THE UNIVERSITY OF ALBERTA

Stormwater Management for the Ellerslie Subdivision, Edmonton, Alberta

by

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Dedication

This thesis is dedicated to my women friends, in too many provinces, who provided support for and comic relief from this project.

Abstract

The potential effects of urbanization of the Ellerslie Subdivision on stormwater runoff and the receiving stream hydrology is investigated. Several stormwater management techniques which may be used to alleviate the negative effects are discussed.

Previous studies have shown that urbanization results in increases to annual runoff yield. Using climatic data over a ten year period and the Thornthwaite water balance procedure it was found that urbanization of the Ellerslie Subdivision, with conventional technologies, would result in an average increase in annual stormwater yield of over 7 times the pre-development rate. The traditional curb and gutter technology would also result in the stormwater containing 400 kilograms of phosphorus, 1300 kilograms of nitrogen and 270,000 kilograms of sediments (and associated pollutants) per year with complete urbanization.

The stormwater management scenario proposed by the author would reduce both the total annual yield and the total yearly pollutant load by at least 50 percent. The author contends that the most appropriate alternatives are those techniques which are low or non-structural and incorporate or replicate the natural environment. This would be accomplished through detailed design early in the planning stage and with conscientiously applied construction techniques. Existing tree stands, wetlands and watercourses are recommended for preservation and incorporation into the new urban area.

Wetlands, in the form of marshes, are discussed as natural treatment and storage facilities, and are recommended for use within the Subdivision. After treatment, the runoff could be used within the Ellerslie Subdivision for recreation in a stormwater lake, irrigation, industrial supply and groundwater surcharging. This use of the stormwater would transform the runoff from a waste product into a resource.

The legal aspects of stormwater management are also discussed, including liablity, maintenance responsibility, riparian rights and institutional requirements.

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1. INTRODUCTION

1.1 Objectives

> "We are molded, we say, by the conditions and surroundings in which we live; but we too often we forget that the environment is largely what we make it" (Bliss Carmen, The Kinship of Nature, 1904:83).

Water services are an integral part of the urban infrastructure and environment. Urban water management is responsible for the provision of water services to residents including supply, collection and treatment of wastewater, flood control, drainage and becoming increasingly important, the provision of water-based recreation and open space (Koelzer and Bigler, 1975). Stormwater runoff drainage, traditionally, has been accomodated within the urban water services by a series of underground sewers in which the runoff flows and is eventually disposed of, untreated, into a receiving water body or stream. The runoff in this system is not useful; but simply, refuse. However, proper management of the stormwater can result in the runoff being a useful water service and an attractive part of the urban community. A large portion of the runoff is then no longer something to be disposed of but rather, an asset to be used by the community, a resource.

The objective in this thesis is to produce a stormwater management scenario for, the Ellerslie Subdivision, Edmonton, Alberta, which will minimize negative effects of urbanization on the natural environment and, at the same time, have a positive effect on a new urban environment. Alternative futures are provided so that the final management choices can be made from a range of alternatives.

1.2 The Problem

The Ellerslie Subdivision is located on the southern margin of the southeast part of Edmonton, a location that until recently has been an area of high growth (Fig. 1.1). The study area was, at the time of research, predominantly agricultural with small portions in woodland, wetlands and country residential land use. The majority land owner, Daon Development Corporation, has proposed that the area be developed into urban industrial and residential land uses.

Traditionally, as an area becomes urbanized the volume of stormwater increases as a result .. .arger amounts of impervious cover being introduced into the drainage basin. The increased annual yield forms a supply of water which may be used for recreation, improved aesthetics, irrigation, and to augment municipal supplies. This idea is not new although little has been done in Canada to put the theory to use. In 1969, Waananen introduced the concept of urban runoff being useful in a watershed. Later, Laycock and MacKenzie (1984) showed how increased yields from the city of Edmonton, Alberta contributed an additional 40 million cubic metres yearly to basin supply.

Urbanization results in major changes in the hydrologic cycle as land use changes and as infiltration is reduced. Evapotranspiration rates are greatly reduced as concrete and pavement replace grain fields, forest and natural water bodies (Gleason, 1952). The combination of reduced infiltration and lessened evapotranspiration results in increased runoff from the newly urbanized areplacement of natural first order streams, which are often ephemeral, by conventional underground sewer systems causes the enlarged volume of water to leave the area more quickly and with more energy. This results in increases of 2-4 times the average peak flow (Whipple, 1977) and increases in annual yields of 1.5-10 times the pre-development levels (Laycock and MacKenzie, 1984). Increased energy also results in erosion and channel morphology changes in the receiving streams and water bodies.

The increased volume of water carries with it the numerous pollutants which line our streets. These include bird and pet faeces, leaves and seeds, road salts, soil eroded during construction, oil and grease from vehicles, road surface materials loosened by traffic, toxics such as zinc, asbestos and PCB's from industrial areas or road spills and particulate fallout from manufacturing and vehicles (Lazaro, 1979; Novotny and Chesters, 1981; Krenkel and Novotny, 1980; Roesner, 1982).

The problem discussed in this thesis, therefore, is how the Ellerslie Subdivision can be developed into urban land uses with minimal disruption and optimal use of the hydrology of

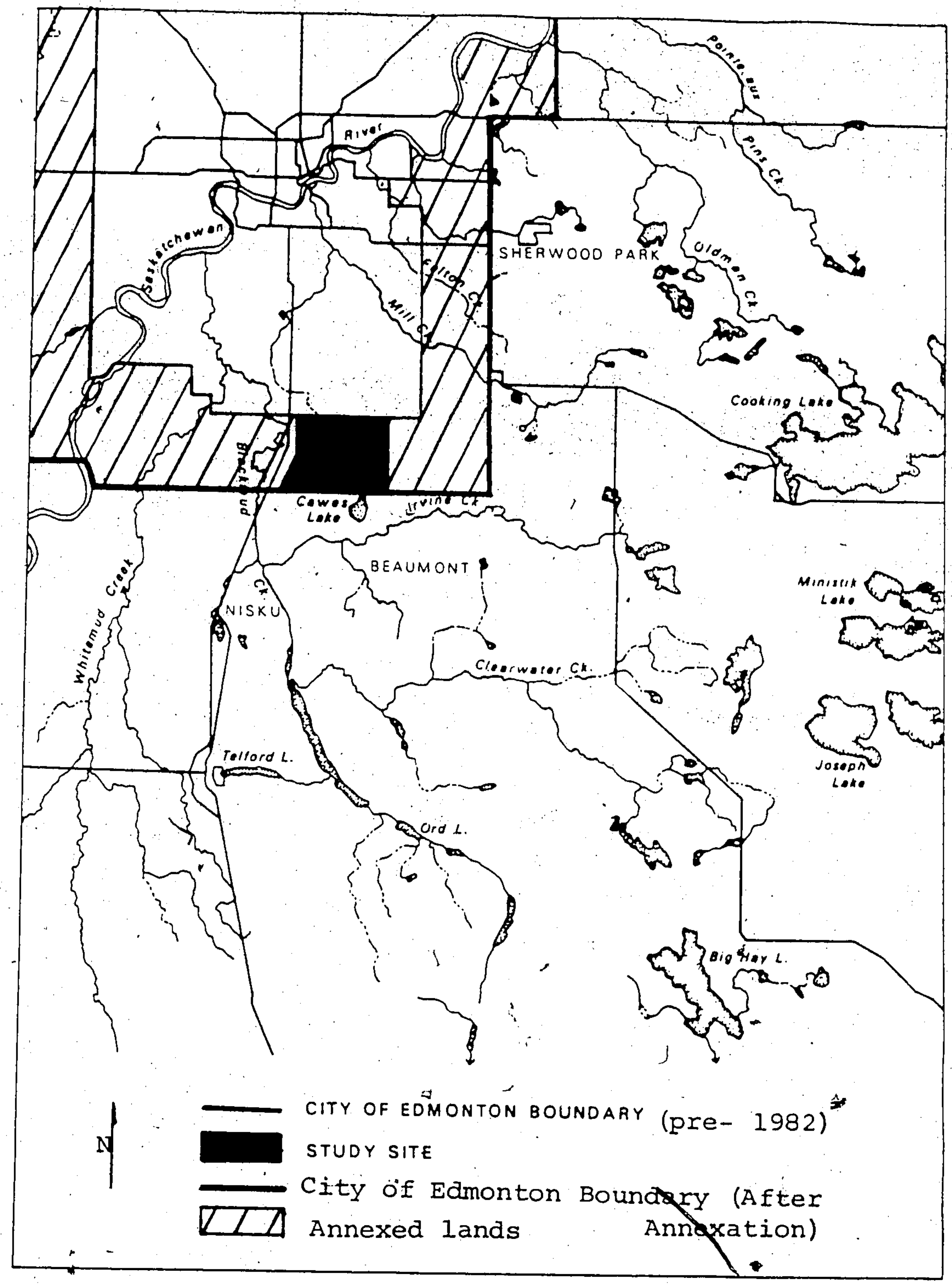


Figure 1.1 Location Map of the Ellerslie Subdivision. (Source: adapted from Stanley Associates Engineering Ltd., 1980b).

the area. Consideration must be given not only to the qua..ty and quantity of the stormwater but also to the cost involved in the various alternatives, the legal and institutional aspects, aesthetics, recreation and the design of the subdivision.

1.3 Thesis Outline

The approach for creating a stormwater management plan for the Ellerslie Subdivision will follow the formula for the Master Drainage Plan (Fig. 1.2; Environm..t Canada, 1980; Poetner, 1981; Bishop, 1974). This involves the identification of changes to various hydrologic characteristics with urbanization, an understanding of the alternatives and recognition of the legal implications involved in the management methods that may be used (Chapters Two and Three). Also, site specific work on existing and proposed land use is required, as well as a study of the climate of the Ellerslie Subdivision (Chapter Four). The next step is the modelling of potential quantitative and qualitative changes in the stormwater runoff as a result of urbanization (Chapter Five) are combined with the stormwater management alternatives information to produceite specific, physical systems and "Best Management Practices" for the control of runoff volume and pollution in the Ellerslie Subdivision (Chapter Six). The focus is upon the use of wetlands, in the form of marshes, for the biological, chemical and physical treatment of the stormwater.

The final stages of the Master Drainage Plan involving detailed economic and design analysis and staging will not be covered in this thesis. What will result in this thesis, however, is a provision of alternative futures from which the most viable approach can be selected.

1.4 Stormwater Management Studies in Geography

The reason for the study of urban stormwater runoff management by a geographer is twofold: a) to study the full impact on the environment and; b) to provide a synthesis of the information available from many disciplines, including geographers. A significant part of the background studies in planning, mapping, water resources, environmental impacts, etc. related

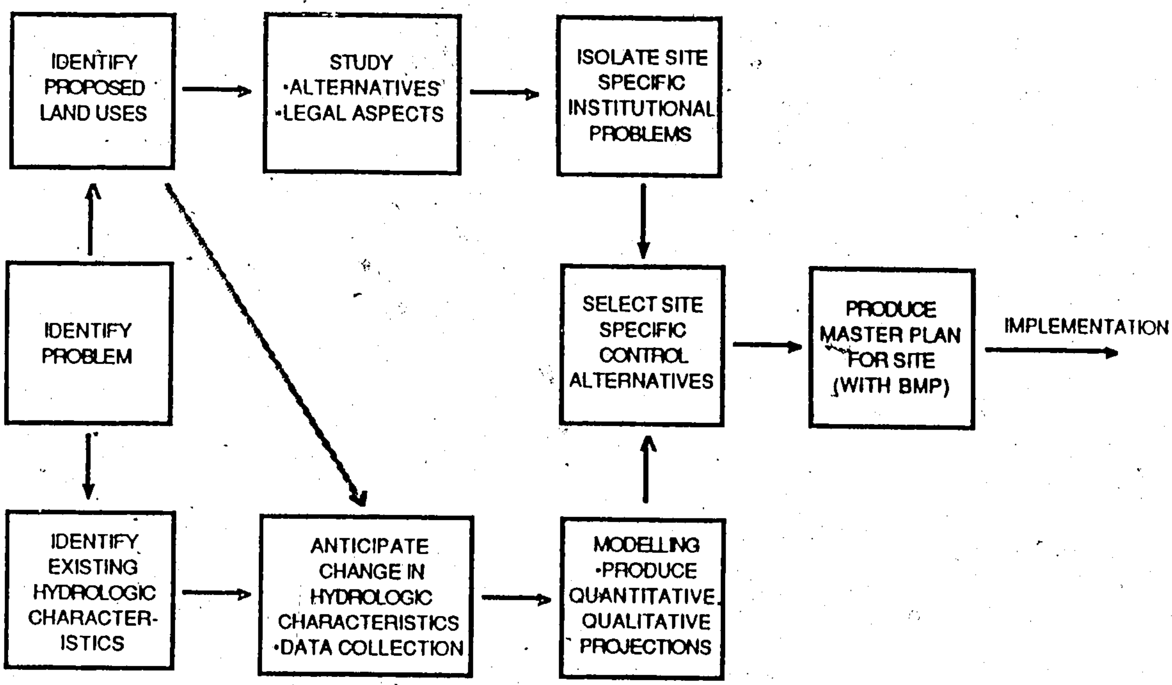


Figure 1.2 The Master Drainage Plan. (Source: author; based upon Environment Canada, 1980; Poetner, 1981; Bishop, 1974)

to stormwater management have been conducted by geographers including Douglas, 1974; Hollis, 1977; Leopold, 1969; Muller, 1967; Laycock and MacKenzie, 1984; Pope, 1980; Thornthwaite and Mather, 1955; and Walling, 1979).

Many studies have been done on the impact of stormwater runoff volumes on a per storm basis. While few have been written on the impact of increased annual flows. However, the large amount of pollutants found in urban stormwater are proportional to the volume of runoff (Randall and Grizzard, 1983). Therefore, the calculation of the annual flow yield is important to fully understand the extent of the impact that a new urban development may have on a receiving stream.

Annual runoff yield will be calculated, in Chapter Five, using climatic data and Thornthwaite water balance procedures (with modifications) for the Ellerslie Subdivision study site, incorporating before and after development land uses. From the yield data, estimates of the potential pollutant loadings will be calculated using concentration levels from physically similar areas. It will then be possible to assess the impact of the urbanization on the environment and to recommend management strategies which will alleviate the effects of increased runoff.

There are many professionals involved in the study of urban tormwater management including civil and hydraulic engineers, landscape architects, planners, hydrologists, lawyers, chemists, biologists and geographers. In addition to the provision of an understanding of the effects on the environment, the geographer can work with the various professionals involved to produce alternative futures scenarios which will be practical, control runoff in terms of both quantity and quality, and benefit the residents. As scientists generally "have a certain professional myopia, they tend to be rather disinterested in human problems" McHarg, 1971:125) the role of the geographer may also be to synthesize the specific knowlege of other professionals with the needs of people and with strong regard for the environment.

1.5 The Purpose

The purpose of the author in writing this thesis is to produce a management strategy that will meet the practical needs of flood reduction, erosional control, runoff quality improvement, cost control, reduced volumes and velocities as well as meet the human needs for aesthetics, recreation, natural environments and a sense of community. Therefore, within the management scenario the:

> aims would be multiple and consciously recognized as evolving in public preferences which themselves would be partly shaped by the process followed. Its means would be multiple, and would take account of a full range of alternatives (White, 1971:105).

The alternative futures that will be suggested for the Ellerslie Subdivision will include a general analysis of the environmental and institutional aspects of the methods. Less conventional alternatives which are low or non-structural and which reflect or incorporate the natural hydrological features and processes will be discussed.

Problems may arise in the acceptance of a non-traditional system from the various government agencies involved. Therefore, a further purpose of this thesis is to illustrate how other non-conventional systems have succeeded and under what institutional incentives or constraints.

2. THE EFFECTS OF URBANIZATION ON STORMWATER HYDROLOGY

2.1 Impacts of Urbanization on Stormwater Quantity

2.1.1 Urbanization and the Hydrologic Cycle

> The world stands like a patient child while the rain pours, drenches, washes, soaks rotten things back to the earth to start all over again (Emily Carr, 1913).

Within the hydrologic cycle of a natural environment each step is a continuation of the one before. With urbanization, the movement of moisture in the hydrologic cycle is redistributed. As natural land uses are replaced with buildings, parking lots and streets, the precipitation cannot infiltrate the soil to become interflow or groundwater. And, the precipitation is no longer used by plants and transpired into the atmosphere nor held in small depressions for evaporation.

The percentage of impervious surface cover increases according to the land uses of an urban area. An industrial or commercial site with the majority of land taken up with buildings and parking lots will have an impervio of 80-90 percent. In contrast, a single family residential area will have a smaller amount of impervious cover, 30-50 percent. A natural landscape generally will have only 5-20 percent imperviousness (Pope, 1980).

The amount of impervious surface cover affects the streamflow (a portion of the hydrologic cycle) by reducing the infiltration to the sub-surface. Also because the rainfall runs off the soil quickly, plant use and evaporation of the precipitation is reduced. With an impervious surface the aeration zone is minimized resulting in reduced evaporation and transpiration to the atmosphere and limited soil moisture storage. Also, under urbanized conditions, interception and depression storage will be significantly smaller, thereby reducing evaporative losses (Hollis, 1977).

As a site is graded, paved and built upon, the surface storage and infiltration are reduced thus leaving a larger amount of precipitation to runoff. In the study area, under existing conditions, the runoff yield is very small, if any, because of the balance of precipitation and potential evapotranspiration combined with sizable soil moisture storage to moderate seasonal differences. With urbanization the soil moisture storage function is reduced and both surpluses and deficits are increased.

Traditionally, urbanization results in the natural, first-order streams, which are often ephemeral, being replaced with an underground series of storm sewers.

> The net result is the virtual expurgation of many first or even second-order channels, each of which played its part in delaying movement of flood peaks, providing channel storage and slowing the average speed at which water was delivered to the larger stream channels (Dunne and Leopold, 1978:694).

Without the first-order streams, flood peaks are earlier and higher and erosion is increased as the energy of the runoff is elevated. The drainage network becomes more efficient in removing precipitation from the area, which results in more runoff in less time flowing into the receiving water body. At present, there are many ephemeral streams in Ellerslie Subdivision (see Figure 4.6). The loss of these streams to underground sewers will increase runoff downstream in Blackmud Creek and eventually Whitemud Creek. Excessive erosion in Blackmud Creek has already necessitated reinforcement of the streambed.

The area of land which drains into a receiving stream and is impervious has been termed the "hydraulically effective impervious area by Miller and Matthew" (1982). Novotny and Chesters (1981) coined the term "hydrologically active areas" which includes all surfaces, including the impervious sites that contribute to surface runoff. Both sources comment, however, that it is important to identify areas of potential or existing impervious cover to be able to best study the quantity and quality of the urban runoff.

2.1.2 Peak Flow

As stated above, as an area is urbanized the reduction of infiltration results in the stormwater flowing more quickly and in larger volumes off the site. This appears on the storm hydrograph as higher peaks and a steeper, shorter, time to the peak (Fig. 2.1). Generally, as the percentage of impervious cover increases The peaks are greater and the rise to peak is more abrupt (Lazaro, 1979). The consensus of hydrologists is that the increase in peak flow, with

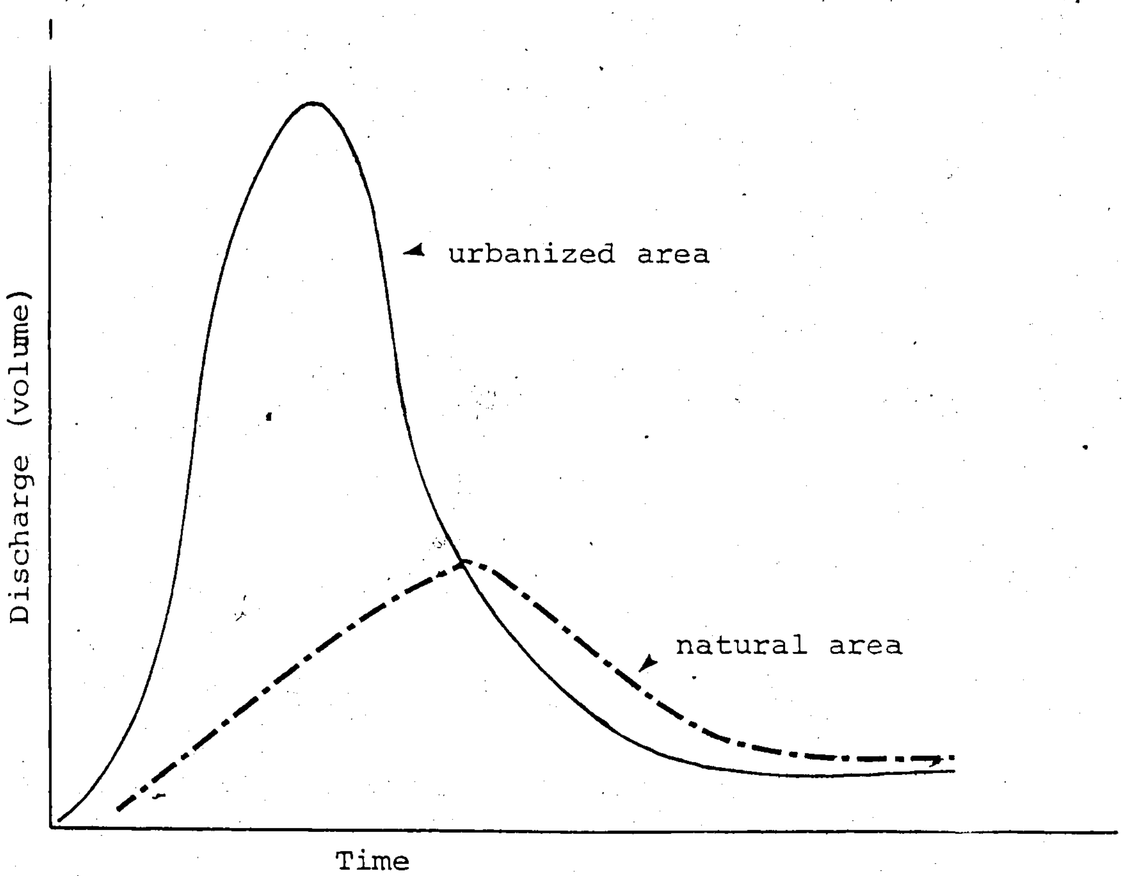


Figure 2.1 The Effects of Urbanization on the Storm Hydrograph. This illustrates a heavy storm in which the urban storm hydrograph rises quicker and higher than the natural area. (Source: author).

urbanization, is 2-4 times the non-urban value (Whipple, 1977; Bras and Perkins, 1975; Espey, Winslow and Morgan, 1969).

In studying the lag between rainfall and runoff, researchers have found the time to peak of urban areas to be approximately one-third of the rural time (Novotny and Chesters, 1981; Dunne and Leopold, 1978; Waananen, 1969). Bras and Perkins (1975) found a 8-40 percent reduction in time to peak in new urban areas; with the effects on peak and time to peak being more marked for shorter, less intense storms.

The more efficient drainage of stormwater in an urban area, with the larger, quicker peaks may cause flash flooding. Urbanization is considered to be a major contributor to the frequent flooding within Chicago (Olson, Macaitas and Vanakojis, 1982). Hollis (1975) found that the recurrance of small floods may be increased 10 times by urbanization. The level of influence of urbanization on flood recurrence and size decreases as the severity of the flood increase (Walling, 1979; Hollis, 1975; James, 1965).

> The explanation of this finding is that during severe and prolonged rainstorms a rural catchment may become so saturated and its channel network so extended that it responds hydrologically as if it were an impervious catch ment with a dense network of surface water drains and so it produces floods of a type and size similar to those of its urban counterpart (Hollis, 1975).

However, in sub-humid regions such as the Edmonton area, severe rain storms of this type are rare.

When creating a drainage plan for a new urban development the immediate concerns are for increased peak flow and the associated flooding possibilities. For this reason, engineers have generally limited their involvement to designing according to peak discharge for a single event. However, the total annual yields, produced by differing land use, should also be studied to gain a full understanding of the urban runoff problems.

2.1.. otal Yields

As discussed above, urbanization results in increased peak flows and increased volumes of runoff per storm event. The more efficient drainage network does not allow for infiltration over time. This results in yearly total stormwater runoff values also increasing in a new urban area. The level of increase in runoff is dependent upon the climate of the area, the ratio of impervious to permeable ground cover and the efficiency of the drainage system. Figure 2.2 is used to illustrate how the loss of infiltration as a site becomes impervious results in more rain water moving directly to surface runoff within the hydrologic model.

Also, the more concrete, asphalt and buildings that replace the natural environment the less evapotranspiration will take place. A change from natural conditions to pavement and asphalt has been found to reduce evapotranspiration by 86 percent (Gleason, 1952). The reduction in evapotranspiration results, directly, in an increase in surface runoff. Urbanization of an area around Moscow reduced evapotranspiration by 62 percent which resulted in an increase in total runoff, or yield, of 155 percent (L'vovich and Chernogaeva, 1977).

Generally, the urban stormwater yields are 2 times the pre-urban development levels (Waananen, 1969). In studying the area around Sacremento Creek, California, James (1965) reported an increase of 2.29 times accompanying the change from rural to urban land use. Wilson (1967) found that urbanization increased the annual yield by 2 times. This general figure is, however, dependent upon many factors

For example, the level of increase in yield is a reflectance of the amount of urbanization in a study area. Hollis (1977) found that when the Canon's Brook catchment became 15.8 percent paved an increase of 30 percent in total yield resulted. Hartman (1972) calculated a 17 percent increase in annual yield following a 7.2 percent increase in impervious cover. While Muller (1967) found that 50 percent of the basin being impervious resulted in a 48 percent increase in annual yield. In 1969, Muller reported an annual increase of 29 percent with a 25 percent increase in the impervious surface.

Also, the general yield increase figure of two times resulting from urbanization will be more or less dependent upon the climate of the study Hollis (1977:63) wrote that "urbanization in a moist climate may produce minimal changes in yield, whilst the same type of development in a drier climate would increase the total stream flow significantly". Laycock and MacKenzie (1984) confirmed Hollis' hypothesis. Using water balance procedures the authors calculated

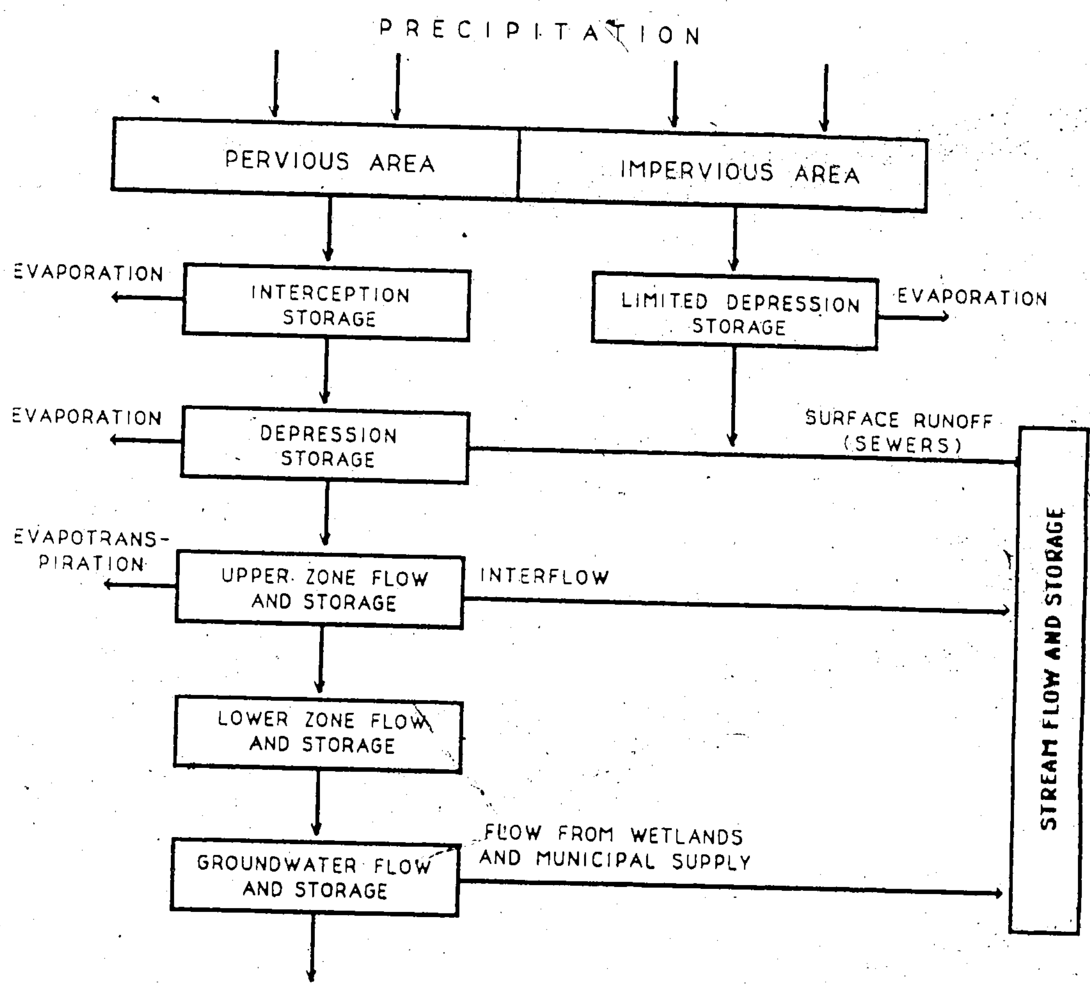


Figure 2.2 Pervious vs. Impervious Area Stormwater Runoff Movement. This diagram is used to illustrate flow within a natural land use site and an urbanized site using conventional

that Ottawa and Vancouver, with their humid climates, had increases of onl[illegible] and 13.3 percent, respectively, in annual yield with urbanization. In the sub-humid climate of the Prairies, increase in annual yield over 10 years of urbanization ranged from "163% in Winnipeg to almost 1000% or 10 times in Medicine Hat (Laycock and MacKenzie, 1984:86).

In studying Edmonton's stormwater yields Laycock and MacKenzie (1984) found that runoff has increased by 454.4 percent or 4.5 times in a ten year period, 1971-1980. "This would represent an addition of approximately 40 million cubic meters (32,000 acre feet) annually to the basin supply from the City of Edmonton" (Laycock and MacKenzie, 1984:89). The authors go on to say that such yield increases "constitute a resource that may be used more effectively" (Laycock and MacKenzie, 1984:89).

In 1969, Waananen thought that stormwater runoff may be of some benefit to a city. After noting the problems involved with increased runoff yields he wrote that: "However, increase in yield is not always adverse in its effects. In some instances the increased discharge of water to urban lakes and streams may serve to offset increased water losses resulting from water supply development, irrigation and air conditioning" (Waananen, 1969:181). Proper planning and management of stormwater can result in the runoff becoming usable and therefore, a resource. The extent to which the stormwater becomes a resource is limited by water quality, treatment (if any), water quantity and a large number of institutional problems. Urbanization of Ellerslie Subdivision will result in larger and more dependable summer yields; improving the quality will give the stormwater runoff enhanced value and greater management potential.

2.1.4 Baseflow

Baseflow is generally believed to decrease with urbanization. As an area becomes urbanized the infiltration to interflow and groundwater is reduced as the ground cover is made impermeable. This leaves more precipitation forming runoff and less water,

> available for soil replenishment and for ground-water storage. An increase in total runoff from a given series of storms as a result of imperviousness results in decreased ground-water recharge and decreased low flows. Thus increased imperviousness has

> the effect of increasing flow peaks during storm periods and decreasing low flows between. (Leopold, 1965).

James (1965) found summer baseflow in an urban area to be 71 percent of the earlier rural value. L'vovich and Chernogaea (1977) found that urbanization caused a 50 percent reduction in groundwater yields. Tennant (1975) recorded a summer baseflow decrease of 30 percent with 65 percent impervious surface cover. Furthermore, Klein (1979), in a study of Baltimore City, Maryland, found that as watershed imperviousness increased the baseflow diminished.

However, not all studies have concluded that baseflow decreases with urbanization. "It appears that the direction baseflow changes is dependent upon the particular physiographic province a stream is located within" (Klein, 1979:955). MacKenzie (1985), in studying Edmonton, Alberta, showed that baseflow has not decreased significantly with increased urbanization. This is likely the result of excessive lawn watering, vehicle washing and other outdoor uses of the domestic water supply supplementing the baseflow levels between storm events (Laycock, 1985). Waananen (1969) attributed a raised groundwater table, which caused an initially ephemeral stream to become a permanent stream, also to the over irrigation of lawns. The existance of contaminants from lawn fertilizers in groundwater (Novotny and Chesters, 1981) confirms that the water used in excessive lawn irrigation is infiltrating to the groundwater.

It seems then, that baseflow may or may not be altered by urbanization. However, the source of the water changes from natural rainfall to municipal supplies.

2.1.5 Stream Channel Morphology

Urbanization, in most cases, involves storm sewers which are used to quickly remove runoff from the city streets. This stormwater often runs directly into a receiving stream. The increases in peak flow, sediments (especially during times of construction), annual yields and shortened time to peak, all result in an altering of the stream morphology from its pre-urban state.

In a study of stream channel cross-sectional area Whipple, DiLovie and Pytlar (1981) found that in New Jersey the urban stream beds were two times wider than the predevelopment stream beds. Robinson (1976) also found that the urban stream had a cross-section twice the width of its earlier rural value. While Hammer (1972) in a study of 78 watersheds near Philadelphia, reported gains in width of 2.19 to 5.95 times with urbanization; dependent upon land use. Douglas (1974:700) studied the Arak Ayer Batu in the Kuala Lumpur, area, before and after becoming urban and found a change "from a deep winding channel ... to a straighter, shallower, wider and steeper channel".

Work by Leopold (1973) is counter to the above findings. In a study of a tributary to the Potomac River, Maryland, the author found that urbanization altered the cross-section into a more rectangular, smaller, deeper and narrower shape. Dunne and Leopold explain such discrepancy to be the result of the time. In the first decade the channel narrows through sedimentation then in the second decade the progressive enlargements begin. This culminates in a "net enlargement resulting from urbanization" (Dunne and Leopold, 1978:699).

Robinson (1976) in his Maryland study also found that the substrate of urban streams tends to be made up of coarser particles than rural streams. The coarser material may protect the bed from deepening thus partially explaining the wider, shallower channel cross-section found by many of the authors.

Dunne and Leopold (1978:701) observed that where the outfall reaches a natural channel or slope "the banks of the latter tend to erode back in bulbous, caving re-entrants, making the channel exceptionally large for a short distance". The authors noted that such erosion to banks may require structural reinforcement. "And so each action creates the need for further construction and more concrete" (Dunne and Leopold, 1978:703). As discussed earlier, Blackmud Creek has required structural reinforcement of its banks because of the increased runoff being channeled into it. This may result in strict peak flow limits being applied to the outfall, from the urbanized Ellerslie Subdivision, by the Alberta regulating body, the Standards and Approvals Division, Department of the Environment.

2.2 Impacts of Urbanization on Water Quality

In the past fifteen years there has been an abundance of literature published relating to the quality aspect of urban stormwater runoff. The sudden interest was the result of the treatment of point sources not ending water pollution problems, something else was entering the system (Pope, 1980). Also, in the United States, institutional responses to urban runoff as a water pollutant necessitated the investigation of the problem. The U.S. Federal Water Pollution Control Act Amendments of 1972, PL 92-500, and the Clean Water Act of 1977, PL 95-217, provided incentives and often funding for the study of water quality as affected by urban runoff. Especially important to the study of stormwater are Sections 201 and 208 of PL 92-500 which provide direction in the management of urban runoff. The federal U.S. involvement extends to support of the Enviromental Protection Agency (EPA) in their extensive research into stormwater runoff (Field, 1980).

