

Zero Discharge Stormwater Management

(or Development Expediency Meets Sustainable Development)

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This chapter presents the stormwater management system for a major development area in Calgary. The stormwater management system is a zero discharge system incorporating sedimentation, biological uptake/treatment and irrigation for disposal of stormwater runoff. The system has been designed, implemented and is in successful operation. The zero discharge stormwater system allowed the development area to proceed without off-site storm services, advancing development by some ten years, and controls/mitigates the effects of stormwater runoff on receiving waters.

New analytical techniques were required to assess the operation of the stormwater system because traditional design storm based methodologies are inadequate for assessing the combined inflow, storage and disposal processes. Continuous simulation, using long-term records of precipitation, temperature, and evaporation combined with estimates of plant moisture requirements formed the basis for the design of the stormwater management system.

6.1 Introduction

As rural land is undergoing urban development there is a great increase in impervious areas such as roads, roofs, driveways or sidewalks. Further, the large amount of impervious area, in the order of 35% to 65% of the overall catchment area, is generally directly connected to the area's drainage system. These factors combine to yield higher volumes of runoff and higher rates of storm runoff for post development conditions than pre-development conditions.

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In a conventional storm drainage system either the downstream storm drainage system of pipes and/or ditches is enlarged or new storm outlets are constructed to accommodate development. In both cases there is discharge of storm runoff to a receiving waterway. No matter to what degree the rate of stormwater discharge is restricted, under post development conditions there will always be a significant increase in the volume of stormwater runoff.

In the past it was assumed that stormwater was uncontaminated and therefore was usually discharged to the nearest watercourse without further concern. It is now generally recognized that stormwater runoff is a significant source of pollutants to receiving waterways.

The Hamptons is a new residential and golf course development in northwest Calgary. The Hamptons is located in the Nose Creek drainage basin, draining to West Nose Creek (Figure 6.1). The rate of stormwater discharge to West Nose Creek is restricted to the capacity of the receiving waterway (Stanley, 1986). The Nose Creek drainage basin is in turn a component of the Bow River basin in Alberta. The Bow River is a world-class trout fishery and has been selected for protection by the regulating authorities, Alberta Environment and the City of Calgary. The City of Calgary and Alberta Environment have implemented stormwater quality enhancement requirements for all new development in Calgary draining to the Bow River system.

This chapter addresses work undertaken by the authors in previous employment with JNMacKenzie Engineering Ltd. (JNM).

6.2 Issues Facing the Development

The natural drainage path from the development area was outside of the City limits of the City of Calgary. Due to provincial legislation, agreements with downstream landowners would be necessary for the discharge of urban runoff into the existing intermittent drainage courses. Alternatively easements would be required from affected landowners to construct a piped storm sewer to West Nose Creek. It proved to be impossible to obtain the necessary agreements and easements from the landowners involved.

6.3 Approach to Development

Storm discharge to West Nose Creek from new development areas, including the Hamptons, is subject to a restriction in maximum flow rate of 2.6 L/s/ha for up to and including a 1 in 100 y return period runoff event based on basin studies completed previously (Stanley, 1986). Stormwater detention is required to

