**	0.6844*	0.8210**
TPH	0.2445	0.1495	0.1578	0.2582	0.1328	-0.6078	-0.3595	-0.2119	0.3601		0.2432	0.1424	0.4922	0.237	0.7091*
TOC	0.9041**	0.8645**	0.7063*	0.4264	0.6105	-0.5215	-0.6730*	-0.2898	0.9632**	0.2432		0.9198**	0.8834**	0.6510*	0.7628*
NH3N	0.7892*	0.7672**	0.6904*	0.3407	0.5141	-0.4714	-0.5126	-0.3177	0.8099**	0.1424	0.9198**		0.7355*	0.5757	0.6517*
TKN	0.7811**	0.7830**	0.6379	0.4163	0.5148	-0.6884*	-0.6548*	-0.3134	0.9098**	0.4922	0.8834**	0.7355*		0.6694*	0.8732**
DP	0.7108*	0.3616	0.4226	0.2618	0.0862	-0.1937	-0.0314	-0.0666	0.6844*	0.2370+	0.6510*	0.5757	0.6694*		0.7965*
TP	0.7663**	0.5327	0.5412	0.4105	0.2929	-0.5652	-0.4174	-0.2110+	0.8210**	.7091*	0.7628*	0.6517*	0.8732**	0.7965**	

aquatic vegetation is affected by water quality variables such as temperature, pH and turbidity. The presence of vegetation will in turn influence other variables such as DO, BOD, COD, TOC, nitrogen and phosphorus. Those variables that correlate significantly with only one variable (TPH, BOD and salinity) do not represent a significant part of overall wetland processes. TPH will be explained later. However, what can be said about BOD and salinity is that their relationship with the rest of the data is weak. A few of the coefficients for both of these variables are above 0.5, indicating a relationship but not one of statistical significance.

To obtain further information on characteristics of the data set and its behaviour over time, a simple *time series analysis* was performed on the data. The REGRESSION command in SPSS plotted each variable against a new column of data (these data, labelled DATE, represented each sampling day as its day in 365 of the year). The results were a graphical tracking of water quality variables over the period of one sampling season. Many showed statistically significant trends over time, the exceptions being TPH, BOD, DP, depth and turbidity.

The lack of trends in depth and turbidity can be explained by various storm events occurring throughout the seasons which cause rise and fall of water level and stirring up of sediments, increasing turbidity. Over long periods of time a trend may be apparent (eg. high levels in June, low levels in August), but over one sampling season and from ten data points water levels and turbidity appear to be random. BOD has a significant correlation with turbidity. That is, when turbidity is high so too is the rate of oxygen depletion and, if turbidity increases during storm events then, it can be deduced that BOD is also influenced by storm disturbances. Although water levels (depth) should correlate with BOD and turbidity, it must be noted that the pond was manually drained at times during this sampling season and therefore not entirely influenced by precipitation.

The time series results for TPH are explained in the raw data (in Table 2). Two thirds of the values were below laboratory detection limits (0.02mg/l) and for analysis purposes had to be entered into the data matrix as zero. Interpretations from this variable offer little valuable information. However, it can be stated that petroleum hydrocarbons were below 0.02mg/l for the 1994 sampling season and, for background data, this is very important because we expect hydrocarbons to increase after the introduction of urban stormwater runoff.

The results from principal components analysis were also limited due to sample size and only four factors, or components, were extracted. However, the relationships that were observed in correlation analysis are substantiated here. The first component with an eigenvalue of 8.87 accounts for 59% of variability in the data set. Correlation values are listed under Factor 1 in Table 6 and all those with values close to 1.00 are included in the 59% of variability. Interestingly, all variables except TPH and BOD have correlation values above 0.5 and the anomalous characteristics of these variables were discussed above. From the analysis of correlation and knowledge of wetland processes it is expected that the variability of this component is caused by physical, chemical and biological interactions.

Factor 2 with 13% of the overall variability is another interesting combination of variables. Turbidity, BOD and DP all have values above 0.5 and depth is very close at 0.497. An explanation for this relationship may be related to storm events. Phosphorus in water bodies is often linked to agricultural runoff and erosion (Bingham, 1994), processes that can be identified in the of variables. Turbidity, BOD and DP all have values above 0.5 and depth is very close at 0.497. An explanation for this relationship may be related to storm events. Phosphorus in water bodies is often linked to agricultural runoff and erosion (Bingham, 1994), processes that can be identified in the Rocky Ridge area. Furthermore, levels of BOD and turbidity increase during periods of heavy precipitation. The variability in this component may be explained by storm events.

Factor 3 with 10% of variability and an eigenvalue of only 1.5 is entirely influenced by TPH. The majority of variation in the data set has been accounted for in the first two components.

Relationships were explored in the data set using linear and multiple regression. Regression is also used to predict the value of one variable using the values of another if the variables are tested to have a significant relationship. For example, temperature, pH, conductivity and depth show a significant relationship with TOC in the 1994 data set (Table 7) therefore, the resulting regression equation can be used to predict the value of TOC for 1995.

Table 6: Results of principal components analysis showing correlation values of each variable for the factors extracted.

