RESEARCH REPORT

Stormwater Control to Prevent Basement Flooding

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STORMWATER CONTROL TO

PREVENT BASEMENT FLOODING

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NOTE: DISPONIBLE AUSSI EN FRANÇAIS SOUS LE TITRE:

RÉGULATION DES EAUX PLUVIALES DESTINÉE À PRÉVENIR L'INNONDATION DES SOUS-SOLE

ABSTRACT

Only an understanding of the multiple requirements placed on the house envelope and the incorporated systems will permit their successful integration into residential construction. Engineers, architects, and urban planners, working for the residential community, should choose only those integrated design options that will result in total acceptable performance of the house, including the basement. Research already shows that unwanted moisture is a surrogate for many indoor air contaminants that can affect human health, and that basements in particular are seen as a likely source of unwanted moisture. These sources include construction moisture, condensation from the atmosphere, and groundwater that is not handled by foundation drains and comes through the floor slab or perimeter walls. Basement flooding is now seen as a significant health issue above and beyond the short-term physical inconvenience normally associated with such flooding.

To evaluate basement flooding caused by stormwater, 10 municipalities across Canada were interviewed in 1991 and questionnaire responses were compiled to document the problems and the remedial measures applied. To further document the problem and identify and propose solutions, studies performed previously by CMHC and CH2M HILL were reviewed. To determine the causes of basement flooding from an urban drainage system viewpoint, the findings from the questionnaire responses and the previous studies were reviewed and evaluated. Potential solutions to prevent the problem, particularly in inner city redevelopments, were identified.

This report highlights planning and procedural factors that frequently inhibit a fuller understanding of urban drainage design. This absence of understanding forms obstacles to the resolution of stormwater drainage problems that are likely to cause basement flooding. Engineering aspects of the basement flooding problem, such as on-lot drainage, sewer surcharge, and major system flow, are discussed. The large diversity in designs, ages, and conditions of existing houses, along with the local climate, reflect the diversity of the factors effecting basement flooding and so preclude any single engineering solution.

Given the greater understanding now emerging in Canada of the behaviour of the house-as-a-system, municipalities should ensure that the National Building Code and National Plumbing Code (or their provincial counterparts) are compatible with local drainage ordinances that govern residential developments so enabling ongoing, healthy, operation of the house-as-a-system.

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INTRODUCTION

During storm events many Canadian cities have experienced varying degrees of basement flooding over the past 10 to 20 years despite increasing knowledge available to urban drainage system designers. In order to understand the reasons for basement flooding, the methods used to convey stormwater away from a property have been reviewed and an assessment made to determine why these methods continue to fail. This report presents an overview of stormwater management practices across Canada and evaluates these practices in relation to the problem of basement flooding. A particular assessment has been made of some aspects of the National Building Code and municipal drainage ordinances.

The purpose of this study has been to review the current Canadian design practices in order to identify areas where they may be inadequate or to identify stormwater management trends, developed by some municipalities, that may help other municipalities/agencies with their design criteria. The document is intended as a reference for technical personnel involved in the design or redevelopment of sewer systems in urban communities and uses data obtained from previous studies, along with results from a questionnaire sent to municipalities across the country.

OBJECTIVES

The objectives of the study were to document the problem of basement flooding in Canada; identify the causes of basement flooding and, where appropriate, propose cost-effective planning and engineering solutions that can be implemented; identify established minimum criteria for municipal designs to allow improved handling of stormwater; review modern technology with the potential to reduce sanitary flows and so permit increased residential densification; discuss some of the major jurisdictional factors that inhibit a clear understanding and resolution of the problems in the design and operation of urban drainage systems; and relay this information to municipalities across Canada through this report.

METHODOLOGY

The methodology employed to address the question of basement flooding consisted of:

- a review of results from questionnaires sent to municipal engineers responsible for urban drainage system design, operation, and maintenance

- a review of previous CMHC reports on basement flooding, and the work by CH2M HILL and other consultants across Canada in evaluating basement flooding and recommending and executing remedial measures

- an assessment of the design practices and remedial measures identified from the above sources, including stormwater management facilities, increased sewer system capacity, and on-lot drainage practices

FINDINGS

The study found that basement flooding is common across Canada and that the lack of understanding on the part of urban drainage system designers on the total response of their systems to wet weather conditions is a serious impediment to successful resolution of problems. Deficiencies that have historically occurred at different stages in the design of urban stormwater drainage systems have resulted in inadequate sewer systems. These deficiencies have led to some basement flooding.

Short duration, high intensity storm events can cause street flooding and result in high infiltration/inflow (I/I) to the sanitary sewer systems. I/I to sewer systems occurs through manhole covers, cracked or open barrel joints in manholes, sewer system cross-connections, broken pipes or cleanouts, cracked and open pipe joints, structural failure of pipelines, and defective lateral connections. The quantity of I/I can be serious enough to have a major influence on sewer system performance. Basement flooding occurs when that influence is severe enough to overload the sewer system and cause residential service connections to back up.

Communities that have experienced extreme basement flooding appear to have studied the situation and in the process have become knowledgeable on most of the factors that influence sewer system flows in their area. This typically entails understanding stormwater drainage patterns, identifying all the I/I sources, and developing an ongoing program to eliminate the most serious contributors. However, these municipalities have no obligation to, and seldom do, transfer their successfully developed methodologies to other municipalities.

Jurisdictional issues can lead to or exacerbate the problem of basement flooding. The on-lot parties (builder, owner) generally do not realize that deficient drainage designs and practices can cause significant stress on the sewer systems and result in basement flooding in their own properties and that of their neighbours. Conflicts can develop over the maintenance of stormwater control facilities, from the homeowners' responsibilities on-lot, to the municipal versus regional responsibilities for sewer system design and maintenance. The age of the sewer infrastructure and its drainage patterns can contribute to the problems.

Municipal systems that operate within the confines of a regional drainage system must fit into the capacity of that regional system. Basement flooding could result from inadequate drainage practices outside of the municipality. Regional facilities may be inadequate and poorly planned, resulting from a merging of municipal plans rather than the use of a masterplan that incorporates, to the fullest extent, the regional drainage area impacts.

A greater understanding of the roles of developer, owner, and municipal authority is evolving and the development process in many municipalities (e.g., Edmonton and Vancouver) is beginning to reflect more equitably the responsibilities of each stakeholder. This will undoubtedly lead to more effective urban drainage systems, particularly in newly developed areas.

CONCLUSIONS

The division of responsibilities for the design, construction, and ongoing operation of on-lot and sewer system drainage contributes significantly to the problem of basement flooding. The construction and maintenance of house service connections appear to be difficult to control due to the large number of parties involved, from the land development stage to the final house completion. Codes and standards for work carried out on the lot (including the National Building Code) need to include and emphasize on-lot drainage considerations. Those responsible for design and operation of the sewer systems should have a clearer understanding of the effect of on-lot stormwater contributions to their systems and how these contributions can cause systems to surcharge and overload. The key to public involvement in improving drainage and reducing basement flooding is better coordination between urban planners, developers, and municipal officials.

There is a need for municipalities to develop master drainage plans that incorporate all their drainage components into one plan. In this way the limitations of that system will be clearly identified following the results of a thorough investigation of all local conditions, including: local soil types, climate, topography, historical system development, and future planning data.

Maintenance of sewer systems is identified as a necessity in stormwater management control and a municipality should establish a program that will ensure proper operating conditions for the municipality and for the homeowner. This is supported through studies in the U.S. that identify the need for maintenance responsibilities to be clearly defined.

There is a need to educate homeowners with respect to the effect of poor lot grading and roof leader extensions on urban stormwater drainage systems, as local surface drainage due to poor lot grading and roof leader extensions can be significant. These contributions might be reduced by educating homeowners.

Code approved backflow valves and sump pumps have failed in some instances but it is generally recognized that the failure is due to improper installation, lack of maintenance, or poor sump pump sizing or selection. These problems could be reduced by establishing installation procedures and standards for plumbers, by training building inspectors, and by educating homeowners.

In planning and designing residential redevelopments in existing urban areas, particularly those involving densification, the impact on the stormwater drainage system should be analyzed by the developer and reported to the municipality. The report should address local surface drainage, sewer system flow, and overland flow implications. The above analyses will provide a basis for determining the risks associated with providing below-grade accommodation in a redevelopment project.

To solve the problem of basement flooding, it will take a great deal of cooperation among the major players, namely, the homeowners, the developers, the builders, and the policy makers, to provide a system that will allocate clear responsibilities and full accountability.

This report concludes that, due to the long-term health impacts of basement flooding, inspection requirements for on-lot drainage, including roof leader extensions, lot grading, and foundation drain discharges, should be on an equal footing with electrical and plumbing components for building construction and be so reflected in the appropriate codes and standards.

1.0 INTRODUCTION

Urban drainage systems are the collection systems used to effectively transport sanitary and stormwater flows to convenient locations for storage, disposal, or treatment and consist of natural depressions, man-made ditches, covered culverts, and pipeline networks. These systems have grown and expanded in a piecemeal manner, paralleling the historical growth of Canadian urban communities. In recent years, serious deficiencies in the performance of these drainage systems, especially during heavy rainstorms, have been identified. In particular, basement flooding with the potential for subsequent health impacts has been one result of these deficiencies. This report, therefore, presents an overview of stormwater management practices across Canada and evaluates these practices in relation to the problem of basement flooding.

To understand the reasons for basement flooding during or following a storm event, it is necessary to review the methods used to convey stormwater away from a property and to understand why these methods fail. Therefore, this work is based on a review of basement flooding events, as a problem in Canadian municipalities, and a determination of how they have tried to resolve their problems. Information was gathered as to their findings, implementation of remedial measures, and the success of these measures. The resulting information was used to identify the potential technical solutions to basement flooding outlined in Chapter 5, while Chapter 6 highlights sections within the National Bulding Code that could be modified to respect the urban drainage issue of peak flows during storm events.

1.1 Study Background

Many Canadian cities have during the last 10 to 20 years experienced basement flooding, predominantly through sanitary or combined sewer backup during rainfall events. This problem of inadequate urban stormwater drainage has resulted in costly rehabilitation and remediation programs for municipalities, along with considerable expense to homeowners. As a result, CMHC has sought to improve the level of housing performance offered to residents and to advise municipalities and other regulating agencies by identifying potential solutions to prevent basement flooding. Design criteria in housing development and drainage system upgrading or development must include requirements to prevent this flooding.

Population growth in urban centres is causing changes to the demographic profiles of certain communities. In some cities, like Vancouver, undeveloped land within city boundaries is generally not available. Yet Vancouver, which is already fully developed, experienced a population increase of 5 percent from 1986 to 1990 as a result of densification. Single-family neighbourhoods are being rezoned to allow for denser housing developments. This densification of neighbourhoods is seen as a method of developing alternative sources of housing stock that will enable people to live and work in the city. Of particular concern to this study, therefore, are the impacts these developments have on stormwater drainage systems and the potential for them to increase the occurrence of basement flooding.

1.2 Objectives

CH2M HILL ENGINEERING LTD. (CH2M HILL) was contracted on 1990 August 12 to prepare this stormwater control study for the prevention of basement flooding, with the following objectives:

- document the problem in Canada.
- identify appropriate and cost-effective engineering solutions that can be implemented.
- identify minimum criteria for municipal designs to allow improved handling of stormwater.
- summarize the results of the study and recommend changes to various codes to facilitate better coordination of such codes.

1.3 Methodology

The work entailed: the compilation and review of previous studies by CMHC into basement flooding; a review of the flooding experience of a selection of municipalities across Canada and an identification of their methods for mitigating the problem; a review of the historical development of urban drainage systems; a review and comparison of various municipal design standards and practices, along with the various national, provincial, and local codes of practice; and the provision of a report summarizing the work accomplished and the identification of possible solutions.

2.0 BASEMENT FLOODING

Over the years the cellars, crawl spaces, and crude basements under residences have evolved into functional areas and occasionally, as a necessity, living spaces. This development of some basements into liveable space has preceded the development of adequate drainage design criteria that specifically identifies the problem of basement flooding due to stormwater[1]. It is now timely that drainage design engineers start to examine stormwater drainage in relation to housing requirements. Flooding has resulted from sewer backup and seepage into basements during storm events and, in the last two decades, many municipalities have been subjected to severe basement flooding problems.

This section reviews the basement flooding experience in a cross section of Canadian municipalities and briefly summarizes the findings of their research. Three sources of data were employed:

- the information collected from a questionnaire survey performed as part of this study
- data obtained during a previous review of drainage servicing criteria for the City of Edmonton[2]
- data obtained during a previous survey of 34 Canadian municipalities in 6 provinces[3]

2.1 Basement Flooding Experience

Table 2-1 summarizes the general flooding experience of 11 municipalities across Canada. This table is limited to available recorded information. Other flooding has occurred but no attempt was made to record the number of homes flooded. Also, the flooding data indicated in the table are not wholly homogeneous. In some instances the data are based upon actual reported flooding complaints while in other cases the data are derived from municipal or agency estimates.

It is evident from Table 2-1 that incidences of basement flooding are common in most of the municipalities surveyed. The extent and frequency of flooding varies considerably, although both eastern and western Canadian cities have recorded significant instances of flooding. Major precipitation events, those that have a return frequency of greater than one in twenty-five years (1:25), are known to overload sewer systems, resulting in some cases in extensive flooding[4].