In Canada no legislation exists specifically relating to stormwater runoff. Those acts which may have some connection to urban runoff will be discussed in Chapters Three and Five. Research is done on stormwater quality, however, in Canada (on a limited basis) by the Ontario Ministry of the Environment and by Federal-Ontario joint commissions (Environment Canada, 1980; International Joint Commission, 1978)

2.2.1 Stormwater Runoff as Non-point Pollution

As urbanization continues the volume of storm runoff increases. Larger volumes of runoff result in an increase in total pollutants entering the receiving system. As discussed earlier, the quantity of runoff increases as the percent of impervious cover increases. Randall and Grizzard (1983) found in their study that the same relationship applies to water quality.

Stormwater runoff is called "non-point" source because the pollutants are a result of accumulation over time and enter the system anonymously. This term differentiates runoff pollution from specific sources of pollution (point sources) such as industrial or wastewater treatment plant outfalls (Wanielista, 1983). Non-point pollution is now understood as a major element in the reduction of stream quality. In the United States, the Environmental Protection Agency has found that 50 percent of that nation's water pollution is supplied by storm runoff (Maloney, Hanmann and Cantor, 1983). This statistic includes both rural and urban runoff non-point sources. In this thesis, however, the concentration is upon urban stormwater pollution.

The majority of pollutants found in stormwater are off the land surface, especially the impervious areas (Roesner, 1982). The non-point sources of pollution in runoff are as numerous as the types of land use and activities which are found within a city. The pollutants include: bird and pet faeces, leaves, road salts, soil eroded during construction, oil and grease from vehicles, road surface material loosened by traffic, toxics such as zinc, asbestos and PCB's from industrial areas.

Also entering the runoff are airborne pollutants including hydrocarbons and gases from manufacturing and [illegible]ion, sulfur and lead from vehicles which reach the surface through dry or wet (precipitat[illegible] fallout (Lazaro, 1979; Novotny and Chesters, 1981; Krenkel and Novotny, 1980, Roesner, 1982). Atmospheric inputs of particulates by both dry and wet fallout can be considerable over urban surfaces. For large urban areas deposition rates range from 7.0 tonnes/km^2 per month to more than 30 tonnes/km^2 per month, with the greater portion of this being removed from the atmosphere by precipitation (Novotny and Chesters, 1981).

Most authors agree that the highest concentrations of pollutants are found in the runoff which first reaches the receiving water body. This concept is called "first-flush". The pollutants listed above are washed from the streets and form a first-flush of pollutants with the initial runoff to reach the outfall. The catch basin itself can also be a source of pollution that is found in the first-flush as materials that have been in the system since the previous storm event are flushed out with the runoff (American Public Works Assoc., 1969). Once the majority of the pollutants are removed from the streets and have formed the first-flush at the receiving stream, the level of pollutants in the runoff decreases rapidly. For this reason, as will be discussed in chapter three, many authors feel that treatment of the first flush may be adequate to reduce the negative impact of urban stormwater on receiving water quality.

The pollutants listed above will be expanded upon in the following discussion within the seven categories of:

1. Nutrients- Nitrogen and Phosphorus
2. Sediments
3. Toxic Metals
4. Petroleum- Hydrocarbons
5. Organic Chemicals
6. Chlorides
7. Oxygen Demand

2.2.2 Nutrients- Nitrogen and Phosphorus

Nutrients, nitrogen and phosphorus, enter the urban runoff mostly as street refuse. The major sources of nutrients are fallen leaves and seeds, grass clippings, fertilizers and pet and bird faeces. The accumulative effect can be substantial as the fallout from one tree can amount to 14.5 to 26 kg/year of leaves (Carlisle, Latterman and White, 1966). The materials often break down to become part of the dust and dirt fraction (less than 3.5 mm) "which is regarded as having the greatest pollution potential of the street refuse materials" (Krenkel and Novotny, 1980:215). In a study of a lake near the City of Ames, Iowa, Antosch (1984) found the nutrient content, especially phosphorus, to be the dominant factor controlling water quality in the lake.

A minimum level of nutrients is necessary for plant production. However, oversupply of nutrients can lead to the overproduction of algae and large plants; which may result in eutrophication of the water body. Both nitrogen and phosphorus are vital to plant growth if either is missing the plants will not grow. This is according to J. Liebig's *Law of the factor in minimum* in which the yield limiting factor is whether the nutrient is available in inadequate plant growth, especially algae. Although there are exceptions, the general rule applies that inland waters are phosphorus limited, while coastal waters and their estuaries are nitrogen limited (Novotny and Chesters, 1981). The Michigan lakes studied by Glandon, et al.(1981) were phosphorus limited with excesses of nitrogen. Fine and Jensen (1981) found, in their study of lake water, tha phosphorus was the controlling factor in the overproduction of algae and used northern lignite fly ash to reduce the effects of the phosphorus. A study on Lake Erola, Florida concluded that except under extreme phosphorus conditions, algal production is limited by phosphorus alone (Harper, Yousef and Wanielista, 1980).

There is some debate over which major land use category, agricultural or urban, has the highest loadings of nutrients in the surface runoff. Hill (1981) and Ostry (1982) found agricultural lands to be the largest contributor of nutrients to receiving waters. Whereas Weibal, Anderson and Woodward (1964) found urban stormwater nutrient levels to be secondary only to untreated sewage. Glandon, et al. (1981) found phosphorus loadings in urban runoff to be 3.2 times higher than agricultural runoff levels. However, the same study found total nitrogen loadings to be 1.6 higher in the agricultural stormwater than the urban runoff.

Both nitrogen and phosphorus are associated with soil particles in runoff (Krenkel and Novontny, 1980). This is illustrated by increases is nutrient loadings during times of urban construction or agricultural activity (Glandon, et al.,1981). Because of the close association with sediments, the nutrients share many of the sediments physical attributes including first-flush effects and sedimentation.

2.2.3 Sediments

As discussed above, soil particles are the primary carriers of nutrients into receiving water bodies. The particulates are also carriers of toxic elements and pesticides (Krenkel and Novotny, 1980). The sediments alone can be a problem as water clarity is affected, stream plants were constructed at Lake Tahoe to protect its almost pristine state but still the eutrophication process continued. The major source was attributed to sediment pollution from unrestricted development around the lake (Zwick and Benstock, 1971).

Construction in urbanizing areas results in extremely high erosion rates. Scientists with the U.S. Environmental Protection Agency (1973) found construction areas eroding at a representative rate of 170 tons/ha/year; compared to a grassland at 0.085 tons/ha/year. Most of this eroded soil would be washed into receiving streams by runoff. The portion of the total suspended solids in urban stormwater that is not from construction sites is mostly in the form of particulate solids from roads and other paved surfaces (Mance and Harman, 1978). Pirner and Harms (1978) found that 96 percent of the total suspended solids were from urban runoff. This is in close agreement with Pitt and Fields (1977) who concluded that, if the sewage is treated, that 97 percent of the total suspended solids resulted from urban stormwater.

Increased sediments resulting from urbanization can seriously affect fish population by disrupting the stream habitat. In the streams of the Anacostia River Basin, Maryland, the sediments entering the streams increased from 15 tons/sq. mile to 45 tons/sq. mile during ten years of urbanization within the watershed. This resulted in a decrease in the number of species of fish and a "major shift" towards less sensitive species (Ragan and Dieteman, 1975:59). Fox (1974) found that urbanizing watersheds were generating 9 times the level of sediments as rural or natural drainage areas. She concluded that 10-50 years would be required for a stream to recover from the construction phase and in some cases hundreds of years may be required (Fox, 1974).

Because of the energy required to remove sediments and particulate pollutants from the surface, the concentration of sediments reflects the flow pattern of the storm event. Concentrations are high when flow is high then "after the rain terminates, the sediment carrying capacity is reduced and the sediment concentration decrease is related to the reduction of flow rate on the recession portion of the surface runoff hydrograph" (Novotny, 1981:82).

of being stirred up later, along with the accompanying nutrients and toxics (Novotny and Chesters, 1981).

Sediments may limit the life of a reservoir or lake as deposition continues. Understanding of the physical characteristics and biological effects of sediments allows for effective management of the pollutants in urban runoff.

2.2.4 Toxic Metals

Urban stormwater runoff is a major source of toxic metals or trace elements in our water bodies (Ostry, 1982). Like nutrients, toxic metals are closely associated with sediments in runoff. Study into this relationship has shown that 50-99 percent of toxic metals are related to sediments (Pope, 1980). This relationship extends to the timing of entry into the receiving water body. Mance and Harman (1978) found heavy metals to be linearly related to suspended solids which were, in turn, linearly related to the rate of discharge.

As the sediments enter streams and lakes the associated metals may undergo methylation by bacteria and change into a potent, toxic organometallic compound. A lowering of pH by humic acids (from leaves and grass) increases the process and then more is available to aquatic life (Novotny and Chesters, 1981). A drop of pH in Ontario lakes, due to acid rain, resulted in increased mercury content in fish (Schneider, Jeffries and Dillon, 1979).

The toxic metals that may be found in runoff are; arsenic, cadmium, chromium, copper, lead, manganese, mercury and zinc (Novotny and Chesters, 1981). Lead and zinc are usually the metals in highest concentration, generally, 80-90 percent of the total metal load (Pope, 1980). Wilbur and Hunter (1975) confirmed the above statement; their results show lead and zinc to be 84 percent of the total total metals wth copper being the next highest concentration. Also in their study Wilbur and Hunter (1975) compared runoff with secondary treatment effluent and precipitation and found the stormwater to "account for as much as 86%

manganese being the next highest with 18 percent. Copper, zinc, lead and arsenic were found in urban runoff from Orlando, Florida, into Lake Erola, by Harper, Yousef and Wanielista (1980) to levels that were toxic to algal growth. These toxic metals are absorbed by algae and passed up through the food chain.

As discussed earlier, the toxic metal concentrations mirror the sediments on the runoff histogram, this is logical as the metals are associated with the sediments. Most studies have confirmed this relationship and like sediments, show a marked first-flush of toxic metals (Bryan, 1974; Brown and Green, 1979; Harper, Yousef and Wanielista, 1980). Revitt, Ellis and Oldfield, 1982:56) in their study of northwest London, England found the maximum metal values "all located towards the recessional tail of the hydrograph and this is particularly the case for Cd" (cadmium).

From a management perspective, some of the important characteristics of the toxic metals of urban runoff are that the metals are closely associated with sediments and as result, most often, show a first-flush effect. Also, loadings of zinc and lead have been shown to increase with a rise in the percentage impervious cover (Klein, 1979). And that urban areas, especially highways and city streets, are major contributors of heavy metals to receiving water bodies (Pope, 1980).

2.2.5 Petroleum Hydrocarbons

The amount of petroleum hydrocarbons entering receiving water bodies via stormwater runoff is, at present, quite substantial and is growing as urbanization continues. For example, the runoff from Philadelphia was found to contain an average of 3,600 kilograms of oil per day (Whipple, Hunter and Yu, 1975).

As with many of the pollutants in urban runoff, hydrocarbons are generally sediment related. Various studies have found associations of hydrocarbons with particulates ranging from hydrologists have yet to reach a consensus in terms of first-flush. Hunter, Yu and Whipple (1975) did find a first-flush of hydrocarbons, while Stenstrom, Silverman and Bursztynsky (1984) found only a modest first-flush. Whereas, Soderlund and Lehtinen (1972) did not find any first-flush effect. This range may be explained by the work of Hoffman, et al. (1982) where the researchers found a first-flush, which they related to particulate hydrocarbons (63.5 percent of the total), then measured a smaller second peak thirty minutes later, which they attributed to soluble hydrocarbons with slower transport rates.

After completing gas chromatograms on samples, researchers have concluded that the petroleum by-products found in urban runoff is either crank case oil or polycyclic aromatic hydrocarbons (PAH). Crank case oil is, by far, the largest hydrocarbon pollutant. Hoffman, et al. (1982) found that a very small watershed which had a high proportion of parking lots produced 105 grams of hydrocarbons, crank case oil, per storm event. Stenstrom, Silverman and Bursztnusky (1984) concluded that hydrocarbons, especially crank case oil emissions, form a major contribution to urban runoff pollution. Klein (1979) reports another source, the person who does a home oil change and then disposes of the used oil by "pouring it into the storm drains or gutters". In a survey, in Baltimore, Maryland, 9 percent of the do-it-yourselfers, listed the storm sewers as their disposal point (Klein, 1979). The actual percentage of those who use the storm sewers for oil disposal is likely higher as this figure includes only those people who have admitted to the dumping.

Another pollutant, the polycylic aromatic hydrocarbons (PAH) are emitted by vehicle exhausts and according to Pope (1980:103) "constitutes a major environmental input". The extremely toxic nature of the PAH, some are known to be carcinogenic and cause mutations, requires that special attention be given them (Pope, 1980; Gravens, Revitt and Ellis, 1981).

Because of the nature of hydrocarbon sources; land use has been established "as the most important parameter affecting oil and grease concentration" (Stenstrom, Silverman and

Residential areas, as expected, have the lowest loadings of hydrocarbons; 9.80 kilograms/km^2/cm of precipitation. While commercial areas have 3 times this rate and parking lots have 25 times the residential rate (Stenstrom, et al., 1984).

2.2.6 Organic Chemicals

Like most of the pollutants in stormwater pollution, the organic chemicals are, generally, associated with the suspended solids. Pesticides in urban areas collect on the materials in the streets; especially the dust and dirt fraction (Novotny and Chesters, 1981). The pesticides entering a receiving water body from a city can be sizable. Bryan (1972) found that concentrations of pesticides from urban runoff was 1.16-1.70 ug/l. This was higher than the pesticide concentration in rural runoff (mean of 0.43 ug/l).

Of particular interest to Novotny and Chesters (1981) is the contribution of polychlorinate biphenyls (PCB) into our waters via surface runoff. Collected on the surface as leaks, spills, dry fallout and disposal sites for capacitors, the PCBs are now finding their way to receiving streams and lakes through surface runoff and interflow. A map of distribution of concentrations, in Ontario and the northeastern U.S., shows urban areas with the highest values. Novotny and Chesters (1981:64) refer to urban areas as a "primary source" of PCBs in runoff. In studying Lake Michigan, the authors found that most large fish species (trout and salmon) contain over 5mg/kg of PCB (Novotny and Chesters, 1981). The tolerance levels set by the U.S. Food and Drug administration is 2 mg/kg for PCB in fish. PCBs are highly insoluble and are found in the particulate matter in water.

2.2.7 Chlorides

In cities with sewage treatment and without combined sewers, the application of salt to streets and highways is the major source of chloride in the watershed (Klein 1979). Hoffman on aquatic life. The salts may create a saline layer in a lake which reduces vertical mixing and leads to a shortage of oxygen in the lower levels (Pope, 1980).

The Canadian guideline for chorides in the water supply is that concentrations not exceed 270 mg/l (McNeely, Neimanis and Dwyer, 1979). Yet, various studies have found extremely high chloride levels in receiving streams during the thaw period. For example, Scott (1976) measured 2600 mg/l; while Hawkins and Judd (1972) found 11,000 mg/l in their study streams. Although this is not a constant yearly measurement, damage may be done to aquatic life and to runoff infrastructure and municipal supplies downstream are affected.

2.2.8 Oxygen Demand

Oxygen demand tests are used to measure the water quality as usable by aquatic life. The U.S. Environmental Protection Agency (1974) identifies the reference level of dissolved oxygen to be 4.0 mg/l. Often, urban stormwater entering a water body has a much higher oxygen demand than is met by the dissolved oxygen in the water. The water body then becomes stressed. Whipple's (1975) results showed that it took an estuary six days to recover, to normal levels of dissolved oxygen, after an extreme rainfall event.

Among the oxygen demand tests, the biochemical oxygen demand (BOD) parameter is often used in studying runoff. Meister and Kefef (1981) found urban stormwater BOD values of 3.0 mg/l to 240 mg/l compared to non-urban values of 3.7- 7.0 mg/l and also found a first-flush effect for BOD. Melanen and Larkanen (1980) found BOD levels of 11-24 mg/l in a Finnish study.

It has been estimated that 0.45 million tons/year of BOD is supplied to surface waters in the United States by urban runoff (Loehr, et al., 1979). Also, for cities with secondary sewage treatment, runoff accounts for 40-80 percent of the annual BOD load. This value may

However, Swain (1985:65) cites several researchers as indicating that measuring BOD levels may not be suitable for stormwater runoff and that "the COD [chemical oxygen demand] test may provide better estimates". The reason for this was that levels of copper, cadmium, lead and zinc were found to have toxic effects on certain aquatic organisms.

2.3 Literature on Urban Stormwater Management in the Edmonton Area

There has been little study done on urban stormwater quantity in Alberta. Laycock and MacKenzie have provided some insight into quantity aspects, as discussed earlier, specific to the Edmonton area and for the Prairies, in general. Also, work has been done by Stanley and Associates (1980, 1981) for the Ellerslie Subdivision on peak flow of stormwater quantity. The study by Stanley and Associates will be discussed in Chapter Four.

Some of the publications on stormwater quality speific to Alberta or Canada include (Environment Canada, 1980; Ostry, 1982; Pearse, Bertrand and MacLaren, 1985).

The limited amount of work produced on urban stormwater quality, in Alberta (and Canada), is the result of many factors. Among the reasons is that, until recently, urban runoff has not been considered a serious form of water pollution. Following that, no municipal, provincial or the Federal government has set up minimal standards for the quality of water flowing into stream or lakes from stormwater outfalls. Further discussion on the issue of standards can be found in Chapters Six and Seven.

2.3.1 Summary

With urbanization comes an increase in the percentage of imperviousness as buildings, concrete and asphalt replace natural conditions. This results in increased quantities of runoff and decreased quality of stormwater. The runoff reaches the receiving water body or stream imperviousness in the new urban area. Laycock and MacKenzie (1984) found that in the sub-humid Prairies that increases in runoff yield, with urbanization, ranged from 1.6 times in Winnipeg to almost 10 times in Medicine Hat. The increase in annual stormwater yield for the Ellerslie Subdivision is discussed in Chapters Five and Six.

3. STORMWATER MANAGEMENT: LITERATURE REVIEW

3.1 Introduction Management- Objectives

Stormwater management is described as "all activities undertaken in studying, regulating, controlling, using and disposing of stormwater" (Poetner,1980:59). Ideally, a stormwater mananagement program will involve not only the physical control of runoff but also the "adminstrative, technical and legal means to evaluate, design and implement stormwater management measures. Thus, the program allows for a comprehensive evaluation and solution to stormwater management problems" (Debo, 1980:654).

The nature of stormwater management has changed in the past few years and continues to change. Stormwater management is now a multi-objective practice (Fok, 1981). No longer is the single-means of whisking the runoff off the streets enough to meet changing needs. However, in reality, the quick removal of stormwater remains the prime concern of developers and municipal governments. Nevertheless, stormwater management objectives have now been expanded (in many areas) to include:

1. minimize damage and hazards due to flooding,
2. reduce erosion and sedimentation in streams,
3. maintain natural infiltration and groundwater recharge,
4. reduce non-point pollution in urban runoff maintain surface water quality,
5. improve the visual and aesthetic impact of the urban environment,
6. provide recreation opportunities,
7. integrate into natural environment- combine with forest or wildlife preserves,
8. use of stormwater and,
9. achieve multiple objectives at reasonable costs

(Environment Canada,1980; Grigg,1978; Poetner, 1980).

Site specific objectives could be met through various alternatives. Potential combinations of methods could be reviewed as alternative futures from which the costs, benefits and enviromental impacts of each scenario could be assessed

The best way to address the multi-objective framework is through the multidisciplinary approach; where specialists from different disciplines work together and communicate their ideas to one another (Lazaro,1979). Numerous disciplines working together within a multi-objective framework allow for tradeoffs to be made between those concerned with environmental protection and the interests of other sectors (Duckstein,1980).

The multidisciplinary approach was used to reduce impact of development on receiving streams in the Lake Tahoe area. Professionals from a number of disciplines worked together to carry out a detailed physical analysis of the site, a market analysis (including public needs and interests), an economic analysis and an evaluation of regulatory requirements. The result was a well planned development which has limited negative effects (in terms of both volume and quality) on the receiving streams; at a very low per lot cost (Finnemore, 1982).

The multiple objectives (or purposes) can be established prior to or as part of the Master Drainage Plan.

3.2 The Master Drainage Plan

The Master Drainage Plan is the principal tool for the analysis of existing and future stormwater runoff situations and for the establishment of drainage solutions (Bishop, 1974). As with the identification of the objectives, the writing of the Master Drainage Plan is best accomplished by the multidisciplinary team. Ideally, the Master Drainage Plan is done on a regional basis with the watershed level being the next desirable. Although the benefits of having a Master Drainage Plan are numerous, most urban areas do not have them (Poetner, 1981). As a result, the majority of Master Plans that are produced are done at the watershed level or even a portion of the watershed, as dictated by the size of the development parcel. Nevertheless, whatever the scale of study, the production of a Master Drainage Plan in the early stages of the planning of a new urban area, is vital to the efficient and economical development of the site (Stanley Associates, 1978).

The first and multi-faceted step in the preparation of a Master Drainage Plan is the collection and analysis of hydrologic data for existing and future land uses (Environment Canada, 1980). Of importance, at this stage, is that the analyses be done with a holistic approach (International Joint Commission, 1978) in which the entire hydrologic cycle is considered. Future land use and associated amounts of impervious cover have a direct relationship to the quantity and quality of the stormwater runoff from the newly developed site. Proper planning will result in less impact upon the environment. Planning within the hydrologic cycle is, however, easier said then done because of the complex mechanisms involved in the natural cycle (Wells, 1974).

The relationship between land use planning and water quality is also becoming important (Whipple, Hunter and Yu, 1978). Because as land use affects water quality, water quality in turn affects land use and housing prices (Shubinski, 1974) The creation of the interdisciplinary team during the early stages of production of the Master Drainage Plan is, therefore, vital as balance can be created between objectives, benefits and multiple uses (Bishop, 1974).

3.3 Design Alternatives- Introduction

Many design alternatives exist for the control of stormwater runoff volumes and non-point pollution. The options range from non-structural to high-structural and from site specific to watershed level methods. What will not be discussed in this thesis is the highly structural, conventional, option of routing the runoff from street grates to sewer pipes to concrete outfalls at receiving streams. This traditional type of system is decribed in numerous introductory engineering textbooks (Hitch, 1972; Barre, 1980)

3.4 Best Management Practice

Best Management Practice (BMP) refers to site specific methods incorpoated by the stormwater management specialists into an urban area for the purpose of controlling non-point pollution. (Finnemore and Lynard, 1982; Minton, 1978). The Best Management Practices should be included in the pre-development planning process with the intent of preserving natural land conditions as much as possible (Finnemore, 1982). To properly develop BMP's "requires an extensive understanding of wet-weather flow characteristics, pollutant characteristics, and the relationship between land use and pollutant mass discharge" (Stenstrom, Silverman and Bursztynsky, 1984). Also important to the development of the Best Management Practices is an understanding of the technologies available.

The objective in Best Management Practice is to decrease the amount of pollutants generated by areas insteadd of treating the polluted flow (Minton, Anderson and Coburn, 1978). BMP's are made of non- or low-structural management alternatives (Finnemore and Lynard, 1984) or of devlelopment activities (Poetner (1980). Non-structural alternatives include land use planning, legislation and maintenance practices, and the use of natural features. Low-structural alternatives involve the use of natural land features with small, simple structures to control runoff pollution (Finnemore and Lynard,1984).

3.5 Land Use Planning

In 1975, Koelzer and Bigler, felt that water resources management had failed to recognize the potential of urban design in water resources planning. However, in the past decade, gains have been made in the understanding of how urban design and planning affect water resources and in the knowledge that land use planning must be integrated with water services planning.

Imperitive to improving the water quality of runoff is the creation of standards or environmental goals that would be similar to the common standard for runoff quantity, which is that the runoff volume (usually peak flow) be maintained at pre-development levels. Once the water quality goals are set "the future amounts and distribution of population, economic development, and land use must be balanced and limited to permit the achievment of the goals" (Powell, 1975:98). This may result in the housing densities or design, the placement of commercial sites or the choice of surfacing material being altered to accomodate water quality requirements.

Maintaining runoff water quality at pre-development levels may not be realistic, for all new subdivisions, at the present time. Just as many areas do not meet stormwater quantity requirements. However, developers do not, generally, make investments or introduce new technologies without reason, therefore the creation of environmental standards will be necessary. Such legislation does exist. Rice Creek Watershed District, Minnesota, requires approval from the Board of Managers for any land development (small or large). The Rice Creek Watershed District requirements include Stormwater Management Plans in which the "general intent of the plan is to ensure that the stormwater runoff from a developed site will at no greater or lesser quality than the stormwater runoff from the site in an undeveloped condition" (Rice Creek Watershed District, 1984:1). Further discussion on the use of standards and ordinances will follow in Chapter Seven.

Stenstrom, Silverman and Bursztynsky (1984) found that in a small, urban watershed in Richmond, California that controlling the runoff from the approximately 10 percent of land, in commercial and parking land use, could result in a 50 percent reduction in hydrocarbon pollution. Land use planning and drainage professionals, then have the opportunity to reduce non-point pollution by controlling the commercial and parking lot runoff at the source.

Multi-family housing has been found to produce more runoff pollution, per housing unit, than single family housing. The authors credit the open space component, in the single family areas, for making the difference as pollutants are held in the lawns and gardens (Whipple, Hunter and Yu, 1978). It may be appropriate then to plan parks or treed areas adjacent to multi-family housing for the purpose of controlling stormwater pollution.

Land use planning could also be used to restrict development on erosion prone sites or in flood plains (Finnemore and Lynard, 1982). But, the conservation of natural features and drainage patterns is the most important way that land use planning can be used to attenuate the effects of urbanization on stormwater. Maintaining natural areas, for infiltration and evapotranspiration, is essential to minimizing change in the hydrologic cycle.

Land use planning, however, can not be used to solve all of the stormwater management problems associated with urbanization.

> Real world situations will often require the application of several practices in combination to provide a comprehensive control system. In these cases, the total system may be more effective than the sum of its component parts. It must be kept in mind that it is not the land use, per se, that affects water quality [and quantity], but rather how the land is managed (International Joint Commission, 1978:72).

3.6 Natural Drainage

Using natural drainage, instead of conventional storm sewers or concrete channels wherever possible, will result in the water balance of the hydrologic cycle being less effected. This involves the identification of natural drainage patterns (general slope, permanent and ephemeral streams) and incorporating the natural conditions into the new urban environment with as few changes as possible (Environment Canada, 1980). Open natural channels are becoming popular with the development industry not only because of the financial savings but also because of the reduction of pollutants, runoff volumes and erosion and the aesthetic value (Urban Land Institute, 1975; Field, 1980).

Natural drainage reduces peak flow because the vegetation decreases velocity of the runoff (Wanielista, 1978). As the velocity is reduced so is the energy for erosion. Total runoff volumes and peaks are also reduced because infiltration and evapotranspiration takes place in the natural watercouse.

Non-point pollution is also reduced by assimilation (plant use of nutrients) and sedimentation in the natural stream or channel (Patrick, 1975; Field, 1980). Natural drainage systems and open grassed ditches can "reduce the delivery ratio of pollutants to a few percent, while areas served by storm or combined sewers will show almost 100% delivery" (Notony and

Chesters, 1981:410).

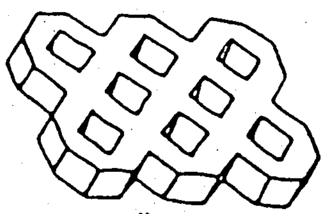
The Woodlands development, just outside Houston, Texas, was "the first city plan produced by ecological planning" (McHarg and Sutton, 1974:73). Within the forested site the natural drainage pattern was incorporated along with the vegetated swales, impoundments, green space storage in the golf course and berms to replicate the non-urban water balance system. The result was an increase in peak discharge of only 55 percent (rather than the 180 percent as was calculated for traditional drainage) and a reduction in expected runoff pollutants of up to 30 percent (Juneja and Veltman, 1979). All at a cost of $4,200,400 for a savings of $14,478,900 over a conventional system. "Such figures [should] accelerate conversion to ecological principles. There is no better union than virtue and profit" (McHarg and Sutton, 1974:77).

3.7 Grass Pavers/ Porous Pavement

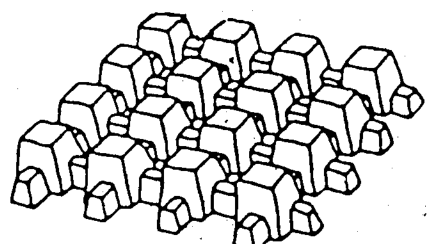
Grass pavers and porous pavement are slightly different technologies which have similar results. Both provide on-site infiltration, therefore, stormwater volumes, peaks and pollutants are significantly reduced at the source. Because both are used as surfacing materials grass pavers are often included as a type of porous pavement in the literature.

Grass pavers are ceramic brick or concrete blocks structured in a lattice form (Fig. 3.1). They provide a hard protective surface but from a distance appear as a grassed area. The pavers are laid on soil, then spaces in the blocks are filled with soil, mulch and fertilizer and then the grass is seeded (Robinette and Sloan, 1984). During a rainfall event the grass and soil absorb the runoff, as percolation and evapotranspiration takes place. Grass pavers are appropriate for parking lots, residential driveways, bikeways, access roads, slope stabilization, walkways in cemetaries and for recreation vehicle parking areas (Heritage Conservation and Recreation Service, 1980).

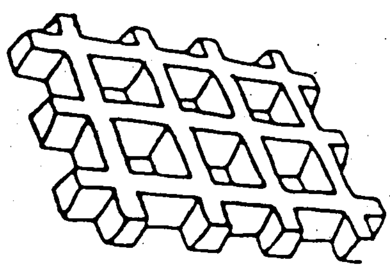
Grass pavers were first used in Stuttgart, West Germany, as a method to introduce green space into the inner city. The green space was used for increased aesthetics and to reduce



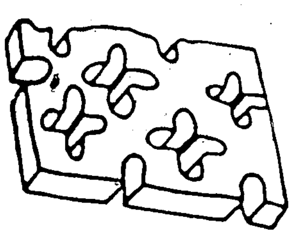
"turfblock"
Paver Systems Inc.
Wausau Tile



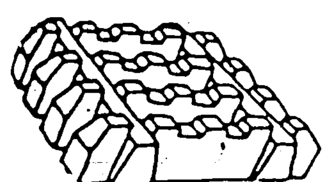
"checker block"
Hastings Co.



"grasstone"
Boiardi Prods.



"grasscrete"
Bomanite Corp.



"monoslab"
Grass Pavers Ltd.

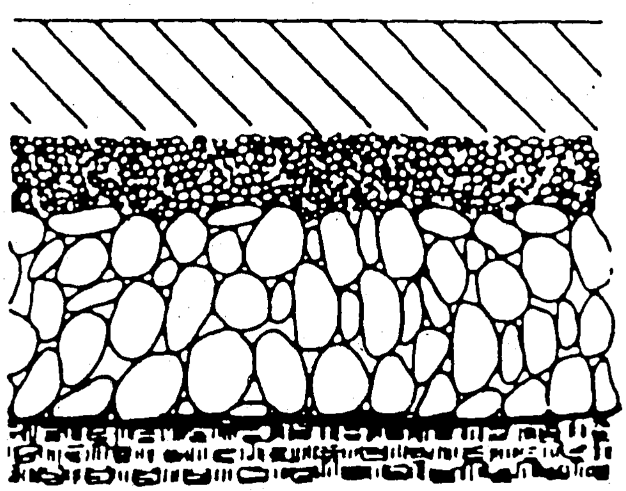
the "urban heat island" effect through decreased levels of concrete. The reduction in stormwater runoff was an unintentional bonus. Since then grass pavers have been used throughout Western Europe and are becoming popular in the United States (Heritage Conservation and Recreation Service, 1980).

Porous pavement is an alternative to conventional asphalt which is impervious to precipitation. Instead of quickly running off the roadway or parking lot the rain filters through the porous pavement into a storage layer. A filter layer or fabric could also be incorporated to reduce the pollution to groundwater or interflow (Fig. 3.2). The basic difference between conventional and porous asphalt is that no fines are used in the mix and a slightly higher amount of asphalt is used for binding. A course material is used for the base which has a large void space for the storage of runoff until it infiltrates into the soil (Clay, 1974). For more details on porous pavement construction see Field, Masters and Singer (1982).

Grass pavers have been found by Clay, (1974) to greatly reduce runoff volumes and successfully remove significant quantities of pollutants. While work done at Virginia Tech has found grass pavers to reduce runoff volumes by 50 to 80 percent (Heritage Conservation and Recreation Service, 1980). The use of porous pavement in Woodlands, Texas, resulted in a 26 percent reduction in runoff peaks and water quality improvements of 10-30 percent (Juneja abnd Veltman, 1979). Murphy, et al. (1981) found, during a study in Rochester, New York, that peak runoff rates were reduced by as much as 83 percent in areas where porous pavement was used. Whatever the reduction rates, the result is that the road or parking lot is no longer impervious and therefore, storm drains and sewers may not be needed for that site.

Clogging from sedimentaion has been found to be a problem with porous pavement, particularly during times of construction. However, this is remedied by occasional flushing (Field, 1985; Environment Canada, 1980).

The costs of constructing a porous pavement parking lot or roadway are equal to, or less than, conventional pavement with stormwater drains and underground sewers (Field,


Porous asphalt course
Filter course
Reservoir course (volume designed for runoff detention and frost penetration)
Filter fabric
Existing soil (minimal compaction to retain porosity and permeability)

to conventional pavement with curb/gutter storm drainage at 150 pounds/m². In Stuttgart, Germany, (the first and most extensive user of grass pavers) "little emphasis has been placed upon measurements of the total costs and benefits; a qualitative perception of benefits to urban amentity and climate apparantly serves as sufficient rationale" (Heritage Conservation and Recreation Service, 1980:5).

3.8 On-site Storage

Other methods which reduce runoff volume (and therefore, reduce peakflow and pollutant loadings) by controlling the stormwater on-site are green belt storage, roof-top storage and parking lot detention. With on-site storage the runoff is retained on-site for evaporation, infiltration and/or evapotranspiration or is held for a short time and then disposed of into the storm sewer system.

Green belt storage involves the temporary storage of stormwater in open space areas. Golf courses and parks are the most used sites for green belt storage. Green belt storage areas are most effective when combined with open, natural drainage channels (Environment Canada, 1980). The storage is provided only for the short time it takes for the runoff to be removed through infiltration and evapotranspiration.

A park in Markham, Ontario, was designed to include temporary storage of runoff. Green belt storage was combined with an underground superpipe (designed to handle up to the 5 year storm events) to provide control up to the 100 year storm. The depression for the 100 year storm had a mean depth of approximately one metre. The total area required for the green space storage was 2.5 percent of the total development parcel size. The advantages of the park space storage was a) that it was inexpensive as the land used was part of the 5 percent park dedication, b) was low in maintenance costs and c) the basement flooding due to storm sewer surcharge was eliminated (Wisner, Mulherjee and Keliar, 1979; Wisner, Kassen and Cheung, 1981). Such provision of green storage as part of a multi-use stormwater management plan agencies and private developers (Tourbier, Westmacott and Goedken, 1979).

Parking lot storage (assuming the conventional fully impervious asphalt or concrete surfacing) merely provides detention for runoff during extreme storm events. The stormwater is held, for a short time, and then released into the storm sewers at a controlled rate, thereby reducing the peak flow.