Factor	Eigenvalue	%of Variability	Cumulative %
1	8.87192	59.1	59.1
2	2.05757	13.7	72.9
3	1.52159	10.1	83.0
4	1.15323	7.7	90.7
5	0.71812	4.8	95.5
6	0.29221	1.9	97.4
7	0.21107	1.4	98.8
8	0.15984	1.1	99.9
9	0.01444	0.1	100.0
10	0.00000	0.0	100.0
11	0.00000	0.0	100.0
12	0.00000	0.0	100.0
13	0.00000	0.0	100.0
14	0.00000	0.0	100.0
15	0.00000	0.0	100.0

FACTOR MATRIX:

	Factor 1	Factor 2	Factor 3	Factor 4
TEMP	.83981	.46666	.18157	.01543
PH	.90925	-.20407	.31071	-.11646
CONDUCT	.80378	.01605	.34490	.41631
SALINITY	.59718	-.07610	.21410	.76234
DO	.66143	-.44899	.20980	-.43509
TURBID	-.68578	.53780	.43380	.13591
DEPTH	-.77834	.49697	-.11246	-.05071
BOD	-.45287	.66246	.13413	-.18048
COD	.96938	.12851	.03261	-.12320
TPH	.42967	-.07196	-.79819	.19920
TOC	.94425	.17481	.12808	-.18866
NH3N	.83906	.16874	.17932	-.19569
TKN	.92262	.12246	-.19778	-.10027
DP	.60994	.63746	-.19012	-.02009
TP	.82178	.33671	-.44995	.05328

To test this hypothesis, the following equation from the 1994 regression of temperature, pH, conductivity and depth is used and TOC is the dependent variable, y:

$$y = f(a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4)$$

where a is the constant -71.668, x_1, x_2, x_3, x_4 are the variables for depth, temperature, conductivity and pH respectively, and $b_1 = 0.418$, $b_2 = 1.603$, $b_3 = -0.011$ and $b_4 = 10.534$ are the coefficients from the regression. Equating these values using 1994 values of x results in an estimate of 49.9 for TOC in 1994.

Table 7: Results of multiple regression of TOC, water depth, temperature, conductivity and pH from 1994 data set.

Dependent Variable TOC
Variables DEPTH, TEMP, CONDUCT, PH

Multiple R	0.96293		
R Square	0.92723	R Square Change	0.92723
Adjusted R Square	0.86902	F Change	15.92832
Standard Error	5.64920	Signif F Change	0.0047

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	2033.31448	508.32862
Residual	5	159.56753	31.91351

F = 15.92832 Signif F = 0.0047

Variable	B	SE B	95% Confidence	Intrvl B	Beta
DEPTH	0.418138	9.239033	-23.331191	24.167466	0.010447
TEMP	1.602684	0.468540	0.398283	2.807085	0.650473
CONDUCT	-0.011234	0.010772	-0.038923	0.016455	-0.225067
PH	10.534077	5.781628	-4.327845	25.395999	0.584320
(Constant)	-71.668348	52.511019	-206.650168	63.313472	

For a prediction of TOC in 1995, the values of x in the equation are substituted with actual values from the 1995 data set. The resulting estimate is 42.2.

To test the significance of the prediction of TOC, the predicted estimate is subtracted from the 1994 value and the difference is compared with the regression residual. That is,

$$TOC_{residual} = TOC_{actual} - TOC_{predicted}$$

The residual value from the equation is 5 and $TOC_{actual} - TOC_{predicted} = 7.5$. The difference between the two estimates is greater than the residual from the regression analysis meaning it is not a good match to the regression. The results are not satisfactory to apply this model for accurate predictions. The model was also tested with other regressions of easy-to-obtain variables with expensive ones and the results were similar and sometimes worse.

3.4.3 Interpretation

The data set from the 1994 analysis shows significant correlation and related variability between most of the variables. However, when interpreting these results, caution is necessary. The data are represented by relatively few sample points and were collected over a short period of time. Trend analysis and principal components analysis are more representative with large data sets. Once these data sets are compiled with future years the data become more substantive and subsequent analyses will produce more statistically significant results. The model for making predictions with regression is more likely to be successful with a larger data set. For small samples the confidence limits are larger and there is a greater chance of error when making inferences about the data (Ebdon, 1985). At the end of each sampling year the new data could be compiled and a larger matrix developed.

3.5 Summary of Water Quality Sampling

Sampling for water quality took place in the wetland for two years prior to the introduction of stormwater. Once stormwater was being diverted through the wetland, water quality sampling took place at the inlet and outlet (only one water quality sample was taken in the wetland during this year). Previous studies indicate some key parameters to measure for contamination in stormwater management wetlands (Makepeace *et al.*, 1995, see Section 1.3.1). Of these, TSS, coliforms and some metals were measured at Rocky Ridge. The remaining parameters were measured under the recommended protocol by the City.

The first two years of sampling represent baseline wetland water quality data (or as close as possible) to be used for comparison with future data after prolonged exposure to stormwater. The stormwater data at Rocky Ridge show some significant differences between inlet and outlet values. These are tabulated in Table 8. A significant increase in concentration occurs for pH, conductivity, salinity, DO and some metals such as potassium, sodium, magnesium and strontium. The highest level of pH reported was 9.05 which is just outside the recommended acceptable range for aquatic systems in Alberta (Makepeace *et al.*, 1995). An increase in conductivity and salinity indicates the presence of dissolved substances (ions and salts) that may be toxic to aquatic life if present at high levels; however, the concentrations found at Rocky Ridge are very low. The level of DO at the outlet is at acceptable levels for aquatic life. The metals which are non toxic and, in the case of potassium and magnesium, necessary for aquatic life (Makepeace *et al.*, 1995) are also found in very low concentrations at Rocky Ridge.

Other elements such as silicon, sulphur and zinc show a significant decrease in concentrations but they exist in very low concentrations and do not pose a threat to downstream aquatic life (*Ibid.*). In most of the samples, turbidity shows a decrease in concentration from inlet to outlet which is favourable to downstream receiving waters.

These are short term initial observations that indicate the wetland is effective in removing some contaminants from stormwater. Critical constituents highlighted by Makepeace *et al.* (1995) as harmful to aquatic life such as TSS, nitrogen and coliforms are not indicated as significantly different but concentrations are lower from inlet to outlet. Concentrations of toxic metals (e.g. cadmium, chromium, lead and silver) are very low and, in many cases, at laboratory detection limits. Other constituents such as organic chemical contaminants are not included in the stormwater data at Rocky Ridge.