- a relatively rare 1983 storm event (estimated peak rainfall intensity of once in every 100 years; 1:100) produced extensive reported flooding in Regina, Saskatchewan. An estimated 8,000 to 10,000 homes or approximately one in every three to four homes throughout the community were affected in some manner.

- Between 1990 August 16 and 17, northwest Calgary was struck by two consecutive major rainstorms (1:50) that caused severe street, lot, and basement flooding.

- A storm event in Calgary, 1988 August 16 resulted in flooding of 1,500 basements. Again, the storm was characterized as relatively infrequent (1:50).

- In Edmonton the extent of flooding was documented from two rainfall events in 1978. A storm on 1978 July 11 resulted in over 1,500 flooding complaints while a storm on 1988 July 5 and 6 produced an excess of 1,100 reported flooding complaints.

- The City of Laval, Quebec, estimates a flooding incidence of approximately 500 complaints per year. Significant flooding from sewer backup occurred as a result of an intense storm event (1:100) in July 1987.

There appear to be a variety of causes for flooding in each of the above municipalities. The causes of these problems are discussed in the next section.

2.2 Causes of Basement Flooding From Stormwater

In order for the lay-person and the non-professional municipal staff to understand the reasons for basement flooding it is necessary to review the methods used to convey stormwater away from a property and why these methods fail. Following is a brief discussion of stormwater drainage from three design perspectives with respect to possible deficiencies:

- sewer system flow
- local surface flow
- major system flow

2.2.1 Sewer System Flow

Sewer systems, although constructed to collect and convey wastewater or stormwater, also convey a certain quantity of extraneous flows. These flows, commonly referred to as inflow/infiltration (I/I), enter a sewer system from indirect sources. Sources that allow direct entry of stormwater (inflow) include downspouts or foundation drains connected directly to the sewer, poorly-sealed manhole covers, area or yard drains, and catchbasins. Indirect sources (infiltration) include defective pipes, open or cracked joints, and deteriorated manhole walls. This extraneous flow occupies pipeline capacity that is normally available for sewer flow. The amount of I/I can vary widely depending on location, system age, structural integrity, and the intensity of the rainfall. Sufficient allowance for I/I capacity is critical in sewer collection facilities. The quantity of I/I, especially during peak flow conditions that occur during storm events, can be serious enough to have a major influence on basement flooding.

Basement flooding results when the drainage system does not have capacity for these extraneous flows. When the level of sewer surcharge or the hydraulic grade line in the sewer system is higher than the basement elevation, service connections to the sewer will be under hydraulic pressure and the sewer will back up through the service connection. This reverse flow enters the home through the sanitary or combined service connection to the floor drain or through the storm service connection into the foundation drain. In the first instance raw sewage enters the basement by reverse flow through the drain. In the second instance stormwater can build up against the house walls and seep through any cracks and unsealed joints in basement walls or cause structural damage to the basement floor and walls.

Combined Sewer Systems

Combined sewer systems are the result of historical design practices and still operate in older sections of some municipalities. Combined sewers were designed to collect sanitary flows along with stormwater related flows; from catchbasins, roof leaders, cross connections, etc. Overflows to nearby waterways are used to relieve combined sewers during surcharge conditions. These older combined sewers have been integrated into the sanitary collection system and contribute stormwater inflows to the wastewater system during rainfall events. Stormwater inflows can dramatically increase peak flows through the wastewater collection system. Although basement flooding may not occur in areas with combined sewers they can cause system constraints for separated sewer systems upstream.

Sanitary Sewer Systems

Sanitary sewers are designed based on population density along with sanitary flow per capita with some allowance for I/I. Although current municipal design practices do not allow sanitary sewers to convey stormwater, the practice in some municipalities has only come into effect in recent years. In some urban areas, prior to the changes in municipal design criteria, sanitary sewer systems still receive flows from stormwater drainage sources. Even after redevelopment to separate storm sewer systems, sanitary sewers can still be dependent on storm frequency if they collect foundation drain flows. The result is an increased risk of hydraulic overloading of the system and possibly basement flooding.

However, the sanitary sewer system in separated areas is intended to not flood. It is critical to recognize that foundation drain flows can be considerable during storm events and, when connected to a sanitary sewer system, can be a major factor in peak flows. Sanitary sewer flow response should not be rain-related and would not normally be described as having a service level of 1:5 year or 1:50 year flooding frequency.

If the capacity of the sanitary sewer is not designed with proper consideration given to the quantity of I/I introduced during storm events, which will vary based on the storm frequency, surcharging could result very quickly and be quite severe. Research is not always performed on the local conditions that influence the rate of I/I. This would include antecedent soil conditions, roof area drainage, the condition of on-lot grading, and cross connections to combined sewer systems. Without due consideration, what would seem like an adequately designed capacity for the sewer system could be severely under designed. The evaluations necessary to adequately estimate the impact of I/I make sanitary sewer systems more difficult to design.

Storm Sewer Systems

Storm sewer systems by design are dependent on stormwater inflows. Over the years the trend has been to remove stormwater from surfaces in urban areas as quickly as possible. Yet, there is an economic limit to the intensity of a storm that the pipeline system can be designed for, and on average the current state-of-practice is for storm sewers to be designed for the worst storm likely to occur every 5 years. Any storm event that is larger than the design event can potentially cause overloading of the overall conveyance system. This includes natural depressions, man-made ditches, covered culverts, and pipe networks. Surcharging of the storm sewer system can back up to the foundation drains and result in seepage through basement walls. Accordingly, the larger the storm event, the greater the risk that surcharge will occur and that subsequently, basement flooding may take place.

2.2.2 Local Surface Flow

Local surface flow refers to the effective drainage system around and between dwellings. It specifically includes the runoff influenced by lot grading, roof drainage, and foundation drains.

One aim in urban design and development is to prevent ponding around and between dwellings. The National Building Code (NBC) outlines the minimum regulations for drainage disposal in Section 9.14.5 and surface drainage, including lot grading and roof drainage, in Section 9.14.6. These regulations are not very extensive and do not outline surface drainage in sufficient detail, nor does it identify the linkage between local surface flow and sewer system flow. The City of Edmonton has developed detailed guidelines on lot grading and roof drainage and made it the responsibility of the developer to make the home builder aware of these requirements through the sales agreement[5].

Lot Grading

The main function of lot grading is to ensure that all rainwater falling on the lot will drain away from the house[6]. The ground elevation at the house is usually the highest elevation with water flowing to property line swales and generally to the roadway at the front or back of a lot. Figure 2-1 shows examples of correct and incorrect lot grading. If the lot is not graded properly, water could flow towards the house and pond to a depth sufficient to enter window wells. Ponding can also result in excessive foundation drain flows, which can impact sewer flows and in turn cause basement flooding. The City of Winnipeg has instituted a lot grading bylaw as part of a cost-effective approach to reducing extraneous flows entering the foundation drain[7].

Roof Drainage

Rain and snow that falls on the roof is collected by the eaves troughs and discharged either to the ground surface through downspout extensions or underground to a sewer system. Downspout extensions are designed to direct roof drainage across the lot, allowing for seepage into the soil or drainage to the roadway. Improper downspout extensions can introduce large quantities of flow to the area around the dwelling, which again results in excessive infiltration through the soil to the foundation drains, or flooding of basements through window wells and cracks in walls. Figure 2-2 shows the correct and incorrect use of downspout extensions.

Older areas of some municipalities still have the roof leaders connected directly to the sanitary sewer system even after sewer separation. Sewer separation programs result in the construction of storm sewers to collect catchbasin flows. The existing combined sewers are left in place without any modification to the building service connections. The result is that roof leaders that had previously discharged to a combined sewer now outlet to the new sanitary sewer. This allows the direct inflow to the sanitary sewer system of all connected roof drainage. The entry of this stormwater runoff increases the risk of basement flooding along with the costs of operating the wastewater conveyance and treatment facilities. Public education programs through notices have been used in Edmonton to encourage homeowners to disconnect roof leaders and use downspout extensions. The success of these programs is limited if the basements in these areas do not flood.

Foundation Drains

It is important to recognize the interaction between stormwater drainage systems and lot grading, roof drainage, and foundation drains. The lack of attention given to the construction and maintenance of these local surface flow parameters has aggravated the problem of basement flooding. The National Building Code, along with provincial and municipal building codes, should be revised to recognize this interaction. The on-lot parties (builder and owner) generally do not realize that deficient on-lot drainage can cause significant stress on the sewer systems and result in basement flooding to both themselves and their neighbours.

Foundation drains have traditionally been installed around residences to lower the localized water table, protect the basement walls from excessive hydraulic forces, and reduce water inflow through cracks and joints. It is recognised that the service life of foundation drains is limited as they become clogged from sediment over time. The