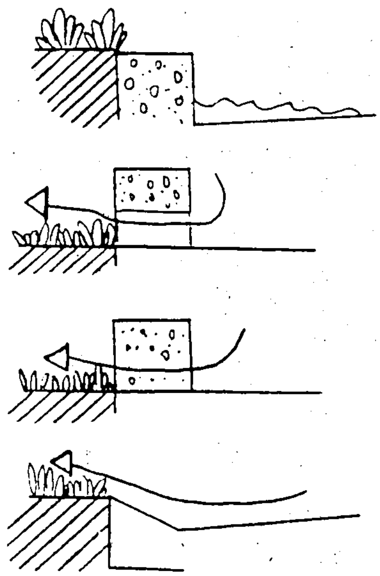
For the detention of stormwater, parking lots are designed with a gentle slope to a slight depression in the least used portions of the lot; to minimize inconvenience to users. Detention parking lots are usually designed to detain runoff to an overall storage depth of only 6-7 cm, at the depression site, with a controlled release rate of 1cm/hour. The five year storm ponds to only 1 cm (Stanley Associates Engineering Ltd., 1974).

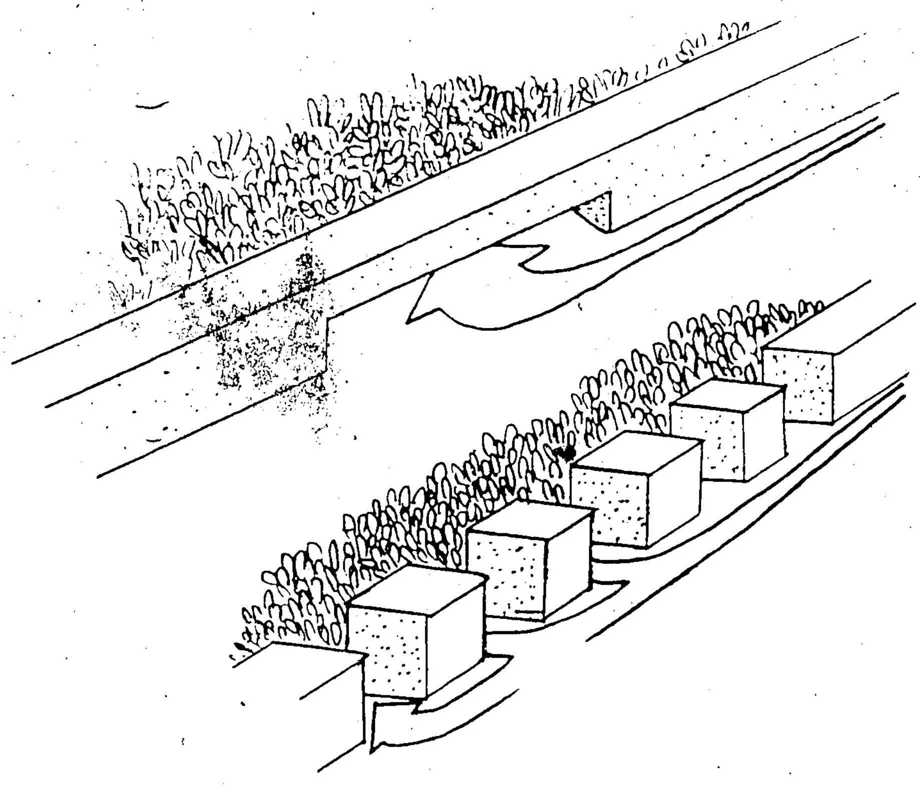
A trucking firm in St. Louis, Missouri used parking lot storage as part of their stormwater management system at their truck terminal. The total cost of $115,000 was $35,000 lower than the estimates for a system without on-site detention (Poetner, 1976).

Conventional parking lot storage can be designed to provide some measure of runoff volume and pollution control by the inclusion of grass strips into the parking area. The grass strips work as a filter for sediments and other pollutants as well as providing small sites for runoff infiltration (Poetner, 1974a). Alternative types of curb configurations could be used to allow runoff to reach the grass strips. These include cuts in the curb, rolled curb or dragon tooth curbs (Fig. 3.3; Robinette and Sloan, 1984).

As discussed in section 3.5, controlling the runoff pollution from parking lots can greatly reduce pollutant loadings, in particular the hydrocarbons, from the entire development parcel (Stenstrom, Silverman and Bursztynsky, 1984).

Rooftop storage involves holding the stormwater on a building rooftop and later slowly depositing it into the drainage system. Most Canadian industrial and commercial buildings have flat roofs which are designed for heavy snow loads. This design requirement means that a roof





stormwater. A rainfall detention ponding ring will be required at the roof drain (Environment Canada, 1980; Poetner, 1974a).

Roofs may consist of 50 percent of the impervious surfaces in an urban area (Environment Canada, 1980; Lazaro, 1979); retaining stormwater on even a portion of the roofs will reduce peak flow. If the stormwater is held for long periods of time, or used on site, then runoff volumes are also reduced. Poetner (1974) writes that gravel barriers on the roof will also reduce peak flow.

In residential areas, as most houses do not have flat roofs, other on-site measures could be used. Putt and Johnson (1978) suggest the retaining of runoff in an on-lot drainage unit made of porous and crushed media. Thereby, each house/lot provides its own immediate retention. The authors felt that the on-lot retention would reduce peak flow from an urban area by 30-40 percent. On-lot detention was also proposed by Schilling (1982) in the form of cisterns or rainwater barrels to reduce peak flow by 20 percent. Schilling writes that it may be possible reduce peak runoff volumes of frequent events by up to 80 percent. In downtown Denver, Colorado, the Denver Urban Renewal Authority required developers to detain, on-site, precipitation falling directly on their properties. This was accomplished mostly through rooftop storage, with some on-site ponding, "at extremely low cost and with little inconvenience to land developers and the public" (Poetner, 1974b:392).

Whether at the large commercial building scale or a small residence there are measures to hold the stormwater on-site. Because most of th e runoff pollutants are not yet in stormwater at the roof level, this water is relatively clean and has large potential for use within the urban area.

Large underground storage tanks may also be used to provide on-site storage. Tanks may be economical if land costs render above ground storage rest[illegible]e. Runoff is detained in the underground tank and then slowly released into the sewer system (Stanley Associates Engineering Ltd, 1974). Underground tanks were used successfully in Scarborough, Ontario, to eliminate basement flooding (Environment Canada, 1980).

3.9 Erosion Control

The majority of erosion in urban areas takes place in two types of sites: construction and receiving streams. The easiest way to reduce erosion from construction areas is to keep the runoff sediments on-site. Then the particulates are restricted from moving too far as well as protecting the receiving waters from sediments and the accompanying pollutants. The amount of soil erosion that takes place is a function of the precipitation and runoff energy, soil characteristics, vegetation cover and the size and slope of the watershed (Krenkel and Novotny, 1980). Management practice is unable to change the energy of the rainfall or the size of the watershed. But, proper management can attenuate erosion by reducing the runoff energy, providing vegetative cover and by keeping the change of slope to a minimum. As discussed in Section 3.6, maintaining the natural drainage patterns, as much as possible, is an important factor in reducing runoff energy.

The techniques available to reduce erosion during times of construction include vegetation strips, filter materials, revegetation, traffic control at construction sites and temporary filter berms. Also, avoiding the baring of the surface whenever possible during the heavy rainfall seasons as much as possible, is useful in reducing sediments in stormwater runoff (Laycock, 1986, personal communication).

Vegetation strips, around the construction sites, are effective in slowing down and absorbing runoff as well as being sediment and pollutant traps. "A minimum of 85% sediment removal can be achieved with a 2.5 m grass strip during shallow (non-submerged) overland flow" (Novotny and Chesters, 1981:442). Filter materials at construction sites produce the same reults as grass strips with more immediate results but can be more costly. The simple use of hay bales, directly around the site, may work well with some limitaions as there are many small spaces between the ground and the material. Also, the the bales sometimes are not tightly bound. Commercial products are also available which produce excellent results. These are filter materials which are buried to a depth of approximately 15 cm and held above ground for about 30 cm, around the periphery of the construction site (Torpe, 1985).

Revegetation refers to the immediate, and often temporary, grass seeding or sodding of large open spaces in a subdivision under construction by the development company (Wanielista, 1979). This is often necessary as the construction period, for a large develoment, may be spread over many years. Mulches of jute, fiberglass or plastic, chemical stabilizers and nettings could also be used as a replacement for grass (Poetner, 1974a). Rawls and McCuen (1978) showed how revegetating open areas immediately after disturbance with grass lowered drainage costs because runoff volumes were reduced. Novotny and Chesters (1981:410) wrote that in urban areas soil conservation practices, in particular good grass cover "may be the best method to reduce pollutant loads".

Controlling traffic in construction areas by reducing speed, using crushed stone for roads and the use of berms on the construction site can reduce sediment pollution (Wanielista, 1979). The berms for traffic control could be filter berms which are temporary gravel or crushed rock ridges constructed across a right-of -way. "They are designed to detain and filter the runoff while, at the same time, allowing traffic to use the right-of-way" (Poetner, 1974a:154).

The most important method in the reduction of erosion at receiving streams is to replicate the natural drainage conditions. Whipple, DiLouie and Pytlar (1981) found that the land use of the land immediately adjacent to the receiving stream determines the quantity and quality of the runoff. The authors recommended the use of a treed buffer strip between urban land uses and the stream to create more a more natural runoff situation.

Channels protected with grass, stone or wire mesh with stone, will also have slower velocity of flow to receiving streams (Novotny and Chesters, 1981). Also, Whipple, DiLouie and Pytlar (1981) suggest the use of boulders in areas of high flow to dissipate energy, and the use of water-loving trees along streams to provide stable banks.

Whatever the technology or ideas available to reduce erosion, most developers will not incorporate them into a construction site or new urban area if it is not mandatory. Such requirements do exist in many parts of the United States. And in Ontario "certain projects are subject to MOE [Ministry of the Environment] review of the adequacy of proposed erosion-sediment control practices" (Enviroment Canada, 1980:155). Nevertheless, generally in Canada and certainly in Alberta the creation of construction site erosion and sediment control regulations are needed. These could take the form of "local initiatives, institute ordinances and/or by-laws requiring erosion and sediment control plans for land disturbing activities" (International Joint Commission, 1978:78).

3.10 Street Cleaning

Street cleaning, traditionally, is done for aesthetics, to remove the visible refuse and large particulates and to keep the storm sewers flowing. The fine solids fraction remains on the street to be swept away by the stormwater runoff. However, the majority of runoff pollutants are assoicated with the street fines. Sartor and Boyd (1972) found that the fine fraction, from street surfaces, was only 6 percent, by weight, of the total solids but associated with the fines was 35-50 percent of the nutrients, over 50 percent of the heavy metals and nearly 75 percent of the pesticides. For this reason many cities are combining vacuum street cleaning with conventional broom sweepers (referred to as advanced techniques). Vacuum street sweeping is one of the few management alternatives available to apply to existing urban areas for the reduction of non-point pollution (Park and Shabman, 1981).

The removal effectiveness of street sweeping is, nevertheless, dependent upon the street surface conditions (Finnemore, 1982). Also important to the effectiveness of street cleaning is the interval between cleaning sessions. In a study done in Washington, D.C., Sutherland and McCuen (1978) found that the frequency of street sweeping had the greatest effect on removal efficienies. In their study the most effective street sweeping operation was a vacuumized street sweeper operating at 3 mph every two days. This resulted in a removal efficiency of 69.6 percent of the total solids; although the authors point out that the removal of fines was aproximately 25 percent which they felt was a poor removal of pollutants.

In a study of San Jose, California, Finnemore (1982) found frequent street sweeping, once or twice per day, on streets in good condition had removal efficiences of up to 50 percent for total solids and heavy metals. The author compared this to the more typical street sweeping programs which clean once or twice a month and remove less than 5 percent of the solids.

In a recent summary of United States EPA research, Field (1980) describes a study of street sweeping in which 50 percent of the solids were removed by conventional sweepers and 93 percent by the employment of advanced techniques. Finnemore (1982) lists the benefits of street sweeping as lower total solids and heavy metals, less need for sewer cleaning, reducing particulates in air pollution and increased aesthetics and public safety.

Problems do exist, however, as street cleaning, street maintenance, water quality issues and city aesthetics are handled by various departments in civic governments, often resulting in "serious administrative and jurisdictional difficulties" (Ellis, 1982:3-46). Therefore, the street sweeping that is done is often incomplete as a result of differing management perspectives. And, because of the inability of street sweeping, except under optimum conditions, to remove most of the fines and because of the institutional problems, Collins and Ridgeway (1980) feel that alternatives which reduce the volume of runoff through infiltration or detention should be considered to aid in the removal of the fine fraction.

3.11 Treatment by Structural Methods

The treatment methods applicable to stormwater runoff fall into three basic categories: physical, biological and disinfection; although often the techniques are combinations of these.

Physical treatment methods include sedimentation, fine mesh screening, high rate filtration, regulators/concentrators and air floatation (Environment Canada, 1980; Wanielista, 1979). Sedimentation in tanks or impoundments (see also section 3.13) have average removal efficiences of approximately 30 percent for BOD and 50 percent for solids. These efficiences can be improved upon by the addition of chemical coagulants. Most of the treatment methods require storage before or during treatment so that sedimentation is usually part of the treatment system, if not the entire system (Field, 1985; Wanielista, 1979).

Fine mesh screening of runoff can remove 40-50 percent of BOD and up to 70 percent of the suspended solids. High rate filtration is finer than screens and often involves a dual media filter such as coal over sand. These filter units can remove 60-80 percent of the BOD and 90 percent of the suspended solids (Field, 1985; Wanielista, 1979).

Regulators/concentrators function by concentrating the solids and sending the concentrated flow to sewage treatment plants and sending the relatively clean water to the storm drainage system. Swirl regulators/concentrators have removal efficiences of 25-60 percent for BOD and 50 percent for suspended solids. An advantage of concentrators over the other physical treatment alternatives is the amount of flow it can treat in a short time; 60 gpm/ft^2, compared to 0.5 gpm/ft^2 for sedimentation and 24 gpm/ft^2 for high-rate filtration (Field, 1985).

Air floatation separates solids from the runoff by introducing fine air bubbles into the water which attach themselves onto the particulates and bring them to the top. The floating particles are then skimmed off. This procedure is usually combined with chemical coagulants for higher removal efficiencies. Air floatation can remove 50-60 percent of the BOD and 80 percent of the suspended solids (Environment Canada, 1980; Field, 1985). Disinfection involves contact with a disinfectant, which is usually chlorine, to reduce fecal coliform levels. Field (1985) found that adequate reductions of coliform can be obtained with contact times of two minutes or less. The fecal material in stormwater is primarily from animals but the stormwater may be contaminated through illegal cross-connectons to sanitary sewer pipes (Environment Canada, 1980)

Conventional biological treatment, as is used successfully for wastewater, is not as effective for stormwater treatment. This is because of problems with overloading and shock conditions during periodic storms. For this reason pre-treatment storage is essential for the use of biological treatment beds (Field, 1985). Natural biological treatment, in wetlands, will be discussed in Section 3.12.

To improve water quality for recreation the city of Boston treats its stormwater with a combination of screens, detention storage, hydrochlorination and an interceptor which sends the concentrated runoff and solids to a domestic wastewater treatment plant. The plant has a removal efficiency of 45 percent for suspended solids (Field and Fan, 1981).

Because of the concentration of pollutants in the first-flush of stormwater runoff many authors feel that the treatment of, at least, the first-flush is important to the improvement of receiving water quality. Also, with limited funds available for stormwater treatment many municipalities have decided to just treat the first-flush of runoff. The city of Vancouver has used an interceptor to send the first-flush to the sanitary sewerage plants (Swain, 1985). In a Florida test case, the first-flush was treated by a combination of detention and a soil filtration unit with very successful results. The authors felt that by using a coupling of sand and alum sludge in the filtration system it could remove 80-90 percent of the first-flush of runoff (Wanielista, et al., 1981). Also, in Orlando, Florida, Wanielista and Yousef (1978) tested the treatment of first-flush by a percolation/detention basin which allowed for infiltration. The percolation ponds had an average removal efficiency rate, for total nitrogen, phosphorus, BOD and suspended solids of 88 percent. One negative result was that slightly higher levels of nitrogen and phosphorus were found in the groundwater.

Test use of swirl regulator/concentrator in Syracruse, N.Y., resulted in approximately 50 percent removal rate for suspended solids (Field, 1985). Whereas, in Billing Brook, England, a gasoline interceptor is used to float off the hydrocarbons from stormwater (Smith, 1974).

Whatever the treatment used, operation, maintenance, capital and land costs will be lower if: a) the storage basins are large and centralized and b) if natural features are used (Finnemore and Lynard, 1982).

3.12 Treatment by Natural Methods- Wetlands

After documenting many studies, van der Valk, et al. (1978:464) concluded that "wetlands are excellent nutrient traps and are, as a result, valuable because they are acting as natural treatment plants removing nitrogen (N) and phosphorus (P) from polluted water passing through them". The wetlands accomplish this by physical, biological and chemical mechanisms. For example, the phosphorus from urban runoff is held in soils by adsorbtion and precipitative reactions with aluminum, iron, calcium, and clay minerals (Nichols, 198[illegible]). Nitrogen is also be removed from the water passing through a wetland, primarily by sedimentation and through the process of denitrification (Willenbring, 1984). Denitrification takes place only in anaerobic conditions by certain bacteria that use nitrate in place of oxygen to facilitate respiration in the oxidation of organic compounds; the final end products are the gaseous N_2 (nitrous oxide) and N_2 (Gersberg, et al., 1983; Willenbring, 1984).

Vegetation also aids in the nutrient and solids removal processes by acting as a physical filter; reducing the flow velocity and allowing inorganic and organic particulates with associated nutrients (and other pollutants) to settle out. The vegetation also provides a substrate in which decomposer microorganisms can attach themselves. These microorganisms assimilate pollutants from stormwater runoff as they grow and reproduce. The wetland vegetation also removes nutrients from the soils in the wetland and incorporates them into its vegetative mass as it grows (Willenbring, 1984). Hickok, Hannaman and Wenck (1977) wrote that the microbial activity is the most important mechanism influencing the improvement water passing through the wetland, with rapid increase in microbial populations directly following a runoff event. The microorganisms remove the nutrients for growth resulting in a decrease in the concentration of nutrients.

The large plants in a wetland area are, however, important for aesthetic appeal. But they too provide assimilation of nutrients. According to Westlake (1973) wetlands dominated by cattails and other emergent macrophytes are amoung the most productive biological systems in the temperate zone. The aquatic and semi-aquatic plants also absorb heavy metals from the runoff water and incorporate them into leaves, roots and stems (Kadlec and Kadlec, 1978).

This concept of improving the quality of polluted water by passing through a natural wetland has been applied in many locations. Documentation includes examples from Canada, Sweden, Hungary, Britain, Poland and many places in the United States (van der Valk, 1978). For example, Saw Grass Lake in Pinellas County, Florida is a 138 hectare wetland that has been used for runoff water quality improvements and to provide flood protection; as well as being an environmental and recreational amenity (King, 1983).

A wetland (marsh) was used as a non-structural treatment method for urban runoff in the Minnesota Watershed District of Minnehaha with successful results. The wetland was found to remove 78 percent of the total phosphorus and 94 percent of the suspended solids. The authors concluded that "this project has demonstrated the treatability and effectiveness of non-structural methods to improve the quality of stormwater runoff from urban areas using natural wetlands (Hickok, Hannaman and Wenck, 1977:IV).

Fetter, Sloey and Spangler (1978) in studying a natural marsh in Wisconsin, which receives wastewater from a city sewage treatment plant, various industrial wastes, as well as agricultural and urban runoff, also found that water quality was improved as water passed through the wetland. Removal efficiencies were 80.1 percent of BOD, 51.3 percent nitrogen, 13.4 percent total phosphorus and 29.1 percent of suspended solids.

Gersberg, Elkins and Goldman (1983) found high rates of nitrogen removal by artificial wetlands; ranging from 50-95 percent. In the study, the authors noted that for energy efficient treatment the natural wetlands were preferable to artificial wetlands.

A great deal of work is being done with natural treatment of runoff by wetlands in the Rice Creek Watershed District in Minnesota. The Minnesota wetlands were visited by the author as part of the field research. The field observations and research done by the Rice Creek Watershed District will be discussed in Chapters 4.5 and 5.2.

3.13 Stormwater Lakes

Stormwater lakes were first designed as an inexpensive alternative to an extensive underground system of large and small storm sewers. The impoundments are used to provide detention storage of the runoff until the smaller storm sewers are free to handle the floe. The expensive large trunk sewers are then not required in many areas. Therefore, the initial (and remaining primary) purpose of stormwater lakes is the storage of surface runoff. Today stormwater lakes range from single purpose (storage) to multiple purposes. The multiple purposes that are the most common in stormwater impoundments include aesthetics, reuse, recreation, wildlife habitat and treatment of runoff. Therefore, stormwater lakes are attractive to developers because of the capital savings for drainage and the urban residents approve because of the amenities that the lake provides.

The number of uses that a stormwater impoundment can have is dependent upon the amount of time that the runoff is held as well as the overall design. Detention lakes (also referred to as dry ponds) are those which store water for only a short period of time; until the runoff is directed into the drainage system. Retention (in wet ponds) involves the storing of water for an indefinite period of time releasing the water into the drainage system very slowly, if at all.

Detention lakes reduce peak flow but do not substantially affect total volumes. Retention lakes reduce peak flow and lower total runoff yields as the water is held in storage, with a portion lost to evaporation (and if not lined, to infiltration) (Poetner, 1976).

Detention facilities provide temporary storage but do not replicate natural conditions; in terms of timing or volumes. This may result in increased downstream flooding as delayed peaks accumulate downsteam (McCuen, 1979; Hawley, Bondelid and McCuen, 1981; Dunn, 1981). Mein (1980) found, in his Melbourne, Australia, study that upstream stormwater basins did not cause higher peaks downstream. Although the author did agree that the possibility exists and that each case should be studied for potential downstream effects.

McCuen (1979) felt that detention facilities should be complemented with other stormwater management alternatives which more closely duplicate natural conditions (see Sections 3.5 to 3.7). Whipple (1981) wrote that detention lakes should be combined with a small retention outlet to form a dual purpose detention basins which would reduce peak flow and runoff pollutants.

The City of Winnipeg, Manitoba, Waterworks, Waste and Disposal Division has had experience in both wet and dry multi-purpose ponds and has recommended that all future developments be retention (wet) lakes (Environment Canada, 1980). Grizzard, Weand and Randall (1978) agree that retention facilities are better because the wet basins improved water quality. The retention lakes and ponds were successful in removing almost 70 percent of the phophorus, 45 percent of the total nitrogen and up to 87 percent of the suspended solids. The authors attributed the difference to the active biological populations and quiescent water columns in the wet ponds.

Permanently wet stormwater lakes are also preferable as they can be built to "form the core of blue-green areas in open space developments, parks and other planned urban developments" (Poetner, 1976:3). In a study of the recreational potential of an Edmonton stormwater lake, Beaumaris Lake in Castle Downs Subdivision, Hinch (1984) found that the developer was successful in making the stormwater lake a recreation amentity in the community. Through the use of a survey, the author found that 69.3 percent of the respondents were satisfied with the recreation function of the lake. Of the residents 90.3 percent of the respondents felt that "Beaumaris Lake made a positve contribution to the overall quality of the urban environment" (Hinch, 1984:110). However, the recreation function of the lake is reduced by poor water quality. Not only is the stormwater runoff entering the lake without any treatment ... upon visiting the lake, the author found that the visual evidence of illegal cross-connections is obvious.

In Edmonton, as in most municipalites, the primary function of wet ponds remains the yield and pollutants to receiving streams as the runoff is held on-site. The improvement of runoff quality, through storage, is accomplished mostly through sedimentation. Two stormwater retention lakes in Winnipeg, Manitoba, were very effective in removing suspended solic [illegible] itrogen, total phosphorus and lead from the water (Chambers and Tottle, 1980). The authors did, however, note a problem with concentrating the lead into a lake; especially if it is to be used for in-water recreation. In Orlando, Florida, stormwater is coagulated with alum before it is entered into Lake Erola. As a result, the nutrients are not available to plantlife and the increase of algal production had not been significant (Harper, Yousef and Wanielista, 1980). Retention lakes were also used in a New Jersey housing complex; with the priorty being the minimizing of effects upon the receiving waters. It was found that with retention basins, planned into a natural setting, that peak flow and water quality were not substantially effected post-development (Hughto and Harley, 1981).

As discussed above, one of the main attractions of stormwater lakes, to developers, is the lower cost compared to conventional drainage. Work by Stanley Associates Engineering Ltd. (1978) found that costs for drainage which included a stormwater lake cost $1720/acre, whereas conventional drainage would have cost $6010/acre, a savings of 71 percent. Chambers and Tottle (1980) found that costs varied according to: distance to the receiving stream, staging of development, size of development, land use in the development and the relationship between the developer and the contractor. In their study of Winnipeg impoundments, the savings ranged from 0 percent for a development adjacent to the receiving stream to 79 percent, over conventional drainage, for a development far from the a receiving stream.

Details on the design of stormwater lakes in a new urban area will be discussed in Chapter Six.

3.14 Legal Aspects of Stormwater Runoff- Legislation

Legislation related to stormwater runoff is dictated at the provincial level and is administered by the province and the city municipality. Federal involvement is minimal. The Fisheries Act (1970) (section 33.2) did provide a definition for the pollutants which Alberta used for its Clean Water Act.

The Canada Water Act (1971) does not have influence on provincial water resources because of the 1930 tufal Resources Transfer Agreement Act which gave constitutional right to the control of natural resources to the province. The Canada Water Act does allow for Federal involvement when (section 9.a) "water quality management... has become a matter of urgent national concern".

At the provincial level (Alberta) various statutes are or can be applied to stormwater runoff. The Clean Water Act (1971) does not make direct reference to stormwater runoff. Inferences could be made, however, and runoff could be included under the Act. Section 1(k) defines "surface runoff" as including any water in a watercourse (a discernible bed) including artificial equivilents. Stormwater may be then covered by the Clean Water Act , provincial jurisdiction, if it is collected into a surface facility or drainage system.

Urban runoff as a source of pollution may then be covered by the Clean Water Act. The usual destination for stormwater runoff is into a stream. The Act states that nothing harmful may be put into a water course.

> Section 17.1 Subject to sub-section (2) no person shall deposit or permit the deposit of a deleterious substance of any type in a watercourse or in surface water or in any place under conditions where the deleterious substance that results from the deposit of the deleterious substance may enter any watercourse or surface water.

Actually using the Act, for prosecution, may be a problem because of the clause relating to being deposited by "a person" as the offenders are usually anonymous and numerous. However, the city or municipality may be considered the responsible party for the depositing of the deleterious substance as they have ownership of the storm sewer system and the outfalls.

The definition of deleterious substance was based on the Federal Fisheries Act. Section the process of degradation or alteration of the quality of that water so that it is rendered deleterious to fish, wildlife, livestock or domestic animals.

Section 17(2) states that subsection (1) does not apply to pollutants deposited by a person with a licence or permit to do so. These list quality limits and terms for deposition specific to each licence. Non-compliance with the terms dictated by the permit or licence can result in fines of up to $25,000 or three months in prison or up to $50,000 and/or 12 months in prison, once a stop order is issued and the deposition continues (Percy, 1984). Again, because of the anonymous nature of non-point pollution it may be impossible to prosecute offenders.

Alberta's legislation is consistent with the conclusions of Poetner (1974), who found that the most common use of ordinances involving stormwater runoff are those governing subdivision regulations. The Alberta provincial Planning Act (1980) requires that stormwater runoff/drainage plans be included in the Area Structure Plan application for a new subdivision. This is through section 1.(2) which describes stormwater drainage facilities as a utility and section 64.(n) which requires the general location of "major transportation routes and public utilities" information be provided by the developer.

The Subdivision Regulations of the Planning Act (1977) makes specific reference to storm runoff. Section 8.(c) states that "the subdivision approving authority shall consider, with respect to the anat is the subject of the application ...stormwater collection and disposal". In Edmonton, for example, before a new subdivision is approved by the City of Edmonton the stormwater system will be analysed by the civic departments of Engineering, Planning and, if on-site storage of any type is included, Parks and Recreation. The basis for approval is entirely site specific with stormwater drainage plans being dependent upon the location of the site in relation to the closest receiving stream and/or available trunk line space.

The Province of Alberta also must approve the drainage plan for the new urban area. The basic requirement by the province is that pre-development peak flows are not increased. There are also differing runoff volume and peak flow regulations depending on the receiving

Blackmud Creek and peak flow must be kept at pre-devlopment levels.

3.15 Private Rights

The ability of a land owner to defend himself/herself against non-point pollution or increased water volumes from urban areas is dependent upon which definition of water applies, diffused or in a watercourse. Once the stormwater has entered a stream via storm sewers or an artificial drainage stream bed or lake, it can be assumed that riparian rights would be relevant. As discussed earlier, the Clean Water Act (section 1.k) includes artificial equivalents under its definition of a watercourse, therefore, the owners abutting a stormwater lake may have riparian rights.

Before the runoff enters a watercourse or drainage system, riparian rights do not apply. At this point the common law rules for drainage apply. These involve the common enemy doctrine, civil law rule and the reasonable use rule. The common enemy doctrine considers the diffused surface water an enemy and gives land owners the right to restrict or remove runoff from their land (Maloney, Hanman and Cantor,1980).

Reasonable use rule allows for changes in the drainage pattern of diffused water so long as the change is "reasonable". This is the most used application of drainage law in the U.S. (Poetner, 1974a). Judgement on the "reasonableness" is based on:

> the nature and importance of the improvements sought to be made, the extent of interference with the water,... the amount of injury done to the other landowners as compared with the value of such improvements, and ... whether such injury could or could not have been reasonably foreseen (Swett and Cutts, 1870).

In a recent Ontario case the judge ruled that the City of Scarborough was liable for the erosion of the Highland Creek and extensive flood damage to the grounds of the Scarborough Golf and Country Club. Judge Cromarty ruled that the plaintiffs riparian rights were violated as the substantial increase of flow with urbanization was not considered to be natural or reasonable and did cause damage to the plaintiff. The judgement was that the City of Scarborough is to pay the Scarborough Golf and Country Club $3,076,146.24, as well as court costs, for damages (Ontario Reports, 1986). The City of Scarborough is appealing the decision.

Alberta, unique in Canada, has adopted civil law rule (Percy, 1984). Civil rule law states that a landowner must receive water discharged over his/her land. The precedent set by the Makowecki v Yachimyc case provides that a lower propery owner must accept the natural surface flow from the upper owner. Percy (1985) wrote that this approach was used because it did not discourage drainage, as does the common enemy rule and, therefore, historically was more suitable to Alberta geography with its many sloughs in the agricultural areas.

In Alberta the Makowecki principle may not be applicable to stormwater runoff even before it reaches a watercourse. Because urbanization results in increased total runoff, it is likely that the stormwater will not be considered natural flow. Therefore, the upper landowner does not have the right to force an artificially increased volume of runoff onto the lower land owner. This has been the seen in the cases of McCord v The Alberta and Great Waterways Railroad Co. (1918) and Hamilton and Hamilton v Carson and Carson (1976).

The downstream riparian owners also have the right to consistent, natural flow levels in the watercourse abutting their land. Riparian rights also include the right to use the water and have it undisturbed in quality and well as quantity (Cook v Vancouver; 1914).

The riparian rights of a landowner for unimpaired water quality, free of stormwater runoff pollutants has precedent in Alberta. In Groat v City of Edmonton (1928) the judge, Justice Duff stated that:

> I agree that the making of streets by macadamizing or paving or otherwise, is a natural use of the land owned by the municipality; and, moreover, that the municipality is under no duty to intercept rain water which, having fallen from the clouds, is pursuing its way under the impulsion of gravity or other natural forces towards a watercourse. But the municipality is not at common law entitled, in its quality as riparian owner, to collect and discharge the filth of the streets though an artificial channel into a watercourse, where it is to settle and remain until the currents generated by the spring thaws carry the mass of it to the lands of lower riparian proprietors. I can see no warrant for this under the common law.

This precedent is applicable to cases involving one defendant. It may be useful, in the future, if the depositor of the offending stormwater runoff can be isolated to one such party including the City of Edmonton or other municipalities or even one subdivision developer. However, the City of Edmonton may be solely responsible because ownership of storm sewer system and the outfalls is dedicated to the City. Such is the case in the Groat v City of

Edmonton case where the judge ruled that riparian rights were infringed upon and the plaintiff was entitled to the remedies sought (McLaren, 1972). Also, in Ontario the City of Scarborough was found to singularly responsible.

Nevertheless, more than one municipality or devloper may be respnsible for the infringement on riparian rights. With multiple polluters the problem of providing evidence of guilt may be lessened by the use of joint and several liablity. "Joint and several liabilty" is defined as the condition in which liablities are shared among a group of persons collectively and also individually (Yogis, 1983). With this doctrine it becomes the responsibility of the defendants to apportion the damages. Such was the situation in Landers v East Texas Salt Water Disposal Co. (1952). In the United States, "this approach has since been adopted in several other states and appears to represent a trend in cases involving pollution injury" (Cox and Walker, 1975).

McLaren (1972) also wrote of the usefulness of multiple defendant suits in environmental disputes. The author felt that the nuisance multiple suits were appropriate for certain pollution problems. Because,"it allows the plaintiff to bring several polluters into court together, and if he [she] is uncertain of the potential liabity any of them permits him [her] to avoid the expense and frustration which he [she] might experience is he [she] chose an inappropriate single defendant" (McLaren,1972:520).

In summary, there is potential for litigation involved with stormwater runoff. Limitations are found in that often the number of parties involved in stormwater non-point pollution or increased quantities are large and each individual contribution may be small. But, as seen, it is possible for a downstream riparian owner to demonstrate his or her rights against a city, municipality or other depositor of runoff.

3.16 Legal Aspects of Stormwater Lakes

Stormwater lakes vary in scale from well under a hectare to hundreds of hectares. The size, and location, of the stormwater lake will usually dictate the responsibility for maintenance. A small lake that is accessible only to a limited number of users may be maintained by a community league which collects fees for that purpose. On the opposite end of the spectrum is a large lake, which may draw its users from the entire city. In such a case the civic government would likely be responsible for maintenance. Maintenance responsibility is, however, not always obvious and conflicts may arise. One possibility is for the developer to be held responsible for a few years, which could be a requirement for subdivision approval, until the community is stable and organized (Maloney, Hanman and Cantor, 1980).

Also, if the housing development extends to the green space (grassed) surrounding the lake, then those owners abutting the lake would have riparian rights of access and use. This problem could be alleviated by dedicating the riparian land to public use. "Whether this confers riparian rights in gross or merely permits limited waterfront activities such as lounging or picnicking is determined by the scope of the dedication" (Barke and Patton, 1979). Developers are avoiding a confrontation between riparian owners and other users by separating a portion or all of the stormwater lake from the nearest land owner with a road or path. The area then becomes available for public or community use.

The level of use of the stormwater lake, whether merely for aesthetics or for water-based recreation, may be dependent on the decision to fence the lake, or not. This decision is based upon the quality of the water, the slope and the shoreline of the runoff lake. It is also made on the perceived problem of liability by the developer and or the municipality. Fencing may be put up to reduce the "attractive nuisance" aspect of the lake or "allurement doctrine": "the presence, a frequented place, of some object of attraction, tempting a child to meddle where he [she] ought to abstain" (Yogis, 1983). However, in Cook County, Illinois, it is the "opinion of the legal counsel of the sanitary district that the use of fencing does not reduce the liablity of the detention facility owner" (Poetner, 1974a:126).