The attempt to develop a model to lower the expense of sampling was not statistically valid due to a small sample size. However, monitoring costs could be lowered by eliminating some parameters in subsequent years especially metals where concentrations were extremely low and pose no threat to aquatic life.

Table 8: Results from Water Quality Sampling at Rocky Ridge Wetland - 1996 (Agra Earth & Environmental, 1997).

PARAMETER	Total Beryllium (mg/L)		Total Boron (mg/L)		Total Cadmium (mg/L)		Total Chromium (mg/L)		Total Cobalt (mg/L)		Total Copper (mg/L)		Total Iron (mg/L)	
DATE	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
July 17*	0.0005	0.0005	0.08	0.02	0.0015	0.0015	0.014	0.016	0.0015	0.0040	0.0080	0.0040	0.58	0.48
August 5	0.0005	0.0005	0.04	0.02	0.0015	0.0015	0.003	0.001	0.0015	0.0040	0.0100	0.0010	5.32	0.34
September 3	0.0005	0.0005	0.04	0.07	0.0015	0.0015	0.013	0.013	0.0015	0.0015	0.0010	0.0005	0.46	0.51
September 4	0.0005	0.0005	0.04	0.10	0.0015	0.0015	0.017	0.006	0.0060	0.0015	0.0080	0.0005	3.31	0.34
September 26	0.0005	0.0005	0.02	0.01	0.0015	0.0015	0.016	0.015	0.0015	0.0015	0.0060	0.0005	1.54	0.18
Mean	0.0005	0.0005	0.04	0.05	0.0015	0.0015	0.012	0.009	0.0026	0.0021	0.0063	0.0006	2.66	0.34
Std. Deviation	0	0	0.01	0.04	0	0	0.006	0.006	0.0019	0.0011	0.0033	0.0002	1.84	0.12
Paired T-Test	N/A		0.52		N/A		0.26		0.75		0.06		0.12	
Alberta SWQO	–		0.5		0.01		0.05		–		0.02		0.3	
Canadian WQG	–		–		0.0002 to 0.0018**		0.02		–		0.002 to 0.004**		0.3	
Glenmore range	N/A		N/A		N/A		N/A		N/A		N/A		0.01 to 20.80	

PARAMETER	Total Lead (mg/L)		Total Lithium (mg/L)		Total Manganese (mg/L)		Total Molybdenum		Total Nickel (mg/L)		Total Phosphorus-ICP		Total Selenium (mg/L)	
DATE	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
July 17*	0.01	0.01	[illegible]	[illegible]	[illegible]	[illegible]	0.0015	0.0015	[illegible]	0.0025	[illegible]	[illegible]	0.02	0.02
August 5	0.01	0.01	0.007	0.006	0.10	0.02	0.0015	0.0015	0.0110	0.0025	0.200	0.050	0.02	0.02
September 3	0.01	0.01	0.005	0.007	0.02	0.03	0.0060	0.0015	0.0090	0.0120	1.200	0.050	0.02	0.02
September 4	0.01	0.01	0.006	0.006	0.09	0.02	0.0060	0.0050	0.0120	0.0070	0.800	0.050	0.02	0.02
September 26	0.01	0.01	0.003	0.005	0.03	0.01	0.0080	0.0040	0.0025	0.0025	0.050	0.050	0.02	0.02
Mean	0.01	0.01	0.005	0.006	0.06	0.02	0.0054	0.0030	0.0086	0.0060	0.563	0.050	0.02	0.02
Std. Deviation	0	0	0.001	0.001	0.03	0.01	0.0024	0.0015	0.0037	0.0039	0.463	0.000	0	0
Paired T-Test	N/A		0.39		0.14		0.12		0.38		0.15		N/A	
Alberta SWQO	0.05		–		0.05		–		–		–		0.01	
Canadian WQG	0.001 to 0.007**		–		–		–		0.025 to 0.150**		–		0.001	
Glenmore range	N/A		N/A		N/A		N/A		N/A		N/A		N/A	

PARAMETER	Total Silver (mg/L)		Total Strontium (mg/L)		Total Titanium (mg/L)		Total Uranium (mg/L)		Total Vanadium (mg/L)		Total Zinc (mg/L)		Total Nitrogen (mg/L)	
DATE	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
July 17*	0.001	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
August 5	0.001	0.001	0.117	0.125	0.032	0.006	0.250	0.250	0.0090	0.0010	0.045	0.012	3.42	1.57
September 3	0.001	0.001	0.124	0.153	0.004	0.007	0.250	0.250	0.0010	0.0001	0.076	0.009	5.94	1.22
September 4	0.001	0.001	0.131	0.145	0.023	0.005	0.250	0.250	0.0100	0.0010	0.061	0.011	13.33	2.69
September 26	0.001	0.001	0.076	0.113	0.016	0.006	0.250	0.250	0.0050	0.0010	0.024	0.010	1.74	1.52
Mean	0.001	0.001	0.112	0.134	0.019	0.006	0.250	0.250	0.0063	0.0008	0.052	0.011	6.11	1.75
Std. Deviation	0	0	0.021	0.016	0.010	0.001	0.000	0.000	0.0036	0.0004	0.019	0.001	4.43	0.56
Paired T-Test	N/A		0.05		0.13		N/A		0.06		0.04		0.15	
Alberta SWQO	0.05		–		–		–		–		0.05		1.00	
Canadian WQG	0.0001		–		–		–		–		0.03		–	
Glenmore range	N/A		N/A		N/A		N/A		N/A		N/A		N/A	