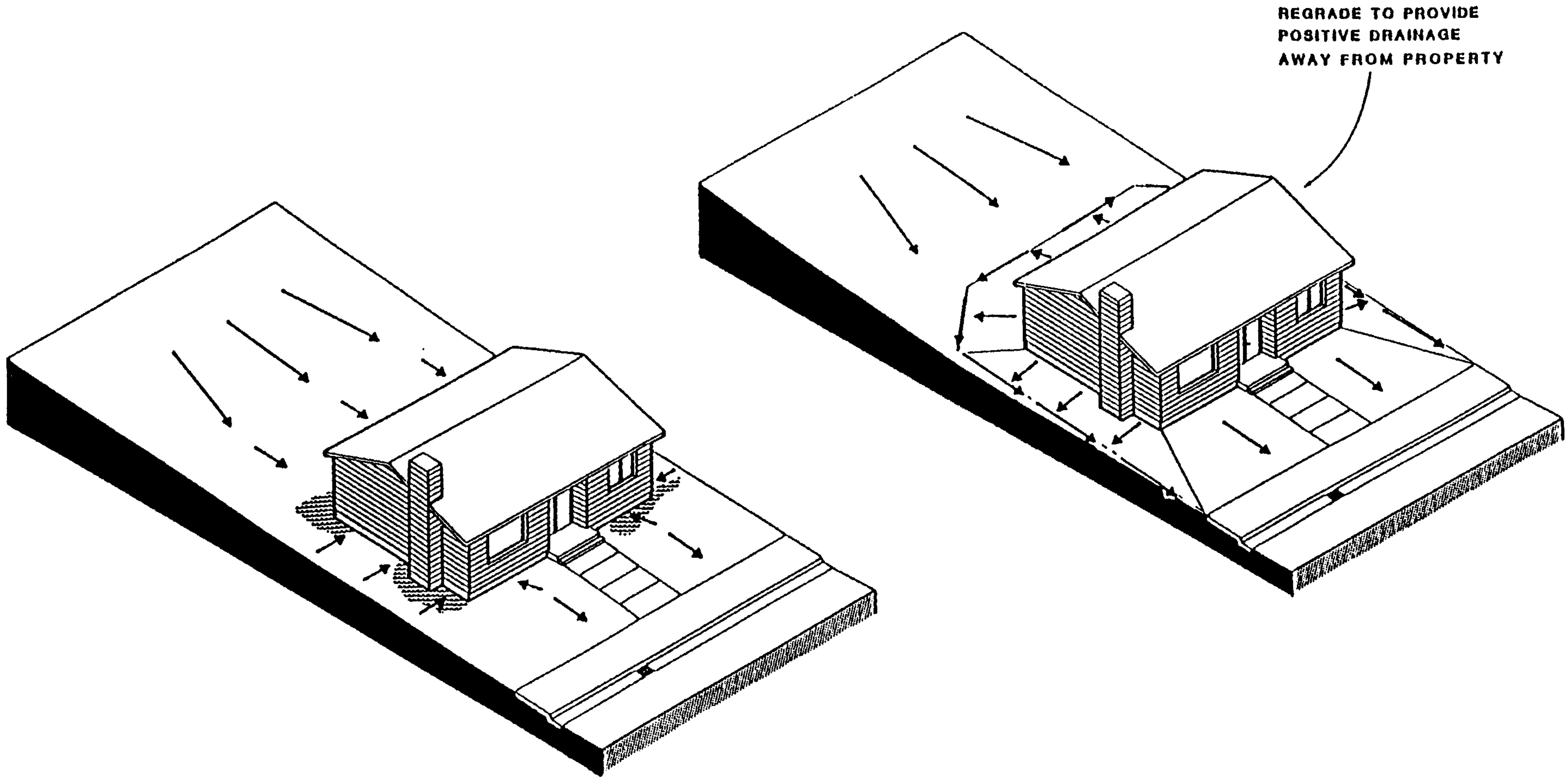


Figure 2-1
LOT GRADING

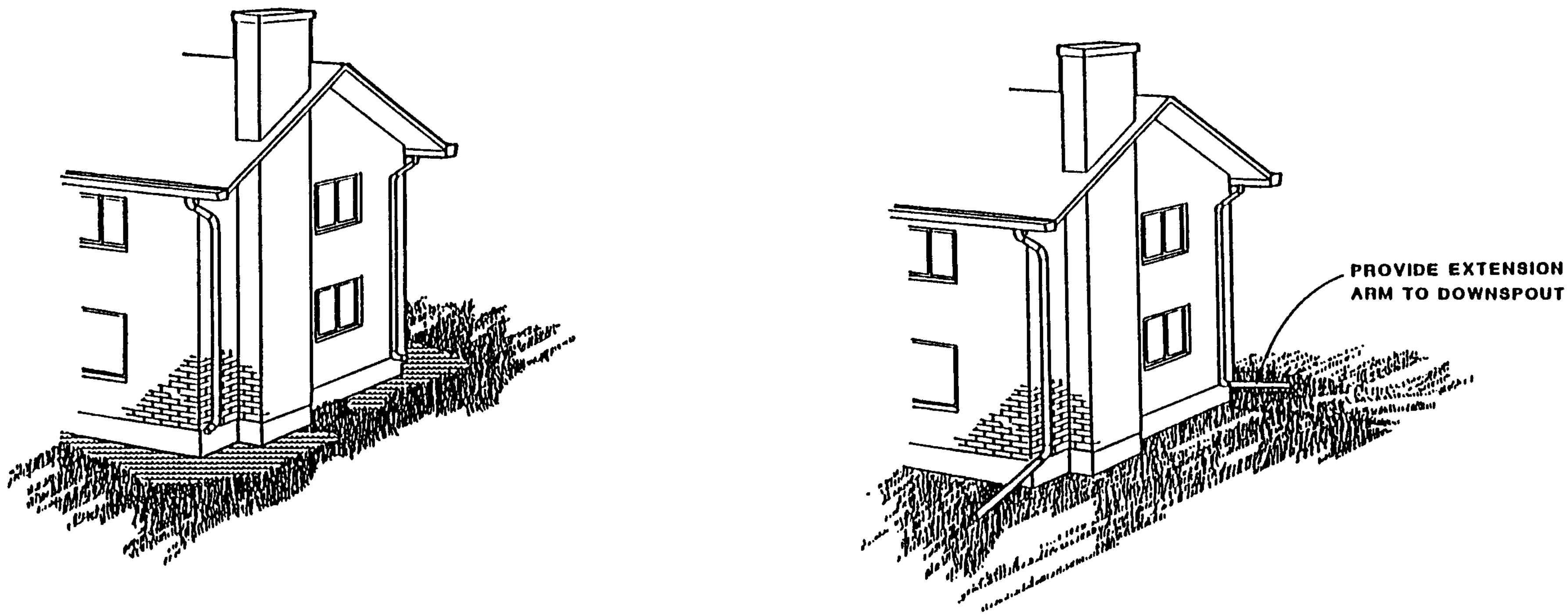


Figure 2-2
DOWNSPOUT EXTENSIONS

City of Vancouver, which still has a combined sewer system in residential areas, has identified the discharge of roof leader flows directly to foundation drains as contributing to basement flooding[8]. Roof leader flows carry leaves and other debris into the foundation drains causing blockages and reducing the performance capabilities of the foundation drain to collect groundwater flows. The result is a build-up of water outside basement walls, which allows for seepage through cracks and joints and could potentially cause further cracking of walls from hydraulic pressures. Figure 2-3 shows how the groundwater level can be effected by the extraneous flows that are introduced from poor downspout extensions or poor lot grading.

Soil permeability is higher in the backfill area as it was disturbed during house construction. Consequently, this allows the groundwater table to rise in the backfill zone that provides the driving head on the flows. Studies done in Edmonton by CH2M HILL, have shown considerable differences in the response of foundation drains to different storm events[9,10]. The range was found to be significantly higher than municipal design allowances for foundation drain contributions to sanitary sewers. The City of Edmonton amended the inflow/infiltration allowance design value following the results of this field evaluation of foundation drain response.

Even with good lot grading and downspout extensions the water that accumulates around the building foundations and is collected by the foundation drains must be removed. Traditionally, the most common receiving sewer for this water was the combined sewer system or sanitary sewer system. Connections from the foundation drain to the storm sewer have only become common in recent developments across Canada.

The solution in the City of Winnipeg was to amend the Sewer Utility Bylaw to limit wastewater sewage flow to that of dry weather flow in all new house construction. In order to meet this criterion, sump pits and pumps are connected to foundation drains to remove extraneous flows from the sanitary sewer system[11].

2.2.3 Major System Flow

Coincidental with the development of a stormwater pipe network system is the requirement to accommodate stormwater from lengthy periods of precipitation and from the flash runoff from short-duration storms. The overland flow routes or major system is designed for this purpose, to convey excess flows during infrequent storm events. The streets are used to store and carry the flow exceeding the pipe capacity, and act as open channels during major storm events. They transport the excess flow to downstream open channels or storage ponds. The major drainage system is usually designed for infrequent storm events with a 1:100 year return period.

The dual drainage concept consists of the surface flow network or major system and the sewer pipe network or minor system. This concept was introduced in Denver,

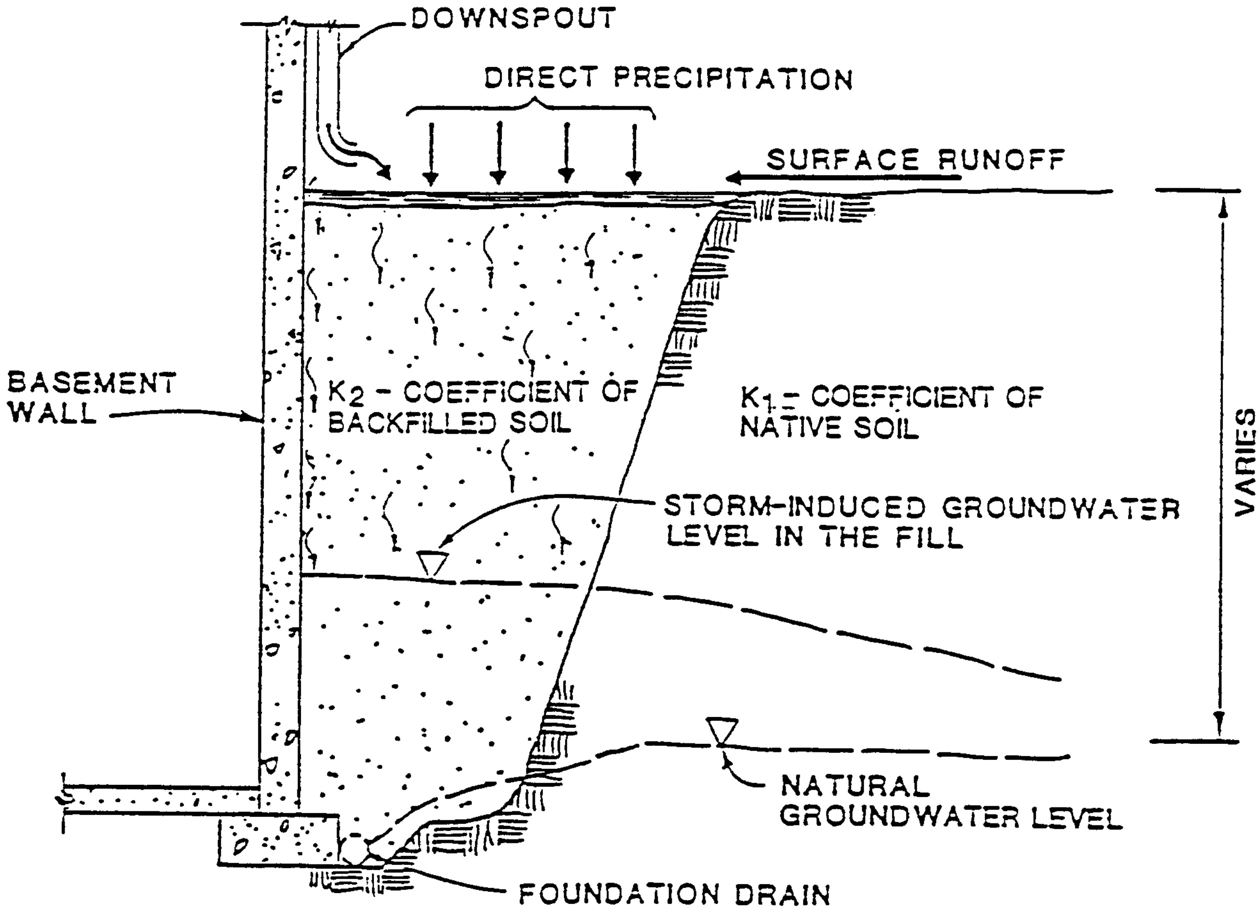


Figure 2-3

STORMWATER INFLUENCE ON GROUNDWATER LEVEL

Colorado in 1969. Yet it was not until 1978 that Markham, Ontario became the first municipality in Canada to develop guidelines that introduced the concept as a method to prevent basement flooding caused by storm sewer surcharge[12]. Therefore, the concept has not been in use for many years.

Older areas that were enclosed by newer developments and newer developments that were designed poorly lack overland flow routes to suitable outlets and have no control devices on catchbasin inlets. Major storm events will hydraulically overload poorly-designed storm sewer systems and cause street flooding. Between 1990 August 16 and 17, northwest Calgary experienced two consequent storm events that caused lot and basement flooding. Street flooding levels were severe enough to cause vehicles to float and to allow water to enter basements through windows and door sills.

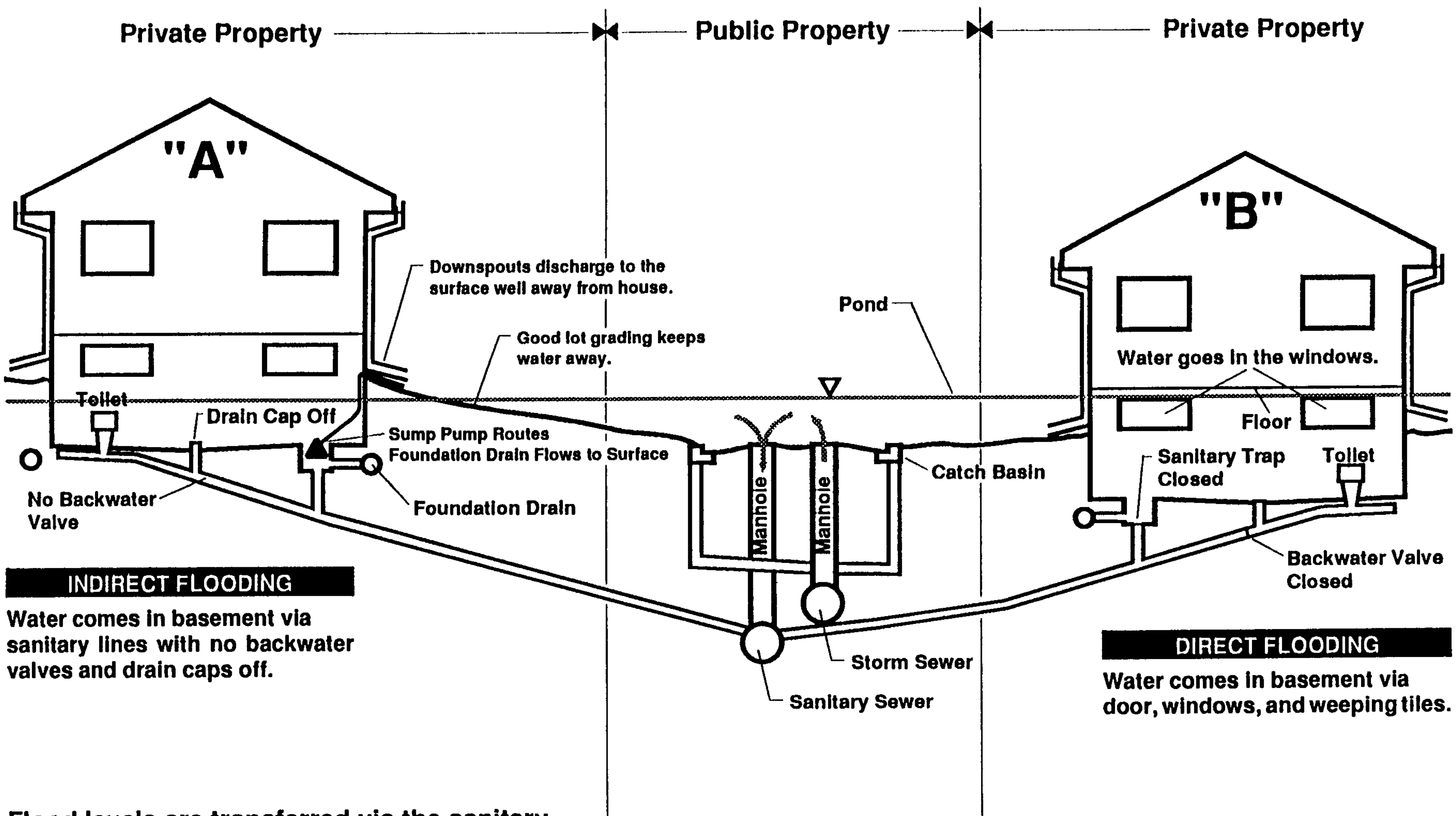
Manholes that are located in low spots subject to ponding during storms contribute large quantities of inflow to the sewer systems. Stormwater will enter sewer systems through the cover holes and the cover-frame joint. Inadequate street slopes and drainage can result in significant ponding over sewer manhole covers. The magnitude of the inflow will vary with the depth of ponding. Sanitary sewers require the openings for ventilation purposes. Valves can be installed in the openings that will close when the pressure on the manhole cover exceeds 1 psi[13]. This will restrict the quantity of inflow so that sewer systems can be designed with known constraints and it will reduce the potential for sewer surcharge from manhole cover inflow.

Shown in Figure 2-4 are examples of two homes that have flooded as a result of overloading of both the sanitary and storm sewer systems. In residence A the hydraulic pressure in the sanitary sewer causes floodwater to backup through the basement drain and plumbing fixtures. In residence B the street flows have risen high enough and quickly enough to enter the basement through windows, door frames, and foundation drains.