Liability for injury or death will depend upon the jurisdiction involved in the dispute. A precedent has not been set in Canada, although deaths in stormwater lakes have occured. In Winnipeg, Manitoba, two children have drowned but litigation was not sought. In Sherwood Park, Alberta, a child drowned but, charges were not laid.

Whatever the size of a stormwater lake it would be easiest for all parties involved in terms of maintenance, access and liability if responsibility is decided upon at the planning stage of the new urban area. This will be discussed in Chapter Six.

3.17 Summary

The literature review reveals that stormwater management initially dealt only with peak flood reduction. This is changing as many stormwater management professionals are concerned with runoff quality, erosion, maintaining natural conditions, recreation, re-use and aesthetics. The writing of a Master Drainage Plan, by a group of diverse professionals, is a way of dealing with the above concerns. There are many low and non-structural methods available for control of urban stormwater flows and pollution. These include land use planning, natural drainage, grass pavers, on-site storage, erosion control techniques, street cleaning, treatment, and stormwater lakes. The type and size of stormwater lake dependant on the developmet parcel size and the multi-use requirements.

Legally, stormwater could be included under various Acts in Alberta. However, in reality only the regulations for subdivisions are, as yet, applied to urban stormwater runoff (Planning Act, 1980; The Subdivision Regulations of the Planning Act, 1977). Water quallity of runoff is not regulated, at the time of writing. There is potental for litigation surrounding urban runoff if riparian rights to unimpaired water quality and quantity are disrupted. Legal problems associated with stormwater lakes are maintenance responsibility, right of access and liability.

The existing stormwater impoundments in Edmonton are disappointing from a water quality perspective but meet the needs of the municipality and the developers and meet the expectations of most of the residents.

4. STUDY SITE

4.1 General

The study site, referred to as the Ellerslie Subdivision, is a 2024 hectare parcel (5000 acres) located in the January, 1981 annexed land of southeast Edmonton, Alberta (53 25'N, 113 30'W) (see Figure 1.1). The Ellerslie Subdivision is bounded to the north by the Restricted Development Area (RDA) and it extends south; 4.0 kilometres to the Edmonton city limits. Highway Two forms the western boundary, with five kilometres between it and the eastern boundary; a country road which is an extension of 50th Street. The study area is in Tp 51, R 24, W. 4M and includes sections 13-16, 21-24 and portions of 17 and 25-28, inclusive.

The parcel is predominantly prime agricultural land which has a Canada Land Inventory rating of Class 1 (no restrictions). An agricultural conservation study which was conducted for the City of Edmonton Planning Department shows a rating of good for agriculture, for the study site, on a five tiered scale of unsuitable to excellent. Limitations were noted because of small patches with drainage problems in the western and central portion and some hilly sites in the eastern fraction of the Ellerslie Subdivision. Because of these small agriculturally limited areas, McKinnon, Allen and Associates (1981) felt the Class 1 rating should be changed to 6w in the poorly drained sites and 2t in the hilly area. The poorly drained areas contain wetlands.

Air photography analysis, with field checks, resulted in a breakdown of existing land uses into four general categories: Agricultural- 75 percent, Aspen-Poplar Woodland 12 percent, Wetlands- 8 percent, and Country- Residential (City of Edmonton, 1985)- 5 percent (Figures 4.1, 4.2).

The landscape of the study area consists of glacial deposits bevelled by lake wave action and mantled by lacustrine sediments. The eastern portion of the Ellerslie Subdivision exhibits hummocky disintegration moraine including many prairie donut features. The western part has a more subdued topography with smoothly bevelled swells and swales (Figures 4.1, 4.3).

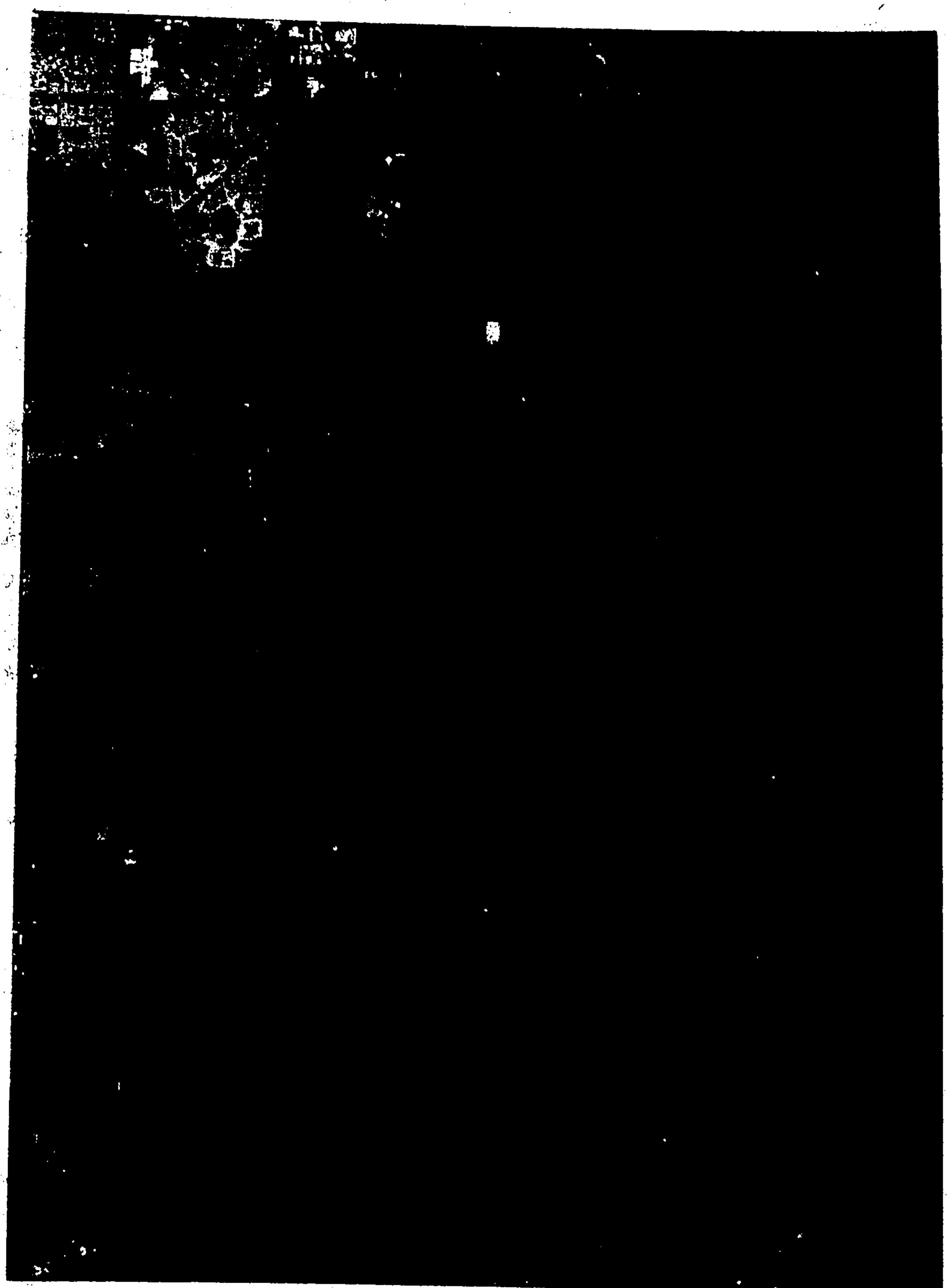


Figure 4.1 Aerial Photograph of the Ellerslie Subdivision. Taken August 9, 1983, scale 1:60,000 (Source: Alberta Energy and Natural Resources, available for public use).

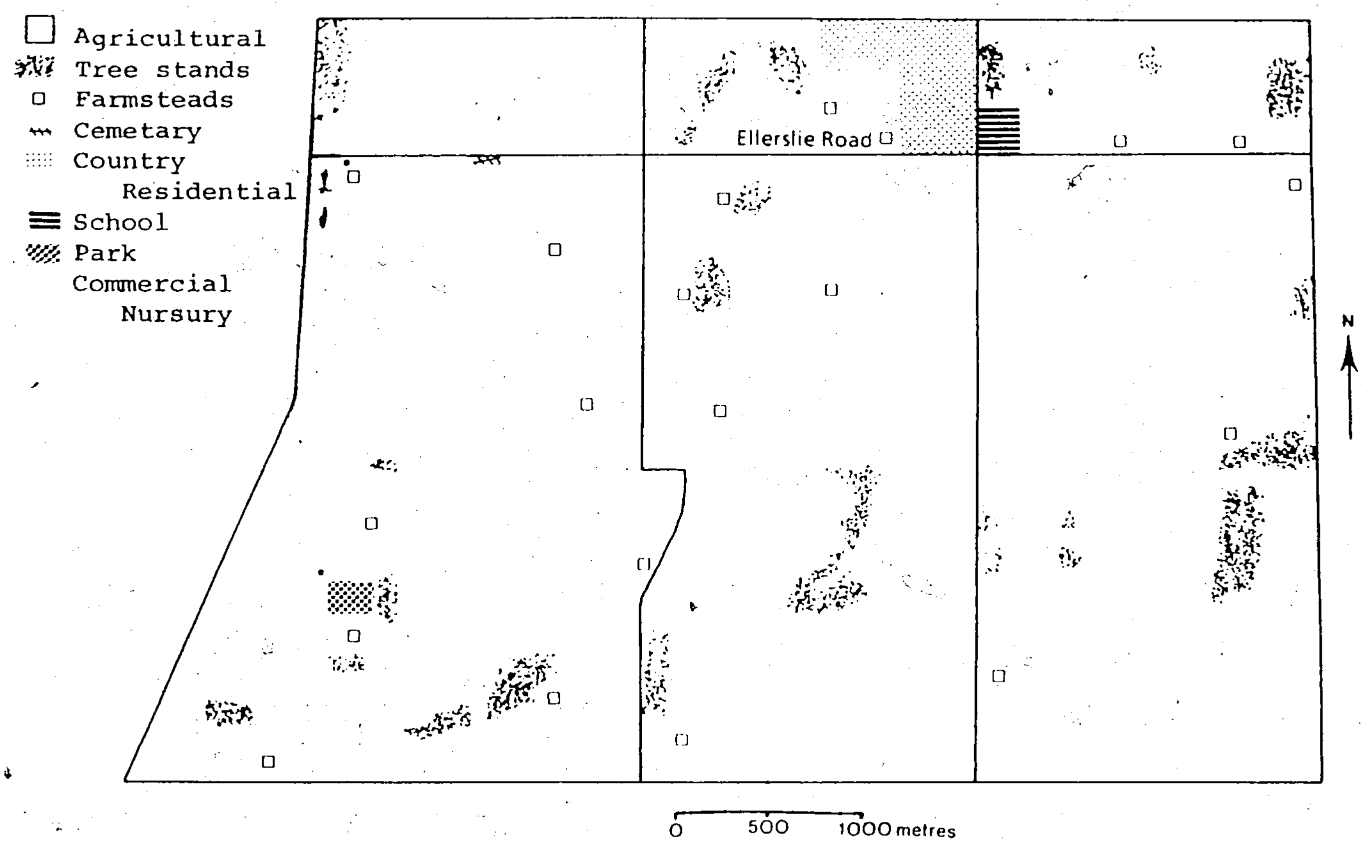


Figure 4.2 Exisiting Land Use of the Ellerlie Subdivision. (Source: author).

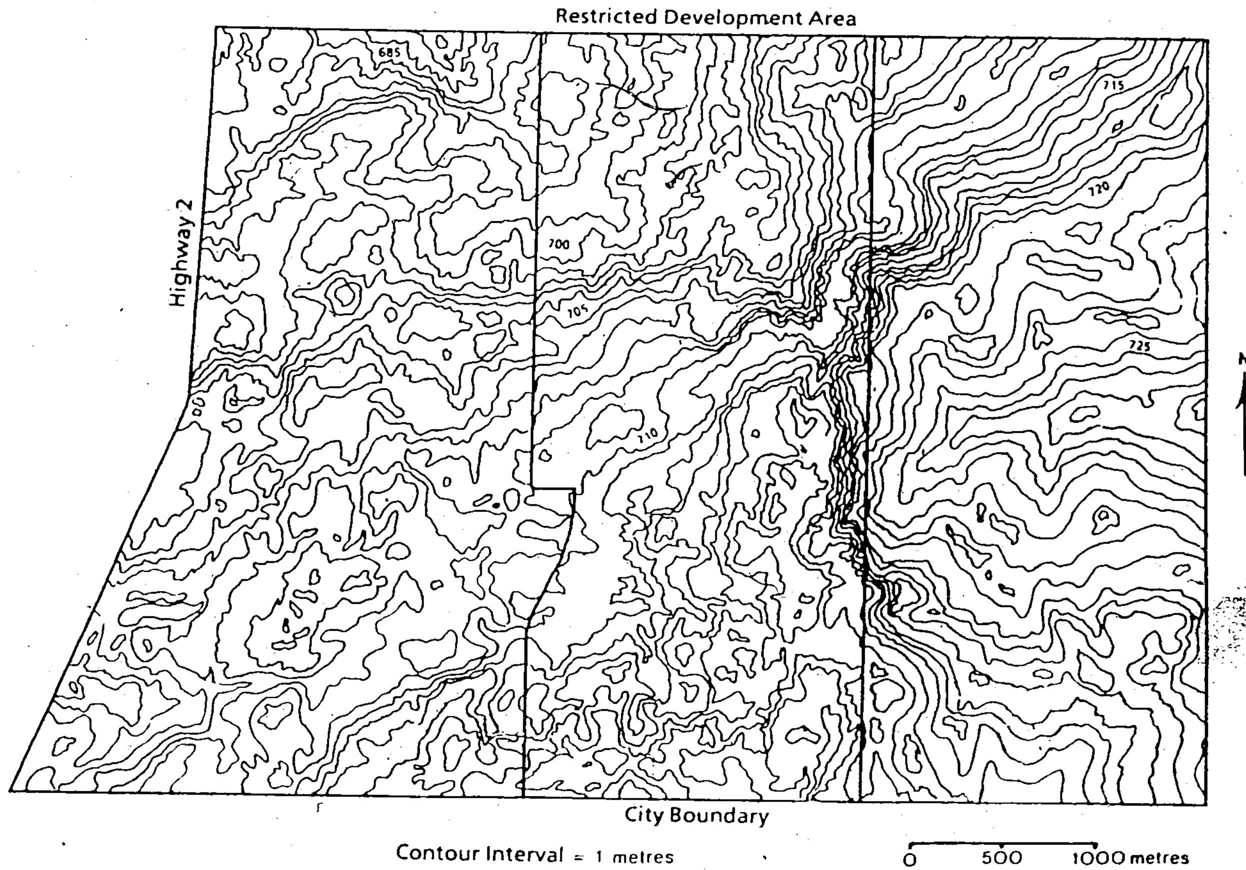


Figure 4.3 Exisiting Topography of the Ellerslie Subdivision. (Source: adapted from Mackenzie Spencer Asociates, 1984, 1985; Stanley Engineering Associates Ltd., 1980a).

The general slope of the Ellerslie Subdivision is higher in elevation in the east (725m) with a gradual drop to 680m to the west-north-west (Fig. 4.3). As written above the far eastern portion of the study site includes a limited number of small hills; while the majority of the study area is flat, lake bed, topography.

4.2 Existing Hydrology

The small amount of natural runoff from Ellerslie Subdivision finds its way to the North Saskatchewan River via the Blackmud Creek. Blackmud Creek, Irvine Creek and Clearwater Creek form the Blackmud Creek Watershed (see Fig. 1.1). Blackmud Creek flows into Whitemud Creek which, in turn, is tributary to the North Saskatchewan River. Whitemud Creek enters the North Saskatchewan River within the Edmonton city limits.

The majority of the surface runoff drains west and west-north-west, flowing into Blackmud Creek (Fig. 4.4). A small portion (225 hectares) in the southeast corner contributes to the Blackmud Creek, southward from the study site, via Cawes Lake and Irvine Creek. The north-south drainage pattern is interrupted by Ellerslie Road and adjoining ditches to the far north of the study area. The other drainage paths flow along natural drainage divides (Stanley Associates Engineering Ltd., 1980a).

Within the Ellerslie Subdivision most years, and seasons, have only limited runoff. This is held in the many permanent and seasonal wetlands which have overflow only during the wetter seasons in the wetter years (Fig. 4.5). Much of this overflow runoff is from snowmelt, some is from heavy rains, especially in the spring before soil moisture from the snowmelt has been depleted.

Channelization and bank reinforcement has already been done on Blackmud Creek; indicating prior erosion of the banks. Therefore, any new discharge from Ellerslie Subdivision must be regulated to ensure that there will be no increase in downstream erosion "above that which would normally occur" (Stanley Associates Engineering Ltd., 1980b:2). Consequently, stormwater management techniques which will reduce the peak flow and total yield will be

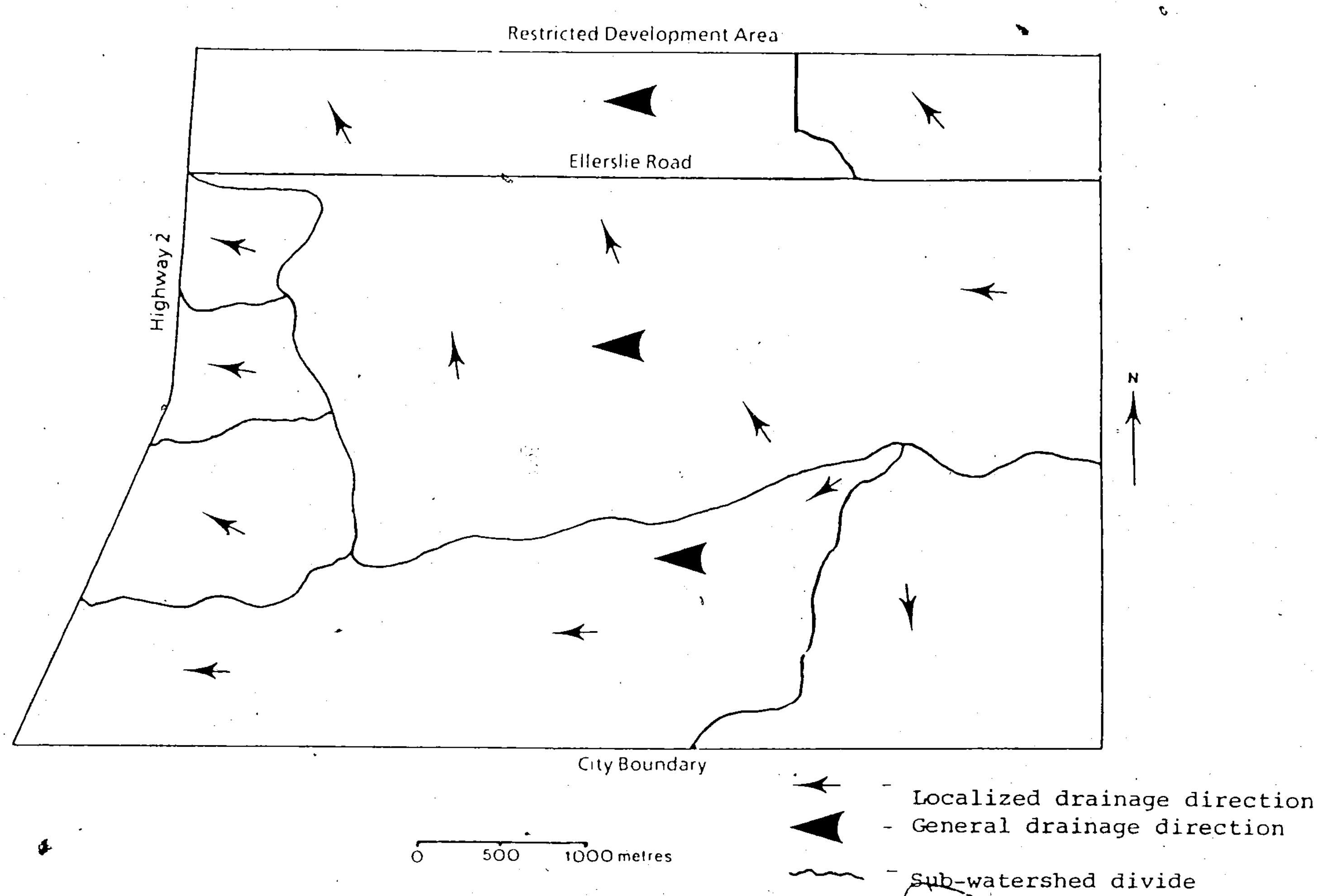


Figure 4.4 Generalized Drainage Pattern for the Ellerslie Subdivision. (Source: adapted from Stanley Associates Engineering Ltd., 1980a).

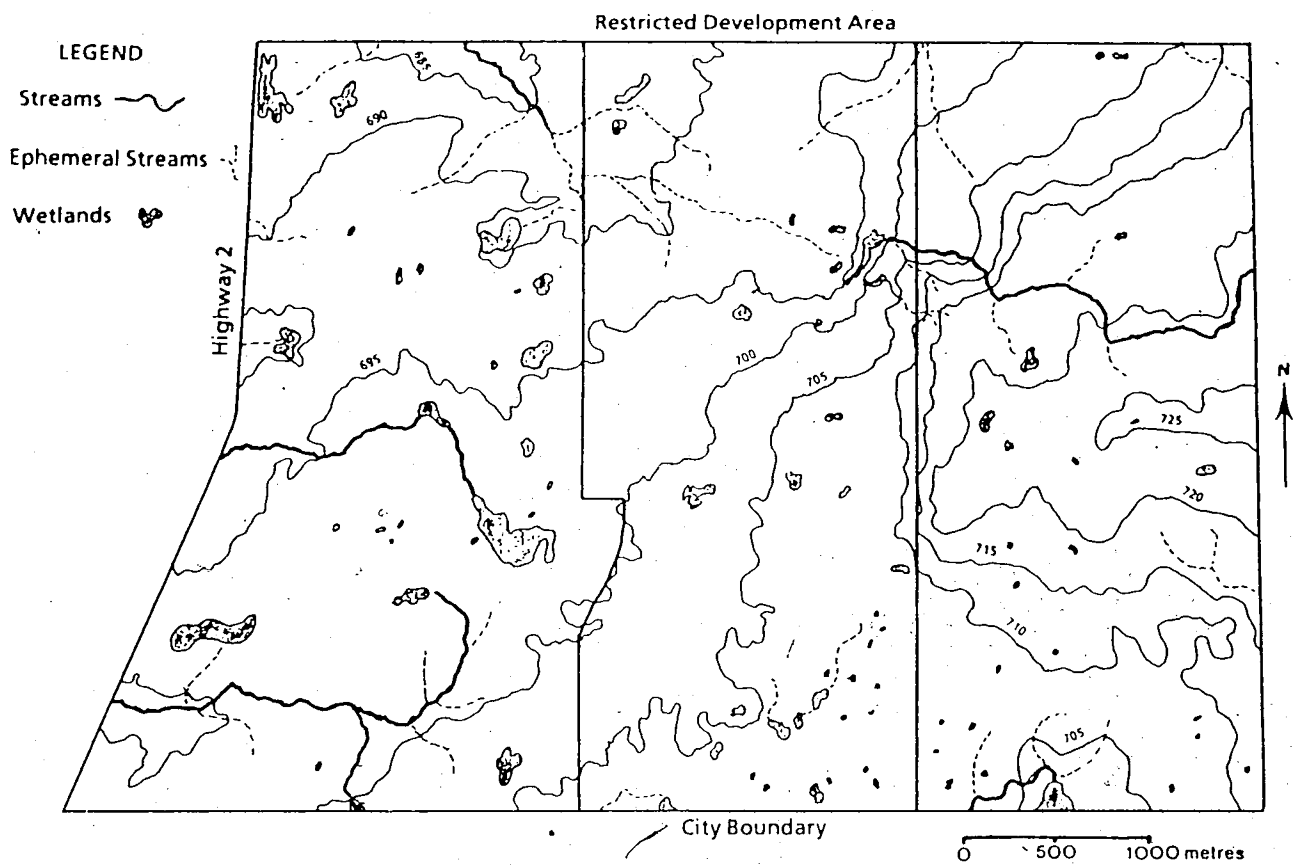


Figure 4.5 Existing Drainage System for the Ellerslie Subdivision. (Source: adapted from Mackenzie Spencer Associates, 1984, 1985; Stanley Associates Engineering Ltd., 1980).

required at the Ellerslie Subdivision.

4.3 Climate

The Ellerslie Subdivision is part of the northern, cool temperate zone which is affected by mild air masses from the Pacific Ocean and cooler, drier air from the Arctic and (mT) tropical marine air via the mid-western United States. This zone is characterized by cold winters and relatively short, cool summers. Over the ten year period studied, the months of January, February, March, November and December all had monthly [illegible] under freezing, with January (-13.5 °C) being the coldest month, on average. July [illegible]mest month with an average temperature, over the ten years, of 16.3 °C (Table 4.[illegible]

Based on the small annual precipitaion, the Ellerslie Subdivision, consistent with much of the prairies, is in the sub-humid climatic category. Over the ten year period studied, the study site received an average of 468.7mm of precipitation per year with over half falling during the summer months of June, July and August (Table 4.2).

Evapotranspiration is the combination of the use of water by plants and subsequent transpiration to the atmosphere and the evaporation of water from the surrounding area (Ward, 1975). In the study area, under exisiting conditions, the potential evapotranspiration exceeds precipitation during the growing season which results in little or no runoff during the low intensity, high frequency summer rainfall events (Table 4.3).

The average precipitation and potential evapotranspiration rates were compared to show how, in a sub-humid environment and with extensive vegetation, precipitation does not meet the potential need by the crops and trees and therefore little rainfall is available to runoff. The average total annual precipitation of 468.7mm does not meet the potential evapotranspiration need of 511.1mm. However, the largest amount of precipitation falls during the summer months when evapotranspiration demand is the greatest so that deficits are usually not extreme (average annual deficit of 42.5mm). The relationship of average precipitation to

YEAR	Jan	Feb	Mar	Apr	May	Jne	Jul	Aug	Spt	Oct	Nov	Dec
1975	-12.1	-15.7	-8.7	-1.0	9.6	12.9	19.8	12.3	10.5	3.0	-4.7	-11.9
1976	-12.5	-8.8	-6.0	6.3	11.0	12.0	15.5	16.2	11.9	3.8	-2.0	-[illegible].9
1977	-12.0	-2.8	-2.8	6.9	10.4	14.2	14.2	11.7	9.3	4.7	-6.7	-17.0
1978	-18.2	-13.4	-3.6	4.7	9.8	15.3	16.4	14.1	9.9	6.5	-6.8	-12.0
1979	-16.4	-22.9	-1.7	0.8	8.1	14.0	16.6	15.0	11.9	6.1	-2.7	-9.3
1980	-16.8	-10.2	-7.2	8.0	11.3	14.5	15.5	12.5	9.0	5.9	-0.7	-15.4
1981	-5.8	-7.3	0.1	4.3	11.2	12.4	15.7	18.0	12.1	4.1	-0.3	-10.9
1982	-23.2	-16.2	-8.6	-0.6	10.0	15.2	16.1	13.0	10.7	4.6	-8.8	-9.4
1983	-10.3	-8.7	-4.4	4.8	9.9	13.6	16.6	16.8	8.4	4.6	-4.2	-19.5
1984	-7.3	-2.7	-3.1	5.9	8.8	14.0	16.8	17.0	7.6	3.0	-9.9	-16.9
Average	-13.5	-10.8	-4.7	4.0	10.0	13.8	16.3	14.7	10.1	4.6	-4.7	-13.2

Table 4.1 Monthly Mean Temperatures for the Ellerslie Subdivision. (Source: adapted from Environment Canada, Annual Meterological Summary for Edmonton International Airport).

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Spt	Oct	Nov	Dec	Total
1975	12.2	15.5	15.7	29.8	52.5	102.6	68.7	98.5	11.4	24.1	6.0	25.7	462.7
1976	11.1	21.5	15.9	11.7	30.2	90.8	74.7	111.1	43.0	9.9	6.7	31.4	458.0
1977	18.1	2.7	6.7	18.9	131.9	12.5	90.7	86.5	38.0	0.4	10.4	18.9	435.7
1978	25.1	9.2	5.2	16.1	64.2	40.6	63.6	111.4	141.5	17.3	39.4	7.0	540.6
1979	4.2	28.[illegible]	.3	31.2	36.4	70.3	111.0	40.9	50.2	12.7	8.6	26.8	429.5
1980	24.2	15.6	9.5	4.0	43.0	131.9	69.2	194.8	55.6	11.2	1.2	44.7	614.0
1981	4.9	7.8	11.8	9.8	46.9	42.3	157.6	10.5	33.4	30.0	3.0	12.6	370.6
1982	67.7	12.7	32.1	16.4	27.9	25.1	204.6	43.2	35.6	39.1	9.0	3.0	516.4
1983	4.9	16.5	19.3	18.3	10.2	151.1	104.5	12.2	36.2	12.2	13.4	10.6	409.4
1984	25.5	4.2	13.1	6.6	55.9	66.2	48.2	30.5	116.3	61.7	12.5	23.9	448.8
Average	19.8	13.5	14.8	16.3	49.9	73.3	99.3	74.0	56.1	19.2	11.0	20.5	468.7

Table 4.2 Monthly Total Precipitation (mm) for the Ellerslie Subdivision. (Source: adapted from Environment Canada, Annual Meterological Summary for Edmonton International Airport).

Year	Jan	Feb	Mar	Apr	May	Jne	Jul	Aug	Spt	Oct	Nov	Dec	Total
1975	0	0	0	19.2	73.2	99.7	127.9	86.0	63.1	24.3	0	0	493.4
1976	0	0	0	41.8	82.2	89.6	112.4	109.2	70.2	24.5	0	0	529.9
1977	0	0	0	50.1	79.5	106.7	107.9	84.0	57.7	27.8	0	0	513.7
1978	0	0	0	34.1	74.1	112.7	120.8	96.9	60.1	35.9	0	0	534.6
1979	0	0	0	17.8	63.0	104.0	123.1	102.7	70.9	34.2	0	0	515.7
1980	0	0	0	53.6	85.0	108.2	116.3	86.5	54.9	33.4	0	0	537.9
1981	0	0	0	34.7	83.5	93.1	116.3	123.7	70.7	24.1	0	0	546.1
1982	0	0	0	22.7	76.6	113.2	119.1	89.7	65.0	29.3	0	0	515.6
1983	0	0	0	36.1	74.3	100.7	121.0	114.5	49.5	25.8	0	0	521.9
1984	0	0	0	39.9	66.7	104.1	122.0	114.2	46.2	29.5	0	0	522.6
Average	0	0	0	35.0	75.8	103.2	118.7	100.7	60.8	28.9	0	0	523.1

Table 4.3 Total Monthly Evapotranspiration for the Ellerslie Subdivision: as computed using the Thornthwaite procedure. (Source: author).

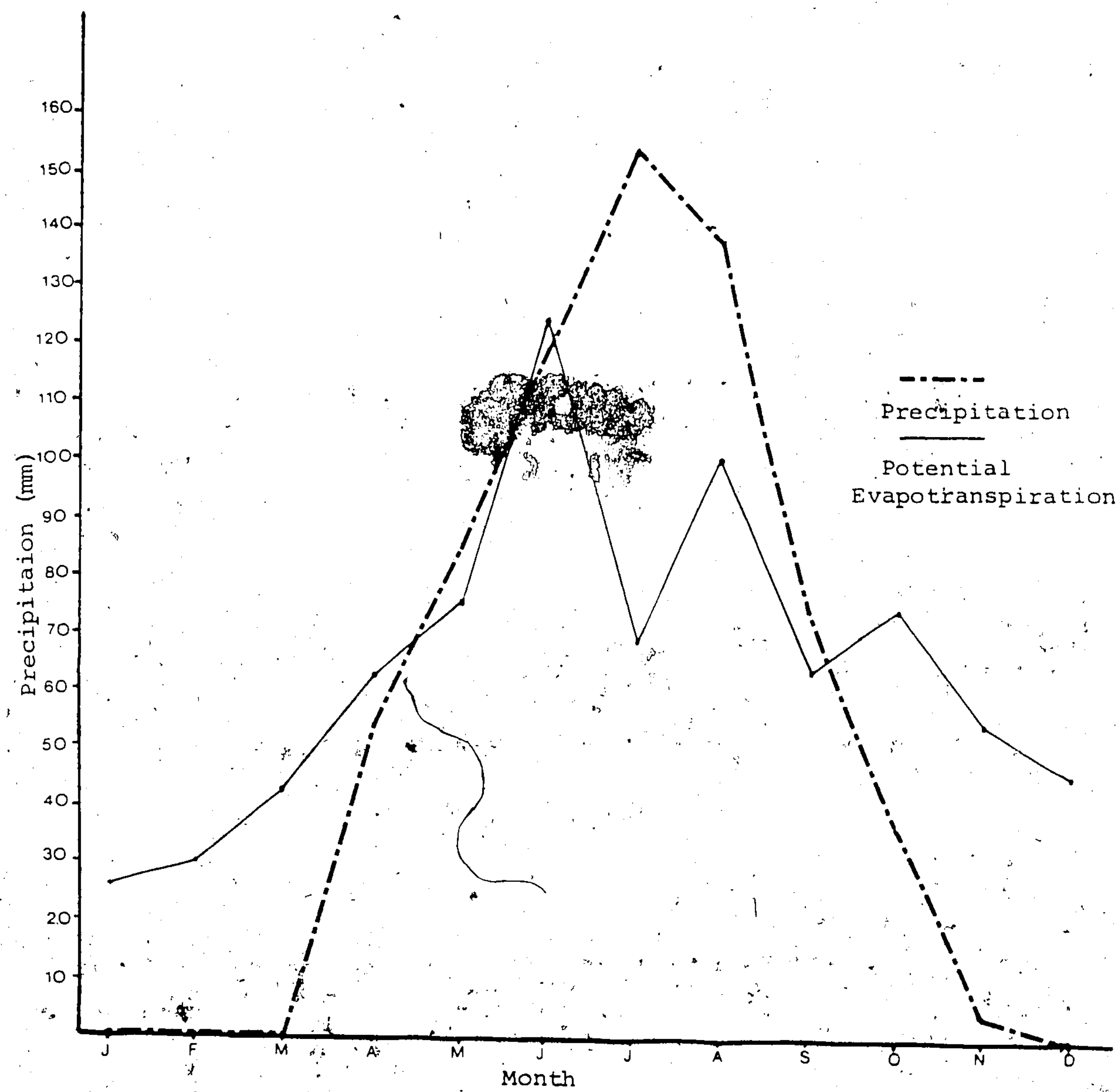


Figure 4.6 Total Monthly Precipitation vs. Monthly Potential Potential Evapotranspiration Averaged Over a Ten Year Period, 1975-1984. (Source: author).

Urbanization will substantially reduce the amount of vegetative cover, pervious soils and wetlands which will result in large decreases in evapotranspiration, which will, in turn, result in large increases in stormwater runoff if appropriate management alternatives are not used to accommodate the increased yield (see Chapter 2.1).

4.4 Potential Future Land Use

The Ellerslie Subdivision is intended for urban development by the majority land owner in the area, Daon Development Corporation. Various consulting firms have been retained to study the feasibility of the development and the physical restraints and plan potential land uses (most notably Mackenzie Spencer Associates and Stanley Associates Engineering Ltd.).

Figure 4.7 is used to illustrate in a very general fashion, the potential future land uses of Ellerslie Subdivision. The subdivision will be, approximately, one third industrial and two-thirds residential. The industrial area is used as a buffer zone between the residential area and Highway Two and as an extension of existing industrial uses north of the RDA. The industrial area will be a mixture of Business Industrial (IB) and Medium Industrial (IM). The aproved Area Structure Plan for the industrial portion of the study site, entitled Ellerslie Industrial, also includes a regional activity and business centre as conceived by the planning consultants as the focal point for the community. Mackenzie Spencer Associates (1984) have planned a stormwater lake to form a portion of this activity centre.