PARAMETER	Water Temperature (°C)		pH		Conductivity (uhmos)		Salinity (ppm)		Dissolved Oxygen		Turbidity (NTU)	
DATE	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
July 17*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
August 3	11	15	8.31	7.36	119	373	0.06	0.18	12.0	15.0	1216	76
August 5	12	15	7.49	8.43	202	364	0.10	0.20	11.0	18.0	308	29
September 3	12	13	6.98	8.98	246	335	0.12	0.17	9.0	17.0	4	8
September 4	10.5	11.5	6.84	8.25	238	348	0.15	0.18	6.0	16.0	83	8
September 26	4.5	6	7.74	9.05	138	292	0.06	0.15	12.0	15.0	96	7
Mean	9.8	11.4	7.26	8.68	206	335	0.11	0.18	9.5	16.5	123	13
Std. Deviation	3.1	3.3	0.37	0.34	43	27	0.03	0.02	2.3	1.1	113	9
Paired T-Test	0.04		0.01		0.01		0.03		0.02		0.16	
Alberta SWQO	Not > 3°C above ambient		6.5 to 8.5***		–		–		min. 5.0		< 25 JU above normal	
Canadian WQG	Variable		6.5 to 9.0		–		–		min. 9.5		< 5.0 NTU above normal	
Glenmore range	N/A		N/A		N/A		N/A		N/A		N/A	

*July 17 data (shaded) respresents "Base Flow", and is not included in calculations for mean, standard deviation or t-test. These are calculated based on storm events only (August 5, September 3, September 4, September 26).

**The guideline is less stringent at higher levels of hardness ($CaCO_3$).

***But not greater than ± 0.5 pH units from background.

Glenmore Range indicates the range of concentrations in storm event discharge from outfalls G-13 (1989 to 1991) and G-18 (1989 to 1993) which empty into the Glenmore Reservoir (Dixon 1994)

Note:

BOD = Biochemical Oxygen Demand
COD = Chemical Oxygen Demand
TPH = Total Petroleum Hydrocarbon - IR
TOC = Total Organic Carbon
TAN = Total Ammonia Nitrogen
JU = Jackson Units for Turbidity
NTU = Nephelometric Turbidity Units

TKN = Total Kjeldahl Nitrogen
NO2 = Nitrite
NO3 = Nitrate
TDP = Total Dissolved Phosphorus (by wet oxidation)
TP = Total phosphorus (by wet oxidation)
TSS = Total Suspended Solids

NFR = Non-filterable residue
Alberta SWQO = Alberta Surface Water Quality Objectives for most sensitive us
(Non-contact Recreational Water Quality in the case of fecal and total coliforms)
Canadian WQG = Canadian Water Quality Guidelines for Freshwater Aquatic Li
(Recreational Water Qualtiy and Aesthetics in the case of coliforms and turbidity
N/A = Not Applicable

T-test:
The result of the paired t-test indicates the probability that the observed difference in the values is by chance alone
A value of 0.05 or less indicates a statistically significant increase or decrease.

Table 8: Results from Water Quality Sampling at Rocky Ridge Wetland - 1996 (cont'd) (Agra Earth & Environmental, 1997).

PARAMETER	Total Calcium (mg/L)		Total Magnesium (mg/L)		Total Sodium (mg/L)		Total Potassium (mg/L)		Total Silicon (mg/L)		Total Coliforms (col/100ml)		Fecal Coliforms (col/100ml)	
DATE	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
July 17*	18.5	29.9	[illegible]	42.9	[illegible]	42.00	[illegible]	12.80	[illegible]	0.76	[illegible]	14500.0	<0.5	<0.5
August 5	30.2	17.8	11.0	24.7	6.92	29.40	4.97	6.30	8.86	1.71	1652.0	1298.0	306.0	288.0
September 3	33.4	21.6	10.3	32.6	6.65	31.60	5.31	6.74	3.28	0.88	0.5	0.5	0.5	0.5
September 4	44.9	20.4	10.5	31.1	5.74	30.10	5.78	6.36	6.89	0.66	78200.0	16520.0	3100.0	31.0
September 26	19.3	15.9	7.4	27.2	5.12	28.70	3.28	5.53	3.22	0.22	7820.0	254.0	238.0	0.5
Mean	32.0	18.9	9.8	28.9	6.11	29.95	4.84	6.23	5.56	0.87	21918.1	4518.1	911.1	80.0
Std. Deviation	9.1	2.2	1.4	3.1	0.72	1.07	0.94	0.44	2.42	0.54	32624.8	6946.3	1268.8	120.7
Paired T-Test	0.06		0.00		0.00		0.03		0.03		0.33		0.35	
Alberta SWQO	variable		variable		variable		–		–		1000		200	
Canadian WQG	–		–		–		–		–		–		2000	
Glenmore range	N/A		N/A		N/A		N/A		N/A		N/A		0.5 - 48,000	

PARAMETER	BOD (5 day)		COD (mg/L)		TPH (mg/L)		TOC (mg/L)		TAN (mg/L)		TKN (mg/L)		NO2+NO3 Nitrogen	
DATE	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
July 17*	[illegible]	26.6	[illegible]	132	0.2	<0.25	20.4	26.6	0.09	0.12	[illegible]	3.70	0.03	0.01
August 5	5.3	5.3	27	38	0.70	0.40	11.0	16.0	0.06	0.02	1.45	1.40	1.97	0.17
September 3	2.9	1.9	40	45	1.40	0.10	11.5	16.0	3.32	0.02	4.80	1.21	1.14	0.01
September 4	22.0	1.4	139	44	0.80	0.10	34.4	17.1	1.96	0.02	4.03	1.05	9.30	1.64
September 26	4.8	3.8	18	42	0.10	0.10	7.2	17.1	0.02	0.04	0.54	1.51	1.20	0.01
Mean	8.8	3.1	56	42	0.75	0.18	16.0	16.6	1.35	0.03	2.71	1.29	3.40	0.46
Std. Deviation	7.7	1.6	49	3	0.46	0.13	10.7	0.6	1.38	0.01	1.76	0.18	3.42	0.69
Paired T-Test	0.34		0.66		0.13		0.94		0.20		0.29		0.16	
Alberta SWQO	Receiving Water Specific		–		–		–		–		–		1.00 (TKN+NO2+NO3)	
Canadian WQG	–		–		–		–		0.16 - 2.20		–		0.60 (NO2 only)	
Glenmore range	N/A		N/A		N/A		N/A		N/A		N/A		N/A	