2.3 Key Factors Related to Basement Flooding

Current and previous surveys into the reasons for basement flooding support the previous discussion with the following key factors identified as dominant in contributing to basement flooding problems:

- Flooding is relatively more frequent and extensive in municipalities with combined sewerage or partially separate sewerage linked to precipitation-dependent inputs such as foundation drains and/or roof leaders. For example, Laval, Quebec, with a current population of 285,000 and a relatively flat topography, still has extensive areas of combined sewerage and reports houses in these areas flood four to five times per year. Regina, Saskatchewan, with a population of 180,000 and a relatively flat topography, has historically permitted connection of foundation drains and roof leaders to sanitary sewers



Flood levels are transferred via the sanitary system to homes with no backwater valves or homes with the sanitary traps left off.

Figure 2-4

STORMWATER BASEMENT FLOODING

and has also experienced extensive basement flooding. One conclusion is that systems carrying precipitation-dependent flows are naturally more prone to overloading.

- Flooding appears to be more prevalent in municipalities with predominantly flat topography, as evidenced by records from Edmonton, Regina, Winnipeg, and Laval. Drainage systems in these municipalities are challenging to design because of the high costs associated with introducing man-made grades and lift stations as natural grades are not available. Shallow pipe grades, lift stations, and stormwater management ponds are necessary features of the stormwater drainage facilities. Systems designed in well drained, naturally sloping municipalities appear to be more forgiving to historical design deficiencies.

- Another common theme in basement flooding is the apparent failure of sewer system design. Many municipalities determined that sewers were undersized for present conditions. This could be a result of uncontrolled urban growth along with deterioration of aging sewer systems, the lack of understanding and information regarding dry and wet weather flow generation, or changing public expectations which identify desing return periods as inadequate.

- Some amount of the flooding experienced in each municipality was attributed to factors other than excessive flows or inadequate sewer capacities. Generally, minor design, construction, and maintenance problems accounted for some number of flooding incidents in each municipality. Examples of the factors contributing to non-precipitation-dependent basement flooding included:

    - poor hydraulic design of junction and transition manholes
    - root intrusions in service connections and street laterals
    - sewers with shallow grades that permit significant local sedimentation
    - debris deposited by vandals or otherwise entering the collection system

    Municipal maintenance and cleaning programs are necessary to ensure sewer systems are maintained in operating order. Although it is recognised that budget constraints usually result in a reactive rather than proactive maintenance programs.

The major findings of an analysis in 1984 of municipalities with acknowledged flooding problems[14] were as follows:

- critical flooding occurs in both combined and separated sewer systems predominantly in areas of low- to medium-density residential land use.

- relatively new sewer systems have been subject to critical flooding. Sixty-five percent of replies indicated a sewer system construction age of about 25 years.

- flooding often cannot be related to changes in the service area. In 50 percent of older systems and 63 percent of systems less than 25 years old, it was reported that no significant changes in land use or density had occurred. This finding is at some variance with comments received during CH2M HILL's review of municipal drainage servicing criteria across Canada as part of a study for the City of Edmonton.

- reported floodings occurred in areas that were designed with a wide range of design storms using the rational method. The frequency of the design rainfall intensity did not correlate with flooding incidence. The reported design frequencies for storm sewers were distributed as follows:

Table 2-2
Design Storm Frequency vs Reported Floodings

Design Return Period	> 5 years	> 2 years & < 5 years	< 2 years
Percentage of Reported Floodings	33%	48%	19%

This finding is perhaps not surprising since the range of design return periods is not that large if one assumes that most respondents in the > 5 year category actually used a 5-year return frequency.

- approximately 64 percent of critical flooding was felt to be related to thunderstorm activity.

A further analysis of basement flooding in Canada reviewed communities that experienced sanitary sewer surcharge as a result of high inflows of stormwater[15]. These inflows resulted from improper surface and lot drainage, unextended downspouts, foundation drain connections to the sanitary sewer, and poor road drainage, which caused inundation of manhole covers in depressed street areas.

Jurisdictional issues can lead to or exacerbate the problem of basement flooding. The division of responsibilities for the design, construction, and ongoing operation of on-lot and sewer system drainage contributes significantly to the problem of basement flooding. Codes and standards for work carried out on the lot (including the National Building Code) need to include and emphasize on-lot drainage considerations. In addition, the people responsible for the design and operation of the sewer systems should have a clearer understanding of the effect of on-lot stormwater contributions to their systems and how these contributions can cause systems to surcharge and overload.

The construction and maintenance of house service connections appear to be difficult to control because of the large number of parties involved from the land development stage to the final house completion. The key to improving drainage and reducing basement flooding is better coordination between urban planners, developers, and municipal officials and engineers. There is an enormous need to educate people with respect to the design basis of urban stormwater drainage systems in order to ensure their cooperation.

3.0 OVERVIEW AND EVOLUTION OF URBAN DRAINAGE SYSTEMS

Sewer systems developed in Canada as a result of industrial development and urbanization occurring at the turn of the century. As the population of communities grew so did the need for a communal sewer system. Advances in the understanding of health and environmental issues resulted in the progression of sewer systems from combined to separated systems. The following is a brief discussion of the historical development of sewer systems.

3.1 Combined Sewer Systems

As communities grew in population, private sanitary disposal systems were no longer able to provide adequate health protection. Sanitary sewer systems grew from the need to provide denser communities with a sanitary collection system that would prevent health hazards and provide for the demands and living standards of developing communities. Coincidental with the development of sanitary collection systems was the need for negotiable transportation routes that would not flood during rainfall events. It was necessary to divert water away from road surfaces. In rapidly developing urban areas, it was evident that a single pipeline could be designed to serve both the need for disposal of sanitary waste and surface drainage. As a result, many cities began to construct combined sewer systems.

Each property was connected to the combined sewer system by a single service connection, which carried domestic sewage and roof water. Site drainage and surface runoff would be collected by road gutters and directed to catchbasins connected to the combined sewer system. The collected untreated sewage and surface drainage was then directed into local watercourses.

At that time basements were built without footing tiles, dampproofing, or even concrete floors[16]. They were not considered to be habitable space at the time and little or no consideration was given to the prevention of basement flooding.

Greater understanding of health hazards and concern for the environment resulted in the establishment of laws and standards of practice regulating the disposal of untreated wastes into the nearest watercourses. As a result, municipalities enacted bylaws and began to construct plants to treat sewage prior to disposal to local watercourses. Treatment plant sizing and operating costs resulted in their capacity being limited to the treatment of sanitary wastes and only a fraction of runoff. During periods when sewers carry flows greater than treatment plant capacity, combined sewer overflows (CSO) divert the excess flow into drainage canals, lakes, or natural watercourses. As much of Canadian urban developments had occurred along main watercourses, this task was relatively easy. Thus, municipalities that had sizeable populations in the late 1930s usually have combined sewer systems located in their core areas that are designed to overflow in wet weather.

In the 1990s these previously developed areas are now being redeveloped with denser housing stock. Accordingly, municipalities have to identify standards of analysis that ensure basement flooding is not a result of this densification.

3.2 Separated Sewer Systems

Continual pressure over the years to improve the operational efficiency and economy of sewage treatment plants resulted in the desire to eliminate rainfall related flows from the treatment plant inflows. This need to reduce the costs caused by high volumes of stormwater received at treatment plants, along with environmental concerns about discharges of raw sewage to watercourses through combined sewer overflows, resulted in the design of separated sewer systems.

The design of separate sewer systems has been generally accepted over the years since World War II. Urban expansion since then has seen new areas of development served by separate sewer systems. In many places these separate sewer systems are extensions of the original combined sewers. Conversion of existing combined sewer systems into separate systems has occurred in the last three decades and is still on-going in many communities. In some cases, complete separation, in some cases, has become impractical because of increased costs.

In a separated system, the concept allows for surface water to be excluded from any sewer that carries sanitary sewage. The result is two completely separate sewer systems, the first to carry sanitary wastes and the second for roof and yard drainage, road drainage, and other surface water. Most properties will have at least one service connection for sanitary sewage connected to the sanitary sewer and possibly a second for roof and foundation drain flows connected to the storm sewer. For properties without storm sewer service connections, roof flows discharge onto the ground surface of the lot and enter the storm system through catchbasins on the roadway. Storm sewers are used to collect yard runoff, road drainage, and other surface water through catchbasins. Storm sewer pipe networks are designed using the rational method, which calculates the volume of runoff based on the drainage area and the intensity of the storm event. To be effective, on-lot runoff must be complimented by street flow capacity to remove stormwater.

Although many sanitary sewers are identified as part of a separated sewer system, it is often more accurate to call them partially separated, as most older properties have only a single service connection that collects sanitary sewage, roof drainage, and foundation drain flows. In some instances, municipalities have disconnected roof leader flows and redirected them to surface discharge in order to separate systems. However, the sewer system is still only partially separated as foundation drain flows, which are effected by storm frequency, are still connected to the sanitary service connection. As the sanitary sewer systems are sized to collect domestic flows, there is still a risk of hydraulic overloading of the system and basement flooding can result.

The main economic reasons for not connecting foundation drains to storm sewers are:

- in older areas it is not economically feasible to disconnect the existing service connections from the combined sewer and reconnect them to the new storm sewer.

- the new storm sewers are not deep enough to allow a gravity connection from service connections.

- storm sewers do not typically extend to all reaches within a subdivision and so are not always available to receive roof and foundation drain flows.

3.3 Modern Stormwater Management

Continual urban development has resulted in urban sprawl. Municipalities continue to grow in population, expanding their spatial coverage and occasionally annexing nearby communities. This process of expansion increases the demands on the urban drainage systems due to the increase in paved areas. Larger volumes of stormwater flows must be routed through municipal storm sewer networks and along overland flow routes.

Studies performed in Denver, Colorado in the 1960s provided data that resulted in the development of a dual drainage design strategy for stormwater management. Storm sewer systems are currently designed using this concept, which separates storm drainage into two components:

- the first is the <u>minor system</u>, which refers to the storm sewer piping system. The purpose of this system is to rapidly dewater road surfaces and, therefore, to provide convenience for pedestrians and vehicles (drainage objective). The design of the minor system is based on the pipeline capacity needed to convey stormwater runoff for relatively frequent storm events.

- the second is the <u>major system</u>, which refers to the combination of roads, ditches, swales, and other catchment surfaces designed to transmit flows exceeding the capacity of the minor system. The design of the major system is based on flood control objectives, using natural drainage principles, retention ponds, impoundments, and inlet control devices, to slow runoff and to increase infiltration into the ground.

The level of service associated with the major and minor drainage systems is described by the return frequency or probability of occurrence given in years of the storm hyetograph used to design the drainage system component. Minor systems are typically designed for a return frequency of 2 to 5 years while major systems are typically designed for a return frequency of 25 to 100 years or more. It is the inadequacy or lack of a complimentary major/minor sewer system that can influence the incidence of basement flooding. Older areas have been enclosed by newer developments, and newer developments have been designed without overland flow routes to suitable outlets.

The dual drainage system is designed so that, during rare storm events when the storm sewer (minor system) surcharges, excess flows follow major system overland flow routes to a natural watercourse or to a manmade stormwater management pond. This pond can be a depressed park with a storage volume defined for runoff control protection up to and including 100-year storm events. In some cases inlet control devices are used to limit the flow entering the minor system and prevent surcharge. Evaluation of the connectivity of areas is required to identify routes to control and direct urban runoff without having to reconstruct existing sewer systems. A drainage methodology needs to be developed that identifies the limitations of the core system and yet facilitates orderly development in accordance with a municipal masterplan.

Flood protection criteria in Ontario was altered in the 1950s after extensive damage was produced by Hurricane Hazel, which became the worst recorded storm in Ontario. Design methodology for major drainage works was changed to reflect the previously unrecognized storm intensity and the volume associated with the hurricane. The Ministry of Natural Resources adjusted provincial policies to prevent any development occurring in flood plain areas unless adequate flood protection was provided.[17] Hence, the design level of protection in Ontario was adjusted upwards as a result of this negative experience.

4.0 CURRENT URBAN DRAINAGE DESIGN PRACTICES

4.1 Current Design Practices

Many Canadian cities have experienced varying degrees of basement flooding over the past 10 to 20 years in both older areas and new subdivisions. The purpose of this chapter is to review the current Canadian design practices in order to identify areas where they may be inadequate or to identify trends that may help other communities in a design criteria review to reduce or eliminate basement flooding.

The sources of data employed were:

- the information collected from the CH2M HILL questionnaire survey as part of this study
- data obtained during a previous review of drainage servicing criteria for the City of Edmonton[18]
- National Building/Plumbing Code
- CMHC, the provinces and property maintenance bylaws

Table 4-1 presents the design practices for storm and sanitary sewers in a tabular format. The 11 municipalities identified for this study include the cities of Vancouver, North Vancouver, Edmonton, Calgary, Regina, Winnipeg, Laval, Ottawa, Scarborough, Halifax, and St. Johns.

4.1.1 Sanitary Sewers

The design of sanitary sewer systems is based on an understanding of the expected wastewater flows for an area. The time variation of these flows within any 24-hour period is an important factor as sewers, which normally are gravity-flow systems, must be capable of handling peak loads. The pattern of flow to the sanitary sewer system is very similar to that of water demand and, in consequence, it can generally be assumed that the peak flow of domestic sewage is the same as that of domestic water demand.

The current state-of-practice in Canadian municipalities is to use an average per capita flow contribution along with a peaking factor to estimate residential sanitary flows. The design peaking factor is calculated using equations that require an estimate of population densities. These are usually obtained from zoning and land use data that has been established by municipal planning departments. Therefore, it is important that land use records are current and updated on a regular basis.