The residential portions remain in the planning phase. The development concept for the more westerly third of the subdivision (Ellerslie West Residential) includes a mix of residential types though dominated by single family housing (approximately 70 percent). The number of proposed housing units is 7,687. Other land uses include parks, churches, schools, neighbourhood commercial areas and roadways (Mackenzie Spencer Associates, 1985). It has been assumed that the, yet to be produced, development concept for Ellerslie East Residential will be similar to Ellerslie West.

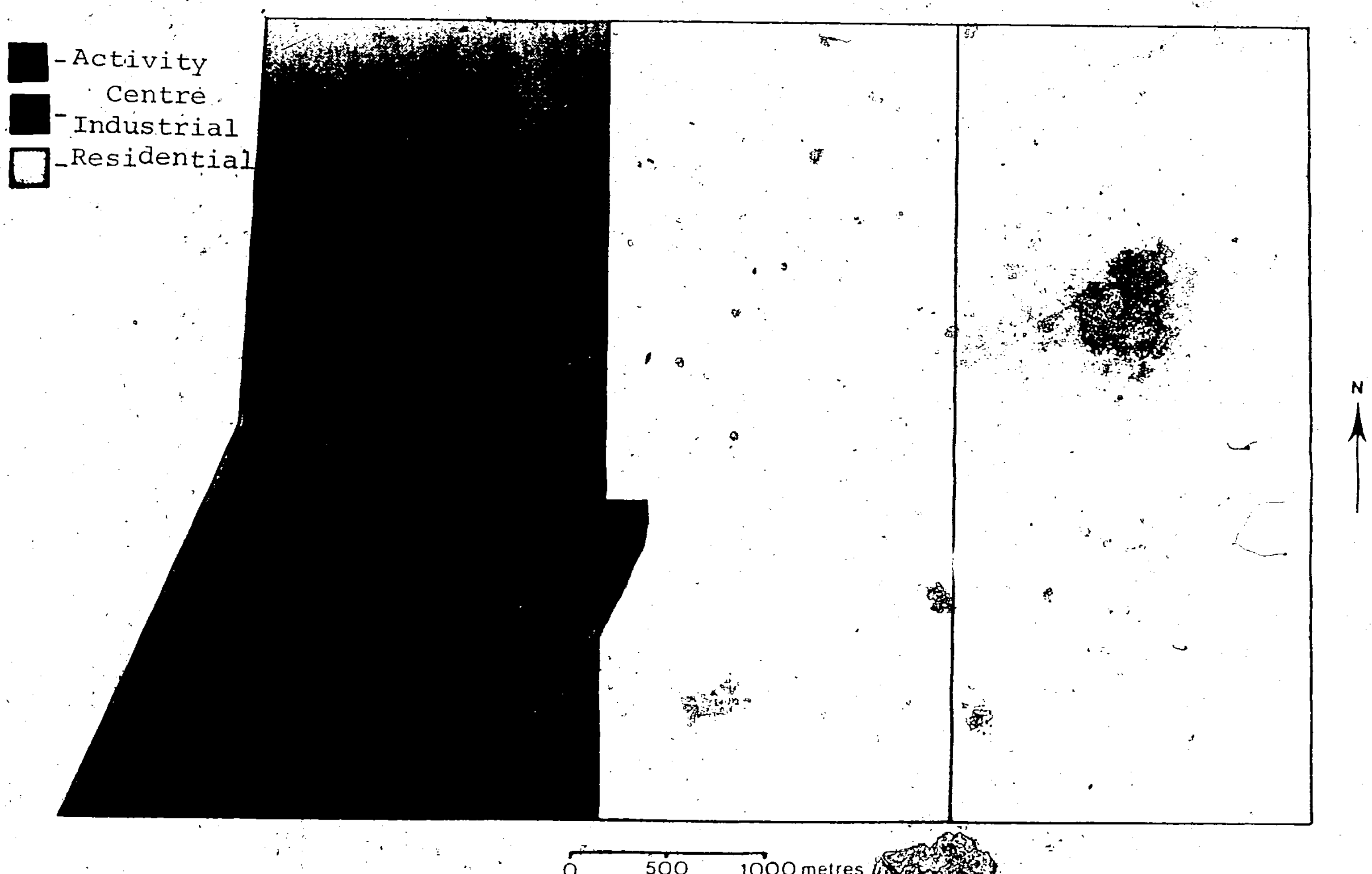


Figure 4.7 General Potential Land Use for the Ellerslie Subdivision. (Source: adapted from Mackenzie Spencer Associates, 1984, 1985).

Unfortuately for Daon Development Corporation, a recent and abrupt downturn in the Alberta economy has resulted in little demand for new industrial or residential sites. Also, Bell Canada has recently purchased Daon Development Corporation and it intends to reduce Daon's land holdings. This has necessitated a stoppage of all planning for Ellerslie Subdivision. It is thought that the actual development of the study site may be twenty years in the future (Spencer, 1986). However, an equally abrupt improvement in the economy may bring unexpected demand.

Because of future uncertainty the Potential Future Land Use Map (Figure 4.7) remains general as future demand may alter the residential and industrial plan structure. Also, one third of the study site remains without a Development Concept. The location of the stormwater lakes given in the plans for Ellerslie Industrial and Ellerslie West Residential are not final and, therefore, are not included. Suggestions to placement of stormwater lakes will be given in Chapter Six.

4.5 Institutional Aspects

To begin a development, in the Edmonton area, approval must be gained from various departments in the City of Edmonton and the provincial Department of the Environment. An Area Structure Plan is written for this purpose by either the municipality, planning authority or the developer (Alberta Municipal Affairs, 1980). Daon Development Corporation retained Mackenzie Spencer Associates to write the Area Structure Plans for the the Ellerslie Subdivision.

Information on stormwater management is required to be part of ASP as dictated by the Provincial Planning Act. In the Planning Act (1980:31, section 64.2.iv) stormwater drainage is considered a utility and that the general location of all "major transportaion routes and public utilities" be included in the proposal. Within the Subdivision Regulations of the Planning Act (1977:13, section 8.c) it is stated that "the subdivision approving authority shall consider, with respect to the land that is the subject of the application... stormwater collection and disposal". In Edmonton the basis for approval is entirely site specific and dependent upon location relative to trunklines, the North Saskatchewan River or any of its tributaries. Ellerslie Subdivision Area Structure Plans will be reviewed by the City Departments of Planning, Engineering and Parks and Recreation.

The Province of Alberta, Department of the Environment, Standards and Approvals Division, has approval authority for the stormwater runoff plans of new urban areas under the Water Resources Act (1982). The review by the Standards and Approvals Division is also done on a project by project system. General guidelines exist, however, as runoff is expected to remain at pre-development conditions, as measured in terms of peak flow, unless an adequate outlet stream exists. The North Saskatchewan River is considered adequate and therefore, does not require control of increased flow. Placement of outfalls at Blackmud Creek does require control of flows as well as assurance that the development will not cause harm to the stream banks (Herminutz, 1985).

Stormwater from the Ellerslie Subdivision could, therefore, be piped into the North Saskatchewan River without controls of any type but would require massive sewers and expensive contruction through existing communities. Another alternative is to route the runoff into the Blackmud Creek at pre-developmemt levels over longer periods of time through the use of storage and other management alternatives. Stanley Associates Engineering Ltd. (1980b:2) studied the two basic alternatives and concluded that discharge into Blackmud Creek, combined with storage, was the "most favourable system".

A complication in the approval process, with the City of Edmonton, is land dedication. When a stormwater lake is included in a Area Structure Plan the facility is considered Public Utility land with no land dedication value. Therefore, the lake is not part of the land that must be dedicated for parks, schools and environmental reserves. This present system assumes a single purpose for the stormwater lake, the utility of storm drainage. Allowances are not yet made for developers who would like to make their stormwater lake into a multiple purpose facility. To create a multi-purpose stormwater lake will require more capital spent on design, water quality improvement systems and on safety and recreational features. If the developers were able to recoup a portion of the finanacial investment in the form of reduced land dedications from other parts of the subdivision, it is likely that better quality, multi-use stormwater lakes would be built. This will be further discussed in Chapter Six.

The City of Edmonton's experience with stormwater lakes, however, has not been wholly positive. Beaumaris Lake, for example, has very limited use because it was planned primarily to be a stormwater storage facility and has dangerously abrupt and unnatural edges as well as very poor water quality. Numerous accidental cross-connections from sanitary sewage lines into the lake further reduce the water quality to the extent that even canoeing on the lake is no longer approved by the Parks and Recreation Department.

Therefore, the ability to demonstrate how the urban runoff water quality can be improved, to allow for multiple uses of the facility, will be vital in encouraging the City of Edmonton to include the stormwater lake as a portion of the reserve dedication from the developer to the City.

4.6 Rice Creek Watershed District/ Minneapolis, Minnesota

The Rice Creek Watershed District became a portion of the field study because there, through a stormwater management team of a Board of Managers, consulting engineers, legal counsel, concerned citizens and funding from the U.S. Environmental Protection Agency, runoff is successfully controlled and treated through the use of natural treatment (and storage) in wetlands and other low and non-structural methods. In Minneapolis, large multi-purpose urban lakes and wetlands are used to store runoff as well as provide water-based recreation, aesthetic interest, water fowl and small wildlife santuaries and educational nature viewing sites.

Rice Creek Watershed District and Minneapolis, although not part of the actual Edmonton study site, are nonetheless, important as prototype stormwater management systems that will be incorporated, as a concept, into the stormwater management scenario for Ellerslie Subdivision. Field investigations of the Minnesota sites were conducted during an early spring runoff period- Febuary 27 to March 3, 1985.

The experience of the Rice Creek Watershed District's Board of Managers with stormwater runoff is useful to the study as, although the Minnesota sites have slightly higher monthly temperatures and levels of precipitation than Ellerslie Subdivision, the sites are also part of the prairie zone and the topography and runoff patterns are similar.

A five year period was used to study mean monthly temperatures and total monthly and annual precipiation (Table 4.3). Of the four months with average mean temperatures below freezing, January was the coldest (-10.3°C). July, as with Ellerslie Subdivision, was the warmest month (23.4 °C).

The average yearly total precipitation was 778.0mm with the highest monthly precipitation in June (Table 4.5). The total annual precipitation is more than sufficient to meet the potential evapotranspiration demand (annual surplus of 115.4mm). However, from Figure 4.8 it can be seen that the precipitation is spread throughout the year more so than in Ellerslie Subdivision (Fig. 4.6). This results in higher surpluses during the spring snowmelt runoff period in the Rice Creek area than in the Ellerslie Subdivision. Also from Figure 4.6 it can be seen that during the growing season the Minnesota sites have a deficit situation, albeit not as lengthy a time as in the Alberta study site.

Therefore, the climates of the Ellerslie Subdivision and Rice Creek Watershed District sites are generally similar. Also, there is a strong similarity in the water balance patterns between the two sites.

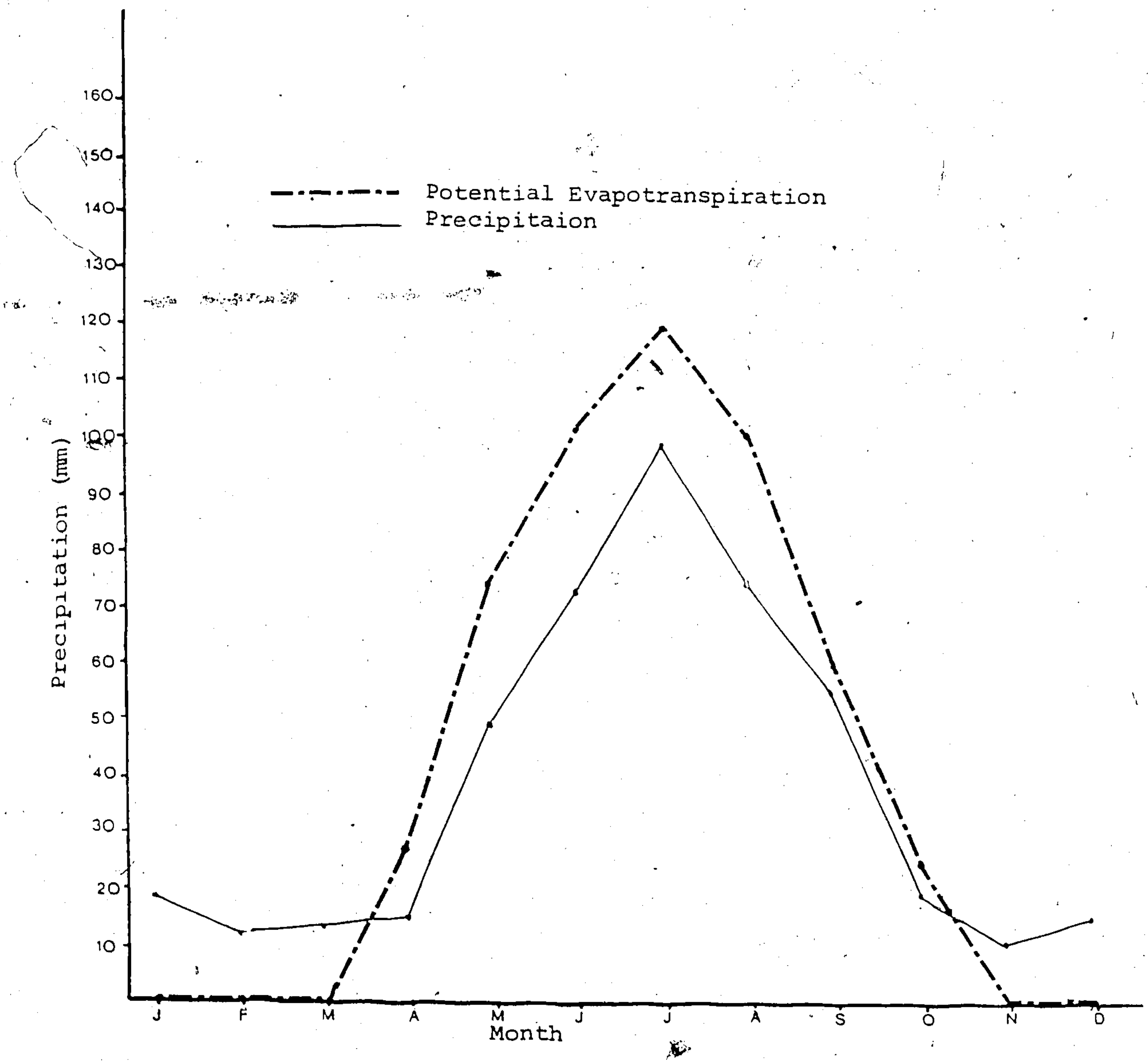
The Rice Creek Watershed District (the District) is located just north of the Minneapolis-St.Paul division. The District includes parts of four counties: Ramsey, Anoka, Washington and Hennepin,, encompassing 201 square miles (52,060 hectares). Creation of the District in 1972 by the Water Resources Board under the State Watershed act "provided local citizens with a legal and financial authority with which to act upon projects initiated within the District, aimed at finding solutions to water problems" (Rice Creek Watershed District, 1984:1).

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Spt	Oct	Nov	Dec
1980	-9.3	-9.3	-2.6	9.5	16.3	19.7	24.0	21.5	15.3	7.3	2.6	-6.8
1981	-7.7	-4.8	3.2	9.5	13.9	19.4	21.6	20.7	15.6	8.2	3.3	-8.1
1982	-16.5	-9.0	-1.7	7.3	13.7	17.6	24.2	22.1	16.1	10.2	-0.3	-3.5
1983	-6.9	-2.8	1.2	5.7	12.6	20.0	25.1	24.9	16.9	9.1	.1	-15.7
1984	-11.1	-2.5	-4.0	8.4	13.3	20.9	22.3	23.1	14.0	10.4	0.7	-7.8
Average	-10.3	-5.7	-0.8	8.1	14.0	19.5	23.4	22.5	15.6	9.0	1.5	-8.4

Table 4.4 Monthly Average Temperature for the Minnesota Study Sites. (Source: adapted from the U.S. National Weather Service Annual Reports

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Spt	Oct	Nov	Dec	Total
1980	23.9	17.0	28.5	21.1	58.2	140.2	58.4	82.8	93.5	16.8	6.6	6.1	553.0
1981	7.6	54.4	18.0	55.1	55.1	112.3	103.9	120.1	37.1	68.3	54.9	23.4	710.2
1982	62.2	10.9	53.1	40.9	54.9	36.6	23.4	96.5	38.1	87.6	83.1	108.5	695.8
1983	17.0	30.2	81.8	100.8	157.5	132.6	77.9	84.8	84.8	66.3	125.2	38.9	992.4
1984	22.4	41.7	37.3	98.0	58.2	201.9	77.0	130.8	67.3	139.2	7.9	57.0	938.5
Average	26.6	30.8	43.7	63.2	76.8	124.7	68.1	102.9	64.2	75.6	55.5	46.8	778.0

Table 4.5 Monthly Total Precipitation (mm) for the Minnesota Study Sites. (Source adapted from the U.S. National Weather Service Annual Reports.


Potential Evapotranspiration
Precipitaion
Precipitation (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
J
F
M
A
M
J
J
A
S
O
N
D
Month

Stormwater management is a major focus of the Rice Creek Watershed District's Board of Managers.. To build any scale of development in the District, approval must be gained from the Board of Managers through provision of a detailed stormwater management plan which "must include methods to be employed to control the rate of discharge and protect the quality of stormwater runoff" (Rice Creek Watershed District, 1984:1). The developer must show that runoff will not be increased in volume nor decreased in quality. The Board's purpose is to protect the many lakes and wetland areas in the District.

Rice Creek has also incorporated the Long Lake Chain of Lakes Improvement Project. This project was/is cost shared with the U.S. Environmental Protection Agency for the "purpose [illegible] nd demonstrating new or improved methods for the prevention, remo[illegible] mination of pollution" from urban runoff (Willenbring, 1984:1). [illegible] up of lakes and wetlands within residential, commercial, industrial [illegible]. The lakes and wetlands basically alternate so that runoff runs [illegible]

[illegible] improvement projects included the diversion of urban stormwater runoff into a 12 hectare wetland (marsh) for pretreatment before its discharge into Lake Josephine. The wetland has been effective in improving the water quality of the runoff. In the first year the treatment system had removal efficiences of 61 percent for total phosphorus, 31 percent of total kjeldahl nitrogen and 80 percent removal of the total suspended solids. The Josephine wetland study authors concluded that the wetland diversion is an effective way to limit nutrient flux into Lake Josephine (Weidenbacher and Willenbring, 1984).

The improvement of the stormwater quality using wetlands, in the Rice Creek Watershed District , is almost entirely natural. A few hand operated weirs are used to regulate flow and to keep runoff in the wetland for extended periods of time. A simple skimming and holding device is also used to remove floatable trash and oil.

total nitrogen and 67 percent total suspended solids. In the study, nutrient removal efficiencies were observed to be over 60 percent and suspended solids to exceed 95 percent in some of the wetlands (Willenbring, 1984). The water in many lakes within the District, which receive wetland treated runoff, is of sufficient quality to allow for in-water recreation such as swimming.

In-water recreation is also possible and very popular at the many lakes included in the Minnepolis Chain of Lakes. Although water quality has been somewhat diminished by urban runoff, which is piped into the lakes, most of the lakes remain swimmable and fishable. A marsh between Lake of the Isles and Lake Calhoun is being used for natural treatment and an experimental area of peat bog wetlands, at Lake Wirth, is being tested for potential improvements in runoff and lake water quality (Hamilton, 1986).

The field investigations in Minnesota were important for the author to witness, first hand, the wetland treatment systems working during the spring runoff. The author also attended meetings with the Board of Managers, the lawyer and the engineers involved with the Rice Creek Watershed District to gain information on the wetland treatment systems and stormwater management methods.

5. METHODOLOGY, WATER BALANCE RESULTS AND DISCUSSION

5.1 Study Site Mapping Procedures

Many sources were used to produce the maps included in this thesis. These include: 1:1000 topography maps with 1 metre contours produced for Daon Development Corporation of the Ellerslie Subdivision by Stanley Associates Engineering Ltd., document mapping (Mackenzie Spencer Associates, 1984; Stanley Associates Engineering Ltd., 1980a, 1980b) and 1980 1:50,000 topography map sheets 83H/5 and 83H/6 (Department of Energy, Mines and Resources, Government of Canada).

Other mapping sources were referenced for specific topics. For geologic information the *Urban Geology of Edmonton* (Kathol and McPherson, 1975) was used. The 1979 soil maps were also consulted (Alberta Energy and Natural Resources, Province of Alberta). Data on the suitability of the Ellerslie Subdivision for agriculture was obtained from the *Agricultural Conservation Study for the Urban Growth Strategy* (McKinnon, Allen and Associates, 1981). Mapping in the City of Edmonton, Planning Department (1981) report was useful for information on the general future infrastructure.

The panchromatic aerial photograph included in this thesis (Figure 4.2) was taken August 9, 1983 and is at a scale of 1:60,000 (Alberta Energy and Natural Resources). Other years and scales of aerial photography were used as references including the City of Edmonton, Planning Department's air photos at 1:2000, dated 1983 and Alberta Energy and Natural Resources imagery at 1:12000, dated 1982.

5.2 Study Site Field Investigations

The initial field investigation of the Ellerslie Subdivision site was conducted in the early spring of 1984. At that time it was noted that many of the ponds and marshes had received substantial volumes of surface runoff although none appeared to be reaching bankfull. Also, no water was observed flowing in the ephemeral streams at this time. April, 1984, had been a dry month, as is normal in the Edmonton region. Therefore, the high water levels in the wetlands were a result of the spring melt of the the November to March accumulated snow (see Appendix A, Tables 9 and 10). As well, during the intial site visit the general geomorphology of the study site, as discussed in Chapter 4.1, was established.

Field investigations to the Ellerslie Subdivision site continued throughout the summer and fall of 1984 and during the rainfall months of 1985. The author attempted to make as many observations, as possible, during the high flow periods. For example, field investigations were conducted in the late afternoon of July 6, 1983 when the total 24 hour precipitation reached 38.0 mm. Also, the study site was observed September 7, during the second day of an intensive rainfall period when 68.8 mm of precipitation fell in 48 hours (Environment Canada, Annual Meterological Summary for the Edmonton International Airport). Less extreme rainfall events were also witnessed. Nevertheless, the important observation made during many site investigations was that at no time did the wetlands or intermittent and permanent streams break bank full levels. Therefore, under existing conditions the majority of the precipitation infiltrated into the soil and the remaining surface runoff was collected in the numerous ponds, marshes and watercources without flooding. However, the wettest year of the ten year study, 1980, which followed an above average winter snowfall, was not observed.

5.3 Minnesota Field Study

The field work done in Minnesota, as discussed in section 4.5, was conducted to investigate the use of wetlands for the treatment of stormwater runoff by the Rice Creek Watershed District and City of Minneapolis. The field investigations were done during Febuary 27 to March 3, 1985. This included the attendance at a Rice Creek Watershed District Board of Managers Meeting (Febuary 27, 1985) and a half day tour of the Rice Creek wetland/lake system provided by the Watershed District's Administrator, Bonnie Torpe. Also, meetings were held with the personnel at the engineering firm of E.A. Hickok and Associates in Wayzata, Minnesota (who provide technical expertise to the District's Board of Managers). Individual field investigations to the facilities in Rice Creek Watershed District and the city of Minneapolis were also conducted by the author.

5.4 Methodology- Urban Stormwater Hydrology

At the present time, the majority of mathematical modelling done by urban hydrology practitioners falls in the category of hydrograph modelling. The models are used to produce peak flow estimates for individual rainfall events (the design storm). One procedure used is the simple and frequently used Rational Method. Other common procedures are the Stormwater Management Model (SWMM) and the Urban Storm Runoff Model (STORM), both of which include runoff quality parameters (Wanielista, 1983). However popular this type of modelling may be, it does not provide estimates of total annual runoff volumes, which are necessary in the prediction of the potential effects of an urbanizing area on the receiving streams and water bodies. Also, these models include many complex variables and constants, a number of which are crude estimates and weaken the final results as "the index variables are too variable" (Jewell, 1980 in Black, 1983:18).

For these reasons a water balance procedure was chosen to produce runoff volume estimates; the Thornthwaite Method (Thornthwaite, 1948; Thornthwaite and Mather, 1955; 1957). The Thornthwaite Method which incorporates climatic information over many years, is used to estimate potential evapotranspiration (PE) and resulting surpluses (runoff) for various storage depths. Sch procedures Wanielista (1983:15) defines as *stochastic models* which are "useful in design and operation of multi-use large water resources systems". Therefore, the water balance approach to urban hydrology is appropriate for study as the author's purpose is to propose a stormwater management scenario which is part of an integrated urban water system. This system should includes water supply, recreational water, wastewater and stormwater runoff (Urban and Clarborn, 1983).

In the Thornthwaite Method the potential evapotranspiration is "strictly a function of climate and is independent of soil types, vegetation and land use practices" (MacKenzie, 1981:6). However, soil type, vegetation and land use affect the depth and distribution of soil moisture storage. Therefore, changes in land use, and associated soil moisture capacity, are reflected in water surplus (runoff) estimates (MacKenzie, 1981).

In this study, the Thornthwaite water balance procedure was computed for a ten year period, 1975-1984, using daily temperature and precipitation information for the months of April to October (inclusive) and monthly temperature and precipitation information for November to March (see Appendix A). The climatic information from the weather station at the Edmonton International Airport was used. The production of daily data created more accurate information to be used in annual runoff yield projections than is normally computed with the Thornthwaite procedure done on a monthly basis.

The results of the refinement of the technique, to incorporate daily data, is most evident in the lower storage depths (ie. the 2mm and 13mm storage capacity). A comparison of previous work by the author (Hurley, 1983) which included monthly Thornthwaite data for the Ellerslie Subdivision, with the daily data generated in this study reveals that the surplus (surface runoff) values are higher in the daily, notably in the lower storage categories. For example, in comparing surplus values at the storage depth of 13mm, for the month of August, during the years 1975- 1982, it was found that the daily data resulted in surplus values 2.6 times the data generated using the monthly climate information. At the 100mm storage depth, for the same time period, all years had 0 surplus for both monthly and daily generated data except for 1980 which had 8.5mm of surplus using monthly data and 16.1mm (1.9 times) with the daily information (see Appendix A, Tables 1-8; Hurley, 1983).

The daily data have a higher surplus than the monthly data because the monthly potential evapotranspiration camouflages the monthly precipitation values and it appears that surface runoff would not take place. The increased accuracy of generating the data on a daily basis allows for those days when the precipitation was higher than the potential evapotranspiration resulting in a surplus, for the lower soil storage capacities, if only for a brief time period.

The use of daily data in the Thornthwaite procedure required a refinement to Table 6 (Thornthwaite and Mather, 1957). This change involved adapting the monthly constant into ten day segments to more accurately represent the mean duration of sunlight for the daily climatic data.

Therefore, after the Thornthwaite procedure was used to generate data through the manipulation of the daily climatic information, data are then inserted into the final equation resulting in surplus (runoff) information for the selected storage depths. The equation is as follows:

$$Ppt = (PE - D) + S +/- SC, \text{ where,}$$

Ppt = precipitation

PE = potential evapotranspiration

D = deficit,

S = surplus (runoff)

SC = storage change

(Thornthwaite, 1948; Thornthwaite and Mather, 1955; 1957).

Also, the water balance equation was revised to more accurately represent the wetland and stormwater lake portions of the study site. The revisions involve assuming no deficit and increasing the potential evapotranspiration (PE) by one half of the average deficit of adjoining areas. The addition to PE is related to the lower albedo and greater heating of water bodies and the one half of the deficit is in recognition of the level of advected heat which may be available for increased evapotranspiration (Laycock, 1985; Park, 1979). Therefore, for the wetland and stormwater lake portions of the study the final Thornthwaite equation used was:

$$Ppt = (PE + 1/2D) + S +/- SC, \text{ where,}$$

Ppt = precipitation

PE = potential evapotranspiration

D = deficit

S = surplus

SC = storage change

(Laycock, 1985; Park, 1979). This refinement assumes the wetlands and stormwater lakes are continually wet.

The completion of the Thornthwaite procedure results in runoff (surplus) data given in millimetres, for various depths of storage (see Appendix A). To calculate the study area runoff yields for both existing and potential land uses, the depth of surplus for each representaive land use stoarge capacity was multiplied by the number of hectares in each category.

The existing "Aspen-Poplar Woodland" and "Agricultural" land uses were assigned storage depths of 150mm and 100mm, respectively. The open space component of the future land use was also assigned a 100mm storage depth (Table 5.1). The "Agricultural" category was designated the 100mm storage depth because the existing agricultural land use is dominated by cereal crops in which wheat appeared, during field the investigations, to be the prevalent crop. According to a previous study by Laycock (1967), the storage depth capacities of various agricultural land uses are forage crops 150mm, cereal grains 100mm and fallow at 50mm.

The presently built up areas, as well as those sites proposed for development, were assigned combinations of storage depths according to the percentage of impervious cover within each land use. A storage depth of 2mm was assigned to impervious areas in accordance with previous works (MacKenzie, 1981; Viessman, 1968; Muller, 1969).

The existing Country Residential sites, with large lots, were given a combination of 25 percent impervious cover (2mm) and 75 percent open space (100mm). The future residential areas were given a 50:50 ratio of impervious cover (2mm) and green space (100mm). The specific future residential housing types is, as yet, uncertain but will likely be dominated by single family units with small areas being dedicated to two-family units, townhouses and apartments (Chapter 4.4).

The industrial/commercial sites, with a high percentage of concrete and asphalt to green space, were assigned storage depth values of 75 percent impervious cover (2mm) and 25 green space percent (100mm) (see Table 5.1).

LAND USE	Storage Depth Area (hectares)				Total Area (hectares)
	150mm	100mm	50mm	2mm	
EXISTING					
Apen-Poplar Woodland	243				243
Agricultural		1517			1517
Country Residential		76		26	102
Wetlands		81	81		162
TOTAL	243	1594	81	26	2024
PROPOSED					
Residential		506		506	1012
Industrial/Commercial		177		531	708
Schools/Parks		182		20	202
Stormwater Lakes/ Wetlands		51	51		102
TOTAL	0	916	51	1057	2024

Table 5.1 Total Area in Each Storage Depth for Existing and Proposed Land Uses, Ellerslie Subdivision. (Source: author).

The Municipal Reserve areas (schools and parks) were assigned 10 percent impervious cover (2mm), as some development in the form of schools and/or community buildings and sidewalks was assumed. The remaining 90 percent of the area was designated the open space category (Table 5.1). An additional category of 13mm may have been appropriate for intensively used, largely bare soil (ie. school playgrounds areas, gravel parking areas). However, the author believed that these particular land uses were too small a category relative to the total 2024 hectare study area, to warrant a separate storage depth category.

The above storage depth combinations are similar to those used in other studies, for example: Kent (1973) used impervious rates of 20-60 percent in residential areas and 75 percent impervious cover in industrial areas. Also, Ellis, Mulamootil and McBean (1983) used rates that averaged 47.3 percent impervious for a suburban residental development.

The wetlands (marshes, in this study) comprise 12 percent of the study site at present (measured during the spring melt period). The stormwater lakes and wetlands in the proposed development make up 5 percent of the potential land use. For both the wetlands and the stormwater lakes, the 50mm and 100mm storage depths were averaged into the revised water balance equation, as discussed above.

The data generated by the Thornthwaite Method, for various storage depths (in millemetres) were then combined with the land use information (in hectares) to produce annual stormwater yield projections (in cubic metres) for both the existing and proposed land uses. The annual yields and discussion of the runoff (surplus) values follows in section 5.3.

The annual runoff yield data were then used in estimations of the nutrient and sediment loads which could be found in the urban stormwater from the potential future land uses. This approach is discussed by Shahane (1982) where monthly or yearly runoff yields are multiplied by pollutant concentrations to reach loading values in kilograms/ hectare/ year. The data produced are, admittedly, rough projections as the concentration data comes from Minnesota (Rice Creek Watershed District, 1979). Nevertheless, the information remains useful as a guide in design considerations because of the similar geography and climatic conditions (Chapt[illegible]). The runoff quality totals will also be discussed below.

The an[illegible]lutant loading data were then used in estimation of the amount of wetland that would be required to treat the runoff, to be made available for multiple use projects, according to the Rice Creek Watershed District (1979) *Wetland Preservation Guideline*. This information is discussed below, while the multi-use projects are discussed in Chapter Seven.

5.5 Water Balance Results and Discussion

As written above, the water balance procedure was done to project runoff increases as a result of urbanization. It was found that, on an average of the ten years studied, that urbanization of the Ellerslie Subdivision, to the proposed land uses, will result in an increase of over 7 times the existing runoff yields. In Table 5.2 the annual yields for each land use are given; as well as the difference between the exisitng and proposed, urbanized, land uses.

On average, from the existing area of Ellerslie Subdivision, dominated by agricultural land uses, only 486,000 cubic metres of surplus precipitation runs off annually. However, from Table 5.2, it can be seen that four of the ten years studied had zero annual runoff yield.

The potential runoff from proposed future land uses averaged 3,000,000 cubic metres. This is represents an average increase in stormwater runoff of 2,700,000 cubic metres accompanying urbanization of the Ellerslie Subdivision. Figure 5.1 has been included to illustrate this comparison of annual runoff yields.

The largest portion of this increase in runoff is from the built up areas of the study site, with a storage capacity of only 2mm. The total area of this storage depth increased from 26 hectares, at the present time, to 1057 hectares in the proposed development (Table 5.1). The Thornthwaite water balance procedure revealed that this shallow storage depth of 2mm, representing impermeable cover had surpluses in all months, but with the largest surpluses during the growing season. Therefore, of the 3,000,000 cubic metres that could, on average run off the new subdivision, nearly 1,900,000 cubic metres (or 65 percent) would run off during the

Table 5.2 Comparison of Stormwater Runoff Yields From Existing and Proposed Land Uses in Ellerslie Subdivision (cubic metres). These figures are the calculated data, actual significant figures are limited to 2 figures. (Source: author).