PARAMETER	TDP (mg/L)		TP (mg/L)		Total Sulphur (mg/L)		TSS (NFR) (mg/L)		Total Aluminum (mg/L)		Total Arsenic (mg/L)		Total Barium (mg/L)	
DATE	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
July 17*	0.078	0.13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.23
August 5	0.018	0.010	0.06	0.07	9.2	3.6	171.0	0.2	3.80	0.26	0.1	0.1	0.19	0.12
September 3	0.209	0.039	0.22	0.04	15.5	2.4	0.2	23.0	0.13	0.27	0.1	0.1	0.10	0.14
September 4	0.777	0.028	0.74	0.05	15.9	2.3	64.0	49.0	1.97	0.20	0.1	0.1	0.17	0.13
September 26	0.082	0.043	0.11	0.06	7.3	2.1	18.0	12.0	1.05	0.18	0.1	0.1	0.09	0.07
Mean	0.272	0.030	0.28	0.06	12.0	2.6	63.3	21.1	1.74	0.23	0.1	0.1	0.14	0.12
Std. Deviation	0.300	0.013	0.27	0.02	3.8	0.6	66.4	18.0	1.36	0.04	0	0	0.04	0.03
Paired T-Test	0.26		0.26		0.03		0.40		0.15		N/A		0.40	
Alberta SWQO	0.150		0.05		–		10 mg/L over background		–		0.01		1.00	
Canadian WQG	–		–		–		10 mg/L over background		0.10		0.05		–	
Glenmore range	N/A		0.012 to 1.955		N/A		1 to 6,588		N/A		N/A		N/A	

*July 17 data (shaded) respresents "Base Flow", and is not included in calculations for mean, standard deviation or t-test. These are calculated based on storm events only (August 5, September 3, September 4, September 26).
**The guideline is less stringent at higher levels of hardness (CaCO3).
***But not greater than ± 0.5 pH units from background.
Glenmore Range indicates the range of concentrations in storm event discharge from outfalls G-13 (1989 to 1991) and G-18 (1989 to 1993) which empty into the Glenmore Reservoir (Dixon 1994).

Note:
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NO2 = Nitrite
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TP = Total phosphorus (by wet oxidation)
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(Recreational Water Quality and Aesthetics in the case of coliforms and turbidity
N/A = Not Applicable

T-test:
The result of the paired t-test indicates the probability that the observed difference in the values is by chance alone
A value of 0.05 or less indicates a statistically significant increase or decrease.

4. BIOLOGICAL MONITORING

Biological monitoring is done to assess the effect of pollutants on aquatic life and water quality. It can be used to determine if a habitat is suitable for living matter (Cairns and Pratt, 1993) and to detect long-term changes in biological responses to pollutants (Rosenberg and Resh, 1993).

Total and Fecal Coliforms (TC & FC) are *indicator organisms* used to estimate the level of microbiological contamination in surface water that may affect human health. These are bacterial organisms and require laboratory analysis. Some studies have shown that this is highest after the first flush of a storm (Makepeace *et al.*, 1995). Alberta's objective for surface water quality is <1000 FC or TC per 100 ml for 90% of the samples (*Ibid.*).

Benthic macroinvertebrates, which are organisms living on bottom substrates, are most commonly used in biological monitoring to assess pollutants on aquatic life because they are ubiquitous, diverse, sedentary and have long life cycles (Cairns and Pratt, 1993). They can be sampled by dip nets and analyzed in the field. Benthic macroinvertebrates can be monitored for genetic composition, bioaccumulation of toxicants, toxicology, and changes in population numbers, community composition or ecosystem functioning (Rosenberg and Resh, 1993).

Species of benthic macroinvertebrates can be used as indicator organisms for water quality as described by Johnson *et al.* (1993). They state that the indicator organism has a known set of physical and/or chemical requirements and any observed change in the organism regarding presence or absence, abundance, morphology, physiology or behaviour is an indication that their life requirements have been altered from the preferred limits. The normal range for organisms is based on previously established classification levels (Rosenberg and Resh, 1996).

Once stormwater is introduced to an aquatic system its regime is altered. The hydrology is changed with a greater inflow volume and water chemistry and the biological community are likely to change due to the introduction of new chemical constituents found in stormwater.

4.1 Community Analysis

Community analysis is an attempt to summarize the consequences of a particular stress on a biological community (Johnson *et al.*, 1993). The species data that are collected are compared to a pollution tolerance key (such as that from Dr. Ruth Patrick in Dunne and Leopold, 1978) to gain an indication of the ecological condition of the habitat. It is reported that a water body hosting a large number of species with high evenness is considered a healthy system (Peavy *et al.*, 1985). On the other hand, dominance by some organisms can indicate high pollution in the system, based on a known tolerance level by those organisms (*Ibid.*).

4.1.1 Biotic Index

Lehmkuhl (1979) describes a method to evaluate a habitat based on pollution tolerances of macroinvertebrates. The procedure uses at least 100 organisms sampled from around the habitat and the biotic index (BI) formula:

$$BI = \frac{\sum n_i a_i}{N}$$

where n_i is the number of specimens in taxonomic group i, a_i is an assigned pollution tolerance score from zero to five for group i (zero for organisms extremely intolerant of pollution and five for organism that can survive high amounts) and N is the total number of specimens (Lehmkuhl, 1979).