Extraneous flow contributions are added to calculated sewer system peak flows. This extraneous water, I/I, can originate from two main sources:

- groundwater
- stormwater runoff

The quantity of I/I present depends on the physical condition of the sewer pipelines and the number of stormwater sources connected to the sewer system. Excessive quantities of I/I can cause hydraulic overloading of pipelines and in some cases extensive basement flooding. Since both sources of I/I are relevant in the investigation of basement flooding, detailed discussions on each follow.

Groundwater

Groundwater infiltration (GWI) enters the sewer system when the pipelines and deeper portions of the manholes are below the natural or artificially-induced groundwater table. In such instances, the head difference between the groundwater table and the pipe or manhole provides a driving force to transmit water through open or cracked joints and deteriorated manhole walls. The rate of infiltration is influenced by soil permeability. Because its source is relatively constant, GWI creates a long-term volumetric problem that reduces the available capacity of a sewer system to handle peak domestic sanitary flows.

Stormwater Runoff

The I/I related to stormwater runoff can be divided into two main areas:

- direct stormwater inflow (SWI)
- rainfall-dependent infiltration (RDI)

SWI is defined as the I/I component that derives from a rainfall event and enters the sewer system without flowing through the soil. Typical SWI sources include catchbasins, downspouts, submerged manhole lids, and area drains. SWI can contribute significantly to peak flows by virtue of the speed with which it enters the system.

RDI is defined as the I/I component that derives from a rainfall event and enters the drainage system by flowing through the soil. RDI percolates through the soil and enters the drainage system through the foundation drain, cracks in pipes, and manhole defects. The feature that differentiates it from GWI is that RDI only influences the drainage system during and following a storm event.

The total amount of I/I can vary widely depending on location, system age, structural integrity, intensity of rainfall, and antecedent soil conditions.

Rehabilitation

Rehabilitation methods are based on the results of source detection work. Source detection represents the investigative work required to identify and isolate defects in the sewer system that contribute to I/I. Source detection methods that have worked well consist of smoke testing, dye testing, manhole inspection, flow isolation, flow monitoring, and closed-circuit television (CCTV) inspection. Once the I/I source has been located, methods for rehabilitation can be identified and compared for cost-effectiveness.

Rehabilitation techniques include reduction of extraneous flows at the source or an increase in the collection and storage capacity of the stormwater system facilities. Reduction of extraneous flows at the source include lot regrading, disconnection of downspouts, connection of foundation drains to sump pumps, slip-lining or grouting of defective pipelines and joints, and replacement of pipes. Increased storage and capacity involves larger pipe sizes, inlet control devices, a third pipe system for collection of foundation drain flows, underground stormwater detention tanks, and stormwater dry and wet ponds.

Most municipalities have used newsletters in an effort to encourage homeowners to correct on-lot deficiencies. However, enforcing lot grading and roof leader policies has limited success due to the inability to actively initiate homeowner participation. The City of Edmonton encouraged lot regrading by implementing a subsidized program in two subdivisions where basement flooding had occurred[19].

Increased storage and pipeline capacity improvements are easier, as they do not rely on public support or involvement, but costs can be considerable. These hydraulic relief measures are a necessity in areas where other means of reducing extraneous flows are insufficient or not feasible. However, the problem of extraneous flows entering the sewer system through foundation drains are not addressed. The City of Winnipeg has altered municipal building codes to include lot grading, sump pump, and roof leader bylaws for all new residential subdivisions[20].

4.1.2 Storm Sewers

Urban stormwater drainage design is based on a number of variables. Runoff from a drainage area is a function of climate and physical characteristics of the area. Factors that may be pertinent in precipitation-runoff relationships include precipitation type, rainfall intensity, duration, and distribution; storm direction; antecedent precipitation; initial soil moisture conditions; soil type; evaporation; transpiration; and the size, shape, slope, elevation, directional orientation, and land-use characteristics of the drainage area. The number of variables that influence stormwater related flows are much higher than those for sanitary flows.

Peak flows result from excess surface-runoff volumes. The conditions that may generate these excesses are intense storms, snow melt, and snow melt combined with rainfall. Maximum flows on urban areas usually result from high intensity short-duration rainfall events. The particular factors that produce maximum flow on a specific drainage area must be determined if reasonable reliability is to be accorded the estimated quantities of discharge.

The limits of a drainage area are usually set by natural physical features. These topographic features are used to delineate drainage areas and along with rainfall intensities, time of concentration, and impermeability of the catchment area, surface runoff flows are calculated. There is an economic limit to the intensity of storm that the pipeline system can be designed for, and on average the current state-of-practice is for storm sewers to be designed for the worst storm likely to occur every 5 years. For storms with return frequencies greater than 1:5 overland flow routes are designed to convey stormwater flows in excess of the sewer pipeline system. This dual drainage concept was described in section 3.3.

In most if not all municipalities, the selection of service level (return frequency of design rainfall) for storm drainage is predicated on experience and tradition rather than explicit analysis. In the long run two forces govern the determination of service level:

- the desire of designers to implement cost-effective (or possible minimum cost) designs
- user (public) feedback on the adequacy of designs. Feedback is usually in the form of complaints or damage claims

4.1.3 Densification

The impact of densification on existing sewer systems must be thoroughly analyzed to prevent their potential overloading. An increase in population density will increase the quantity of sanitary flows to either a combined or separate sanitary sewer system. The sewer capacity available in the immediate sewer systems may be sufficient, but the analysis must also include an evaluation of downstream conditions. Capacity must also be available in the downstream sections of the sewer systems. If not, the sewer will back up or cause flooding in areas downstream of the densified area. Densification can cause both the sanitary and storm sewer volumes to increase considerably.

A change in population density can, and generally does, result in an increase in the impervious to pervious area ratio. Single family residential areas are replaced by apartments or townhouses with larger roof areas and parking lots. As a result, surface runoff occurs more rapidly, increasing the peak flows to the storm sewer system. There is less pervious area available for the stormwater to infiltrate into the ground. Therefore, larger sewers are required to convey the rapidly generated flows away at a much faster rate than previously.

4.2 Deficiencies in Current Practices

4.2.1 Sanitary and Combined Sewers

Sufficient allowance for adequate peak I/I capacity is critical in evaluating or designing sewer systems. It is the lack of attention given to all the I/I sources that has resulted in the undersizing of sewer systems. Allowances for I/I have traditionally been based on textbook figures with little or no consideration given to the particular features of the developed area.

In the course of the last 10 years, the City of Winnipeg has carried out extensive tests on foundation drain flows and on-lot drainage. The results have indicated the impact of weeping tile response to rainfall on deficiently graded lots. The City of Edmonton, while assessing its municipal standards for upgrading, studied pipe flow variation based on different standards. For a typical subdivision with a population of 1,000 people, the sanitary sewer flow based on normal dry weather flow plus allowances for groundwater infiltration and weeping tile response to a 1:25 year storm is estimated at 0.11 m^3/s. Calculation of the design flow, based on the City of Edmonton 1978 design criteria, yields a flowrate of 0.01 m^3/s, i.e., a tenfold difference[21]. There is no doubt that extraneous flows into the sanitary drainage systems have been significantly underestimated. The current design challenge is to come up with realistic standards so that analyses represent the real world. Subsequently, the complete stormwater drainage system, from roof leaders and lot grading to the sewer system, will be designed with greater control.

Nearly all municipalities have discontinued the practice of allowing foundation drains and roof leaders to connect to sanitary sewers in new developments. It is only in older areas where the practice is continued, although education programs (newsletters, etc.) are used to encourage downspout disconnection and installation of sump pumps for foundation drain flows.

Manhole inflow allowances are felt to be a critical issue in many communities. An Edmonton study of the North East Drainage area identified that 54.4 percent of storm related extraneous flows were a result of inflow through holes in manhole covers[22]. These inflows were in fact a reflection of inadequate overland flow routes resulting in street ponding. Results of a study on manhole inflows carried out by the Neenah Foundry Company are presented in Figure 4-1. Similar tests can be performed on various manhole covers to determine the potential level of inflow and possible methods of inflow prevention.

Discussions with the City of Regina identified manhole cover holes as a major source of inflow. Field tests have shown that a 2-ft head of water results in 2.0 L/sec of

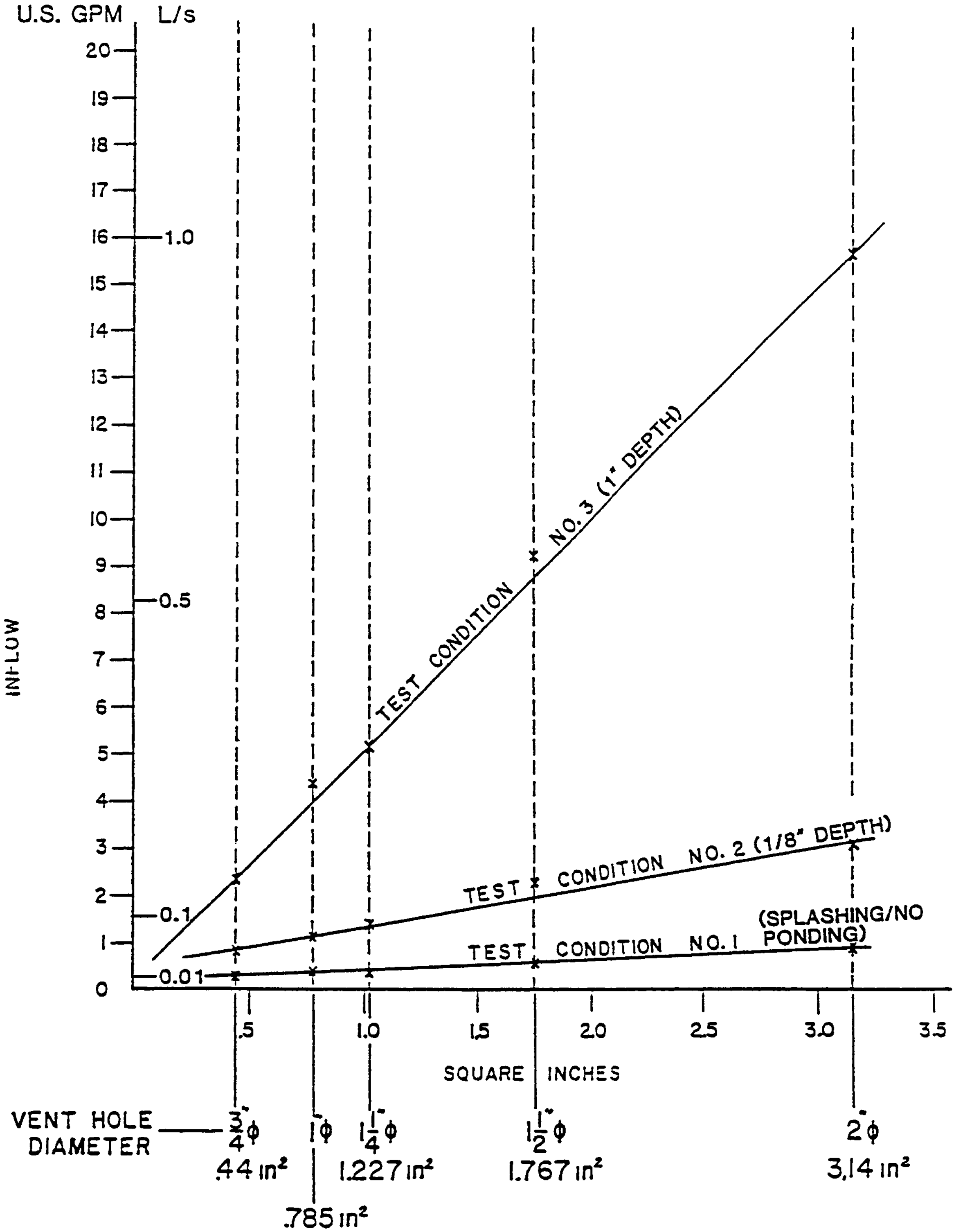


Figure 4-1

VENT HOLE / PICK HOLE INFLOW
(NEENAH FOUNDRY)

inflow per hole. Short duration, high intensity storm events cause severe street flooding in Regina and result in high inflows to the sanitary sewer system via manhole covers. The quantity of inflow has been serious enough to have an influence on basement flooding[23]. For more critical situations, where sags in roadways can result in significant ponding over a manhole cover, the inflow allowance would likely underestimate manhole inflows unless some inflow control device were used. Typical major flow route designs allow ponding to curb levels (approximately 150 mm) for a 1:5 year event. Consideration should be given to the type of manhole covers used in an area and whether or not they have rim seals or rain stoppers. Rain stoppers are devices that normally remain open to allow for venting of the sewer system but close at pressures greater than 1 psi.

Review of the total system I/I allowances show a wide variation, from 0.00 to 0.28 L/sec. Communities that have experienced extreme basement flooding appear to have studied the situation and in the process have become knowledgeable on all the factors that influence sewer system flows in their area. This typically entails understanding all the I/I sources and developing an ongoing program to eliminate the most serious contributors.

4.2.2 Storm Sewers

The continuity and interaction between the various stormwater management facilities is often unrecognized by drainage system designers and can result in serious basement flooding. Some municipalities have developed master drainage plans to coordinate stormwater management practices for each drainage watershed. In this way the future limitations of the system will be clearly identified following the results of a thorough investigation of the local conditions, incorporating local soil types, climate, topography, historical system development, planning data, etc. Followup inspection to ensure proper installation and maintenance of stormwater facilities is often neglected, thus causing later flooding problems.