	EXISTING DRAINAGE AREA					PROPOSED DRAINAGE AREA					DIFFERENCE
	1	2	3	4	TOTAL	A	B	C	D	TOTAL	
Area (Km2)	2.43	15.18	1.02	1.62	20.24	7.08	10.12	2.02	1.02	20.24	
Area (Ha)	243	1518	102	162	2024	708	1012	202	102	2024	
1975	0	0	68,796	-169,938	0	1,405,026	1,338,875	52,920	-106,998	2,689,823	2,790,965
1976	0	0	60,970	-222,426	0	1,245,195	1,186,570	46,900	-140,046	2,338,619	1,500,075
1977	0	0	65,650	-220,158	0	1,340,775	1,277,650	50,500	-138,618	2,530,307	2,684,815
1978	0	731,676	122,822	-238,302	616,196	1,845,579	1,921,282	154,024	-150,042	3,770,843	3,154,647
1979	209,223	1,334,322	120,858	-374,544	1,289,859	1,259,532	1,760,448	201,558	-235,824	2,986,114	1,696,255
1980	0	426,558	126,162	-74,358	478,362	2,190,198	2,181,872	131,762	-46,818	4,457,014	3,978,652
1981	26,973	500,940	88,494	-467,208	149,199	1,353,519	1,401,114	108,840	-294,168	2,569,305	2,420,106
1982	1,458	1,259,940	172,956	-312,498	1,121,856	2,390,916	2,558,336	235,580	-196,758	4,988,074	3,866,218
1983	0	560,142	89,768	-444,852	205,058	1,325,907	1,387,958	114,638	-280,092	2,548,411	2,343,353
1984	0	0	65,442	-287,874	0	1,336,527	1,273,602	50,340	-181,254	2,479,215	2,701,647
AV'GE	23,765	481,358	98,192	-281,216	322,099	1,569,317	1,628,772	114,706	-177,062	3,135,773	2,713,673

Existing Land Use
1 Aspen-Poplar Woodland, 150mm storage - 243Ha
2 Agricultural, 100mm storage - 1518Ha
3 Country Residential, 20% 2mm - 26Ha, 75% 100mm - 76Ha
4 Wetlands, 162Ha

Proposed Land Use
A Medium, Business Indus'l/Com'ty Com'l, 75% 2mm - 531Ha, 25% 100mm - 177Ha
B Residential, 50% 2mm - 506Ha, 50% 100mm - 506Ha
C School and Parksites, 10% 2mm - 20Ha, 90% 100mm - 182Ha
D Stormwater Lakes/Wetlands, 102Ha

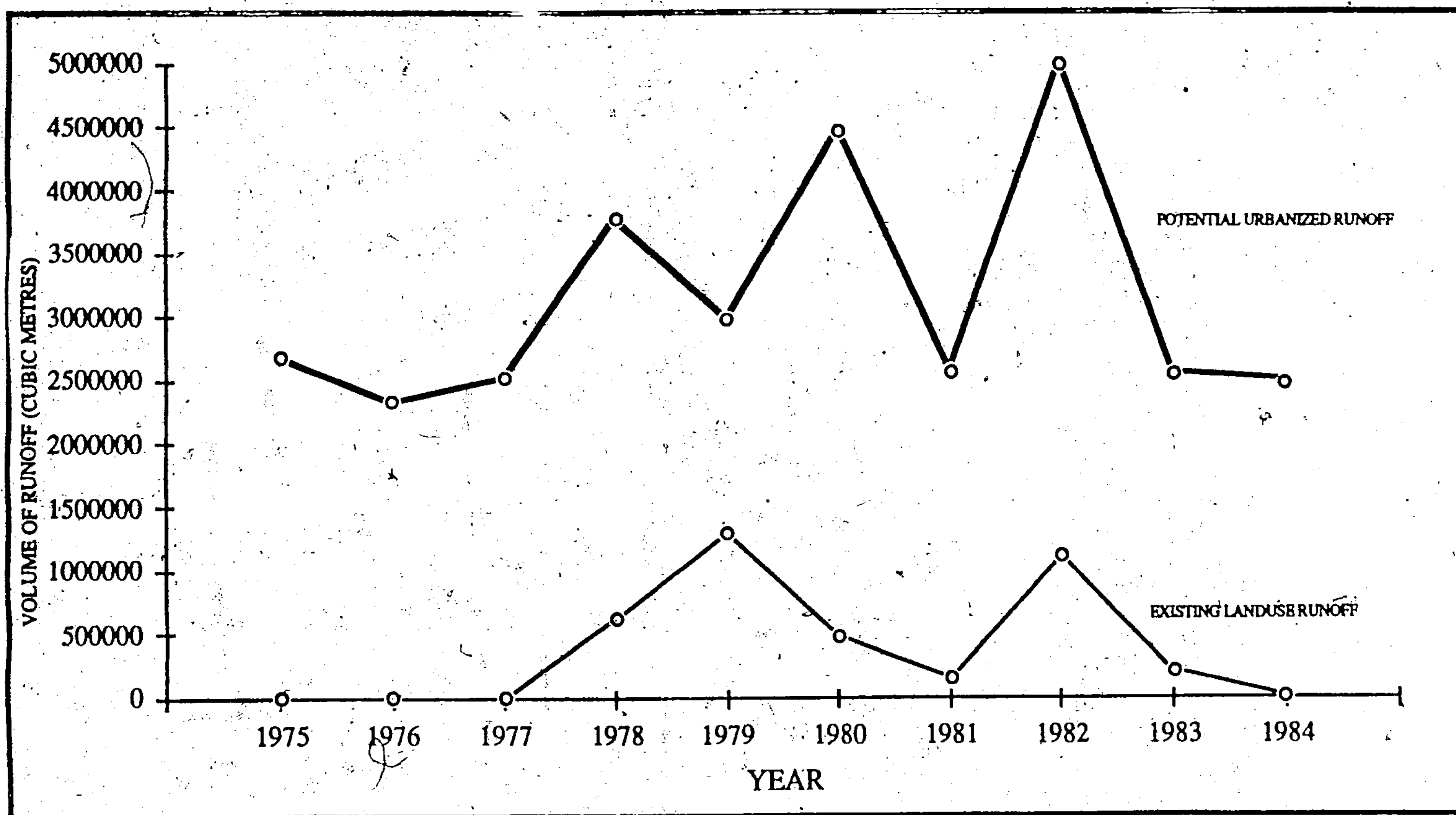


Figure 5.1 Existing vs Potential Urbanized Runoff Yields for Ellerslie Subdivision, 1975- 1984.

(Source: author).

summer months.

Whereas, the surpluses from the agricultural (100mm storage depth) and wooded areas (150mm storage depth) were small, if any during the summer months, with surpluses found following the winter resulting from snowmelt when the potential e potranspiration is minimal.

It is important to note that in the production of the water balance data for the urbanized areas, it was assumed that the conventional curb and gutter technology would be used with some storage in the wetlands and stormwater lakes. Curbs and gutters may be used in portions of subdivision but it is hoped that use of the management techniques discussed in Chapter Six will reduce the dependancy on this traditional technology. The extensive use of rooftop storage, wetland and stormwater lake storage, natural stream bed drainage, grass pavers, etc., may make the use of curbs, gutters and storm sewers redundent in parts of the new urban area. In addition to storage the alternatives will increase the amount of permeable cover thereby reducing the total runoff yield.

Also, in a conventional urban area, the large amounts of concrete and asphalt increase the advected heat. Therefore, the evaporation rates in the stormwater impoundments would be increased resulting in less total yield to the receiving watercourse. This alone may result in a decrease in annual yield from over 7 times to below 7 times the pre-development levels.

5.6 Runoff Quality Projections

The runoff yield values were combined with pollutant concentration values to produce loading values in kilograms/ hectare/ year and for the entire Ellerslie Subdivision (Shahane, 1982). This resulted in a projection that, if conventional curb and gutter technology is used the 2024 hectare parcel, would produce 400 kilograms of phosphorus per year, 1300 kilograms of nitrogen and 270,000 kilograms of suspended solids (sediments) on an annual basis (Table 5.3).

The knowledge of sediment production is important in the design of storage facilities for stormwater runoff. But the understanding of the total sediment load is vital also because of the pollutants that are associated with the sediments, many of which are harmful to people (see

Table 5.3 Annual Loadings of Pollutants in Stormwater Runoff From Ellerslie Subdivision as a New Urban Area. (Source: adapted from Hickok, Hannaman and Wenck, 1977; Author).

Pollutant Loads	Total Phosphorus (kg/ year)	Total Nitrogen (kg/ year)	Total Solids (kg/ year)
A-Loads per hectare	0.21	0.64	133.8
B-Loads for study site	425.0	1295.0	270,810.0

Chapter Four). Therefore, the design options which reduce the sediment load (and associated pollutants) to receiving streams and water bodies, including stormwater lakes, would be desirable.

An understanding of the amount of nutrients that will be affecting the receiving water bodies is also important to the design of multiple purpose facilities, and treatment facilities, to limit eutrophication processes and associated water quality problems.

According to the Rice Creek Watershed District (1979), as indicated in their guidelines, it would take 127 hectares of wetlands to treat the total annual nutrient load estimated at 1700 kg/year. However, not all of the small stormwater lakes need be connected to a wetland but certainly a large, artificial lake would have increased usefulness with improved water quality.

Also, many non-traditional stormwater management techniques are proposed for use in the Ellerslie Subdivision which would reduce the runoff volume and total pollutant load. If these techniques are incorporated into the Subdivision the total annual nutrient load will be reduced thereby reducing the volume of wetland treatment required.

6. STORMWATER MANAGEMENT FOR THE ELLERSLIE SUBDIVISION

Water is constituted by hydrogen and oxygen, but water's properties are not-reducible to those of it's constituents. It has what realist philosophers call *emergent powers* (Blaskar, 1975 in Sayer, 1983:55).

6.1 Objectives in the Stormwater Management Proposal

The objectives in the stormwater management proposal for the Ellerslie Subdivision, as addressed in this thesis, are to:

1. Minimize changes to the hydrologic cycle with urbanization,
2. Reduce total yields and peak flow,
3. Reduce total pollutant load,
4. Produce recreational and aesthetic amenties for homeowners.

The objective of minimizing the negative changes in the hydrologic cycle is the most important because if the infiltration, evapotranspiration and drainage processes are allowed to continue with some similarity to the pre-urban rates then the water balance will be affcted less and stormwater yield and pollutant load will not be drastically increased. Many of the alternatives discussed below could be used in the Ellerslie Subdivision to provide areas for infiltration and/or evapotranspiration. Other alternatives could be used to provide storage and/or treatment or make use of the urban runoff.

To meet the above objectives, members from many disciplines will work together to form an integrated stormwater management system. In actuality this was being done, as early in the author's involvement with the project (as a geographer) regular meetings with the developer, urban planner, drainage engineer and landscape architect were taking place. However, as written in Chapter 4.4, planning of the Ellerslie Subdivision was curtailed in the spring of 1986. When the planning of the Subdivision resumes it is assumed that the above disciplines will again be represented as well as, at some time, an architect (e.g. to contribute information on rooftop storage), a lawyer, maintenance and safety specialists and a biologist (for wetland design).

As discussed in Chapter Five the use of conventional curb and gutter and storm sewer technology in Ellerslie Subdivision will result in an average annual runoff yield of 3,000,000 cubic metres of runoff or over 7 times the pre-uban volume and annual pollutant rates of 1700 kilograms of nutrients and 270,000 kilograms of suspended solids (and associated pollutants). Use of the management alternatives discussed below will reduce total runoff yield, peak flow and total pollutant load.

6.2 Stormwater Management Alternatives for the Ellerslie Subdivision

Stanley Associates Engineering Ltd (1980 a,c) has concluded that the stormwater lakes for storage of rainfall will be the most cost-effective alternative for control of stormwater once the Ellerslie Subdivision is urbanized. The design specifications for the stormwater lakes have not been finalized, therefore it is intended that the suggestion for design and placement of the stormwater lakes and wetlands, as well as the other management alternatives given in this thesis will be considered in the final design. It is assumed that natural drainage, open vegetated channels, will be incorporated into the stormwater lake-wetland system as much as is feasible.

The planning consulting firm, Mackenzie Spencer Associates Limited (1984,1985) in association with Stanley Associates Engineering Ltd (for Daon Development Corporation), assigned 21.3 hectacres (52.7 acres) of land to stormwater lakes in the industrial area (see Table 6.1) and 17.9 hectares (44.2 acres) in one-half of the residential area. It has been assumed that the other half of the residential area would have been alloted a similar amount of land for a total of 57.1 hectares (141.1 acres). This includes a 15.5 hectare lake, which had been planned as part of a large community park, which was to be augmented with water from the municipal supply (Spencer, 1986). In addition to the space for stormwater lakes, 6.0 hectares (14.8 acres) has been alloted to park space around a portion of the retention ponds, including the lake/park. Other stormwater lakes are part of larger park systems which amount to 70.2 hectares (174 acres) of open space, including a large community level park and an athletic park. Combined park space totals 76.2 hectares (188.45 acres) as assigned by Mackenzie Spencer Associates Ltd

Table 6.1 Total Area in Each Sub-group of the Open Space Category. (Source: Adapted from Mackenzie Spencer Associates, 1984, 1985: author).

Total Area	Stormwater Lakes (hectares)	Parks (hectares)	Wetland (hectares	Total Open Space (hectares)
Proposal A	57.1	70.2	0	127.3
Proposal B	57.0	31.3	39	127.3

(1984, 1985). This is in addition to the large amount of land dedicated to schools, which is often not built upon, and which could be useful within the stormwater management system.

In this study, the 57 hectares of land dedicated to stormwater lakes in previous work, by Mackenzie Spencer Associates Ltd. (1985, 1986) as described above, will also be dedicated as lake detention storage. The wetland portion (39 hectares), with its high aesthetic and educational value, will be included as part of the park dedication resulting in a total of 102 hectares of open water in the Ellerslie Subdivision. The 102 hectares of open water is a minimum assigned area which could be increased by the use of linear, shallow basin wetlands as portions of the open channel, natural drainage system. It is hoped that institutional restrictions regarding detention facilities and land dedications will be lessened by the time the Ellerslie Subdivision is urbanized. Consequently, more land may be available to wetland and stormwater lake development on what was park or school land dedication. This concept is expanded upon in Section 6.4.1. The stormwater management system for the Ellerslie Subdivision, as described in the following text, will be dominated by the use of natural, open channel drainage, wetlands, and retention ponds (stormwater lakes) but will also include many other alterich will serve to reduce runoff volumes and pollutant loads.

6.2.1 Environmental Planning/ Natural Drainage

The less that the existing hydrologic cycle is altered the less the level of increases in runoff volume and pollutant load. The natural system is not perfect but significantly less stormwater runoff and accompanying pollutants flow from it than would from a new urban area developed with conventional stormwater management technology. Minimizing change in the water balance will require planning the Ellerslie Subdivision around existing natural features. Therefore, the preservation of the wetlands, streams and tree stands is important in the reduction of potential stormwater runoff quantity and non-point pollution, especially during the construction phase.

The sites which are recommended for preservation are included in Figure 6.1. The tree stands indicated on the map could form a focal point in a new urban park area or school yard while providing an area for infiltration and evaptranspiration. The wetlands will be useful as treatment and storage portions of the stormwater management system as well as for aesthetic appeal. (see Sections 3.3.8 and 6.2.2). Parts of the tree stands, wetlands and/or the natural drainage courses may be required by the City of Edmonton as environmental reserve dedication according to the Planning Act (1980) section 98.a.

Figures 6.2 and 6.3 are existing marshes in the Ellerslie Subdivision. Both these marshes, if preserved, will visually enhance the the urban area as well as providing storage and treatment of stormwater.

As multi-family housing has been found to produce more runoff pollution per unit that single family housing because of the smaller open space component (Whipple, Hunter and Yu, 1978) the existing tree stands could be incorporated into these higher density sites to provide areas of infiltration. Placement of the multiple family housing around the wetlands would also be appropriate as the marshes are useful for treatment and storage. Either the tree stand or the wetland could form the focal point of the open space area in the multi-family site.

Also, as discussed in Chapter 3.3.1, a majority of the hydrocarbon pollution comes from the small percentage of land used in commercial sites, parking lots and gas stations (Stenstrom, Silverman & Bursztynsky, 1984). Therefore, care should be taken in the placement of these land uses relative to the stormwater lake and the drainage system into it. Pollution from parking lots and gas stations could be reduced through various on-site measures as discussed in Section 6.2.5.

Natural drainage for the collection, transportation and temporary storage of runoff is discussed in Chapter 3.3.2. By including natural channels and vegetated swales in the Master Drainage Plan for Ellerslie Subdivision the planners will be reducing the changes in the hydrologic cycle which normally accompany the urbanization of an area. The open channels will also provide space for infiltration and evapotranspiration (vegetation will grow in channels

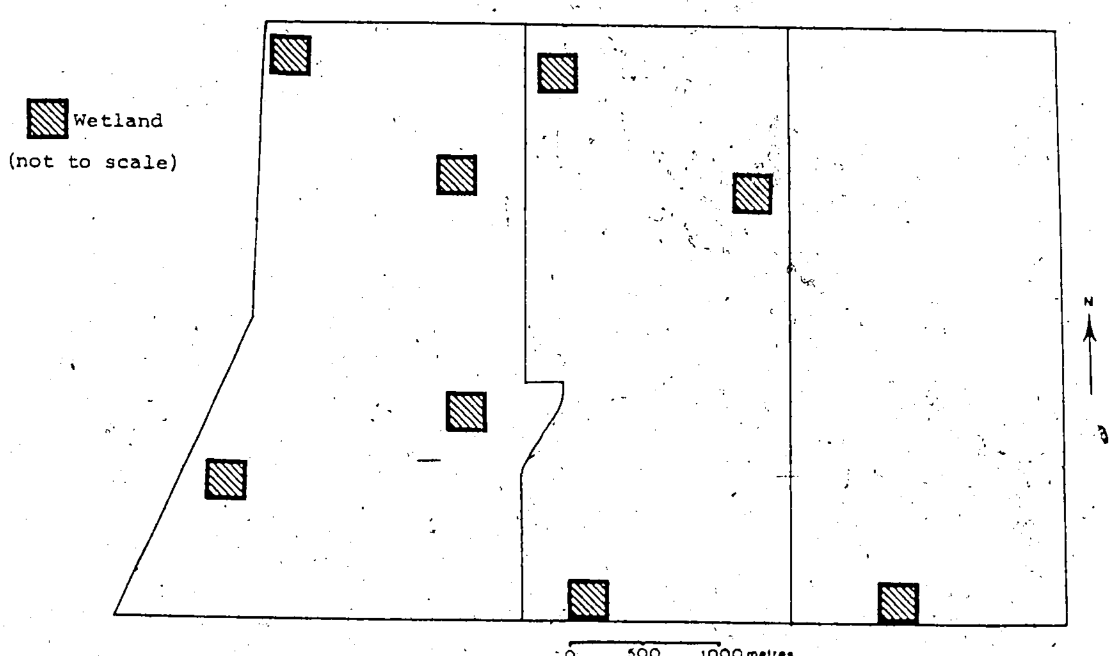


Figure 6.1 Wetland Perservation Sites in the Ellerslie Subdivision. (Source: author).

Figure 6.2 Existing Marsh in the Ellerslie Subdivision that is recommended for preservation and incorporation into the new urban area. (Source: author).

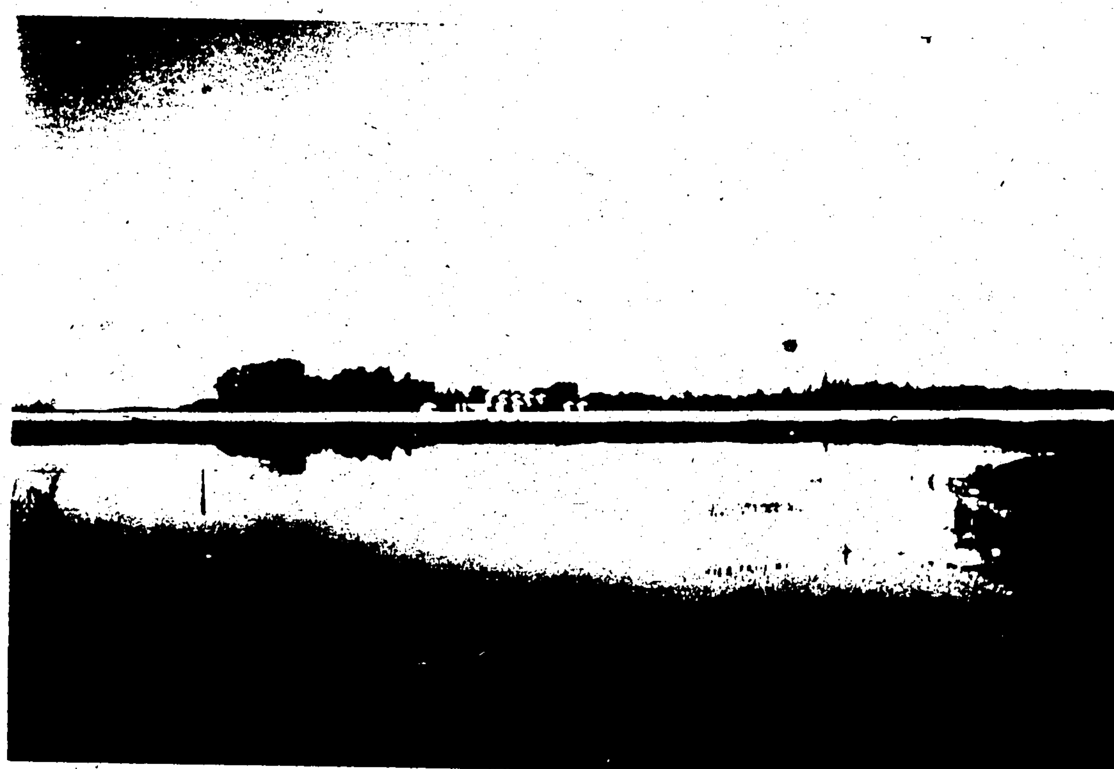


Figure 6.3 Existing Marsh in the Ellerslie Subdivision that is recommended for preservation and incorporation into the new urban area. (Source: author).

between rainfall events) resulting in reduced pollutant loads, total yields, peak flows and erosion. Therefore, it is suggested that the permanent and ephemeral streams (see Figure 4.5) be preserved, and new open channels be created for the drainage of runoff in Ellerslie Subdivision. Extensive use of natural drainage will result in substantial savings for the developer of the site as expensive deep trenching, and reinforced concrete and ceramic pipes will not be required in many areas. Conventional storm sewers would be necessary in some locations but their use should be kept to a minimum.

By replicating natural drainage patterns and providing treed areas for evapotranspiration and infiltration, the water balance is altered less than with traditional drainage. Also, the small pockets of trees and shrubs in the urban areas can employ more water than the regional PE (potential evapotranspiration) levels for similar species because of the advected heat which is available for use of the extra surface flow. Therefore, the indicated potential increase in annual yield, with urbanization, from the Ellerslie Subdivision of seven times the pre-urban level may be greatly reduced. And, less storage in new stormwater lakes would be required. Also, on-site storage and infiltration measures in the built-up portions of the subdivision will be used to reduce the total yield and storage requirements (see 6.2.5).

According to estimates, given in a joint study by the Urban Land Institute (1975), American Society of Civil Engineers and the [U.S.] National Association of Home Builders, properly designed open channels (street swales) can provide up to 19,000 M^3 of runoff storage per km^2 of developed area. Therefore, in the Ellerslie Subdivision 380,000 cubic metres, or more than 10 percent of the annual yield, could be stored in the natural channels. However, in the Ellerslie Subdivision, except for extreme events, the natural drainage channels would be utilized for the transport of runoff to the wetlands and stormwater lakes with minimal stormwater held in the open channels at most times.

Natural (or natural design) drainage channels can provide interest and aesthetics to an urban development if planned properly. Figure 6.5 is a photograph of an open channel in a new urban area in the city of Sherwood Park, just east of Edmonton during a spring thaw period.

The use of fencing is slightly harsh but as the houses are on higher ground, the open space with trees and natural drainage is still visible from the structure. Figure 6.6 is an example of open drainage in the Rice Creek Watershed District. This photograph is of natural drainage in an institutional, park-like setting of a small university. The Rice Creek example also illustrates how natural drainage without fencing can be incorporated into a urban area. Note also how in both the Sherwood Park and Rice Creek Watershed District examples, the natural design channels curve and bend over relatively short distances, a natural stream has been replicated. Such is not the case with the channel alterations provided by the Government of Alberta, Ministry of the Environment for the Blackmud Creek just south-west of the study site, near Highway Two (Figure 6.7; see also the aerial photograph in Chapter Four Figure 4.1).

In the Manual of Practice for Urban Drainage (Environment Canada, 1980) a warning is given on the necessity of regular private and public maintenance of channels for the proper functioning. This should not prove to be a problem for the Ellerslie Subdivision as maintenance responsibility should be established early in the development process (Section 6.5.2). Also, public awareness campaigns should be conducted to educate homeowners on the personal merits of their involvement in the stormwater management system (see section 6.5.3).

In summary, the preservation and use of natural drainage, including naturalized open channels, and wetlands as well as the preservation of treed areas are central to stormwater management for the Ellerslie Subdivision to minimize changes in the water balance. Such techniques "which closely duplicate or enhance the original drainage pattern of the site are used in order to enable runoff to be managed as a resource for aesthetic and recreational enjoyment" (Environment Canada, 1980:164). The natural channels themselves could be aesthetic. In addition, the aesthetic and recreation value of the Subdivision would be further enhanced if the runoff is collected into well-designed wetlands and stormwater lakes.

Figure 6.4 An open channel in Sherwood Park, Alberta during the spring melt. (Source: author).

Figure 6.5 Use of natural open channels for transportation of urban stormwater runoff in the Rice Creek Watershed District, Minnesota. (Source: author).

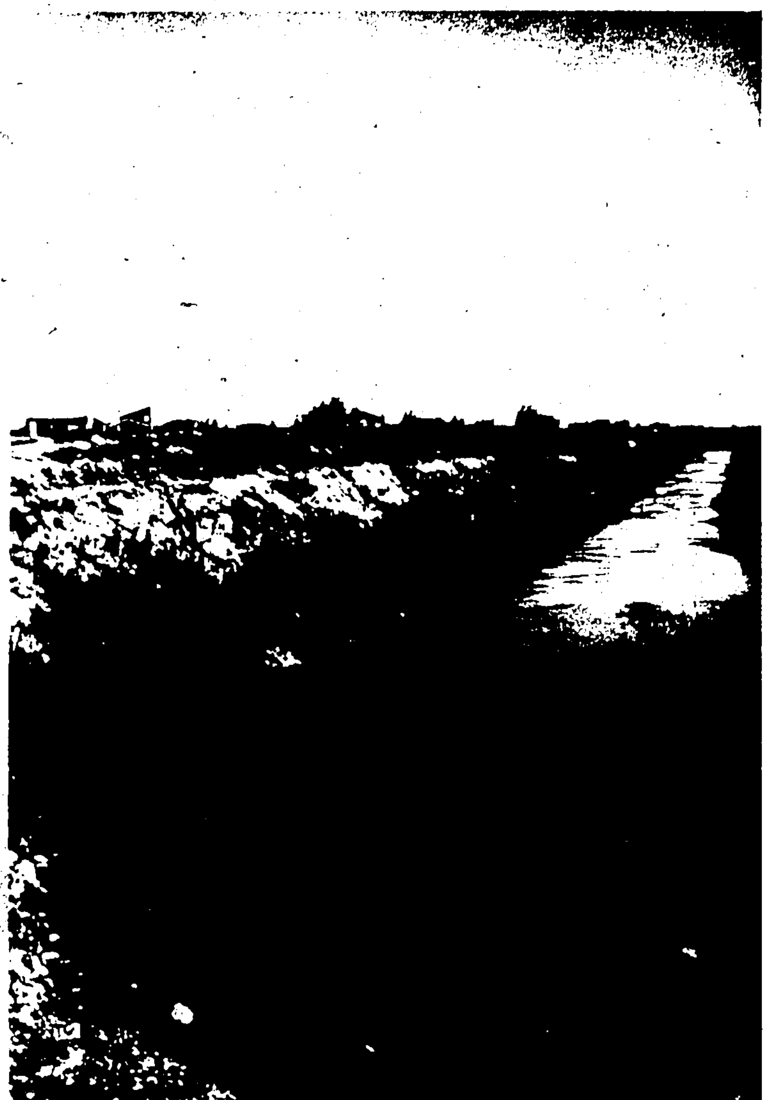


Figure 6.6 Channelization of the Blackmud Creek; an example of an alteration to a stream bed which will cause downstream erosion problems. (Source: author).

6.2.2 Wetlands for Storage and Treatment of Stormwater Runoff

As discussed in sections 3.3.7 and 4.5 the use of wetlands for treatment of runoff has resulted in high removal efficiencies of phosphorus, nitrogen, and suspended solids. Therefore, the incorporation of wetlands, in the form of marshes, for storage and treatment of urban runoff is suggested for Ellerslie Subdivision. Potential locations of the wetland storage/treatment sites can be seen in Figure 6.4. The final location and number of the wetlands will be dependent upon decisions made by the various professionals involved in the planning of the subdivision. As discussed in Chapter 5, to treat the entire annual runoff volume would require 127 hectacres of marsh wetlands. However, the calculation assumed the use of conventional technologies throughout the subdivision, while the drainage plan proposed by the author will result in much lower pollutant levels. Therefore, less wetland would be required. The various methods of treatment, including wetlands, combined with the on-site measures should reduce the pollutant load from the urbanized Ellerslie Subdivision by at least 50 percent.

Although it is ideal that all of the runoff be treated it is not necessary and the runoff should be cleaner that is traditionally found in urban areas. Nevertheless, treatment of stormwater that will be flowing into the main stormwater/recreation lake is vital. The minimum amount of land proposed to be dedicated to wetlands will be 39 hectares. Any increase in this allotment, resulting from the ue of linear wetlands in the natural drainage systm or from increased dedication would be advantageous to the water quality in the stormwater lakes.

The natural wetlands that are now being used, in other locations, for water treatment are simple systems with limited structural design requirements. In the Ellerslie Subdivision, use should be made of existing wetlands (see Figure 6.2 & 6.3), including enlarging the existing marshes or creating new ones. The town of Arcata in Northern California is successfully using marshlands for wastewater treatment that have also become popular recreation areas for the public. The Arcata marshes were made on abandoned, neglected land. The area was cleared, a few islands created, and groundwater and surface runoff was routed into the area. No vegetation was introduced into the wetlands as "nature did the rest" (Price, 1987:52).

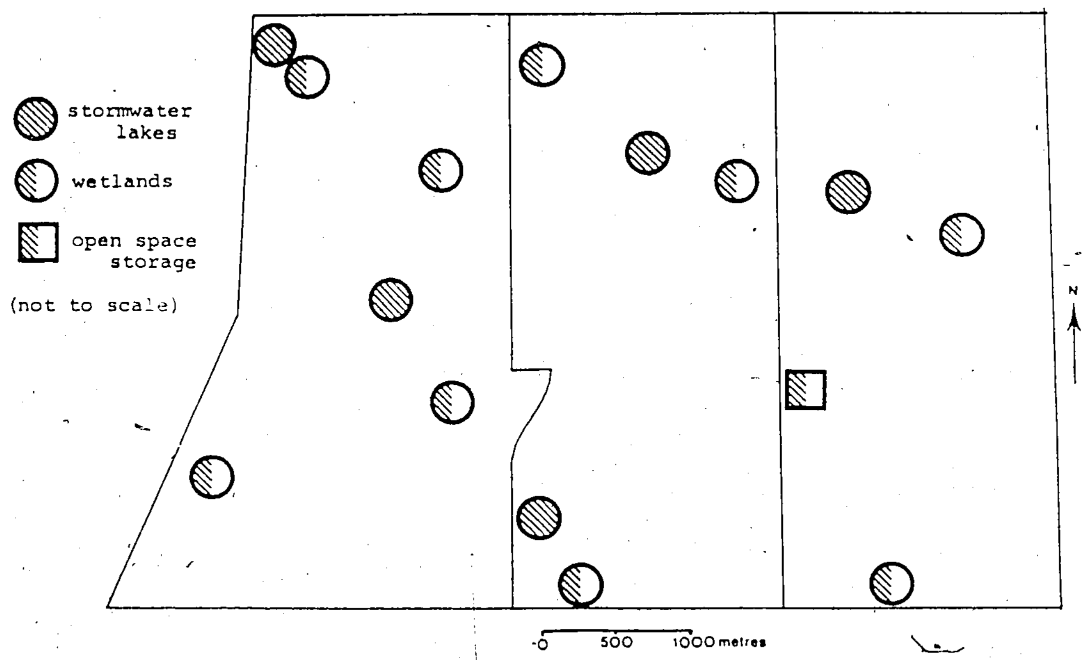


Figure 6.4 Potential Location of Stormwater Lakes, Wetlands, and Open Space Storage Facilities in the Ellerslie Subdivision (Source: author).

Figure 6.7 Potential Location of Stormwater Lakes, Wetlands, and Open Space Storage Facilities in the Ellerslie Subdivision. (Source: author).

Rice Creek Watershed District uses existing wetlands for treatment of runoff. The lakes which the treated runoff flows into have sufficient water quality for swimming. The wetland/lake system is very natural with minimal structures. These include culverts under roads to comodate the natural movement of runoff from wetland to lake, a simple structure for collection of floatables and hand operated weirs to increase exposure time of the stormwater to the soils and vegetation in the wetlands (Figure 6.8).

A weir with hand operated gates, is also used in Sawgrass Lake, Florida to control the water in the wetlands. There they use the weirs to replicate the natural floodings during the wet season (King, 1983).

Weirs could also be used in the Ellerslie Subdivision to regulate the time that the runoff is treated in the wetland. The collecting of runoff in the wetlands for treatment also serves to detain the runoff either for eventual flow into a stormwater retention lake or to the receiving stream (Blackmud Creek) at a controlled, slower rate thereby reducing the peak flow to Blackmud Creek.

The successful treatment of stormwater in the wetland which drains into Lake Josephine, in the Rice Creek Watershed District, results from approximately 45 days of retention time (Hickok, Hannaman and Wenck, 1977). Such extended amounts of time of high water does not cause damage to the trees on the periphery of the marsh, especially if species are established under a natural, ephemeral, flooding regime (Carter,et.al, 1978; King, 1983). Therefore, the Ellerslie Subdivision wetlands could also include trees for visual enhancement, and to strengthen the shoreline, without concern for loss of trees during times of high water directly after rainfall events.

The type of marshes that presently exist in the Ellerslie Subdivision are categorized as a) deep basin, permanently wet (Figure 6 or b) moderately deep basin, only occasionally dry (Figure.6.3). The author proposes that with urbanization the large wetlands be of the deep basin catagory. The smaller marshes, some of which may be linear and form a portion of the natural drainage system through the residential or industrial development, may be moderately

Figure 6.8 A hand operated weir on a wetland in the Rice Creek Watershed District, Minnesota. (Source: author).

deep dry or shallow basin (dry much of the time).

In addition to the primary benefit of the wetlands, the treatment and storage of the runoff, the marshes will also add recreation and aesthetic value to the Ellerslie Subdivision. In a study of visual, recreational and educational values by Smardon (1978) wetlands, especially fresh water marshes, rated highly relative to other landscapes. Visually, the marshes were judged as having higher visual aesthetic value than other landscape types including open water or river vistas. As well, the diversity of vegetation and wildlife make them important for educational purposes. The author found that even small wetlands, in an urban environment, were useful for creating a sense of openness. "Wetland systems can serve to structure development or provide needed solitude for wilderness or semi-wilderness experiences for urban dwellers" (Smardon, 1978:541).

The marshes in Arcata, California have become a valuable resource for approximately 112,800 people each year visit the wetlands for hiking, bird watching and picnicks. "The sanctuary's beauty and utility have united the community in its support. People who had never looked at birds before are proud of the marsh" (Price, 1987:53).

The Ellerslie Subdivision may then, if plans for wetlands are executed early in the development process, include marshes which will be valuable in many ways. Ducks Unlimited Canada and their biologists may be interested in providing expertise for the wetland development in new subdivisions. However, the personnal from Ducks Unlimited would be expected to work within the multi-disciplinary planning team for the Ellerslie Subdivision. Ducks Unlimited has not been involved in an urban development scheme before but they are willingto consider the project, depending on the quantity and quality of permanent manageable marsh land habitat in the subdivision. If Ducks Unlimited became involved in the wetlands in Ellerslie Subdivision they may be willing to provide financial assistance to "pay for all, or part of, the potential wetland(s) development costs (outlet control structures, ditching, etc...) interpretive features such as marsh boardwalks and signage to encourage public appreciation and education...assume future maintenance cost and undertake the necessary design work"

(Russell, 1985) of the relevant marshes.