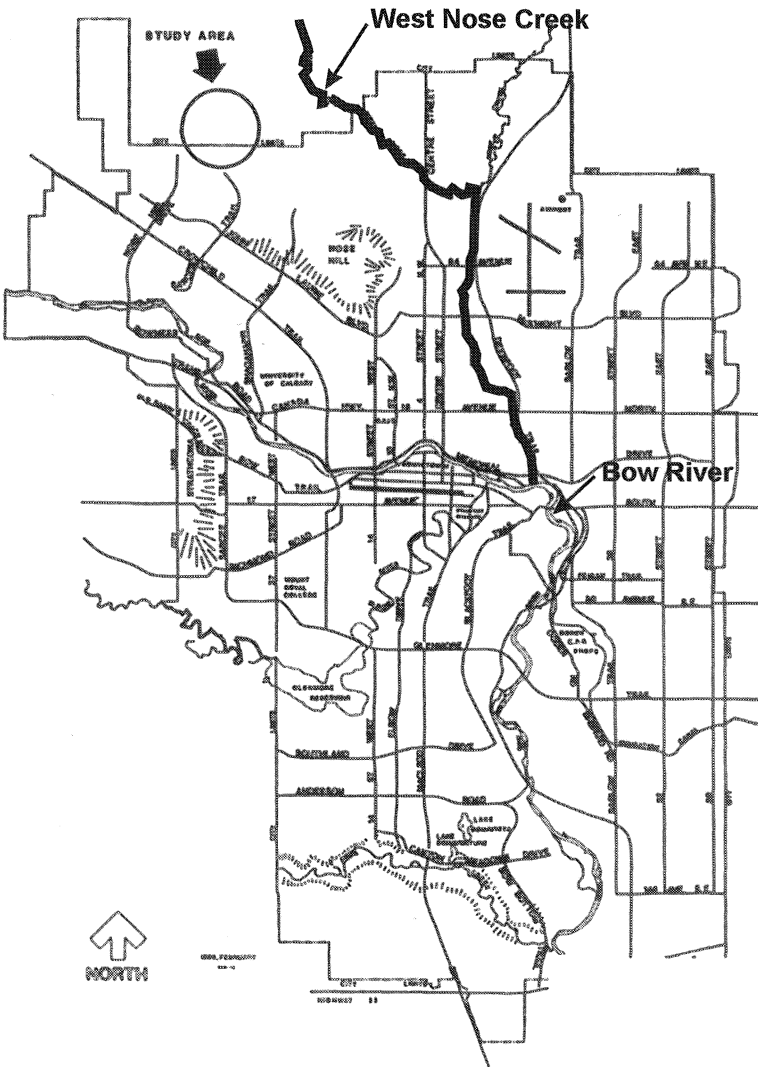


Figure 6.1 Location plan. Interim off-site drainage.

reduce the rate of storm runoff. Thus, the stormwater management planning for the Hamptons development area considered the use of stormwater detention facilities from the onset. The critical issue delaying the development of the Hamptons area was the lack of an off-site storm sewer to dispose of stormwater runoff after retention of the runoff in stormwater detention facilities.

Development planning was revised to include a golf course as an amenity and marketing feature. A golf course provides the physical location for the necessary stormwater detention facilities, and more importantly, the means of disposal of the stormwater runoff through irrigation.

The approach of temporarily storing all stormwater runoff in stormwater storage facilities and then disposing of the runoff by irrigation on the adjacent golf course provided several benefits:

- advancement of the project development schedule;
- reduction of post development flows in the receiving waterway;
- reduction of off-site storm drainage costs, albeit at increased on-site costs;
- reduction of pollutant loading to receiving waterway; and
- a significant step towards sustainable development through reduction of off-site quantity and quality assimilation demands and re-use of stormwater runoff

6.4 The Stormwater Management System

6.4.1 The Study Area

The development area is situated north of the Edgemont/Hawkwood development area (Figure 6.2). It is bounded on the west by Sarcee Trail NW, on the east by Shaganappi Trail NW, on the north by Stoney Trail NW (Transportation and Utility Corridor) and on the south by Country Hills Boulevard NW.

The study area changed under interim and long-term development conditions (Figure 6.2). As part of the normal development process the drainage boundaries will change as a result of re-contouring the land to make it more suited to urban development and neighborhood layout. The stormwater management system was designed to accommodate the changing drainage patterns and boundaries. Under interim development conditions the stormwater detention facilities serviced development within the Hamptons development area, the pre-development area west of Sarcee Trail NW, and the pre-development area to the east of the Hamptons. Interim development comprised some 230 ha while long-term development comprises some 189 ha.

6.4.2 Off-Site Considerations

Storm runoff from both the interim and long-term Hamptons Catchment area is retained on-site in stormwater detention facilities on a golf course within the overall development area. Stormwater runoff is disposed by means of golf

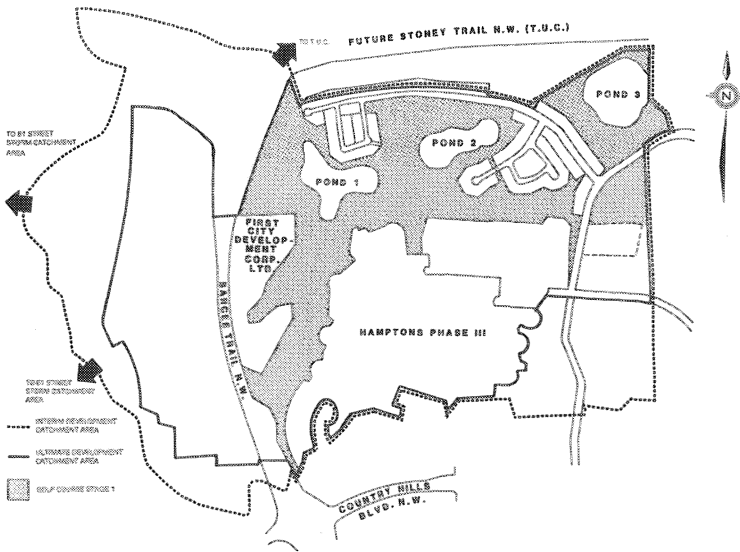


Figure 6.2 Study area.