For instance, with the advent of storm sewer service connections to individual lots, the short-term volume problem of improper lot grading, roof leader discharge, and foundation drain flows can be transferred to the storm sewer system. The same local drainage problems that aggravated the sanitary and combined sewer systems can now exceed the capacity of the storm sewer system unless properly accounted for in the design. Correctly designed stormwater management facilities incorporate all the drainage practices throughout the municipality, from on-lot drainage practices to major facilities such as storage.

4.2.3 Design Practices

System analysis by computer is a desireable and often necessary feature of modern urban system design. However, caution must be exercised when using sophisticated models to calculate the responses of the system to storm and other inputs. Firstly, the interpretation of results from model analysis calls for experience in the hydraulic behaviour of the collection facilities. Too often results are accepted and presented by computer modelers without a critical review by design and operations engineers who have more knowledge on how the systems should and do operate. Also, the availability of different computer models, including many that are microcomputer-based, has grown. These models have various features that may or may not be suitable for an analysis of the existing or planned system, i.e., analysis of a sanitary sewer system (with or without I/I) may call for a different set of features than a storm sewer or combined system. On the other hand, the reviewer at the municipality should also be trained and have the proper expertise to enforce appropriate concepts and spot any errors in the computer analysis and recommendations. A lack of understanding by the reviewer could often result in inadequate designs or in some cases over design of stormwater management facilities.

Given the costs associated with developing a computer analysis database along with the sophistication of this method to analyze urban drainage systems, the use of these advanced systems must be matched with a commensurate improvement in the accuracy and applicability of input data. This provides the municipalities with the challenge of having available realistic field data for calibration, verifying of the analytical models, and establishing effective design criteria for development for urban expansion. Realistic field data includes flow monitoring of the sewer system to measure the response to rainfall events and infiltration tests to measure the response of drainage tiles.

Implementation of stormwater control facilities requires a followup analysis to ensure they were installed properly and are operating as initially planned. This requires a review of whether roof leader discharges and lot grading are maintained at the required standard. Control facilities must be inspected to ensure they were installed correctly using design elevations, size, locations, etc. On-lot and off-lot maintenance is a necessity in stormwater management control and a program must be established that will ensure proper operating conditions.

4.2.4 Design Improvements

Local Surface Flow

Discharges from lot grading and roof leaders must be clearly identified to developers and homeowners as being an integral part of the stormwater drainage system. Specific guidelines must be developed by municipalities as to the most efficient means for controlling local stormwater drainage. Analysis of design and construction practices may result in solutions to problems experienced by homeowners regarding soil subsidence and roof leader practices. Proper soil compaction in the backfill zone may reduce the need for continual regrading. Different extensions from roof leaders may help to resolve some of the frustrations experienced by homeowners such as icing during spring and fall, disconnection from strong winds, or obstructions during yard maintenance.

Foundation drain flows must be eliminated from sanitary sewer systems. This current state-of-practice has only recently developed in some municipalities and as a result must be a consideration when analyzing the downstream constraints to newly developing areas.

Municipalities are responsible for local street drainage and must identify areas where ponding could result in inflow to the sewer system. Manhole covers could be replaced, with water tight manhole covers, in poorly graded street areas where inflow to the sewer system could be considerable.

Sewer System Flow

Sanitary and combined sewer systems must be rehabilitated in a cost-effective manner to increase their operating capacity. A detailed analysis on an area-by-area basis is required to determine the necessary improvements. A number of municipalities had found that basement flooding resulted from a variety of different problems encountered in different developments. Some were a result of historical design practices and some were a result of rapid development with inadequate inspection procedures and planning.

General maintenance programs must be developed and implemented. It is important that municipalities realize the need for proper maintenance. The City of Ottawa has identified shallow grade pipelines as requiring consistent maintenance. These pipelines are flushed three times a year as opposed to the annual schedule of the overall pipeline system[24].

On-lot improvements, such as the installation of backflow preventers and sump pumps, need to be further researched to test their reliability and effectiveness in isolating the basement from sewer system backup. Basement structures should be further researched to ensure cracks and poorly sealed joints, as seen in concrete walls, can be eliminated.

Major System Flow

As the dual drainage system is a relatively new stormwater drainage concept in Canada, an effective major system is feasible only for the newer developed areas. Existing street drainage systems, overland flow routes, and storage facilities must be incorporated into an overall master drainage plan. Depths of flow on the streets must be designed to prevent the development of hazardous conditions during storm events. Overland flow routes must be continuous and storage facilities must be designed with appropriate controls on inlet and outlet flowrates. Door and window sill elevations must be correlated to the expected 1:100 year depth of street flow to avoid basement flooding from severe street flooding.

For the older areas, particularly those being redeveloped, major systems are not likely to be in place. In such instances, municipalities should investigate, by computer analyses, how the drainage system behaves under the extreme rainfall events and assess the likely damage that could be caused by both surface inflow to basements and sewer surcharge. Innovative solutions consisting of off-line storage in parks or underground tanks have been applied in many Canadian municipalities to control this problem.

4.3 Review of Previous CMHC Reports

CMHC has commissioned a number of reports on aspects of basement flooding that are relevant to this study. The three reports reviewed as background for this study were:

- *Advances In Basement Technology*. The Becker Engineering Group with Scanada Consultants. CMHC. 1989.
- *Field Evaluation Of Foundation Drain Response*. CH2M HILL ENGINEERING LTD. CMHC. 1989.
- *Protection Of Basements Against Flooding. Trends and Impacts of Drainage Regulations*. Paul Wisner and Associates Inc. CMHC. 1990

While the Becker Engineering Group report dealt with basement technology in the most general perspective, several design aspects and useful trends relevant to basement flooding were highlighted:

- functions of the basement within society have changed dramatically, from a storage space initially to a utility area, then to a recreational or livable space used as extensively and invested in as heavily as the upstairs accommodation.
- basement problems account for a high number of customer complaints in the housing industry, highlighting the public expectations of useable, livable space.
- ninety percent of basements are cast in situ concrete.

The engineering design issues discussed in the report were:

- structural adequacy/durability
- moisture exclusion
- energy efficiency
- control of construction water
- exclusion of radon, and other gases
- affordability
- serviceability

The discussion of moisture exclusion bears significantly on local drainage considerations. The continuous granular drainage layer discussed in the report in reference to rationalizing basement elements would be an improved, though expensive, mechanism to efficiently remove stormwater from the individual lot. From a drainage engineer's perspective, it is important to see that these drainage layers connect to adequately sized sewerage systems.

CH2M HILL's report documented the results of a series of tests carried out at several residential lots in the City of Edmonton. Its value is that it presents full-scale flow measurements of the foundation drain response to simulated rainfall events. From an urban drainage viewpoint, the important conclusions are:

- foundation drain contributions to wet weather flows in the sewer system are significant. Up to 0.49 L/sec were recorded.

- there is considerable variation within geographical areas.

- roof leader disposition and lot grading conditions are important parameters. Compliance with the guidelines presented in this report (Chapter 2) achieves significant reduction in flows to the foundation drain.

It is worthwhile to note that followup studies are currently being conducted at a special research facility in Sherwood Park, Alberta to quantify the impact of lot slopes, soil permeability, and other parameters on foundation drain flows. This program, jointly sponsored by Alberta Municipal Affairs, the City of Edmonton, and the County of Strathcona, will provide important contributions to knowledge of on-lot drainage in urban settings.

In Paul Wisner and Associates *Protection of Basement Against Flooding-Trends and Impacts of Drainage Regulations*, problems as they relate to drainage practices as well as current techniques used to identify, prevent, and alleviate these problems were reviewed. As part of the background research for the report, national, provincial, and municipal drainage policies and guidelines for protecting basements were evaluated.

The conclusions of the study are:

- basement flooding requires a holistic approach to its solution and coordination of the on-lot, drainage system, and plumbing/building procedures aspects.

- there are no consistent standards and procedures across Canada for dealing with basement flooding and the issues, such as infiltration and inflow, associated with overloading sewer systems.

- the key to public involvement in improving drainage and reducing flooding is better coordination between urban planners, developers, and municipal officials. The consultant recommended this as an expanded role for CMHC.

- storm sewers should be allowed to accept infrequent (1:10 to 1:25 year) overflows from the sanitary system.

- national policies should be established for monitoring and modeling of sewer systems. A database of measurements, monitoring techniques, and modeling procedures should be computed.

- consumers should be better educated in selecting on-lot protection devices (sump pumps, backflow preventers) and should be educated through newsletters or open houses following design/procedures research.

5.0 POTENTIAL SOLUTIONS TO BASEMENT FLOODING

5.1 Local Surface Flow

Basement flooding from localized surface flow through window wells and cracks in basement walls is an easily identified problem and probably the most straight forward to solve. It does, however, require an understanding of how surface drainage should occur and how it is traditionally managed on a lot-by-lot basis. Key to the avoidance of basement flooding from this source are:

- correct downspout disposition and adequate lot grading away from the dwelling
- swales between lots providing positive drainage to the roadway
- once the stormwater is on the roadway, an efficient major and minor drainage system to remove the stormwater before it reaches excessively high levels to result in basement flooding

Since one of the purposes of a foundation drain is to remove subsurface and, therefore, surface-ponded water, the question of foundation drain design cannot be separated from efficient on-lot drainage. Therefore, it is important to have a proper outlet for the foundation drain, either a sump pump or a connection to the storm sewer. Foundation drains should not be connected to the sanitary sewer.

5.2 Sewer System Flow

5.2.1 Basement Protection Devices

Basement protection devices can be installed in sewer service connections to prevent the backup of sewer flows to floor drains and foundation drains. A number of municipalities have instituted bylaws that require the installation of backflow valves and/or sump pumps in new developments. It is difficult and expensive to enforce similar bylaws in older developments. Although, for areas where flooding is a continual problem, the advantage is that individual homes are better isolated from sewer backup.

A sump pump system is comprised of a sump (catchpit) to collect foundation drain flows and a pump that moves the flows to either the below-grade storm sewer or to surface drainage across a lot. Installation of sump pumps allows the dwelling to be completely independent of the stormwater sewer system and, therefore, cannot be flooded from storm sewer backup even under the worst rainfall conditions. However, the concern is that they are electrically powered and are at risk to power failure during storm events. This may be curtailed by using a combination of an electric and stand-by sump pump system. Stand-by units are available on the market that are powered by either battery or household watermain pressure.

Studies in Winnipeg, Manitoba have identified that homeowners have concerns about sump pumps. Some of these are noise of sump pumps and odor from the sump pit, freezing of the sump pump discharge pipe, power outages, and sump pump failure. Detailed investigations revealed that the majority of the problems were a result of incorrect sump pump sizing or design, or faulty installation by the developer. Continued education and ongoing development of industry standards would help to alleviate some of these concerns. The City of Winnipeg has taken the initiative to develop an information sheet explaining the correct care and maintenance procedures for homeowners. The City of Winnipeg has revised its building bylaw to require sump-pit drainage systems in all new homes. This regulation applies both to homes built in new subdivisions and to infill houses in older neighbourhoods[25].

Backflow valves are installed in service connections to prevent the backup of sewer flows into the basement. The valves are designed to stay open during normal operation when flows are exiting the dwelling and to close if the flows are reversed. Backflow valves have failed in some instances but it is generally recognized that the failure is due to improper installation or lack of maintenance. These problems could be reduced by establishing installation procedures and standards for plumbers, training building inspectors, and educating homeowners. The City of Winnipeg has amended its building bylaw to require installation of backup valves in sanitary sewer lines to prevent backup into the basement.

Backflow devices and sump pumps are intended to prevent all basement flooding. It is generally recognized that they fail with some indeterminate frequency. Nevertheless, they could be used as an additional safety feature against basement flooding.

5.2.2 Operation and Maintenance of Sewer Systems

Ideally all maintenance, by both the homeowner and the municipality, should be preventive. However, it is mainly municipalities that at selected times, on a predetermined schedule, carry out maintenance activities on municipal sewer systems. Little or no work is ever carried out on service connections to the sewer system and backflow prevention devices. These activities should be designed, from a content and frequency viewpoint, to ensure that the facilities will perform the tasks for which the system was originally designed. However, an ever-increasing amount of operation and maintenance (O&M) time is being spent on corrective and emergency activities. Serious deficiencies have been recognized because of a combination of inadequate design and increased residents' expectations, particularly to prevent basement flooding. Tasks such as addition of extra catchbasins, repair of seriously deteriorated manholes, and measures aimed at reducing system I/I become part of O&M activities. Normal preventive maintenance, such as line flushing and catchbasin cleaning, is not done as scheduled because of the costs involved. Shortage of trained staff is a reflection of those costs.

A major challenge in urban areas is knowing what is in the ground and its state of repair. Inventory programs are expensive because of the sheer number of components to be inventoried. A government-sponsored program in Ontario, "Lifelines", entails preparation of a computerized inventory of all drainage system components of an urban drainage system. Special packages have been developed (SIMS for sewers and WIMS for water distribution systems) and the information collected and stored can be the launch pad for an effective, ongoing maintenance and rehabilitation program. Other provinces should be made aware of this initiative and develop similar programs. There is a need for an exchange of information between provinces and municipalities. Research and investigations into sewer system deficiencies should be networked across the country to prevent any unnecessary duplication.