As the marshes will be used for treatment of urban runoff, especially the removal of phosphorus, nitrogen and suspended solids, there may be concern with the possibility of creating a long term nutrient sink. However, especially in moderate to cold climates like that of the Ellerslie Subdivision, only a small portion of the total vegetative production is actually collected in the organic soils (Nichols, 1983; Reader & Stewart, 1978). Also, the wetlands in the Rice Creek Watershed District have not yet shown any signs of long term accumulation of pollutants (Willenbring, 1985). Harvesting of the large plants (cattails) in the fall may reduce nutrient sink generation.

As the use of wetlands will serve to replicate a portion of the pre-urban hydrology of the area the effects of urbanization will be lessened. Continued percolation from the organic soils in the wetlands to the groundwater will result in baseflow levels not being substantially reduced. As well, the open water and plant life will add to the evapotranspiration from the urbanized Ellerslie Subdivision. Therefore, the hydrologic cycle will be less affected less than under normal urban development conditions. Also, runoff will be stored in the wetlands for extended periods of time before entering into a stormwater retention lake or Blackmud Creek thereby reducing the expected increases to peak flow and total annual yield. And, the quality of the water flowing into the retention impoundments and Blackmud will be improved because the wetlands will capture in its soils and plant structure much of the nutrient, sediments and associated pollutants which, if conventional storm sewers had been used, would have been deposited into the receiving stream.

Urbanization of the Ellerslie Subdivision, as proposed would then include marshes with visual, recreational and educational value while providing treatment of runoff for the stormwater lakes within the subdivision and for output to the Blackmud Creek. The removal efficiency of the wetlands will be a minimum of 50 percent for nitrogen and phosphorus as well as the suspended solids.

6.2.3 Stormwater Lakes

There is no doubt that the use of stormwater lakes for the detention of urban runoff is an inexpensive alternative to large trunk sewers. The design challenge is to produce a stormwater lake which is multi-purpose in nature; a facility with varied recreation opportunities and beautiful to view. General discussion on stormwater lakes can be found in Chapter 3.13.

The Ellerslie Subdivision will have at least 57 hectares of stormwater lakes at permanent water level (PWL) when urbanized (Section 6.2; Mackenzie Spencer Associates Ltd., 1984,1985). Potential locations of the stormwater lakes can be seen in Figure 6.4. The author recommends that these lakes all be retention impoundments for aesthetic and water quality reasons. The lakes will be as large as possible with preference given to a system of a few large lakes over many small ponds distributed throughout the subdivision (Debo, 1977; Mein, 1980; Wisner, Mukerjee and Keliar, 1979). Also, wherever possible, wetlands are to be combined (upstream) from the stormwater lakes to provide treatment of runoff.

Mackenzie Spencer Associates (1985) include a large recreation lake in the western residential portion of the study site, to give additional appeal to potential home buyers. This lake, as proposed by Mackenzie Spencer Associates (1985), would receive minimal stormwater runoff and will be filled largely with municipal supplies. This approach does not recognize the resource potential of urban runoff.

The author agrees with the inclusion of a large recreational lake in the Ellerslie Subdivision but recommends that it be a stormwater impoundment downstream from a large wetland. The system would also include a limited number of low structural alternatives including an aeration device (waterfall/ sculpture) and possibly the chlorination of the runoff from the wetland. This would be more cost effective than the exclusive use of municipal supplies. However, augmenting the lake, with municipal water or local groundwater (if available), may be necessary occasionally. Nevertheless, if managed correctly the stormwater could form the greater part of the water supply for the recreation lake. Field observations and discussions with residents in the Rice Creek Watershed District assured the author that swimming did take place in one of their larger lakes (Lake Josephine) which receives considerable volumes of runoff via a wetland.

Care should be taken in the planning and development stage to ensure that the lakes are as natural looking as possible. In doing so, the developer would be creating multi-purpose amenities. The use of asymetrical, curving shorelines will result in stormwater lakes that appear natural and are pleasing to the eye (Untermann, 1978). Also, shallow embankments (1:7 slope) will add to the natural appearance of the lake (Chambers and Tottle, 1980). This gentle slope would also be safer than the 1:4 slope common to stormwater impoundments.

Also, the depth of the lakes should be a minimum of 3 metres to enable fish to live, year round, in the stormwater lake (Gill and Kelly, 1978; Poetner, 1974a). The lake could be stocked with sport fish for recreation and others for mosquito control. Such is the case in Arcata, California, where salmon were raised in the wetlands and stickleback were introduced for mosquito control (Price, 1986). In a new urban development in England, beam, tench and carp were stocked in the stormwater lakes to counteract flies (Smith, 1974). Whipple, et al (1983) found that the common goldfish is often recommended to control mosquitos. The biologist who will be assisting in the planning of the wetlands for the Ellerslie Subdivision should also be consulted as to which type of fish would be the most appropriate for mosquito control in the stormwater lakes and wetlands, in the Edmonton area bioregion.

The safety of the stormwater lakes is also an important design consideration. As discussed above, the use of a gentle slope makes the lake safer. In addition, care must be given to the location and type of input and discharge outlets. Marcy and Flack (1981) suggest the use of lattice grids over the entrances to lakes to reduce flow velocities and floating inlets to discharge the runoff water at the surface to limit undertow currents in the impoundment. Such low structural features may be useful in the Ellerslie Subdivision. However, in most cases the runoff would be flowing initially into the wetlands, therefore, the lattice grids may not be necessary. The lattice grids may be useful over the outlets into the wetlands to dissapate runoff energy. Also, movement to the runoff from the wetland to the stormwater lake will be delayed after the rainfall event, for extended periods of time, therefore, the flow will be slow and likely to pass through an open, vegetated channel which will further diffuse the energy of the water.

Many jurisdictions require fencing around stormwater management facilities as they feel it reduces their liability. It is proposed that the fencing of the stormwater lakes and wetlands will be kept to a minimum within the Ellerslie Subdivision. Where fencing in necessary, the author suggests that inconspicuous chain link or light coloured cast iron be used as these materials will not interfer with the view to the waterbody. Other less structural alternatives may also be appropriate for incorporation into the Subdivision. For example, the City of Dartmouth, Nova Scotia used rose bushes to restrict access to a stormwater lake while providing interest (Micheals, McBean and Mulamootil, 1985).

The amount of community open space surrounding the stormwater lakes is dependent upon the extent of private ownership of the waterfront and the land use around the impoundment. The author recommends that private ownership of the shoreline be limited. Preference should be given to stormwater lakefront and wetland shore ownership being entirely public. Extending access to the water amenities to all members of the Ellerslie Subdivision is important for the creation of community responsibility and appreciation relating to the facility (see section 6.5.3).

Also, from the developer and marketing perspective, Weicher and Zerbst (1973) found that housing prices increased more when the homes faced the park, with a water body, than houses which backed onto the public space (as is the case in most Edmonton stormwater lake situations). To most Canadians the backyard is a more private space than the front yard. Therefore, it may be preferable to have the space directly around the lakes as public park, recreation space, with a bike path or roadway separating the lake and the first row of residences.

Complete public ownership of the land adjacent to the stormwater lakes will also simplify maintenance functions and responsibilities. This is expanded upon in sections 6.5.2 and

6.6.1.

The primary purpose of stormwater lakes is in the detention of stormwater for gradual entry into a receiving stream, thereby reducing the peak flow. The retention facilities also result in the reduction of total annual yield. Nonetheless, recreation is now often cited as an additional primary purpose of large stormwater lakes. Generally, however, primary contact recreation is not permitted in Canadian stormwater lakes because of impaired water quality. The water in the large recreation/ stormwater lakes, in the Ellerslie Subdivision, which will have been treated in the wetlands, will be of sufficient quality for primary contact water based recreation. On-going water testing will be part of the regular maintenance program to monitor the lake water quality. As discussed above, augmenting the treated runoff may be necessary during extended dry periods. Therefore, recreation will be a additional primary function of the stormwater lakes in the Ellerslie Subdivision. The recreational aspect of the Subdivision will also be a marketable amenity to potential home buyers.

Many people are willing to pay more for property near recreation areas and/ or sites with aesthetic appeal as "environmental benefits are capitalized as increased property values" (Poudel, 1978:i). Numerous authors have shown that increased property values result from land being in close proximity to recreation areas or open space (Knetsch, 1964; Kitchen and Hendon, 1967; Corner, Gibbs and Reynolds, 1973). As well, Darling (1973) found that an urban water facility has large value to the community. David (1968) found that the value of water-based recreation facilities is reflected in propety value and that land values were lower around lakes with poor water quality. Hinch (1984) in a study of residents' reponses, in the community around Lake Beaumaris in Edmonton, Alberta, found that 90.3 percent of the residents felt that the stormwater lake improved the overall quality of the urban environment. Although, as in the David (1968) study, poor water quality was cited as a negative value.

The recreation and aesthetic value of the stormwater lakes in the Ellerslie Subdivision should be high as the water will be clear and clean. The impoundments will appear to be natural lakes and will be surrounded by green space, recreation facilities, natural design vegetation areas and walking/ paths. The paths could be used to link up the recreation space around the stormwater lakes to that surrounding the wetlands.

The stormwater lakes and recreation areas will require continuous maintenance. This will be discussed in section 6.5.2.

In summary, the stormwater lakes in the Ellerslie Subdivision will contain runoff of high water quality because it has been previously treated in wetlands. If a stormwater impoundment cannot be downstream from a wetland the runoff will be, nevertheless, improved through other treatment techniques (6.2.4), on-site storage (6.2.6) and other best management practices.

The author recommmends that no housing have direct waterfront lots but rather that public space be adjacent to the lake. The front of the houses will then face the lake, separated from the public open space by a road or pathway. The complete public ownership will encourage community involvement in the stormwater management for the Ellerslie Subdivision and provide extensive access for maintenance.

6.2.4 Non-wetland Treatment

In some locations it may not be feasible to treat runoff in a wetland before entry into a stormwater impoundment and other types of treatment may be necessary (see Chapter 3.3.7). Such cases may include parts of the industrial portion of the Ellerslie Subdivision or high use commercial, parking lot, areas. These are land uses which carry high pollutant loads, especially hydrocarbons and suspended solids, and would require treatment. Therefore, the author suggests that instead of, or in addition to, wetland treatment that one of two options be utilized in the industrial and commercial areas.

One option involves using an interceptor to send the first-flush of runoff, or the solids collected by a swirl regulator/ concentrator, to the sanitary sewerage plants via a carefully constructed sanitary sewer connection. Vancouver, B.C. uses an interceptor system to treat the highly polluted first flush (Swain, 1985). This method combined with an aeration device, such as a water fountain for visual interest, will produce relatively clean stormwater lakes though not useful for primary contact recreation. Also, a small amount of sedimentation will take place in the stormwater lake further improving the runoff before entry into Blackmud Creek.

The other option is to have ponding in the parking lot, temporary storage, combined with fine mesh screening (Chapter 3.3.7). As above, sedimentation will continue in the stormwater lake.

The removal efficiences of both options would be further improved by the use of grass strips, or porous pavement being incorporated into the parking lots, as well as extensive use of roof-top storage. Nevertheless, either combination of methods would result in removal efficiencies of at least 50 percent for suspended solids and associated hydrocarbons.

Street sweeping and public awareness in relation to leaf collection (nutrients) and the hazards associated with dumping of toxic substances into the stormwater system would also be effective in reducing the pollutant load. These issues are discussed in Sections 6.4.2 and 6.5, repectively.

6.2.5 On-site Storage/ Infiltration

On-site storage and infiltration are best management practices as they are used to reduce non-point pollution to the receiving stream by keeping the runoff at the location where it falls. These are inexpensive techniques which, when incorporated early in the planning process, can save on storm water drainage costs by reducing the total runoff yield. Some alternatives also provide treatment through infiltration into the soil or through filtering (see Chapter 3.3.3).

The author proposes that grass pavers be used for the hard surface recreation areas in the Ellerslie Subdivision wherever possible. Grass pavers create the illusion that the hard surface is grassed, therefore, it would be especially appropriate to use them in the high pedestrian traffic, highly visual areas, around community buildings and main recreation areas. The developer could also encourage and offer the option to home and business owners for grass paver private driveways and parking areas at minimal cost increase over a traditional asphalt surface (Figure 6.9).

For roads and bike paths porous pavement is recommended in the Ellerslie Subdivision. The production costs would be higher than with conventional asphalt but curbs and gutters would not be necessay so that the total construction costs would be equal to or less than a traditional system (see Chapter 3.3.3).

If the City of Edmonton insists on conventional technology with curbs and gutters then cuts in the curb, rolled curbs or dragon tooth curbs (see Figure 3.3 and 6.9) could be used (Robinette and Sloan,1984). These curbs would allow runoff to flow into vegetated swales parallel to the street or grassed areas around parking lots. Grass strips could also be incorporated in large parking areas alone or combined with parking lot storage to reduce total runoff volumes.

Temporary on-site storage and infiltration could also take place in the grassed park areas and school yards. Slight depressions would detain stormwater from the surrounding vegetated and impervious areas. The stored runoff should not be large in volume assuming the parking lots will be of porous pavement with grass strips, and the buildings would include roof top detention storage. Shallow areas of depression storage should also be encouraged in residential grassed yards. In industrial and commercial areas saucers could be constructed around trees to collect water from the surrounding area to provide moisture and save on irrigation costs (Robinette and Sloan, 1984).

Because flat topped roofs are designed for heavy snow loads, in Canada, the addition of a detention ponding ring at the drain would make the roofs available for the storage of up to 15 cm (6 inches) of rainfall (see Chapter 3.3.4). Therefore, with little increased financial investment substantial amounts of storage would be available in the industrial/ commercial parts of the Ellerslie Subdivision. This water will then be available for use within the Subdivision (see section 6.3).

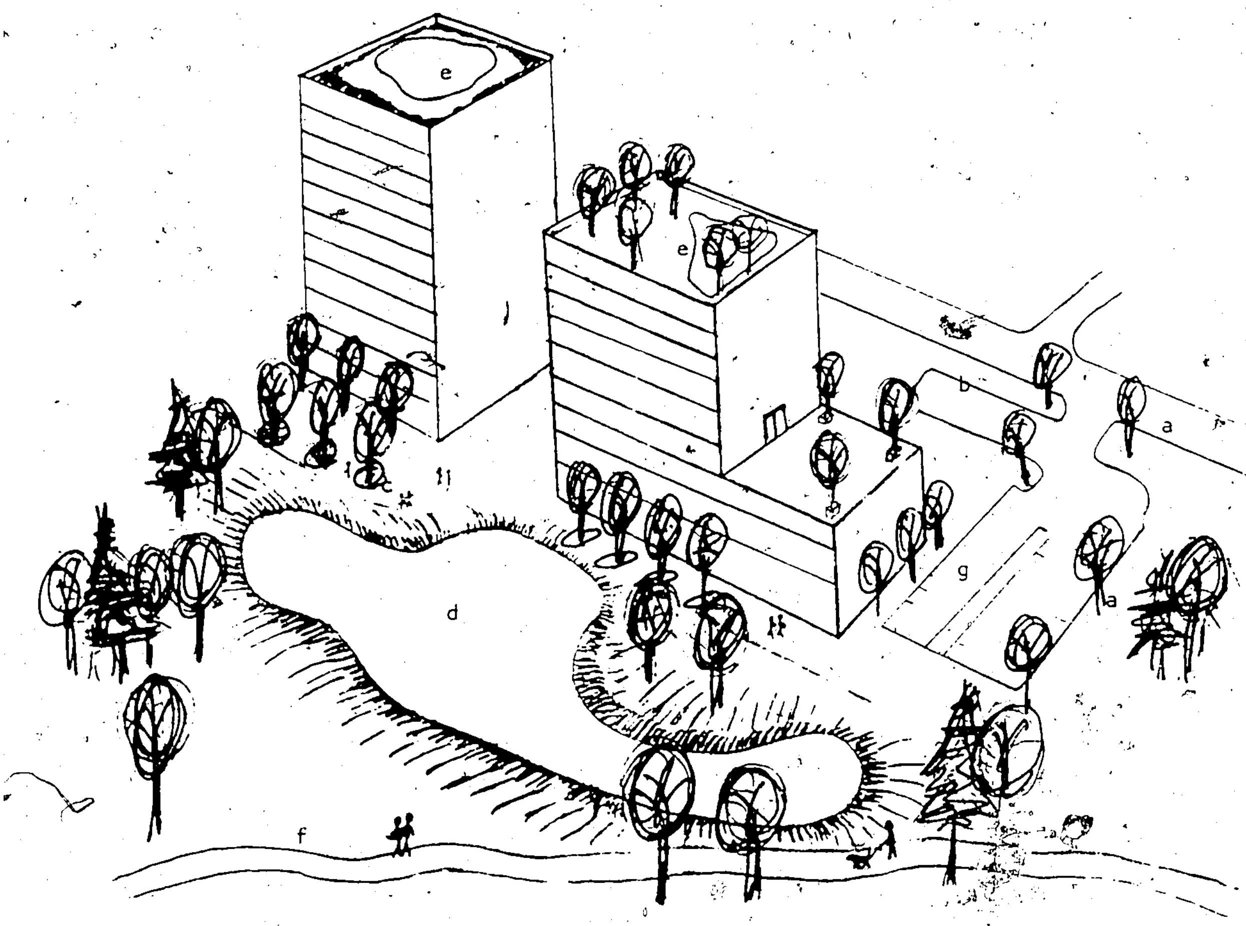


Figure 6.9 Examples of On-site Alternatives: a) curb cuts, b) grass strips, c) tree saucers, d) stormwater lake, e) rooftop storage, f) grass pavers, g) porous pavement. (Source: author).

The author proposes that Daon Development Corporation make roof top storage mandatory for the owners of flat topped buildings at both the industrial and commercial sites.

On-site storage in the residential areas will consist of rain barrels, cisterns, grass paver or porous pavement driveways or an on-lot drainage unit (see Chapter 3.3.4). These alternatives could be provided by the developer or, with possible financial incentives from the community league or the City of Edmonton, by the homeowner.

Therefore, with minimal capital costs the various types of on-site alternatives could be used to provide storage and/ or infiltration thereby reducing the peak flow, total yield and pollutant load to Blackmud Creek. The level to what these parameters will be reduced is difficult to estimate because of the involvement of individual land owners.

6.2.6 Erosion Control

The construction phase of development results in extensive surface erosion. It would be in Daon Development Corporation's best interest to practice erosion control during the construction phase of the Ellerslie Subdivision as without it runoff volumes are high and erosion and sedimentation will be problems. Therefore, the methods described in Chapter 3.3.5 are recommended for construction erosion control. In particular the developer may be interested in the low cost use of reinforced hay bales or grass strips or the more efficient filter fabric, held in place by large stones, around the construction site. It will be especially important that the filter cloth method be used around the circumference of the wetlands and along the watercourses, which are being preserved. Also, the Metropolitan Toronto and Region Conservation Authority requires the use of filter traps, made of filter cloth and rip-rap stones, during the construction period, upstream of an outfall to a receiving stream, when surface flows are concentrated (Aitken, 1987). The author recommends that similar sediment traps be used during the construction phase.

Because the study site is so large the author proposes that the grading of the surface be staged so that vast amounts of bare soil are not left exposed for extended periods of time. No more land should be graded that can be built upon in one construction season. This may require slightly more organization during the construction phase but would be worthwhile as drainage costs would be reduced. Also, as discussed in section 6.2.1, the author recommends that grading be kept to a minimum.

If any large areas must be graded Laycock (1986) suggests that the developer wait until after the often heavy June rains have ceased.

The outfall to Blackmud Creek from the Ellerslie Subdivision will be slow and controlled. Therefore, a great deal of bank protection will not be needed. Nonetheless, the bank could be reinforced with grass and willows.

The Ellerslie Subdivision will contain an extensive network of natural open channels for the transportation of runoff. It is important that the new channels are grassed as soon as possible and that existing stream beds are protected. Cattails and willows will invade the channels with time and provide further bank reinforcement.

The above erosion control methods will reduce the total suspended solids, peak flow and annual yield that reach the Blackmud Creek from the Ellerslie Subdivision especially during the construction period.

6.2.7 Summary of the Design Alternatives and Best Management Practices

The basic design approach to urban stormwater management for the Ellerslie Subdivision, as proposed by the author, is to replicate the pre-development landscape as closely as possible. This will result in less change to the hydrologic regime relative to that which normally accompanies urbanization.

It was estimated in Chapter Five (5.4 and 5.5) that with the use of conventional technologies, the Ellerslie Subdivision would produce an average annual yield of 3,000,000 cubic metres of flow per year as well as 1700 kilograms of nutrients and 270,810 kilograms of suspended solids per year. This represents an over 7 times increase over existing runoff values. However, if all the alternatives described in this chapter are incorporated into the stormwater management system the combination would reduce the total annual yield and pollutant load, with urbanization, by at least 50 percent. Therefore, the total annual yield flowing into the Blackmud Creek from the Ellerslie Subdivision, would be approximately 1,500,000 cublic metres or less than four times the present runoff value. The peak flow at Blackmud Creek will be controlled at pre-development rates. The pollutant oad to the receiving stream will also be reduced by one-half, at least, to 860 kilograms of nutrients and 135,400 kilograms of suspended solids per year.

This efficiency in reduction of total annual yield from the Ellerslie Subdivision may result in insufficient flows reaching the retention ponds to maintain optimum water depth during low flow periods. For example, assuming that the author's proposal is incorporated into the Subdivision, a dry year such as 1976 could result in less than 750,000 cubic metres of runoff for supply to the stormwater management lakes and wetlands. Therefore, during the extreme dry years the lakes, most noteably the large recreation lake, may require supplemental wa from the municipal supplies or local groundwater. However, located in Regina, Saskatchewan (which has a a drier climate than Edmonton) is Wascana Lake which is made up almost entirely from surface runoff and has been maintained very well.

The high flow periods should not require special attention. Although there may be limitations on the recreational use of the stormwater lakes during such periods. The proposed stormwater management system could accomodate larger volumes with little effect on the system. For example, the time that the runoff is detained in the wetlands could be shortened to ensure space for incoming flows. However, this will result in the runoff not being fully treated. Therefore, the weirs should be opened prematurely only when absolutely necessary. Also, the treatment time of the runoff flowing into the large recreation lake must not be reduced.

As discussed in section 6.2.1 the open channels could also be used to store up to 380,000 cubic metres of flow during high flow periods For safety reasons, the runoff should be detained in the open channe.s fo- the shortest tim. possible.

Also, care must be taken, during the high flow periods to ensure that the stormwater is not allowed to flow into the Blackmud Creek too quickly after an unusually large rainfall event to avoid the possibility of downstream flooding.

Nevertheless, in all but the most extreme periods, the stormwater management proposed by the author should reduce annual runoff yields and total annual pollutant loads, to Blackmud Creek, by at least 50 percent.

The design solutions that are recommended to produce these reductions in yield and pollutant load are dominated by the use of wetlands, for treatment and storage, stormwater lakes for storage; and the use of natural channels for transportation of runoff.

The best management practice of preserving the natural land uses as much as possible to reduce potential pollutant increases with urbanization is important in the proposals given in this thesis. Other best management practice alternatives are recommended, which should be incorporated early in the planning process, for example: roof top storage, parking lot and green space infiltration (see Figure 6.10).

Best management practice also includes institution based alternatives such as tax changes (6.5), street sweeping (6.4.2) and public awareness (6.5) which will be discussed below.

6.3 Use of Urban Stormwater Runoff Within the Ellerslie Subdivision

The term often used in the literature for the use of runoff is *reuse* . However, reuse implies a connection with sanitary sewerage and, therefore, is not adopted here.

The stormwater runoff from the Ellerslie Subdivision that will be held in the stormwater lakes, wetlands, rooftops and rainbarrels will be available for use within the Subdivision. The collection of runoff into the large stormwater/ recreation lake makes use of the runoff for recreation purposes. Other possibilities include using the runoff for fire fighting, irrigation, industrial supply and groundwater recharging (Dean and Lund, 1981).

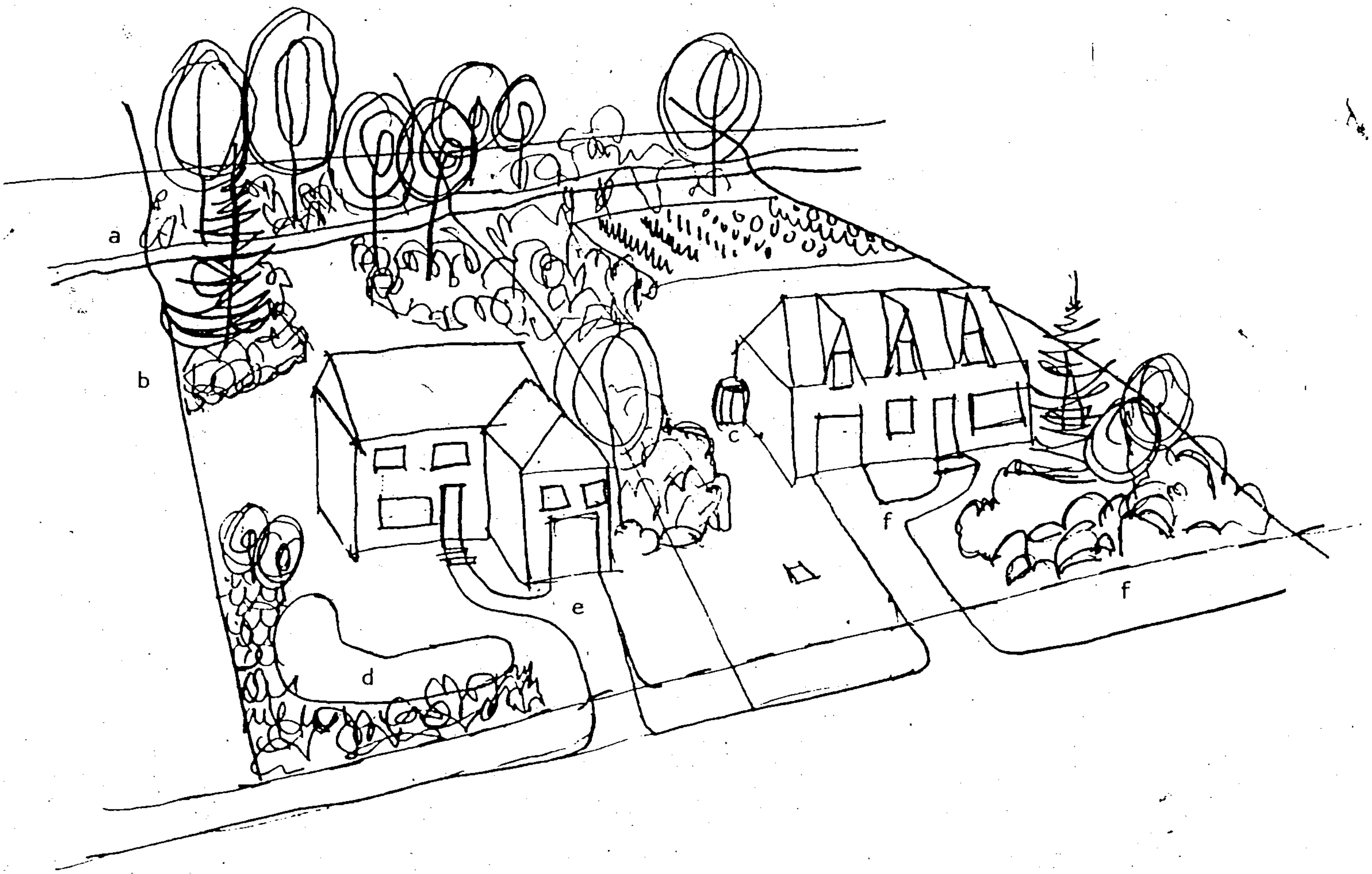


Figure 6.10 Best Management Practice for Residential Sites: a) open channel, b) natural design landscaping, c) rainbarrel, d) temporary ponding on lawn, e) grass pavers, f) porous pavement. (Source: author).

Debo (1980:655) referred to stormwater runoff as a "resource out of place". Laycock and MacKenzie (1984), Urban and Claborn (1983) and Waananen (1969) have also discussed the potential of stormwater as a resource. This potential has been realized in the Republic of Singapore where urban stormwater is harvested, stored and treated t supply 36 million gallons (163,656 cubic metres) of water supply to the eastern half of the city (Hydata, 1984).

To make use of the stormwater within the Ellerslie Subdivision, treatment may be required. Treatment alternatives have been discussed in sections 6.2.2, 6.2.4 and 3.3.7. Rainfall harvested directly from the rooftops will not require additional treatment assuming the rroftops are kept free of debris.

Also, stormwater ponded in residential or park areas can be used for irrigation without treatment, as the water has not come in contact with the impervious areas in which the majority of the pollutants are accummulated. The runoff collected in the stormwater lakes, which has undergone treatment, could also be available for municipal uses such as irrigation and fire control.

The wetland treated runoff held in stormwater impoundments and the on-site retained runoff could be useful in the industrial portion of the Ellerslie Subdivision if water is required for cooling and processing. Field and Fan (1981a,b) showed, in a hypothetical case study how the use of reclaimed, treated stormwater combined with municipal supplies would result in a savings of $900,000 per year to an individual industry. "Further savings are realized when the multi-purposes of pollution control, drainage and aesthetics are considered " (Field and Fan, 1981b:34). The opportunity for such savings would be an additional, marketable, benefit to offer potential industrial companies.

Nevertheless, the most important use of runoff in the Ellerslie Subdivision is in the multi-purpose recreation/ stormwater lake. The runoff will be treated by various techniques, most noteably wetland treatment (section 6.2.2). Additional treatment with chlorine may also be appropriate as primary contact water recreation is one the purposes in the provision of the lake (DeCook and Foster, 1984). This could be done at the aeration site as the water flows from the wetland into the lake. A hypochorination facility is used in the city of Boston, combined with storage and screening of the stormwater to improve water quality for recreation activity (Field and Fan, 1981a).

To have a truly useful recreation lake within the urban community would be an attractive amenity to potential residents and a powerful selling feature for Daon Development Corporation.

From a hydrological perspective, the use of runoff within the Ellerslie Subdivision for recreation, visual amenities, irrigation and industrial supply will keep a portion of the runoff on-site thereby reducing the total yield to the Blackmud Creek. The use of stormwater for irrigation will result in the runoff following more closely the pre-urban hydrologic regime as the runoff is used by the plants for evapotranspiration and a portion infiltrates to become groundwater recharge. Therefore, the use of runoff within the Subdivision will reduce total yield and the accompanying pollutant load, and will aid in the partial replication of the pre-urbanized hydrologic cycle.

The use of stormwater within an urban area will be a non-conventional approach to urban stormwater management. In conventional systems, runoff is drained from urban communities as quickly as possible and deposited into a receiving stream or water body. The use of stormwater in the Ellerslie Subdivision for recreation and to enhance municipal supplies will result in runoff no longer being a form of wastewater but rather, it is useful within the community, i.e. a resource.

However, the extent to which the developer of the Ellerslie Subdivision transposes the stormwater from what is traditionally considered wastewater into a resource is dependent upon many factors. The various levels of innovation that could be introduced into the stormwater management scenario for the Ellerslie Subdivision are discussed in the following section (6.4) on alternative futures. The potential limitations and incentives on the incorporation of non-traditional alternatives in runoff management are then discussed in section 6.5.

6.4 Alternative Futures

The purpose of providing alternative futures is to ensure that the best management approach, with the most appropriate technologies, can be implemented at the time the actual development of the site takes place. The describing of various options also provides for flexibility in future decision making. Therefore, listing the alternative futures of stormwater management for the Ellerslie Subdivision is desireable because of the likelihood that urbanization of the Subdivision will take not take place for twenty years (see Chapter 4.4).

The alternative futures given below are in the order of decreasing effects on the receiving stream (Blackmud Creek to the Saskatchewan River) and water body (Cawes Lake). Also, the alternative futures, with the exception of number 1, are combinations of management methods with number four being the least traditional and lowest structurally of the combinations. The alternative futures that are discussed in this section are: 1) Storm sewers to trunk sewers to outfall, 2) Storm sewers with stormwater detention impoundments, 3) Storm sewers with wetland treatment and stormwater detention and retention impoundments, 4) Natural drainage, wetland and other treatment, stormwater retention/ recreation lakes, on-site storage, use of runoff. 0

Alternative futures number one involves extensive use of small and trunk sewers for the quick tranportation of runoff to Blackmud Creek. The storm sewers would form the minor system. The major system, providing protection from the 25-100 year frequency storm, would be in the large trunk sewers and roadways. This alternative has, however, been dismissed by Stanley Associates Engineering Limited (1980b) as being too expensive for the Ellerslie Subdivision and the use of stormwater impoundments was recommended.

The second alternative involves the use of storm sewers and numerous stormwater retention impoundments for the minor system. The major system would consist of storage in roadways and green belt storage in playing fields and around the stormwater lakes. The incorporation of many single purpose lakes in the Ellerslie Subdivision has been suggested by Mackenzie Spencer Associates (1984, 1985). The use of stormwater impoundments has become conventional and the developer would gain approval relatively easily from the various government departments; assuming that maintenance responsibility for the stormwater lakes is predetermined.

However, in both alternatives one and two, stormwater is eventually deposited into the receiving stream without ever being useful within the community. With the exception of limited visual amenity from the stormwater lakes in alternative two. Also, changes with urbanization in runoff volume and water quality are not considered. In alternative two, peak flows are delayed and reduced but almost the entire stormwater yield (over 7 times the existing yield) and accompanying pollutants are deposited into the North Saskatchewan River via Blackmud Creek. Alternatives three and four are provided to deal with the increased yield and pollutant load in stormwater runoff with urbanization.

Alternative three includes, in the minor system, storm sewers for the transport of runoff and stormwater impoundments for storage. This alternative will combine the use of both retention and detention impoundments, with retention lakes, downstream from the wetlands. The wetlands will provide treatment of the runoff as well as storage. Mackenzie Spencer Associates (1985) discussed a large recreation lake that would be filled entirely with municipally supplied water. Preferable to this, would be that the lake would be part of the stormwater management scenario and receive treated runoff from a large wetland. The major system, like alternative two, would be in the roadways and green belt storage. This alternative would reduce the total annual yield a small amount and substantially reduce peak flow and time to peak.

Alternative four is the combination of methods recommended by the author in section 6.2. This stormwater management scenario is dominated by wetlands for treatment, retention lakes for long term storage and natural channels and roadside swales for the transportation of runoff. The scenario also includes various other treatment techniques which will be used in conjunction with the wetlands to treat the runoff to a sufficient quality so that primary contact water based recreation will be permitted. This management system also includes on-site storage and infiltration through various methods. The runoff will also be used within the Ellerslie

Subdivision for irrigation and recreation and to augment municipal supplies. The 25-100 year storm could be stored in the open channels which under less dramatic rainfall events will be used to transport the runoff to a wetland or impoundment.

In alternative futures number four the effects of urbanization on the receiving stream are reduced by the replication of the pre-urban hydrologic regime as much as possible. This would be accomplished by retaining the wetlands and tree stands, using natural drainage systems and storing runoff on-site thereby allowing for continued infiltration and evapotranspiration and treating runoff to improve water quality. A rudimentary estimate of the alternative futures number four combination would reduce by 50 percent the annual yield and pollutant load that would be expected to accompany the urbanization of the Ellerslie Subdivision.

However, many of the methods incorporated in alternative number four are not conventional and may require the developer to spend extra time in the approval process with various goverment departments, this will be discussed in section 6.5.4.

6.5 Institutional Aspects of Stormwater Management for Ellerslie Subdivision

6.5.1 Best Management Practices by Governments

Best Management Practices are those management alternatives which reduce potential total pollutant load from urban stormwater by various on-site means. One such method is street cleaning which can be used to reduce the solids, heavy metals and other associated pollutants in the runoff (see Chapter 3.3.6).