course irrigation under long-term development conditions. However, until the golf course was constructed and the golf course irrigation system was functional, an interim stormwater disposal system was required.

Interim disposal of storm runoff was accomplished using an automated, real time control, off-peak system discharging to the existing storm sewer system outside the Hamptons catchment area (Figure 6.3). A lift station discharged stormwater through a force main from the detention facilities at the capacity of the off-site storm system. The automated control system prevented pumping of stormwater during storm events; pumping was only allowed when capacity was available in the off-site storm system. The design and operation of this temporary system was verified with a continuous simulation model. This verification process confirmed the viability of detaining the stormwater runoff in a system controlled in real time, based upon downstream system capacity.

As the golf course construction is now completed and the golf course irrigation system is in operation, the stormwater runoff is disposed of by golf course irrigation. Stormwater runoff is pumped to the golf course irrigation system at an average rate of $0.023 \text{ m}^3/\text{s}$ for the period May 1 to October 31. The pumping rate of $0.023 \text{ m}^3/\text{s}$ was derived from a maximum irrigation demand of 300 acre feet ($370,000 \text{ m}^3$) apportioned over the May 1 to October 31 period. Golf course peak irrigation rates will be determined by available time for irrigation, typically after golfing hours.

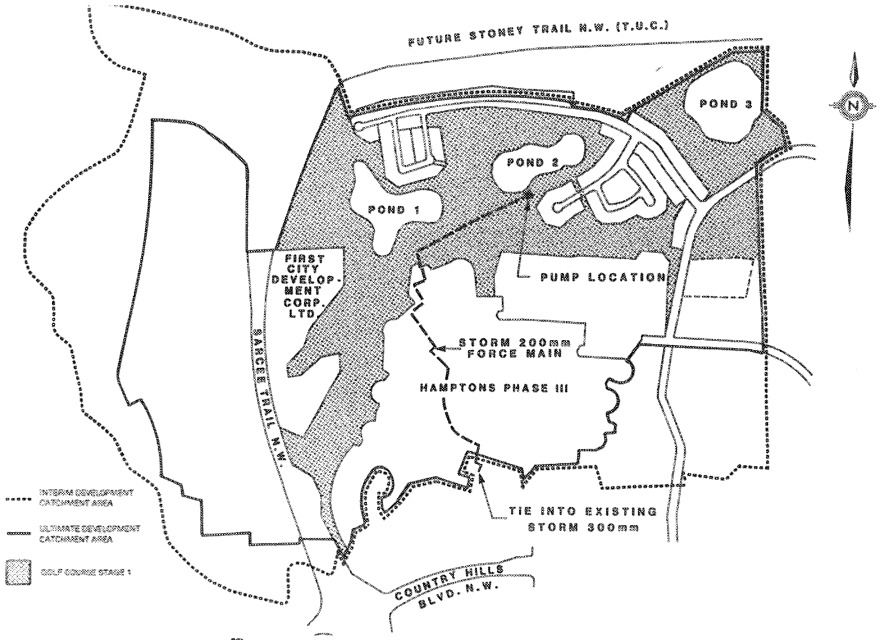


Figure 6.3 Interim off-site drainage.

Regulatory agency policies do not allow the design of systems that apply irrigation amounts in excess of the plant demand. That is, no system of this type can be implemented if it relies upon groundwater infiltration as a part of the disposal mechanism. The only disposal route is through the consumptive use of the applied irrigation water through plant uptake and transpiration. Therefore, the irrigation system does not operate during periods of rainfall or when the surface soil on the golf course has sufficient moisture to provide optimum plant growth. The analysis with the continuous simulation model accounted for irrigation demand only during the growing season and the decreased irrigation demand during and following rainfall events.