Communities can be quantified using a measure of the *species richness* (S'), that is, the total number of species in a community. Species richness is measured in terms of the sample size (N) because of the difficulty involved in counting all the species present. The following formulae are used to measure species richness:

$$S' = (S - 1)/\ln N$$

$$S' = S/\sqrt{N}$$

where S is the number of species.

4.1.2 Diversity Indices

Species richness is not a complete description of a community. Two communities may have the same number of species but different composition if analyzed more closely: one community may be dominated by a particular species whereas the other may have no dominance and be equally represented by all species. For this reason the *evenness* of the community is included in an analysis and the combined measure (richness and evenness) is known as diversity.

Simpson's Index is part of a group of indices known as dominance measures which are weighted toward the most abundant species. The measure represents the probability of any two individuals belonging to different species:

$$D = 1 / \sum p_i^2$$

where p_i is the proportion of each species in the community. These proportions are squared so the sum of the values is not 1 and the reciprocal is taken so that the value increases with increasing diversity (Magurran, 1988). Simpson's Index varies from 1 to the total number of species (S). Evenness of the community (or equability of species representation) is given by comparing the diversity with the maximum possible diversity (equal representation by each species). Since the maximum possible diversity is equal to the number of species, evenness (E) is represented by the following formula:

$$E = D / D_{max} = D / S$$

This varies from 0 to 1 with increasing evenness.

Berger-Parker Index is also a dominance index which measures the proportions of the most abundant species. It is simpler to calculate than Simpson's Index:

$$D = \frac{N}{n_{max}}$$

where n_{max} is the number of individuals in the most abundant species. Similar to Simpson's Index, the reciprocal is used so that an increase in the value reflects an increase in diversity and a reduction in dominance (Magurran, 1988).

Shannon's Index is the most common diversity index. It is based on proportional abundance of species and, unlike Simpson's and Berger-Parker, it emphasizes rare species. It is also known as the Heterogeneity Index and is calculated as follows:

$$H' = -\sum(p_i \ln p_i)$$

where p_i is the proportion of individuals in the ith species.

4.1.3 Species Abundance Models

Information gathered about species abundance from diversity indices are a summary description of the community. *Species abundance models* describe the community by retaining the proportion of individual species in ranked order (Magurran, 1988).

The patterns are displayed graphically by plotting the log of species abundance against its rank order (Figure 16). Ranks are arranged so that the most abundant species is given a value of one and the rest of the species are numbered sequentially from one with the least abundant given the highest rank order. In determining which model a community represents, a goodness-of-fit test is used which compares the expected pattern with the observed set of values (Magurran, 1988). The formulae to calculate the expected data sets are found in Magurran (1988).

4.1.3.1 Geometric Model

The geometric model is based on the premise that the first species to occupy a habitat takes up a portion of the space and the resources available. The second species takes the same portion of what is left of the space and resources available. Each subsequent species does the same and is left with decreasing space and resources. The abundance of the species is proportional to the amount of resource they utilize (Magurran, 1988). The geometric model represents a species-poor community often found in a harsh environment. Species richness and evenness are low.

4.1.3.2 Logarithmic Model

The logarithmic model is similar to the geometric model except that it assumes the species arrive at random rather than at regular time intervals. One species may arrive before its predecessor has occupied its complete portion of the space available or after it has occupied most of the space. The abundance ratios are not constant and the plotted pattern will not be a straight line.

4.1.3.3 Log-normal Model

The pattern most often displayed by communities is the log-normal model reflecting a small number of abundant species and a large proportion of rare species (Magurran, 1988). When plotted as a frequency distribution, the log of species abundance forms a normal curve: few species will be low in abundance and few species will be high but the majority will fall in between these values. The log of the number of individuals places less emphasis on the very high numbers.

4.1.3.4 Broken Stick Model

The broken stick model is analogous to a stick breaking at one instant into the same number of pieces equal to the number of species. This is a truly random pattern of a competitive community where each species has equal opportunity of occupying the resource. The community is highly diverse with high evenness of species.

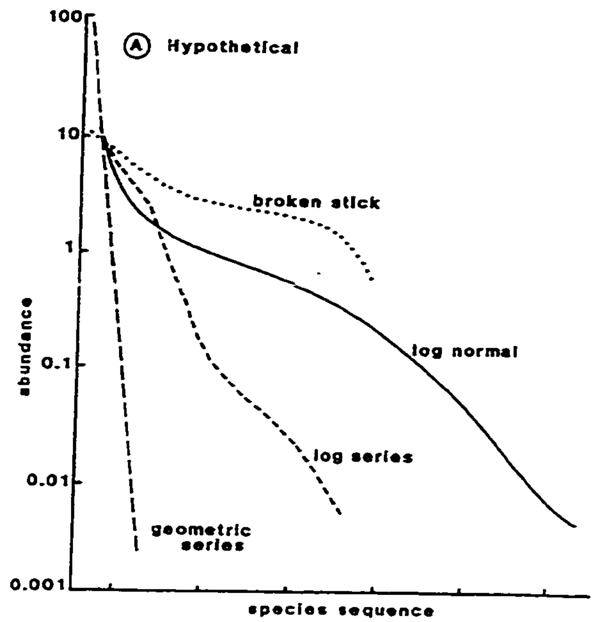

Figure 16: Four main species abundance models: geometric, logarithmic, log-normal and broken stick. The log of species abundance is plotted against species rank or sequence from the most abundant as the first rank (Magurran, 1988).

4.2 Investment and Return

Biological monitoring efforts must be thorough enough to demonstrate a representative sample yet not prohibitive in investment of resources. Kent (1994) reports that the rate of return from sampling decreases with an increase in investment, revealing that an exhaustive sampling effort may not be worth the gain in knowledge.