The City of Edmonton does not have an extensive street sweeping operation and, as is the case in other parts of the city, will provide minimal cleaning of the roadways in the Ellerslie Subdivision. The Roadways Operations Section, of the Transportation Department, sweeps the arterials once a week, the industrial collectors once per month and the residential collectors only 2-3 times per year (Murphy, 1986). The streets are flushed after every sweeping. This amount of steet sweeping is inadequate. Such a program would result in less that 5 percent removal of the solids in the runoff (Finnemore, 1982). Terry Murphy, (1986) Director of the Roadways Operation Section, City of Edmonton realized that the present program is not sufficient but felt that only public pressure on the City council would result in any change to the existing practice. Therefore, it may be necessary for the Ellerslie Subdivision community league to become politically involved to improve the street cleaning service as provided by the City of Edmonton. Another, less desireable, alternative would be that the community hire the City to provide additional cleaning at a reasonable cost. It is to the advantage of the residents and their stormwater lakes that the total volume of solids that reaches the wetlands be kept to a minimum.

The City of Edmonton, the Province of Alberta and the Regional Planning Commission could also be involved a best management practice for the Ellerslie Subdivsion by introducing and enforcing the use of erosion control methods, especially during the construction phase (see section 6.2.6).

The Planning Department of the City of Edmonton could also become involved in stormwater runoff yield and pollution abatement by requiring that natural water bodies, including wetlands, existing drainage channels and tree stands be preserved in new urban areas.

The municipal government could also contribute to the reduction of pollutant loadings by keeping the streets in good condition. Roadways that are well kept produce 2.5 times less total suspended solids than those in need of repair (Krenkel and Novotny, 1980). Also, the use of hydrophobic substances instead of salts for road de-icing, will reduce sodium surges during snow melt periods.

Reduction of nutrients in stormwater would also be accomplished if the City of Edmonton were to implement a by-law requiring dog owners to pick up their pet's faeces. If this has not been implemented when the Ellerslie Subdivision becomes urbanized the community league could encourage dog owners to *stoop and scoop* through signage and the local media.

The Province of Alberta could join the federal government in the reduction of lead in stormwater runoff by reducing the taxes on unleaded gas to make it the same price as leaded, until leaded gas is no longer available in Canada (International Joint Commission, 1980). This would encourage people to leave the pollution control devices on their veicles and use the non-leaded gas.

The local government, the City of Edmonton, may also be involved in the maintenance of the stormwater lakes in the Ellerslie Subdivision and in community awareness, this will be discussed below.

6.5.2 Maintenance

Local governments are usually responsible for maintenance of stormwater lakes and the surrounding park areas, after the one or two year period of developer responsibility (Poetner, 1980). Such is the case in Edmonton, where the Parks and Recreation Department provides upkeep of the stormwater lakes and park areas. This may not be the maintenance system that is established for the Ellerslie Subdivision. The Daon Development Corporation may be willing to provide extended maintenance of approximately five years (Winter, 1985). By the end of the five year period the residential neighbourhoods may be sufficently matured to have a strong community league which would become responsible for maintenance of the stormwater lakes on their own or in conjunction with the City of Edmonton. As noted in section 6.2.2, Ducks Unlimited may provide maintenance of the wetlands.

The legal responsibility for maintenance of the stormwater lakes and wetlands should be established early in the planning-development stages.

Regardless of whoever is eventually responsible for maintenance of the stormwater lakes, the Daon Development Corporation is intial ly responsible for the design, contruction and early maintenance of the impoundments. The wetlands will likel be developed in association with Ducks Unlimited. How the stormwater lakes and wetlands are designed will affect maintenance procedure. The author's design recommendations for the stormwater lakes are given in section 6.2.3. The recommendation for total public ownership of land directly adjacent to the stormwater lakes and wetlands will ensure easy access for maintenance, as well as a consistent level of service.

In-water recreation should be possible in the large recreation/ stormwater lake if the design suggestions given by the author implemented by the developer. Primary contact water based recreation by residents will necessitate testing of water quality on a regular basis. This service is provided by both the Province of Alberta and the City of Edmonton. The Daon Development Corporation will determine which procedure is the most appropriate or if both will be necessary. Minimum levels of water quality for primary contact recreation, enforced by the local board of health, will have to be met.

Also, people active in water based recreation will require supervision. Daon Development Corporation, the City of Edmonton or the Ellerslie Subdivision community league will, therefore, be required to provide lifeguard services. Who pays for this service should also be established in the maintenance agreement.

It will also be necessay to decide upon who has responsibility for maintenance of the park space surrounding the stormwater lakes and wetlands. Extra care by the personnel in keeping the green space free of grass cuttings, seeds and leaves will aid in the control of nutrients in the impoundments.

Occasional maintenance in the form of opening and closing the hand operated weirs, holding the runoff in the wetlands, will also be required l. The simple structure used for collection of floatables will need to be cleaned periodically. The wetlands themselves will require minimal upkeep, excepting sporadic harvesting of the large plants in the fall to reduce the possibility of the creation of a nutrient sink.

The large majority of nutrients will be kept out of the stormwater lakes by various methods, especially the wetlands. Nevertheless, in time, the stormwater lakes and wetlands may require maintenance to decelerate the process of eutrophication. The traditional method for this is dredging. However, dredging is costly and time consuming. Also, dredging, by reducing the macrophytes and the attached algae will result in an increase in phytoplankton (Lee and Jones, 1980).

An alternative to dredging has been created and tested by E.A. Hickok and Associates, in Minnesota. The procedure is a sediment harrow method, modelled after a Swedish prototype, which slows the release of phosphorus in the water and reduces nitrogen through denitrification, with an injection of calcium nitrate into the bottom sediments. The process which was tested in Long Lake part of the Rice Creek Watershed District, was successful in improving the lake water quality. Also, the harrow sediment treatment was completed in five weeks, compared to the six months needed for dredging, and at a 75 percent savings in cost over the conventional dredging method (Willenbring, Miller and Weidenbacher, 1985; Hickok and Associates, 1985). E.A. Hickok and Associates received an award from the Smithsonian Institute for the planning, development and testing of this method (Hickok, 1985).

The stormwater lakes in the Ellerslie Subdivision will not require work to stop eutrophication for decades. By then, it is likely that the sediment harrow method described above will be more common, with a Canadian firm able to provide the service. The procedure used will be decided upon by whomever is responsible for maintenance at that time.

Responsibility for maintenance of the multi-purpose stormwater lakes and wetlands, in the Ellerslie Subdivision, will eventually fall with the Parks and Recreation Department of the City of Edmonton or the community league made up of local residents. Either way, the task of keeping the lakes clean, water quality high and the wetlands functioning well, will be lessened if the community members are aware of their role in reducing the effects of urbanization on stormwater.

6.5.3 Community Awareness

Most members of the public have a limited awareness of where the rain and street litter go after a rainfall event and few realize that runoff usually enters a stream untreated. A public educated in the function of the lakes, wetlands and other components of the stormwater management strategy for the Ellerslie Sudivision and in their role in the scenario, could be valuable to those responsible for the maintenance of the system. If the Subdivision community members are made aware that their actions are reflected in the quality of the lake, the actions of the residents may change.

Awareness of the stormwater management system should begin as soon as a potential home buyer shows interest in the Ellerslie Subdivision. Often the primary function of stormwater impoundments is shielded from the public. The education can continue into the building stage as home owners are encouraged to use grass pavers or porous pavement for their driveways, and to use rain barrels and other on-site measures (see section 6.2.5). Also, the residents should be encouraged to plant grass, trees and other vegetation as quickly as possible. Inspiration could come from the developer by vegetating public areas early in the development process.

The education on the responsibility of citizens in maintaining high water quality in the lakes and wetlands should begin with the introduction to the Subdivision and continue as an on-going process. This responsibility is to not add to the pollutants which collect in the streets and become part of the urban runoff. Awareness programs in other locations have had positive results (Poetner, 1980; Finnemore, 1980). For example, in Madison, Wisconsin, a strong citizen leaf control program was instigated, after the public showed concern for water quality, and this was successful in reducing nutrient loadings in the lake (Ahern, Armstrong and Stanforth, 1981).

The awareness program for the Ellerslie Subdivision should deal with the refraining from dumping anything into the streets or natural drainage courses including leaves, seeds, grass clippings, animal droppings, used vehicle oil, paint, household cleaners, cigarette butts and other litter. Encouraging the residents keep the streets as clean as possible is especially important in Edmonton where street sweeping is not done as often as it should be. Residents must be shown how their actions directly affect water quality.

Residents can also have an effect on runoff yield. The, increasingly popular practice of using impervious inter-locking concrete pavers in large areas of private yards should be discouraged in the Ellerslie Subdivision as the stormwater yield would be increased by such methods. The more positive on-site hard surface infiltration alternatives should be encouraged in the public awareness process (see Section 6.2.5. and Chapter 3.3.3

Who provides the education programs for the Ellerslie Subdivision is closely linked to maintenance responsibility. Therefore, the developer, Daon Development Corporation, will provide the information early in the life of the subdivision . After a few years, as maintenance responsibility shifts, so will the education responsibility of either the City of Edmonton, the community league or a combination of both.

The education process will involve the production of literature, workshops, signage and personal exchange of information. Field (1980) writes that government sponsored films (videos) on urban stormwater control should be made available to community groups.

An extension of the concept of residents taking responsibility for runoff from their property is that they feel financially responsible for high quality maintenance of the recreation areas, including the recreation/ stormwater lake. This will be discussed in the following section.

6.5.4 Acceptance of Non-conventional Approaches to Stormwater Management

Changes are taking place in the approach of developers and government agencies to urban drainage and stormwater management. Many of the alternatives recommended above for the Ellerslie Subdivision are non-traditional and will require change in the way that Daon Development Corporation develops the site and in the approval process by the City of Edmonton.

After citing many problems associated with a stormwater lake (Beaumaris) in the city of Edmonton, Hinch (1984:125) writes that: "Assuming that all parties involved have learned from the problems associated with the earlier lakes such as Beaumaris, the current trend toward the development of urban stormwater lakes should continue with the recognition that the lakes can play an important role by providing richness and variety within the urban environment".

From the Beaumaris example it is hoped that the City of Edmonton has understood the importance of water quality in a recreation/ stormwater lake and maintenance of the lakes and surrounding areas. Also, it is important that the City recognize the potential of stormwater lakes to be multi-purpose facilities. Change is required from the way that, at present, all stormwater lakes are generalized into one type of land use category. The existing zoning procedure does not reflect the potential for multi-purpose lakes.

The Daon Development Corporation would be providing a useful prototype should they develop the multi-purpose stormwater/ recreation lake and wetland treatment system. The role of the City of Edmonton could be to encourage the development of multi-purpose facilities through land dedication allowances.

The present interpretation of The Planning Act, 1980, used by the City of Edmonton, assumes that a stormwater lake is useful only for the single purpose of the utility of runoff drainage and is assigned the land use zoning of Public Utility Lot (PUL). The PUL area is not part of the 10 percent of land that is required as dedication from the developer to the City. Many people including the author, Stanley Associates Engineering (1984) and the Edmonton Regional Planning Commission (1979) feel that some flexibility is needed in land use policies which are relevant to stormwater lakes.

In the case of the Ellerslie Subdivision it would be more appropriate to zone the main recreation/ stormwater lake and some of the smaller stormwater lakes as Municipal Reserve (MR) because they will form major recreation sites within the community (The Planning Act, 1980; section 99(1)). The City of Edmonton will not readily agree to this because of its experience with stormwater impoundments; most of which have been single purpose lakes with no treatment of runoff. Daon Development Corporation will be required to demonstrate how the wetlands and other alternatives will be incorporated into the management system to improve the runoff quality. The work in this thesis will, hopefully, be useful in the explanation of the wetland treatment system by Daon Development Corporation to the City of Edmonton.

The wetlands, natural drainage systems and some of the stormwater lakes, which incorporate existing ponds, would be suitable for classification under the Environmental Reserve zoning (The Planning Act, 1980; section 98). To gain approval for these as Environmental Reserve dedication the Daon Development Corporation must take precautions in the grading of the site to ensure that these features remain in their natural state.

The issue of land dedication is important to Daon as the 10 percent of the development (or money in lieu of) that must be given to the City represents a substantial amount of capital. If the developer were able to include parts of the stormwater system under the reserve requirements then additional funds would be available for the creation of recreational amenities. All those involved in the Ellerslie Subdivision would gain from a more progressive arrangement. The City of Edmonton would gain a low maintenance multi-purpose lake-wetland recreation system within its boundaries. The Daon Development Corporation will save a portion of the large investment required for an urban drainage system and they will have a series of amenities to offer potential buyers. New residents will gain from the easy access to water based recreation and educational wetlands. Also, professionals involved in stormwater management will have a Canadian state-of-the-art stormwater management prototype to observe.

As discussed above, community awareness will be important in the optimal functioning of the stormwater management system. And once the urban drainage system and its relation to recreation is understood it is likely that residents will be willing to pay for maintenance, as has been found in other studies (Baxter, Mulamootil and Gregor, 1985; Debo, 1977). Therefore, whoever finally becomes responsible for maintenance could implement a system of payment for the service. This could be in the form of a membership to the community league or a utility payment to the City. Such a system has been successfully used in Boulder, Colorado where an equity tax is applied for use of drainage facilities. Incentives are available for reducing runoff from a private site or to a developer for providing extra storage (Thompson, 1982). Other authors have found that once educated on the subject of urban stormwater management, people generally accept the drainage utility fee as they do other utilities which are provided for them (Poetner, 1980; Finnemore;1980).

Therefore, the residents of the Ellerslie Subdivision will have to accept change, as will the City of Edmonton and the Daon Development Corporation, to have a successful multi-purpose stormwater management system.

6.6 Legal Aspects of Stormwater Management for the Ellerslie Subdivision

As discussed in Chapter 3.4, legal issues affecting stormwater management include riparian rights, liablity and maintenance.

The issue of riparian rights will not affect the Ellerslie Subdivision (assuming the recommendations given in this thesis are incorporated) as there will be no privately owned land abutting the water bodies (excepting the natural drainage channels). The land surrounding the lakes will be public park land, maintained initially by the Daon Development Corporation and then by the City of Edmonton or the community league.

Daon Development, along with whomever is responsible for long term maintenance, will be expected to provide extensive safely measures to ensure no accidents take place. Liability for accidents in stormwater lakes has yet to be assigned to any party in the Canadian courts.

Responsibility for maintenance of the stormwater lakes, natural channels and wetlands in the Ellerslie Subdivision should be established early in the planning process. A legal agreement outlining the responsibility of the developer in the building and maintenance of the facilities with requirements for safety should be made between the Daon Development Corporation and the City of Edmonton. Also included in this document should be a recognition of where maintenance responsibiltiy falls once Daon's time period is over. By initiating such an agreement, Daon Development Corporation would be expressing to the City of Edmonton their long term committment to the Ellerslie Subdivision.

6.7 Summary

By meeting the objective of minimizing negative changes to the hydrologic cycle to as little change as possible, the alternatives given in this chapter, if used by the developer, will substantially reduce the runoff yield and pollutant load that would normally accompany the urbanization of a new urban area. This in not to say that the natural system is perfect. Flooding can take place in a natural environment, as it did in the Ellerslie Subdivision area during 1974. However, significantly less runoff flows from the Ellerslie Subdivision under existing conditions than would if it were urbanized using the conventional drainage technologies. Therefore, the developers of the new urban area should incorporate alternatives which are the least damaging to the environment and make the most use of the resource. Also, the alternatives proposed should, to some degree, lessen the intensity of the high flow periods and drought conditions.

Using traditional technologies, the Ellerslie Subdivision would generate, on average, 3,000,000 cubic metres of urban runoff annually, as well as 1700 kilograms of nutrients and 270,000 kilograms of suspended solids and associated pollutants, per year (see Chapter 5.5, 5.6). Use of the management alternatives discussed would reduce these values by at least 50 percent. The management alternatives include wetlands and other means for treatment of runoff, stormwater retention impoundments, natural drainage channels and various on-site storage and infiltration methods.

The use of the treatment methods outlined will enable the runoff to be used within the Subdivision for recreation and irrigation and to augment municipal supplies. The recreation component of the management system is another primary use of the multi-purpose stormwater lakes.

7. SUMMARY

7.1 7.1 Summary and Conclusions

As an area becomes urbanized, forests, fields and wetlands are replaced with buildings and roads. Under traditional development conditions this change would drastically reduce infiltration and evapotranspiration rates and result in increased yield and peak flow. The alterations to the hydrologic cycle also result in changes in the receiving stream morphology and baseflow as well as in increased erosion levels. Also, accompanying the increase in total volume of runoff, with urbanization, are numerous pollutants including nitrogen and phosphorus, sediments, toxic metals, petroleum hydrocarbons, organic chemicals and chorides. Most of the pollutants are associated with the total suspended solids.

Stormwater management techniques are incorporated into a subdivision design to deal with the changes in runoff as an area becomes urbanized. Conventionally, only peak flow is regulated by municipalities in Canada so it is only peak flow that has been considered in drainage plans. This has resulted in a general approach to urban runoff that management merely involves the use of gutters and storm sewers to rush the stormwater from the area as quickly as possible. Nevertheless, change is underway in the stormwater management field.

Urban stormwater management is evolving into a multiple objective practice. A multidisciplinary team approach to urban drainage will ensure that the numerous objectives are considered. These objectives include the reduction of total flow volumes and pollutant loads, preservation of highly pervious areas such as forests and natural channels, provision of recreation and aesthetic areas and the use of runoff within the new urban area as well as the traditional objectives of minimizing property damage and providing flood control.

In this thesis, annual runoff yield data were used to form the basis for the stormwater management proposal. The runoff yield modelling was chosen because of the project requirement for an overall impact of urbanization of the Ellerslie Subdivision on the receiving streams and water bodies. The Thornthwaite water balance procedures (Thornthwaite, 1957;

Thornthwaite and Mather, 1955, 1957) were used to estimate potential evapotranspiration and resulting surpluses (runoff) for various land use storage depths over a ten year period. This modelling revealed that the incorporation of conventional technologies in the urbanized Ellerslie Subdivsion would result in an average increase of over 7 times the existing annual water yield.

The runoff yield data were then utilized to make projections of the annual pollutant load in the surface runoff. It was found that the potential average annual volume of 3,000,000 cubic metres of urban runoff would be accompanied by 1700 kilograms of nutrients and 270,000 kilograms of sediment and associated pollutants.

The data were then used in the production a stormwater management proposal for the Ellerslie Subdivision. The use of annual runoff yield data in the design of a stormwater management system is what sets this study apart from previous works. Numerous studies have been conducted on increases in annual runoff yield with urbanization (Waananen, 1969; James, 1965; Hollis, 1977; Muller,1967; Hartman, 1972; Laycock and MacKenzie, 1984). However, these authors do not discuss design alternatives to accomodate the potential stormwater yields. Also, stormwater management proposals for new urban developments are submitted on a regular basis across Canada but the engineers writing the reports use peak flow data for various design storms to create the management scenario (Stanley Associates Engineering Ltd., 1980a,b; Paul Theil Associates Ltd., 1983; Fred Schaeffer and Associates Ltd., 1987). Therefore, the use of annual yield data and runoff quality projections, which demonstrate the effects of urbanization on receiving streams and water bodies, to propose stormwater management alternatives is innovative. This is not to suggest that peak flow data should not be used but, if storage is provided to the degree noted for peak flows then monthly and annual values become more important in facilities design.

The proposal discussed in detail, in Chapter Six, is the author's preference of the four alternative futures outlined.The stormwater management scenario proposed by the author would reduce the total annual yield and total yearly pollutant load by at least 50 percent. This would be accomplished through careful design early in the plannning stage and with conscientiously applied construction techniques. Existing treed sites will be incorporated into park areas. Wetlands and natural drainage channels will be preserved and linked to form part of the runoff storage and transportation system. Pre-urbanized infiltration rates would be replicated through the use of grass pavers, porous pavement and vegetated swales. Various erosion control methods are proposed for use during the construction phase. And, recreation and aesthetic requirements will be met through the provision of multi-purpose stormwater lakes and wetlands.

The stormwater management proposal includes numerous treatment techniques, noteably the the use of wetlands, that could be incorporated into the system to treat the runoff so it would be useful within the community.Also, after treatment the runoff would be less detrimental to the receiving stream, Blackmud Creek and the major water body present, Cawes Lake.

As well, after treatment and/ or storage the runoff could be used within the Ellerslie Subdivision for recreation, irrigation, industrial supply and groundwater recharging. This use of urban runoff will tranform the stormwater into a resource, within the Ellerslie Subdivision.

Substantial financial savings may be made by the use of the non-conventional approach to stormwater management in the Ellerslie Subdivision. Urban drainage is the largest servicing cost supplied by the developer. The utilization of natural and open channels, in most areas, to supplement of underground sewers would reduce these costs significantly. Furthermore, the many techniques employed to reduce total volume and increase infiltration would result in less runoff flowing into the stormwater transportation system. And, the use of stormwater to augment municipal supplies would also contribute to the financial savings within the Subdivision. The various alternatives including the wetlands and clean stormwater lakes would be financially positive as the developer would have marketable amentities to offer potential home owners.

As proposed, the new residents of the Ellerslie Subdivision would be made aware of the effects of urbanization on stormwater runoff and their role in the optimum functioning of the runoff management strategy.

Also, maintenance and liability responsibility for the wetlands, open channels and the stormwater lakes would be established early in the planning process through legal agreements.

In summary, the developer of the Ellerslie Subdivision, Daon Development Corporation, by using the stormwater management system recommended by the author in this thesis, has the opportunity to create a subdivision that would:

1. a) have at least 50 percent less total runoff yield and pollutant load than would normally accompany urbanization,
2. b) encompass multi-purpose stormwater lakes that would be of sufficient water quality to allow for primary contact water-based recreation,
3. c) include wetlands that would be highly aesthetic, provide treatment of runoff and be educational sites, and,
4. d) save substantially on drainage costs.

7.2 Future Research

Stormwater management and urban hydrology are relatively new topics of research, a great deal of which is done at the practitioner level. Nevertheless, there is a lack of published Canadian information. As most Canadian jurisdictions responsible for stormwater management, and many of the Albertan municipalities, do not yet have regulations or policies requiring developers to consider runoff yield or quality, little research has been done on these important aspects of urban drainage. Therefore, the author recommends that the various agencies involved in stormwater management continue to consider runoff yield and quality regulations and related policies to protect our water resources.

The production of regulations controlling stormwater volume and quality from new subdivisions, and smaller developments, will be the most cost effective approach to reducing the effects of urbanization on receiving streams. The Metropolitan Toronto and Region Conservation Authority is, at the time of writing, considering the possibility of stormwater yield a ity control policies.

ey, Hanman and Cantor (1980) suggest the use of local ordinances to control the stormwater volumes and quality from a new urban area. The ordinance would also be used to protect natural systems and establish maintenance responsibility early in the subdivision approval process. Axline (1982:200) agrees with the creation of ordinances for the control of runoff pollution and volumes and suggests that they be: "regulations that are politically acceptable to local governments, yet are strong and specific enough to be enforceable".

However, the policy makers will require regionally specific information on stream flow to ensure that quality and volume regulations are not unreasonable. Also necessary, is additional research into multi-purpose facilities, especially those which will reduce non-point pollution.

Encouragement for research and practice of multiple means, multiple purpose alternatives could be in the form of government grants (Goldfarb and King, 1982; Piecuch, 1983). The grants program could be from either federal or provincial governments. Although it is likely that the funds would be distributed and projects monitored by the province because water resources and related land management fall largely under provincial jurisdiction. Or, in areas where the local municipalities are responsible for stormwater management, the municipality may choose to monitor the grant program.

Funding should also be made available to universities to study annual yield and pollutant load in urban runoff for the policy makers. Also, as urban stormwater is, ideally, a multidisciplinary issue, non-engineering faculties should be provided with financial incentives to conduct research in this engineering dominated field.

As well, further research is required concerning the individual pollutants in urban runoff (especially PCB's and petroleum hydrocarbons), the total annual yield (which carry the pollutant load), long term value of wetlands in urban areas, use of runoff, legal aspects of stormwater, long term studies on natural drainage systems and in the management techniques which simulate pre-urban infiltration rates.

The stormwater management system proposed by the author, if incorporated into the Ellerslie Subdivision, could be a prototype for a long term study of natural drainage systems. The study could be a test how of effectively the effects of urbanization could be reduced through the low and non-structural alternatives which are recommended. The water quantity and quality levels of Blackmud Creek, Cawes Lake and the wetlands could be monitored before, during and at various intervals after the construction period. Should the monitoring of the stream flows and water quality reveal that the stormwater management proposal discussed in this thesis is as successful as is anticipated then other developers may incorporate the proposed techniques in their new urban areas.

The stormwater management proposals provided by the author, if developed, could be used to demonstrate that when the processes of nature are considered, the resulting design is of value to both the members of the community and the environment.

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Appendix A

Thornthwaite Data (1975- 1984) Tables 1- 10.

Month	Ppt mm	PE mm	Surplus 2mm	13mm	50mm	100mm	150mm	250mm	Deficit 50mm	100mm
April	29.8	19.2	20.4	17.1	17.1	0	0	0	0	0
May	52.5	73.2	24.6	8.9	8.9	0	0	0	0	0
June	99.7	102.6	63.0	37.6	0.6	0	0	0	29.6	0
July	68.7	127.9	32.7	11.6	0	0	0	0	13.4	0
August	98.5	86.0	46.3	23.9	0	0	0	0	25.4	24.9
Sept.	11.4	63.1	0	0	0	0	0	0	14.8	14.8
October	24.1	24.3	9.8	0	0	0	0	0	11.9	11.9
Nov-Mar.	75.1	0	[illegible]7.8	54.8	42.2	0	0	0	0	0
Total	462.7	496.3	264.6	153.9	68.8	0	0	0	95.1	51.6

Appendix Table 1. 1975 Thornthwaite data for various storage depths for the Ellerslie Subdivision. (Source: author; Environment Canada, Annual Meterological Summary for Edmonton International Airport).

Month	Ppt mm	PE mm	Surplus 2mm	13mm	50mm	100mm	150mm	250mm	Deficit 50mm	100mm
April	11.7	41.8	5.5	0	0	0	0	0	0	0
May	30.2	82.2	8.1	0	0	0	0	0	33.1	0
June	90.8	89.6	42.5	21.9	0	0	0	0	22.7	22.7
July	74.7	112.4	35.3	13.3	0	0	0	0	40.1	40.1
August	111.1	109.2	65.4	31.4	0	0	0	0	0	0
Sept.	43.0	70.2	26.8	7.2	0	0	0	0	3.1	3.1
October	9.9	24.5	2.4	0	0	0	0	0	14.6	14.6
Nov-Mar.	86.6	0	48.5	48.5	33.6	0	0	0	0	0
Total	458.0	529.9	234.5	122.3	33.6	0	0	0	113.6	80.5

Appendix Table 2. 1976 Thornthwaite data for various storage depths for the Ellerslie Subdivision. (Source: author; Environment Canada, Annual Meterological Summary for Edmonton International Airport).

Month	Ppt mm	PE mm	Surplus 2mm	13mm	50mm	100mm	150mm	250mm	Deficit 50mm	100mm
April	18.9	50.1	9.0	1.6	1.3	0	0	0	0	0
May	131.9	79.5	101.9	64.2	24.4	0	0	0	0	0
June	12.5	106.7	0	0	0	0	0	0	50.0	8.2
July	90.7	107.9	52.6	21.4	0	0	0	0	35.3	35.3
August	86.5	84.0	44.1	18.3	0	0	0	0	10.7	10.7
Sept.	38.0	57.7	17.4	[illegible]	[illegible]	0	0	0	0	0
October	0.4	27.8	0	[illegible]	[illegible]	0	0	0	16.2	16.2
Nov-Mar.	56.8	0	27.[illegible]	27.5	[illegible]6	0	0	0	0	0
Total	435.7	513.7	252.5	133.1	24.4	0	0	0	112.2	70.4

Appendix Table 3. 1977 Thornthwaite data for various storage depths for the Ellerslie Subdivision. (Source: author; Environment Canada, Annual Meterological Summary for Edmonton International Airport).

Month	Ppt mm	PE mm	Surplus 2mm	13mm	50mm	100mm	150mm	250mm	Deficit 50mm	100mm
April	16.1	34.1	5.7	0	0	0	0	0	0	0
May	64.2	74.1	33.0	10.4	0	0	0	0	0	0
June	40.6	112.7	6.6	0	0	0	0	0	51.2	26.6
July	63.6	120.8	31.7	19.2	0	0	0	0	57.2	57.2
August	111.4	96.9	77.0	64.0	27.0	0	0	0	44.7	44.7
Sept.	141.5	60.1	106.2	87.5	71.2	48.2	0	0	0	0
October	17.3	35.9	8.1	0	0	0	0	0	0	0
Nov-Mar.	85.9	0	63.2	52.2	18.8	0	0	0	0	0
Total	540.6	534.6	331.5	233.4	117.0	48.2	0	0	153.1	128.5

Appendix Table 4. 1978 Thornthwaite data for various storage depths for the Ellerslie Subdivision. (Source: author; Environment Canada, Annual Meterological Summary for Edmonton International Airport).

Month	Ppt mm	PE mm	Surplus 2mm	13mm	50mm	100mm	150mm	250mm	Deficit 50mm	100mm
April	31.2	17.8	27.3	26.3	26.3	26.3	26.3	0	0	0
May	36.4	63.0	23.9	5.6	0	0	0	0	0	0
June	70.3	104.0	35.2	10.4	0	0	0	0	23.2	0
July	111.0	123.1	65.7	32.7	0	0	0	0	27.0	0.3
August	40.9	102.7	12.7	1.7	0	0	0	0	46.6	46.6
Sept.	50.2	70.9	20.6	6.3	0	0	0	0	21.1	21.1
October	12.7	34.2	2.3	0	0	0	0	0	21.1	21.1
Nov-Mar.	76.8	0	85.8	80.1	61.6	61.6	59.8	0	0	0
Total	429.5	515.7	207.9	163.1	87.9	87.9	86.1	0	139.0	89.1

Appendix Table 5. 1979 Thornthwaite data for various storage depths for the Ellerslie Subdivision. (Source: author; Environment Canada, Annual Meterological Summary for Edmonton International Airport).

Month	Ppt mm	PE mm	Surplus 2mm	13mm	50mm	100mm	150mm	250mm	Deficit 50mm	100mm
April	4.0	53.6	1.4	1.5	1.5	0	0	0	1.9	0
May	43.0	85.0	24.0	13.0	0	0	0	0	60.8	16.6
June	131.9	108.2	68.2	46.0	1.6	0	0	0	0	0
July	69.2	116.3	30.3	9.0	0	0	0	0	8.2	6.6
August	194.8	86.5	150.1	125.7	66.1	16.1	0	0	1.5	0
Sept.	55.6	54.9	36.9	23.3	12.0	12.0	0	0	0	0
October	11.2	33.4	6.1	0	0	0	0	0	0	0
Nov-Mar.	105.2	0	86.1	81.7	44.7	0	0	0	0	0
Total	614.9	537.9	403.1	300.2	125.9	28.1	0	0	99.0	23.2

Appendix Table 6. 1980 Thornthwaite data for various storage depths for the Ellerslie Subdivision. (Source: author; Environment Canada, Annual Meterological Summary for Edmonton International Airport).

Month	Ppt mm	PE mm	2mm	13mm	Surplus 50mm	100mm	150mm	250mm	Deficit 50mm	100mm
April	18.3	36.1	8.8	5.5	5.[illegible]	0	0	0	[illegible]	[illegible]0
May	10.2	74.3	0.6	0	0	0	0	0	[illegible]	[illegible].6
June	151.1	100.7	109.1	93.3	54.3	4.3	0	0	5[illegible]	53.2
July	104.5	121.0	56.3	32.6	32.6	32.6	0	0	[illegible]	0
August	12.2	114.5	0	0	0	0	0	0	99[illegible]	49.9
Sept.	36.2	49.5	15.8	0	0	0	0	0	13.5	13.5
October	12.2	25.8	6.1	0	0	0	0	0	16.5	16.5
Nov-Mar.	64.7	0	40.7	40.7	14.1	0	0	0	0	0
Total	409.4	521.9	237.4	170.1	106.5	36.9	0	0	215.3	145.7

Appendix Table 9. 1983 Thornthwaite data for various storage depths for the Ellerslie Subdivision. (Source: author; Environment Canada, Annual Meterological Summary for Edmonton International Airport).

Month	Ppt mm	PE mm	2mm	13mm	Surplus 50mm	100mm	150mm	250mm	Deficit 50mm	100mm
April	6.6	39.9	1.1	0	0	0	0	0	0	0
May	55.9	66.7	27.7	2.8	0	0	0	0	10.1	0
June	66.2	104.1	34.9	18.0	0	0	0	0	19.2	10.0
July	48.2	122.0	24.8	7.8	0	0	0	0	68.4	68.4
August	30.5	114.2	1.3	0	0	0	0	0	88.7	88.7
Sept.	116.3	46.2	96.0	74.6	0	0	0	0	9.2	9.2
October	6.6	29.5	1.1	0	0	0	0	0	0	0
Nov-Mar.	118.2	0	64.8	58.7	21.7	0	0	0	0	0
Total	448.8	522.6	251.7	161.9	21.7	0	0	0	195.6	176.3

Appendix Table 10. 1984 Thornthwaite data for various storage depths for the Ellerslie Subdivision. (Source: author; Environment Canada, Annual Meterological Summary for the Edmonton International Airport).

Month	Ppt mm	PE mm	Surplus 2mm	13mm	50mm	100mm	150mm	250mm	Deficit 50mm	100mm
April	9.8	34.7	3.2	2.8	0	0	0	0	0	0
May	46.9	83.5	19.5	0.8	0	0	0	0	24.7	0
June	42.3	93.1	12.3	0	0	0	0	0	37.0	14.8
July	157.6	116.3	97.3	60.5	2.8	0	0	0	11.5	11.5
August	10.5	123.7	3.2	0	0	0	0	0	62.0	58.9
Sept.	33.4	70.7	18.3	7.1	0	0	0	0	46.8	46.8
October	30.0	24.1	21.6	9.9	0	0	0	0	0	0
Nov-Mar.	40.1	0	68.5	61.8	33.0	33.0	11.1	0	0	0
Total	370.6	546.1	243.9	142.9	35.8	33.0	11.1	0	182.0	132.0

Appendix Table 7. 1981 Thornthwaite data for various storage depths for the Ellerslie Subdivision. (Source: author; Environment Canada, Annual Meterological Summary for Edmonton International Airport).

Month	Ppt mm	PE mm	Surplus 2mm	13mm	50mm	100mm	150mm	250mm	Deficit 50mm	100mm
April	16.4	22.7	11.5	11.5	11.5	11.5	0.6	0	0	0
May	27.9	76.6	15.0	2.9	0	0	0	0	17.5	0
June	25.1	113.2	2.0	0	0	0	0	0	88.0	54.6
July	204.6	119.1	154.5	126.9	75.3	25.3	0	0	4.4	4.4
August	43.2	89.7	14.4	0	0	0	0	0	39.0	0
Sept.	35.6	65.0	17.0	5.3	0	0	0	0	21.3	10.3
October	39.1	29.3	33.4	11.4	0	0	0	0	1.6	1.6
Nov-Mar.	124.5	0	126.1	118.9	96.2	46.2	0	0	0	0
Total	516.4	515.6	422.6	278.4	183.0	83.0	0.6	0	171.8	70.9

Appendix Table 8. 1982 Thornthwaite data for various storage depths for the Ellerslie Subdivision. (Source: author; Environment Canada, Annual Meterological Summary for Edmonton International Airport).