6.4.3 Physical Layout of the Stormwater Management System

The development area contains a deep ravine. The ravine area was generally too steep for residential development. The stormwater detention facilities required for stormwater runoff were located in the lowest part of the development area, the ravine area. Construction of dams across the ravine created reservoirs for storage of stormwater runoff.

The overall stormwater management system comprises the three stormwater detention facilities, the conveyance works between the individual facilities and the golf course irrigation system, and the outlet for the overall system. The three stormwater storage facilities were located in the bottom of the ravine; the facilities are at different elevations, Pond 1 being the highest and Pond 3 the lowest (Figure 6.2).

At permanent water level (PWL) the stormwater storage facilities contain approximately 160,000 m³ of water. This storage volume is often referred to as dead storage and is not available for irrigation. The three stormwater storage facilities are sized such that the water level fluctuation above the PWL for Ponds 1 and 2 in a 1 in 100 y event will be 2.0 m, and 2.25 m for Pond 3. The detention volume, some 170,000 m³, is contained in the live storage above the PWL. The available live storage is sufficient to contain a 1 in 100 y return period detention volume. Through the continuous simulation analysis the determination of detention requirements considered extended storm periods and short dry periods when no irrigation would occur. The system is also designed to eliminate the detained volume in each year of operation in order to eliminate annual carry over of detained volumes.

6.4.4 Project Design Flood

The stormwater storage facilities are impoundments behind dams across the ravine in the golf course. As such, the design of these facilities is governed by the regulations of the Water Resources Act, Dam and Canal Safety Guidelines (Alberta Environment, 1983).

The recommended project flood is based on the size and hazard potential classification of the structure in question (Alberta Environment, 1983).

The hazard potential related to a dam is dependent on physical size, capacity and downstream conditions. The hazard potential relates to the potential for loss of life or damage should the dam overflow in an emergency event.

The determination of the hazard potential is somewhat subjective. There is no immediate development planned downstream of the three stormwater storage impoundments in the Hamptons. Therefore no loss of life is expected and economic damage is expected to be minimal should the storage capacity of the dam be exceeded.

The Dam Safety Branch guidelines state that for each individual project, a design flood must be calculated by an acceptable method and routed through the catchment area, reservoir and outlets without affecting the integrity of the dam.

Based on the Alberta Environment guidelines, the recommended project flood for these facilities is the 100-y to 0.5 probable maximum flood (PMF) flood. The PMF for the urban catchment of the stormwater storage facilities was defined as the flood that would result if all climatic conditions were at the condition that would result in the maximum precipitation possible for the catchment area.

On a conservative basis a 0.5 PMF was selected for the stormwater storage facilities as the project design flood.

The 0.5 PMF project design flood was calculated on the basis of applying one half of the probable maximum precipitation (PMP) over the catchment area. Point values for PMP over a 10-d period were obtained from Atmospheric Environmental Services for the Calgary area. The PMP values for a 6 h duration were used as the critical short duration high intensity component of the overall 10 d period. The mass of rainfall for the following hours were averaged in order to achieve the 10 d total precipitation. These values were then divided by two to obtain the values for 0.5 PMP and plotted against time (Figure 6.4).

The 0.5 PMP was input to the simulation model to produce a runoff hydrograph that was routed through the catchment area to the three stormwater storage facilities. There is no piped discharge from the three stormwater storage facilities and hence no overflow from the facilities would be allowed.

The 0.5 PMF project design flood has a runoff volume of 371,400 m³. The project design flood will be detained within the three stormwater storage facilities with a water level fluctuation of 4.25 m above PWL. There is an additional freeboard allowance of 1.0 m above the project design flood level in the facilities.

6.4.5 System Operation

The three stormwater storage facilities in the Hamptons are designed to function as one system in terms of storage. As the three facilities are at different elevations, and have different contributing areas, an automated control system that regulates water levels on individual ponds and discharge between ponds was utilized. The automated control system is equipped with sensing devices that continuously monitor water levels, spilling from upper ponds to lower ponds or pumping as required to maintain prescribed water levels on individual ponds. Overshot gates that can maintain a selected upstream water level for variable discharge control the interconnection between ponds.