The ever-increasing technical aspects of drainage system O&M have presented municipal authorities with the further challenge of training personnel. Employees must be trained in the technology, the equipment, and the maintenance of the equipment associated with:

- closed circuit TV
- dye testing and source detection methods
- oil and chemical spill prevention and handling

Municipalities should institute inhouse courses and seminars for O&M personnel in computer literacy, operator certification, and other areas. O&M personnel need these skills to effectively manage their operations, particularly the quick response required to achieve success under emergency conditions.

The greatest challenge facing an O&M team is to meet the expectations of today's homeowners. Basements of homes owned by people in the 1920s and 1930s kept the footings below the frost line and the space was used for storage and furnaces. In the 1990s, basements are converted into suites in some communities to provide affordable housing and increase available income for homeowners trying to buy property. The possibility that drainage collection systems might be designed to surcharge or that pump stations might be subjected to power failure or a serious equipment malfunction are issues that seldom occur to the homeowner until the first flooding event. There is an enormous need to educate people with respect to the design basis of our urban systems, and the people with the greatest interaction with residents are O&M staff.

5.3 Major System Flow

Major system deficiencies are a result of discontinual major systems, improper location of low points, inadequate number of catchbasins, and incorrect overland or street grading. Correction of these deficiencies requires the coordination of municipal design engineers and contractors. Inspection and routine checks during construction help to eliminate potential major system flow problems. In existing urban areas, with discontinual major system routes and ponding at low points, more detailed studies are needed to develop the appropriate flood relief measures. This may incorporate the installation of more catchbasins if the storm sewer has adequate capacity, relocation of inlet points to stormwater management ponds, inspection of curb heights, sealing of manhole covers, raising the elevations of individual structures during redevelopment, etc.

5.4 Limits on Densification/Redevelopment

Controls on densification and redevelopment must be established. Redevelopment should not be restricted, but the full cost of system expansion should be carried out by the development. The increased flows to the drainage systems must be fully analyzed and considered before the development occurs. If the development would overtax existing sewer systems, increase the likelihood of surcharge, and/or seriously affect other property owners in the region or area, then the developer should be made responsible for any upgrading requirements, even beyond the property limits, or else limits should be placed on densification and redevelopment.

5.5 Present Preventive Methods

Table 2-1 summarizes the preventive methods that the 11 municipalities have instituted to alleviate the incidences of flooding. Flood relief programs are comprised of one or more of three main components:

- sewer system improvements that included accelerated road drainage separation programs, installation of relief sewers, and sewer capacity upgrading usually through installation of larger pipes and/or pumping facilities, and installation of storage facilities and inlet control devices

- on-lot improvements, including removal of roof leaders and occasionally foundation drains, installation of sump pumps or backflow prevention devices, and improvements to lot grading

- other management measures, including bylaws, public education programs, and flood relief insurance programs

Many municipalities have promoted various on-lot improvements. In all cases, these programs for existing areas have been fostered through either education programs or inducements such as grants. None of the municipalities have been able to take any legal recourse in developed areas, i.e., bylaws forcing on-lot corrections. The City of Edmonton has been unique in its non-regulating approach to improving existing lot grading problems. It has supported individual homeowners with the improvement of their lot grading through a grant program[26].

In many cases, bylaws have been enacted to amend practices in new developments. The City of Edmonton amended the sewers bylaw to disallow any connection of foundation drains to sanitary sewers, since 1988 September, in all new developments. It has also instituted a bylaw that requires all new developments to have foundation drains connected to sump pumps and backflow valves installed in service connections.

A number of municipalities have promoted the use of backflow prevention devices and/or sump pumps to better isolate the individual home from sewer backup. These measures remain somewhat controversial since they incur additional costs, are not wholly failure-proof, and place responsibility on the homeowner for ongoing maintenance. Nonetheless, municipal officials identify these measures as a rational step toward increasing the level of protection.

No municipality has a flooding compensation insurance program in place. In the case of the City of Ottawa and of the City of Winnipeg, flood insurance was disparaged as an inappropriate means of mitigating flooding. Flood damage compensation can in some situations may be more economical than extensive rehabilitation of the sewer systems.

6.0 DISCUSSION OF ISSUES

Urban drainage system planning and design is not a straight forward process. A number of non-engineering factors can influence the implementation of proper or improved drainage practices to avoid basement flooding. Some drainage practices create complications while others may provide unforeseen benefits. The following is a discussion of some of these relevant factors, policy issues, and related technology.

6.1 Jurisdictional

6.1.1 On-lot Inflow/Infiltration

Urban drainage systems include pipeline systems, a treatment plant, lift stations, and numerous miles of service connections from the main sewers to houses. Many of the problems that exist in the drainage system originate from these service connections. Problems such as cross-connections, subsidences, collapses, and excessive infiltration through cracks or open joints occurring at the service pipes create significant unplanned demands on the capacity and create pollution problems to the whole system. Even though stormwater control measures such as lot grading and roof drainage have been identified, it is difficult to enforce new bylaws in older urban areas unless redevelopment is occurring. On-lot inflow/infiltration prevention measures can be promoted but rarely enforced if homeowners are unwilling to incur extra expense. It is also difficult to promote change when the homeowner knows that their on-lot drainage practices complied with regulations at the time of construction.

6.1.2 Regional Drainage Systems

Some municipal systems operate within the confines of a regional drainage system. Regional facilities may be inadequate and poorly planned, resulting from a merging of municipal boundaries rather than a masterplan that incorporated the extent of the regional drainage area. Problems could be a result of inadequate drainage practices outside of the municipality (e.g., insufficient regional trunk sewer capacity). Municipalities with serious I/I problems can contribute to capacity problems in regional collection systems and result in flooding of adjacent municipalities. Conflicts can develop over the maintenance of stormwater control facilities starting with the homeowners' responsibilities on-lot, to the municipal versus regional responsibilities for sewer system design, maintenance, and age.

Some of the municipalities across Canada are grappling with this jurisdictional problem in one form or another. For instance in Vancouver, the Greater Vancouver Regional District has overall responsibilities for trunk drainage. Analysis of the subcatchments for capacity, etc., is generally done in the individual municipalities. So one utility's output becomes the input for another's analyses and the need for consistent application of agreed-to hydraulic and hydrologic principles is sometimes lost.

6.2 National Building Code

Building regulations in Canada are the responsibility of each provincial and territorial government. The National Building Code (NBC) is set up as a code of minimum regulations for public health and safety and is prepared as a recommended model code to be used by appropriate authorities. As such, it is used as a basis for provincial and territorial building codes.

The minimum regulations for drainage disposal and surface drainage are outlined in the NBC under Sections 9.14.5 and 9.14.6. The applicable clauses from the NBC (1990) are as follows:

> "Subsection **9.14.5. Drainage Disposal**
> **9.14.5.1. Drainage Disposal.** *Foundation* drains shall drain to a sewer, drainage ditch or dry well.
> **9.14.5.2. Sump Pits**
> (1) Where a sump pit is provided, it shall be not less than 750 mm deep, 0.25 m^2 in area and be provided with a cover.
> (2) Where gravity drainage is not practical, an automatic sump pump shall be provided to discharge the water from the sump pit described in Sentence (1) into a sewer, drainage ditch or dry well.
> **9.14.5.3. Dry Wells**
> (1) Dry wells may be used only when located in areas where the natural *groundwater level* is below the bottom of the dry well.
> (2) Dry wells shall be not less than 5m from the *building foundation* and located so that drainage is away from the *building*.
>
> Subsection **9.14.6. Surface Drainage**
> **9.14.6.1. Surface Drainage.** The *building* shall be located or the *building* site graded so that water will not accumulate at or near the *building*.
> **9.14.6.2. Drainage away from Wells or Septic Disposal Beds.** Surface drainage shall be directed away from the location of a water supply well or septic tank disposal bed.
> **9.14.6.3. Catch Basin.** Where runoff water from a driveway is likely to accumulate or enter a garage, a catch basin shall be installed to provide adequate drainage.
> **9.14.6.4. Downspouts.** Where downspouts are provided and are not connected to a sewer, provisions shall be made to prevent *soil* erosion."

The foregoing critical housing requirements are not the domain of urban drainage designers yet their random use can greatly influence sewer design capacity.

The above regulations should be expanded in the next edition to include standards that will help prevent basement flooding. Suggested items to be included are:

- control of surface drainage flow to sanitary sewers
- downspout discharge location
- installation of backflow valves to prevent against sewer backup
- drainage of reverse grade driveways
- impact of densification on sewer system flows
- requirements to tie on-lot drainage with urban drainage design

The conclusions at the end of this report could be included as a checklist of items impacting basement flooding. Consideration of these issues in the National Building Code will greatly assist in heightening the awareness of the factors causing basement flooding.

6.3 Potential for Demand Modification

Demand modification refers to the conservation of water within the residential, commercial, and industrial sectors and the effect this has on water distribution and wastewater collection facilities. Water conservation is usually perceived as a short-term effort to minimize the effects of temporary water shortages due to drought, a pipeline failure, or other emergency situations. Yet, water quantity and quality problems in the U.S. have resulted in State legislation that has effectively caused a re-evaluation of how water is used. This practice of reviewing consumption patterns to determine the areas where wasteful consumption could be altered through water-efficient practices, technologies, and processes is becoming more common. Water utilities are now identifying the potential of water conservation measures for effective and efficient water and wastewater management.

Plumbing and building codes can be used to enforce the use of water efficient fixtures and appliances. These include low-flush toilets, low-flow shower heads, low-flow faucets, and reduced-water use dishwashers and clothes washers. Water permits can be used to impose the same requirements on users before a property transfer or zoning change. This would encourage replacement of conventional fixtures and appliances in older residences and buildings. Along with saving water, these appliances and fixtures can save energy. A reduction in hot-water use coincides with reduced water heating costs. The success of implementing water conservation programs depends on careful planning that includes a full range of options, along with the potential savings, costs, benefits, and effort of each option on the utility, the users, and the community. Public awareness, voluntary cooperation, and commitment by consumers is essential to achieve any reduction in water use[27].

The result, is an inexpensive increase in available sanitary sewer capacity by relying on changes in public attitude towards water use. The side effect is a potential reduction in the occurrence of basement flooding due to the extra capacity to carry stormwater I/I. However, the role in contributing to reduced flow in sewer systems is unlikely to have a significant impact on basement flooding as dry-weather flows are small compared to I/I which is the major contibutor to surcharge during wet-weather conditions.

6.4 Control at Construction Phase

The construction of house service connections appear to be difficult to control because of the large number of parties involved from the land development stage to the final house completion. There are too many uncertainties and too few checking processes. To solve the problem, it will take a great deal of cooperation among the major players, namely, the homeowners, the developers, the builders, and the policy makers, to come up with a system that will provide clear responsibilities and full accountability of the drainage system. Perhaps the owner may have to assume the responsibilities of both the developer and the builder, and one city inspector will ensure that control devices are installed and maintained properly.

Coordination between municipalities, developers, and homeowners is lacking when it comes to understanding the respective roles and responsibilities of each stakeholder in the operation of a stormwater drainage system. The development of on-lot strategies regarding local surface flow become ineffectual if they are not properly instituted by developers or maintained by homeowners. Municipalities that exist within a regional system must contend with the political and financial constraints of surrounding municipal and regional policies.

The procedures and bylaws for the control of basement flooding should be clear, concise, effective, practical, and responsive to public concerns. The policy maker can help the industry a great deal in facing the challenge of ensuring properly built drainage systems not only to satisfy drainage criteria, but also to assist in the prevention of basement flooding. The first thing that can be done is to eliminate some of the unnecessary rules and procedures. It is no surprise that even some of the most experienced people in the land development field do not know all the steps they have to take to get the necessary approval before they can build a drainage system. What this creates is a huge maze of legislation where no one understands exactly what needs to be done and this can easily lead to unclear responsibilities. When things go wrong, it is extremely difficult to determine who made the mistake and when the mistake was made. If procedures on approval and inspection can be simplified, it not only results in a saving to the developer, which will in turn benefit the homebuyers, but also reduces the chance of things going wrong.

An increase in cooperation among different levels of government, different government departments, owners, developers, and builders is necessary in the future so that everyone will be working towards the same goal of building better drainage systems to serve the public.

6.5 Other Issues

A recent survey of stormwater management practices in the U.S. provided some interesting results. Among the problems most frequently identified were:

- designers and administrators are often intimidated by the complexities of system modeling, statistical probabilities, and other technical jargon.

- drainage is often seen as a low priority item compared to roads and sanitation; yet, drainage is an integral part of road construction and all subservice failures affect road service performance when pipe repairs are required.

- there is little knowledge of the state of repair of drainage infrastructure, which makes ongoing maintenance difficult to schedule or budget, although inspection along with condition assessment records should be initiated.

- masterplans, if available, were cumbersome to interpret or used advanced computer analysis that was beyond the capability of engineering staff to easily modify and reuse.

- a comprehensive planning and policy document, backed by effective ordinances and enforcement powers, rarely existed.

- there is a lack of reliable data.

- day-to-day maintenance was driven by complaints and political pressures, resulting in a dearth of preventive maintenance activity.

More interesting, perhaps, is what were found to be the characteristics of successful programs identified in the same survey.

- problems identified and solutions found: municipalities with successful programs appeared, without exception, to have committed adequate resources at the outset to identify and quantify the problems, formulate options for problem resolution, and focus on the chosen solutions. Most of them had gone on to develop a coordinated program that took advantage of the unique physical and political environments in which they functioned.

- development tightly controlled: development was controlled, not in the sense of restricting development, but in ensuring it bore the full cost of system expansion. Each successful program had well developed procedures to control development, detailed submittal requirements, adequate inspection staffs, and streamlined enforcement procedures.