A sample size can be determined for a desired level of confidence, or precision. The *coefficient of precision* (*D*) is the level of precision obtained in a particular sample estimate. It is determined using the standard error of the means:

$$D = \frac{SE}{\bar{x}} = \frac{s}{\sqrt{n}\,(\bar{x})}$$

where *SE* is the standard error, *s* is the standard deviation, *n* is the number of sampling units and $\bar{x}$ is the arithmetic mean (Elliott, 1983). The formula can be rearranged as follows to calculate the sample size required for a known coefficient of precision:

$$n = \frac{s}{D\bar{x}}$$

4.3 Rapid Assessment Monitoring

A high level of precision is not always attainable because of the sample size needed. Recently, an alternative to intensive quantitative biological monitoring, the *rapid assessment approach*, has been applied to community analysis (Resh and Jackson, 1993). In its infancy it is still controversial and there is a need for the protocols for its application to be expanded to cover more types of pollution (Rosenberg and Resh, 1996). The technique uses qualitative assessment on benthic macroinvertebrates to cover large sampling areas in a short period of time. Whereas quantitative sampling requires detailed studies with large sampling units from several sites in the habitat (Resh and McElravy, 1993), rapid assessment makes use of greatly reduced sampling and less effort on data analysis (Resh and Jackson, 1993). It is analogous to using a thermometer to assess human health (Resh and Jackson, 1993). The approach uses one of the many biological measures (such as biotic index or diversity indices) to characterize the pollution status of a community (Rosenberg and Resh, 1996). The end result is a lower cost monitoring programme with sufficient results to identify water quality problems (Resh and Jackson, 1993).

4.4 Summary of Biological Monitoring

The presence or absence of organisms in a biological community indicate, in general terms, the characteristics of the water body (Peavy *et al.*, 1985). For example, abundant algal populations are associated with nutrient-rich water (*Ibid.*). Species composition and diversity are monitored to determine the presence of pollutants and if they are altering the natural ecological balance (Landers and Knuth, 1991). Natural purification of surface water depends on this balance by employing complex processes of physical, chemical and biological processes all working simultaneously (*Ibid.*). For optimal water quality treatment it is important that all processes are operating efficiently.

The use of diversity indices in water quality monitoring is related to the idea that high diversity indicates a balanced, stable community (Rosenberg and Resh, 1996). The indices are routinely used; however, Rosenberg and Resh (1996) report there are many shortcomings associated with their application, including the understanding of a balanced community. There is natural variability that occurs within a biological community in response to pollution that is not yet understood (Rosenberg and Resh, 1996). Furthermore, identification of organisms should be done to the species level which is not always possible because of a lack of identification keys for the immature stages of many aquatic insect groups (Rosenberg and Resh, 1996).

Although the natural balance will be altered in a stormwater wetland such as that at Rocky Ridge, the objective of monitoring the biological community is to first, determine the natural balance and second, assess these changes after prolonged exposure to stormwater. Alterations are expected but the question remains whether the wetland will achieve a new balance that is still effective in stormwater treatment. The information will be useful for management strategies that may be needed to improve facility operations (e.g. vegetation harvesting, water level drawdown).

5. DISCUSSION

The rationale for developing urban stormwater treatment wetlands is based on the benefits of wetland processes. In addition to removing pollutants from water, the benefits of including a wetland in an urban development are many. Wetlands are an economical alternative to expensive infrastructure of conventional wastewater treatment facilities. Natural vegetation provides a feature which many urban home buyers find desirable and, for the developer, this is a win-win situation. There are economical benefits from the cost added to lots adjacent to the wetland and the reputation of being a "green" developer assures interest from buyers in future developments. Local residents benefit from aesthetic enhancement of more natural features such as water, vegetation and waterfowl. The City of Calgary is likely to benefit from enhanced property values with higher taxes (van Duin *et al.*, 1995) and from a cleaner return of storm runoff to the Bow River.

Although there are many known benefits in utilizing wetlands for water treatment, the use of natural wetlands (rather than constructed wetlands) has been discouraged by some wetland experts (e.g. Hammer and Bastian, 1989 and Stockdale, 1991) because of unknown long-term effects on wetland ecology. The risks associated with their use are that of destroying the wetland ecology and creating a hazard for human health. The uncertainties surrounding the use of wetlands for projects such as that at Rocky Ridge can only be answered by implementing and maintaining a comprehensive monitoring programme.

According to Mitsch and Gosselink (1993) hydrology is the single most important determinant in the establishment and maintenance of wetland processes. Residence time, a function of basin morphology, determines the extent of pollutant removal and the storage capacity determines the mass loadings of pollutants. These parameters should be detailed in the monitoring plan so that appropriate management action can be taken should it be needed to improve effectiveness. This may be in the form of increasing retention time to improve pollutant removal (Landers and Knuth, 1991, recommend two to five days), adjusting water levels or plant harvesting.

The City of Calgary measures the success of stormwater facilities like Rocky Ridge on inlet/outlet water quality, ecology of the wetland, acceptable human health criterion and acceptance by the community (City of Calgary, 1996a).

Makepeace *et al.* (1995) recommend an extensive list of water quality parameters to measure for stormwater assessment including microbiological contaminants and organic chemical contaminants that are harmful to aquatic life and to humans with respect to drinking water (see Section 1.3.1). Landers and Knuth (1991) report that most wetland projects lack adequate monitoring to determine adverse ecological effects. Wren *et al.* (1997) concur there is a lack of data to assess the potential hazard of stormwater pollutants on fish and wildlife. They recommend initial measurements of inlet/outlet water chemistry, sediment chemistry, determination of benthos community and assessment of vegetation in the first year of operation. If ecological impacts are suspected Wren *et al.* (1997) recommend a more detailed investigation.

Rocky Ridge wetland does support some wildlife, therefore, a potential exists for biomagnification of toxic pollutants.

Water quality analysis of stormwater at Rocky Ridge only reveals if the wetland is retaining pollutants. It does not provide information about wetland water quality or ecology after the introduction of stormwater. Critical information is missing in the data provided in Table 8 to assess adverse ecological effects in the wetland, the potential hazard to wildlife and management needs.

In addition to water chemistry, biological monitoring is needed. The best water quality assessment programme involves chemical, physical and biological monitoring (Rosenberg and Resh, 1993). Several authors agree (Landers and Knuth, 1991; Wren *et al.*, 1997; Pitt, 1995), ongoing intensive monitoring of pollutant removal is necessary in the initial stages of a project (and periodically thereafter) in conjunction with long-term monitoring of species diversity and of bioaccumulation of pollutants in wetland organisms.

Rocky Ridge is an experimental project and a thorough monitoring effort is needed to assess its applicability in future developments. It no longer functions as a natural wetland, therefore its management needs are unknown. A lack of monitoring and management could lead to its demise. All engineered facilities in the City must have a management plan in place to ensure proper operation of the system. Similarly, an aquatic system receiving stormwater for treatment purposes requires regular monitoring and management to function as a living system. Unfortunately, the duration of monitoring programmes and sampling efforts are often minimized or eliminated due to project budgets.

The monitoring programme at Rocky Ridge suffered the fate of budget limitations. The effort of stormwater sampling in 1996 does not comply with the City's requirements for new stormwater facilities. The City requires five storm events and three non-storm events to be sampled at inlet and outlet by automatic samplers and, five in-pond samples in each open water season (City of Calgary, 1996b). The variables measured, however, are in keeping with the requirements of the City (*Ibid.*).

Given the diversity of expertise required for wetland management, good communication across disciplines is essential to prevent operation problems. One event at Rocky Ridge serves as an example of the type of problems that may arise from lack of project coordination. The contents of the sedimentation vault were emptied into the pond by the developer without consultation with biologists on the project. The sediment-laden water may have had adverse effects on the benthic community and wetland processes. Educating local residents about the processes involved in this new kind of storm management facility may be effective in preventing other anthropogenic disturbances.

The goal of a monitoring programme is to generate useful water quality information. The process requires integration of sampling, laboratory analysis, reporting and information utilization by a group of professionals in diverse fields (Ward *et al.*, 1990). As stated by Hicks and Stober (1989), a monitoring plan provides a point of reference for maintaining a meaningful information base throughout the life of a project. In other words, the monitoring effort and documentation should be consistent with the operation of the facility. Only with the compilation of data from years of operation can sound statistical inferences be made about the long-term capability of a naturally occurring wetland as a stormwater treatment facility.

6. CONCLUSIONS

Calgary's conventional storm drainage practices utilize underground conduits that drain excess surface water to the Bow River system. Stormwater that drains into the receiving water is loaded with sediments and contaminants that are harmful to aquatic life and water users downstream of Calgary. The addition of wetlands into the City drainage plan can lower contaminant levels of stormwater runoff and preserve water quality of the Bow River system.

The use of natural wetlands as sinks for stormwater pollutants is not endorsed by all wetland scientists because of unknown long-term effects. Calgary is expanding its boundaries into regions where ponds like that at Rocky Ridge are ubiquitous and the use of such wetlands for stormwater control has many apparent advantages. The use of these wetlands in the City's stormwater drainage plan may reduce infrastructure costs, create natural settings within the City, improve stormwater quality and educate residents about the value of prairie wetlands. However, the long-term assessment of a natural wetland as a stormwater treatment facility is needed to assess the associated risks and to determine their applicability in future developments. The fact that they are ubiquitous in potential development areas surrounding Calgary and offer inexpensive alternatives to stormwater treatment warrants the need for a comprehensive monitoring programme to evaluate their use.

This study outlines a framework for water quality monitoring of a stormwater treatment wetland and provides baseline information for water quality assessment of the Rocky Ridge stormwater wetland in particular. Results from monitoring the first year of stormwater treatment at Rocky Ridge indicate that the wetland is effective in removing pollutants from stormwater. Further data collection at Rocky Ridge is required, over several additional years, to make a complete assessment of its operation.

7. RECOMMENDATIONS

The following recommendations are based on the preliminary study at Rocky Ridge stormwater treatment wetland and literature that has been reported in this thesis.

1. Monitoring programmes are invariably developed with budget constraints; therefore, it is important to define precisely the objectives of monitoring and determine which water quality variables need to be measured to attain those objectives.

2. A map of the site should be constructed that includes drainage basin characteristics, hydrography of the wetland to estimate retention time, flow characteristics and sampling locations. Other baseline conditions are noted here, namely, wetland surface area and water depth.

3. Sampling for a comprehensive monitoring programme should be extensive in the first year of operation to obtain a statistically-valid baseline sample. Subsequent years could be sampled less intensively. Monitoring a stormwater wetland for the previously-stated purpose (Section 1.1) should include water chemistry and biology according to:

- Precipitation data should be collected and compiled for each sampling year for reference from year to year.

- Samples should be taken during major rainstorm events at the point where runoff flows into the wetland and where water flows out. Ideally, these should be measured using automatic samplers that measure flow rates and capture the first-flush of the storm. The parameters to be measured should focus on wetland and downstream water quality and contaminants that are harmful to human and aquatic life (see Section 1.3.1).

- Sampling should be conducted in the wetland to establish and monitor the biological community. This could be done using rapid assessment techniques to reduce costs.

4. All information should be tabulated annually after each sampling season with descriptive statistics consistent with those in Table 4 for reference and comparison with future samples.

5. Comprehensive monitoring at Rocky Ridge should continue until sufficient data are acquired to make comparisons between years and to detect trends that will indicate the capability of this natural wetland for stormwater treatment in the Calgary area.

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