The catchment areas tributary to respective facilities and the size of the individual facilities are not proportionate. Most of the overall catchment area drains to Pond 1. Pond 1 is at the highest elevation of the three ponds in the overall system. The large catchment area to Pond 1 dictates that the storage

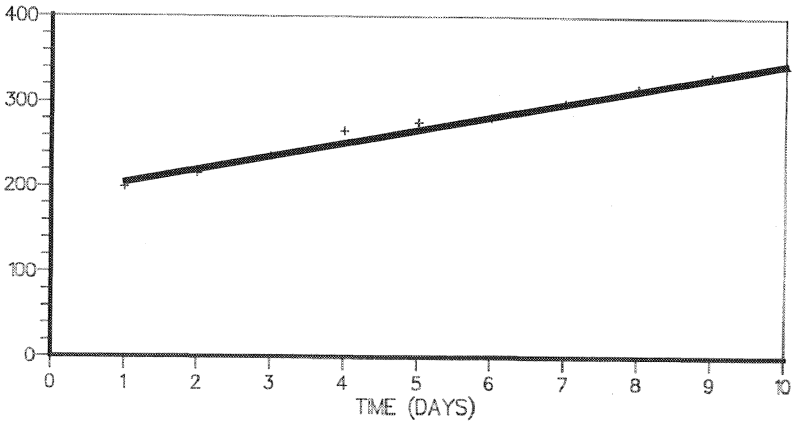


Figure 6.4 Calgary probable maximum precipitation.

capacity of Pond 1 is fully utilized and that flow to the downstream ponds will occur. Overflow from upper ponds to lower ponds is conveyed by means of a gravity pipe network from Pond 1 to Pond 2, and from Pond 2 to Pond 3. Water can be re-circulated from Pond 1 to Pond 2 and Pond 3 by means of the irrigation distribution system.

The automated control system regulates water levels in the three ponds, pumping or spilling as required to maintain specified water levels. Since completion of the golf course and its associated irrigation system, stormwater is disposed by means of golf course irrigation. No discharge from the stormwater management system takes place during periods of rainfall as the golf course irrigation demand is satisfied by rainfall at that time. Prior to the completion of the golf course, stormwater was disposed by an automated off-peak discharge system to the existing piped storm drainage in an adjacent catchment area.

The operation of the stormwater management system is summarized in Figure 6.5.

1. Up to a 1 in 100 y return period runoff event
 - Ponds 1 & 2 operated to the same levels
 - No discharge to Pond 3 until Ponds 1 & 2 reach 2.0 m of live storage
 - Maximum water level in Ponds 1 & 2 is 2.0 m above PWL
2. During a 1 in 100 y return period runoff event
 - Ponds 1 & 2 maintained at 2.0 m above PWL, spilling to Pond 3
 - Pond 3 fills to 2.25 m above PWL

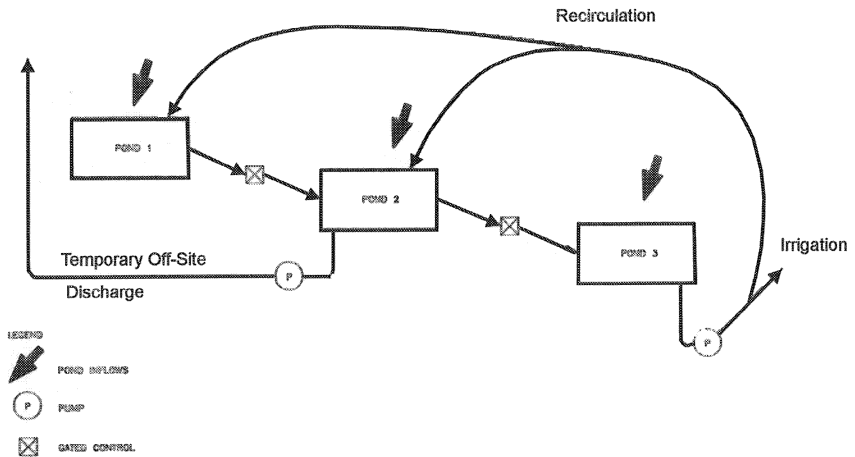


Figure 6.5 Distribution of 24-hr 0.5 PMF rainfall.

3. Greater than a 1 in 100 y return period runoff event
 - Ponds 1 & 2 rise together above 2.0 m above PWL
 - Pond 3 has local inflow and fills above 2.25 m above PWL
 - No spill to Pond 3 from Ponds 1 & 2 until Ponds 1 & 2 reach 4.0 m above PWL
 - Ponds 1 & 2 maintained at 4.0 m above PWL while spilling to Pond 3

6.5 Simulation Analysis

The stormwater management system was analyzed and designed on the basis of a hydrologic and hydraulic simulation of the performance of the system. System operation is complex; involving differential storage rates, automated pumped discharge, and variable and random periods available for stormwater discharge.

The approach chosen for the analysis of the stormwater management system is continuous simulation. This approach allows a probability analysis of runoff in the study area. The probabilities attached to various events, or put another way, their return periods, are correctly determined so as to carry out properly any associated risk analysis. The probabilities are determined by frequency analyses of the simulation results, in exactly the same way as if there were recorded data available.

An alternate simulation approach is to utilize synthetic design storms for the study area that have a probability of occurrence, or return period, associated with the design storm. The probability of occurrence, or return period, attached to a synthetic design storm is questionable, as it is not determinable what characteristic of the synthetic design storm has that probability of occurrence: the duration of the rainfall event, the peak intensity of the rainfall event, the total volume of the rainfall event, a combination of all three, or the runoff resulting from the rainfall event. There can be, therefore, no direct comparison of the runoff from what is referred to as a 1 in 100 y return period synthetic design storm to the 1 in 100 y return period runoff determined from a frequency analysis of recorded or simulated data.

Given historical recorded data, calibration of the simulation analyses can be undertaken. The use of the synthetic design storm approach does not allow calibration, as there is no recorded data that can be used for calibration. This continuous simulation technique and the computer model used in the analysis were calibrated during the Nose Creek basin planning process of which the Hamptons development is a contributing area (Stanley, 1986; JNM, 1988).

Perhaps the primary benefit of continuous simulation analyses is that the frequency of occurrence of conditions of interest can be properly estimated. For example, occurrence of a given water level in a stormwater storage facility depends not only on the rainfall volume and distribution, but also on antecedent conditions such as soil moisture in the catchment area and the existing water level in the storage facility prior to runoff commencing. Any stormwater management system that incorporates storage (hence any stormwater drainage system with a restricted discharge rate) is extremely sensitive to conditions prior to a rainfall event. A period of relatively low intensity of rainfall, but considerable volume of rainfall, may fill, or at least partially fill, the stormwater storage available. The system will then react quite differently to a significant rainfall event than had the stormwater storage been empty.

Using the design storm simulation technique, the frequency of the rainstorm average intensity is known from an intensity-duration-frequency relationship (IDF Curve), however, the rainfall distribution over the selected duration of the synthetic design storm and the critical antecedent conditions are usually specified according to an arbitrary design rule, if considered at all. The frequency of occurrence of the design condition therefore represents some unknown combined probability of rainfall and antecedent conditions. Hence the frequency of occurrence of the resulting condition of interest (e.g. water level, runoff rate) is also unknown.

Continuous simulation allows a direct observation of the frequency of the condition of interest from the modeling results such as pumping duration, annual maximum water levels, annual and monthly water level duration analysis.

Conditions of interest can be observed from the continuous simulation results on whatever time basis is desired. Often annual maximum and minimum values are recorded so as to carry out an annual frequency analysis. The continuous simulation analysis inherently considers all of the factors affecting a condition of interest as long as those factors were simulated, and hence accounts for the effect of joint probabilities in conditions such as water levels, maximum storage values, or pumping duration.

Long-term continuous hourly precipitation and temperature records beginning in 1960 were used to simulate the operation of the stormwater management system under different outflow criteria in order to determine the system storage and pumping capacity required. Through such operational studies it was possible to determine the overall system's response to extended wet weather conditions (multiple rainfall events).

The continuous simulation analyses addressed the stormwater management system as one combined facility rather than three separate facilities for the purpose of determining the volume of stormwater storage required in the system. Separate routing analyses were undertaken to ensure that the required stormwater storage, distributed between the three stormwater storage facilities, could be fully utilized under operational conditions.

Discharge from the stormwater storage facilities is only allowed during periods of no rainfall. For both the interim pumped discharge to the existing adjacent piped storm drainage system and the long-term pumped discharge for golf course irrigation this was modeled by not allowing any discharge from the system until runoff to the system had ceased. In the case of the interim pumped discharge to the adjacent development area the modeling approach considers that capacity in the adjacent storm sewer system is not available until runoff to the system has ceased. In the case of the long-term pumped discharge for golf course irrigation the modeling approach considers that there is potentially no irrigation demand during periods of rainfall.

For each year of the continuous simulation analyses the maximum stormwater storage volume occurring in the overall system was extracted from the continuous simulation analysis in order to carry out a probabilistic frequency analysis to determine the 1 in 100 y return period stormwater storage required.

A requirement of the probabilistic frequency analysis is that the individual events in the analysis (in this case the annual maximum stormwater storage volumes) are independent; that is the maximum stormwater storage in one year is not affected by the maximum stormwater storage in the previous year. In practice this requires that the live stormwater storage in the overall system must return to zero each year prior to the next year's maximum storage value. In other words, there must be no carry over storage from one year to another. If there is carry over storage a different probabilistic analyses is required.

A further consideration in considering carry over storage from one year to another for the Hamptons stormwater storage system is that the operation of the stormwater storage should be equivalent to other stormwater storage facilities in the City of Calgary. No stormwater storage facilities in Calgary utilize carry over storage from one year to another. Hence the stormwater storage system for the Hamptons was sized such that there was no carry over storage over the period of the continuous simulation analysis.

The discharge rate for the overall stormwater management system was fixed by either the interim off-peak discharge to the adjacent development or the long-term irrigation demand. Stormwater storage required to control a 1 in 100 y return period event was increased until no carry over storage was required in the period of simulation. Due to regulatory requirements, only the plant water demands have been met with the irrigation system. There is additional capacity for disposal in this system should disposal be allowed through excess application of irrigation and infiltration to groundwater.

The computer model utilized for the continuous simulation analyses was a modified version of the QUALHYMO model (Rowney and Wisner, 1985).

6.6 Stormwater Quality Enhancement

It has often been assumed that stormwater is uncontaminated and therefore stormwater has been directly discharged to the nearest watercourse without further concern. Generally, it is now acknowledged that that direct stormwater discharge can have detrimental effects on receiving waters in terms of the water quality of the stormwater runoff as well as the rate of stormwater runoff.

The potential for significant input of pollutants from stormwater runoff to a receiving watercourse is now generally recognized, and specifically recognized by Alberta Environment and the City of Calgary. Stormwater runoff, particularly after a prolonged period without rainfall, is contaminated through contact with street litter, eroded swales, deicing chemicals, animal droppings, traffic residue, fertilizers, biocides and atmospheric dust fall. Major constituents of street runoff (organic matter, algal nutrients, coliform bacteria, heavy metals and pesticides) have been found in the form of suspended solids.

The Hamptons stormwater management system retains all stormwater runoff without any discharge to the receiving watercourse. There is, therefore, 100% retention and removal of all stormwater pollutants from the receiving watercourse.

Due to the summer only discharge from the stormwater management system, all winter runoff is retained in the stormwater management system for an extended period. Further, as no discharge from the stormwater management

system is made during periods of rainfall, summer runoff is also retained in the stormwater management system. Average hydraulic residence times are:

- summer runoff: 4.4 months
- winter runoff: 10.4 months

The expected hydraulic residence times are such that removal of suspended sediment in the stormwater storage facilities is anticipated to be high.

Notwithstanding the argument that the Hamptons stormwater management system achieves a 100% removal of all stormwater pollutants discharged to the receiving watercourse (80% removal is the current objective of both Alberta Environment and the City of Calgary), the stormwater management system does not address disposal of accumulated sediments/pollutants in the storage facilities. The Hamptons stormwater system is not unique in this matter. The accumulated sediments in the stormwater storage facilities can be, and have been, removed physically. The issue of disposing of the removed sediments, depending on their pollutant makeup, has yet to be addressed in Calgary.

6.7 Conclusions

This chapter has presented a major development area in Calgary for which a stormwater management system incorporating sedimentation, biological uptake/treatment and irrigation with stormwater runoff has been implemented and is in successful operation. The zero discharge stormwater system allowed the development area to proceed without off-site storm servicing, advancing development by some 10 years, reduces the demand upon the potable water supply, and controls/mitigates the effects of development on receiving waters. Development expediency and sustainable development have met in Calgary. To date the partnership is going well.

The long-term disposal of the accumulated sediments in the stormwater storage facilities remains an issue due to the pollutants present in the sediments. Indeed this is an issue for all stormwater sedimentation facilities. There is a saying that ‘ We will have to generate problem solvers galore, for every problem we solve creates ten problems more’. We end this chapter with this thought.

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