- maintenance responsibility understood: almost every successful program clearly defined maintenance responsibilities. In several cases, a stormwater utility district was developed as a funding mechanism. In others, regional facilities were maintained by homeowners' associations. Enabling legislation withstood legal challenges.

- public relations programs successfully executed: these appeared to ensure the cooperation of the general public.

7.0 CONCLUSIONS

The conclusions arrived at as a result of this study primarily relate to basement flooding in existing or redeveloped areas. In summary, we find that redevelopments and new developments typically result in municipal population increases, increased impervious areas, and, therefore, higher loads on the sewer systems.

1.0 Based on the questionnaires returned as part of this study and previous work by CH2M HILL and others, basement flooding related to rainfall events is a common problem. Evidence supplied by Edmonton, Calgary, and other municipalities across Canada points to frequent annual incidences.

2.0 Due to ignorance, malpractice, or lack of knowledge, deficiencies at different stages of the design have added up to inadequate sewer systems.

3.0 There is still, within the engineering community, a general lack of knowledge on how urban drainage systems behave under infrequent but heavy rainfall events. The rational method of storm drainage design is no longer appropriate for the complex, branching systems that have evolved and are still evolving in modern cities. Sanitary sewer systems in many municipalities are still being designed without adequate allowance for inflow and infiltration, particulary that associated with rainfall events, to reflect real situations. Storm sewer designs and stormwater management facilities are not properly planned or coordinated by means of a master drainage plan. Inadequate understanding of design methodologies and concepts by both the practising engineer and approval reviewer often result in improper stormwater management controls. Difficulties during the construction stage and improper inspection and maintenance of the installed facilities are often causes of flooding.

4.0 In regard to a typical redevelopment project involving below-ground living space, basement flooding can occur in three basic ways:

- Local surface flow entering through cracks in basement walls or window sills can cause flooding. The water that causes this is stormwater that falls locally and is not successfully drained to the sewer systems.

- Sewer system backup from the sanitary or combined sewer system can cause water in the sewers to drain back into the basement. In most cases, the sewer becomes overloaded because of hydraulic constraints and the resultant surcharge causes sewer backflow. The storm sewer system can sometimes become surcharged. If there is a connection from the storm sewer to the foundation drain, the surcharge in the storm sewer system will cause increasing pressure around the foundation, which can result in entry of stormwater through cracks in basement walls and floors. The origin of this water will generally be from upstream reaches of the catchment.

- Major system flow (in areas designed both with and without major systems) can and often does result in basement flooding. This situation occurs when surface ponding or flows are sufficiently high enough to cause water to enter basements through doors and windows. This typically occurs in urban areas that were developed prior to acceptance of stormwater management through the design of the dual drainage (major/minor) systems.

5.0 There is a growing need for a more coordinated approach to prevention of basement flooding for existing dwellings, newly developed areas in city fringes, and in inner city redevelopments (particularly if these result in densification). Adequate national engineering guidelines and standards should be agreed-to by all provinces and put in place to ensure urban drainage systems are designed to prevent basement flooding. These should specifically include direction on:

(a) on-lot drainage
(b) infiltration/inflow calculation and allowance
(c) acceptable sewer system analysis and design methods
(d) use of sump pumps and backflow prevention devices

The National Building Code and provincial codes and regulations should include more detailed site drainage requirements and on-lot design specifications. The design and performance of backflow prevention devices and residential sump pumps currently used in Canada should be reviewed, practices in other countries examined, and national standards drafted for review by all stakeholders. These efforts should be targetted to the year 2000 National Building Code, with a submission by Canadian Home Builders Association (CHBA)/Canada Mortgage and Housing Corporation (CMHC) in the 1995 Code.

6.0 In planning and designing residential redevelopments in existing urban areas, particularly those involving densification, proponents should be required to prepare a drainage impact statement. This statement should address and answer the following questions.

(a) Local Surface Flow

- can local surface flow be successfully directed to the collection systems without ponding or adverse effects on adjoining properties?

(b) Sewer System Flow

- is the development causing an increase in flow to the sewer systems?
- is there a history of sewers surcharging/basement flooding in the area?
- have the sewer systems been adequately analyzed, designed, and maintained for current and future developments within the catchment? Does the analytical model correctly reflect infiltration/inflow?

(c) Major System (Overland) Flow

- how is stormwater managed in case of a major storm (1:100 year or greater)?
- is there a defined major system and, if so, what is the allowable depth of flow in the redevelopment area?
- if there is not a defined major system, what is the allowable depth of ponding in the event of a major storm?

(d) What is the impact with respect to the master drainage plan?

The answers to the above questions and the analyses used to arrive at them will provide a basis for determining the risks associated with providing below-grade accommodation in a redevelopment project.

7.0 Areas of jurisdiction are not always clearly defined, understood, and communicated to all the parties involved in the development and maintenance of stormwater management facilities to prevent basement flooding. Coordination between municipalities, developers, and homeowners is lacking when it comes to understanding the respective roles and coordinating the standards and responsibilities of each stakeholder in the operation of a stormwater drainage system. The development of on-lot strategies regarding local surface flow become ineffectual if they are not properly instituted by developers or maintained by homeowners. Municipalities that exist within a regional system must contend with the political and financial constraints of surrounding municipal and regional policies.

8.0 Jurisdictional discrepancies in the planning, design, construction, and operation of sewer systems that currently exist should be addressed, their impact on stormwater management and basement flooding assessed, and measures taken to correct them.

The principal interface here is the on-lot drainage/sewer system.

- on-lot responsibility during planning/design rests with the architect and is governed by the National Building Code (or provincial equivalent) and local bylaws. Stormwater drainage aspects (lot grading, foundation drain design/flow, downspout disposition, etc.) are generally not adequately specified or emphasized. Major code improvements are required in this area.

- on-lot responsibility during construction is normally the responsibility of the builder with the municipal inspectors performing a quality assurance role. Too little emphasis is placed on stormwater drainage aspects by both parties. This report recommends that inspection requirements for on-lot drainage should be equal to electrical and plumbing considerations .

- on-lot responsibilities for maintenance, after construction, rests with the homeowner. Bylaws need to be formulated and enforced to ensure homeowners maintain correct lot grading and downspout disposition so that sewer overload and, therefore, flooding to their own or their neighbour's basement is avoided.

- sewer system responsibility during planning/design typically rests with a consultant or developer's engineer. There are no nationally accepted guidelines or standards for sewer system analysis and design. There is a need for major improvement in this area, particularly in dealing with infiltration/inflow and computer analysis of sewer systems.

- sewer system responsibility during construction generally rests with or through the developer, along with the contractor and engineer. There is a need for responsibility in this area. This report recommends that this responsibility rest with the developer and that the municipal/developer agreement name the inspection engineer. It should also detail inspection frequency and number of reports to be prepared.

- responsibility for sewer system or stormwater management facility maintenance rests with the municipality when transferred over from the developer.

The impact of jurisdictional differences is that stormwater management is viewed differently in each jurisdiction. Accordingly, regulations, codes, and practices at all levels should be reviewed and revised to ensure these divisions are adequately bridged. Specifically as the on-lot parties (builder, owner) generally do not realize that deficient drainage can cause significant stress on the sewer systems and be the cause of basement flooding to both themselves and their neighbours, upstream and downstream, and although sewer system operators understand why their facilities are overloaded during rainfall events, they cannot correct on-lot drainage.

9.0 Residential water conservation and demand modification can be effective in reducing stress on water supply and sanitary sewer flows if it is publicly accepted. The role in contributing to reduced flow in sewer lines is likely to have a minor impact on reducing basement flooding by allowing some extra sewer capacity[28].

10.0 Current practices of basement flooding prevention based on the survey of 11 municipalities are:

- backflow preventers
- sump pumps
- roof and foundation drain disconnection
- inlet control devices
- stormwater management
- public education programs

Solutions to basement flooding often solve the problem in the short-term without identifying inefficiencies within municipal design standards and practices; however, they are a safe means of isolating individual homes from basement flooding.

11.0 National bodies, such as CMHC, should continue their efforts in informing the development, consulting, and municipal engineering communities and the public of the extent of basement flooding. The health, legal, and social implications of the problem need to be better understood by all stakeholders.

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APPENDIX A

CMHC - DRAINAGE STUDY
MUNICIPALITY QUESTIONNAIRE

Name of Municipality:______________________________

Population:______________ Growth in Last 3 Years: ______________

Expected Growth in Next 3 Years: ________

Urban Drainage System
Total Area:______________________ Combined:______________
Separated:______________

Criteria - New Areas
Sanitary Flows:______________________ L/capita/d
Peaking Factor:______________________
I/I Allowances:______________________
Weeping Tile Connected to: San: ___
Storm: ___
Sump Pump: ___
Other: ___

Downspouts:______________________

Design Storms for Storm System: Major System______________
Minor System______________

Basement Flooding History:

Event:______________________

No. Flooded:______________________

CGY/23252/99723252.Q

Preventive Methods:

Backflow Valves: ___
Sump Pumps: ___
Other: ___

Is basement flooding a factor in redevelopment of existing areas? Explain.

Are basement suites the norm within redeveloping residential inner neighborhoods?

How does the municipality control redevelopment of older areas?

Does the municipality have a lot grading bylaw in place? How is it enforced?

What is the municipality's experience with backflow preventers?

Are there jurisdictional issues that affect implementation of more adequate drainage systems?

On-lot inflow/infiltration: ___
Regional collection system: ___

	VANCOUVER	NORTH VANCOUVER	EDMONTON	CALGARY	REGINA
RECENT FLOOD EXPERIENCE - # OF HOMES	Do not maintain records	Do not maintain records	July 1984 - 16 July 1984 - 113 June 1984 - 36 July 1985 - 43 July 1986 - 154 July 1987 - 337 Sept. 1987 - 380 July 1988 - 1300 July 1990 - 340	July 1979 - 120 Aug. 1988 - 1500 Aug. 1990 - 320+	1975 - 2 - 10,000 July 1983 - 8-10,
CONTRIBUTING FACTORS	Roof leaders discharging into foundation drains	Lack of maintenance by homeowners	Inadequate major drainage system Undersized sewers	Outdated/undersized storm sewers Poor lot grades	Caps left off sew Direct catchbasin connections Common manhol
PREVENTIVE METHODS	Backflow valves Sump pumps Rerouting roof leader discharges to a separate pipe that ties to the service connection downstream of the foundation drain connection	Sump pumps (rarely used)	Backflow valves - new requirement Sump pumps - common for new developments	Backflow valves recommended Sump pumps recommended Catch basin inlet restrictions Public education program	Backflow valves recommended Sump pumps recommended Caps on sanitary traps Construction of stormwater detention facilitie

Table 4-1
MUNICIPAL DESIGN CRITERIA

	VANCOUVER	NORTH VANCOUVER	EDMONTON	CALGARY	REGINA	WINNIPEG	LAVAL	OTTAWA	SCARBOROUGH	HALIFAX	ST. JOHN'S
POPULATION:											
1987	438,000	36,100	576,249	647,285	180,000	600,000	270,000	305,000	500,000	114,000	90,000
1990	455,500	38,300	605,538	693,000	180,000		285,000	315,000	520,000	114,000	100,000
1993	472,100	39,100	637,800	746,200	180,000		300,000	325,000	533,000	114,000	105,000
DRAINAGE SYSTEM AREA (km^2)	116	13	350	500	110	198	250	75	180	42	65
COMBINED SEWER SYSTEM	> 60 percent (all residential)	None	15 percent	None	5 percent	> 50 percent	60 percent	8 percent	5 percent	45 percent	23 percent
SEPARATED SEWER SYSTEM	< 40 percent (West End & Ind./Comm. areas	100 percent	85 percent	100 percent	95 percent	< 50 percent	40 percent	92 percent	95 percent	55 percent	77 percent
DESIGN CRITERIA											
SANITARY FLOW (L/cap/d)	455	None	350	380	380	272 + 2246.5 L/d/ha	320	450	350	250	275
PEAKING FACTOR	Harmon's PF	None	Harmon's PF	Harmon's PF	Harmon's PF	Harmon's PF or Babbitt PF (minimun of 2.0)	Harmon's PF	PF Graph (ranged from 3 to 6)	Harmon's PF	Harmon's PF	Harmon's PF
I/I ALLOWANCE (L/s/Hectare)	0.13	None	0.28	45 L/day/mm.dia./km (in areas with high groundwater) No inflow allowance	Minimal - mostly 0 (based on empirical data)	0.14 to 0.28	0.06 to 0.32	0.62	0.26	0.00	0.26
WEEPING TILE CONNECTED TO:	Storm	Storm	Not to sanitary	Storm & sump pump	Sanitary through a sump with no pump	Sump pump/ground surface	Storm	Storm/ditch	Storm	Storm & dry well	Storm
DOWNSPOUTS CONNECTED TO:	Storm	Storm if available	Surface discharge	Surface discharge	Surface discharge	Surface/splash pads	Storm	Surface discharge	Storm	Storm or surface drainage	Storm or surface drainage
STORM SYSTEM											
MAJOR	25-year	25-year	100-year	100-year	25-year with 100-year retention ponds	10-year (at least)	100-year	100-year	100-year	100-year	5-year
MINOR	5-year	5-10-year	5-year	5-year	5-year	5-year	2-5-year	5-25-year	5-25-year	5-year	5-year
BASEMENT FLOODING	Yes	Minimal	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes