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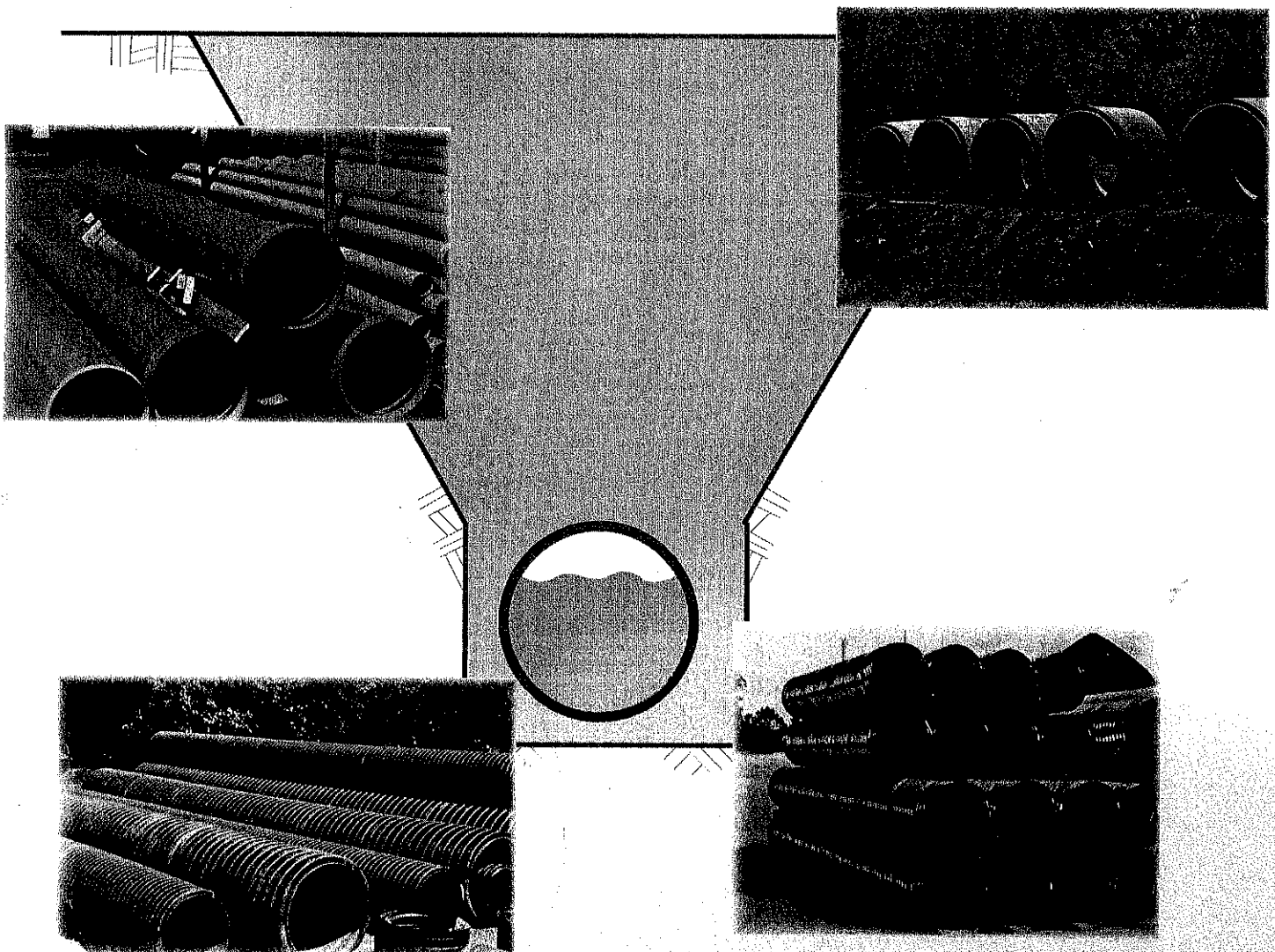
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Durability and Performance of Gravity Pipes: State of Current Practice



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Durability and Performance of Gravity Pipes: State of Current Practice

By Shelley McDonald
Urban Infrastructure Rehabilitation Program

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Executive Summary

This report outlines the results of returns from two questionnaires, the first of which was sent to 80 cities and municipalities across Canada; the second to the departments of transportation of the 10 provinces. The municipal questionnaire addressed storm and sanitary sewers; the provincial questionnaire, storm drains and culverts.

The survey showed that of the four pipe materials of interest – reinforced concrete, corrugated steel, corrugated HDPE and PVC – most of the storm and sanitary pipe in place today is non-reinforced and reinforced concrete. Most of the culverts (60 to 95%) are constructed of corrugated steel pipe.

The choice of pipe product is usually made by the municipality or the provincial transportation department rather than design engineers or manufacturers. Several standards are used to specify the bedding conditions; however, some geographic regions use the same standard.

The questionnaires provided good information about the inventory of storm and sanitary sewer systems, as well as the number and type of culvert pipe in place. The design parameters and the installation methods were also well recorded. All sections were answered completely, with the exception of the section dealing with performance. As a result, some key data, which could have been used to help municipal engineers and provincial departments of transportation plan their renewal and rehabilitation schedules, are not available.

1 Introduction

Sewer, sanitary and drainage pipes are integral components of urban infrastructure systems. In order to obtain information on the current state of use of various types of pipe material for storm and sanitary sewers and culverts between 450 and 900 mm (18 and 36 in.) in diameter, two questionnaires were created and sent to various municipalities and provincial departments of transportation. They had four sections, namely: inventory, design, installation and performance.

The criteria used for city selection were population and location. In particular, it was hoped to have responses from cities with more than 100,000 people, through to those towns with less than 10,000 people. Of the 80 questionnaires, 38 were completed and returned, and 21 were received partially completed (74% response rate). Among provincial departments of transportation, six completed and returned questionnaires (70% response rate) and one did not have the diameter range of interest in its culvert-pipe inventory; that is, all culverts were larger than 900 mm (36 in.) in diameter.

Previous questionnaires circulated to cities by organizations such as the Federation of Canadian Municipalities and the National Research Council yielded higher response rates. The lower response rate (74% and 70%) here was attributed to the fact that too much time and effort were required to answer the questionnaire. Other organizations said the requested information was not available, or that they did not have the particular diameter range of pipes in question.

The content of the questionnaires, the method of city selection, the target audience, and the type of information collected were reviewed by Heward Gough¹ of Statistics Canada. He commented that the municipal survey achieved

a representative sampling of both geography and population because large and small cities from each province completed questionnaires. The provincial questionnaire had western, central and eastern representation. Mr. Gough further noted that the geographic representation has statistical relevance, in that it leads to geographical stratification. In theory, the variance of results within a stratified region is small (Heward Gough, private communications).

The total length of sanitary sewer pipe represented by the survey was 17,725 km, approximately 15% of the 109,000 km in place across Canada (Duncan Ellison, private communications).² Even so, the results presented in this report, though useful and indicative of current practice, are still an approximation.

This report summarizes the results of questionnaires sent to Canadian municipalities and provincial departments of transportation. Note that in this report, the words "city" and "municipality" are used interchangeably. The survey was conducted between October 1996 and April 1997. A copy of each questionnaire is included in the Appendix.

2 Inventory

2.1 Municipal Storm and Sanitary Pipe Inventory

Of 80 questionnaires sent out, 38 were completed and returned. The population represented by the responses is 5.7 million (36 cities). In total, the survey covers 14,425 km of storm sewer pipe and 17,725 km of sanitary sewer pipe in 33 cities. Sanitary-pipe data cover both the separated sanitary and the combined sewer pipe.

Figures 1 and 2 show the distribution of storm and sanitary pipe diameters. Of the storm

¹ Heward Gough works with the Social Survey Methods Division of Statistics Canada. He has extensive experience in questionnaire design and data interpretation.

² Duncan Ellison is the Executive Director of the Canadian Water and Wastewater Association.

sewer pipe, currently 43% have diameters ranging from 450 to 900 mm. The share of sanitary pipe, within the diameter range for this study, is approximately 18%. The number of cities responding to each question, and the length of pipe represented, are included in brackets in the figure titles.

For the remainder of this report, results are presented for the diameter groups 450 to 600 mm and 675 to 900 mm only. Figures 3 through 6 illustrate the percentage of pipe material (storm and sanitary/combined) within

each group. There are a number of municipal areas with significant distances of sanitary sewer constructed of vitrified clay and brick. These materials are referred to as "other" in the figures, along with any other pipe material not listed in Question 5 that a city may use. Figure 3 shows that 90% of the storm sewer pipe with diameters of 450 to 600 mm is made of non-reinforced or reinforced concrete. For the larger diameters (675 to 900 mm), 93% of the storm sewer pipe is made of concrete (see Figure 4).

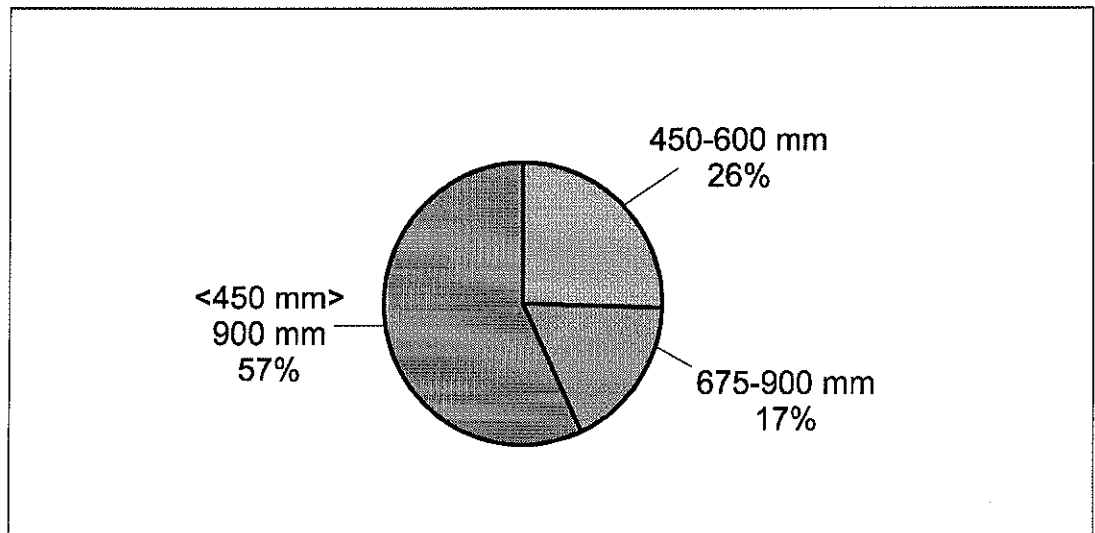


Figure 1. Storm-sewer pipe diameters (32 cities: 12,600 km of pipe)

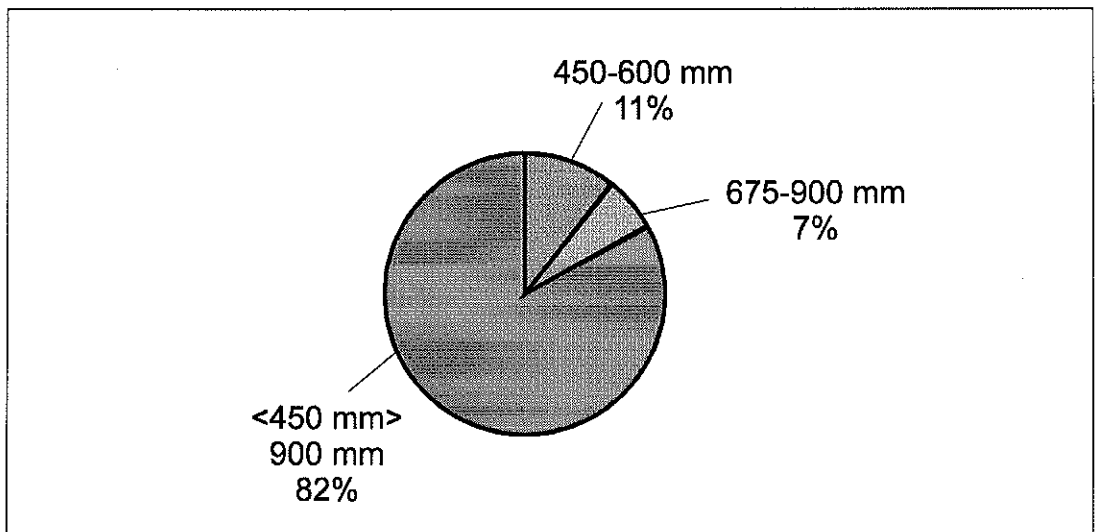


Figure 2. Sanitary-sewer pipe diameters (27 cities: 14,370 km of pipe)

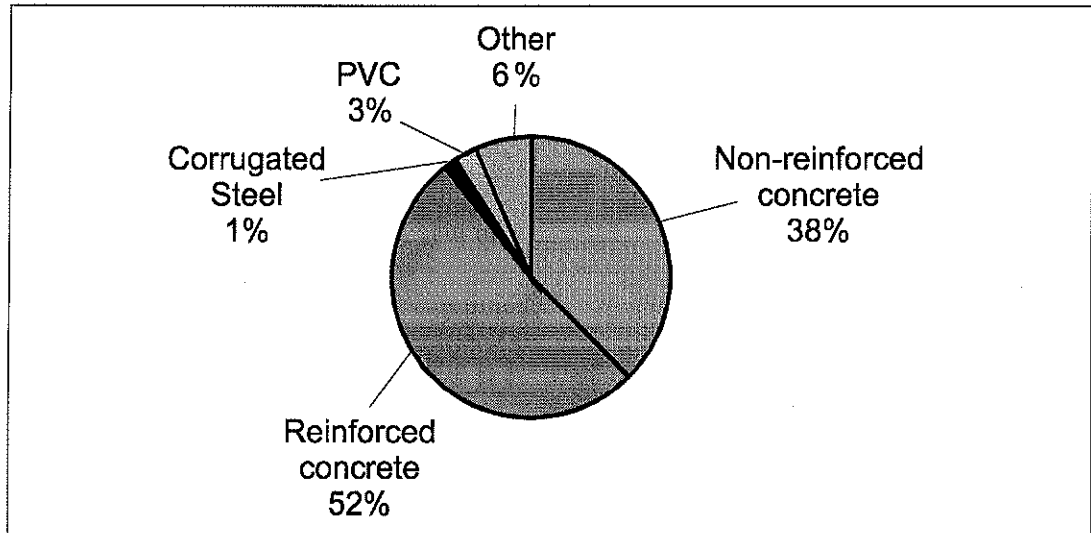


Figure 3. Storm-sewer pipe materials for pipe diameters of 450 - 600 mm (30 cities: 12,500 km of pipe)

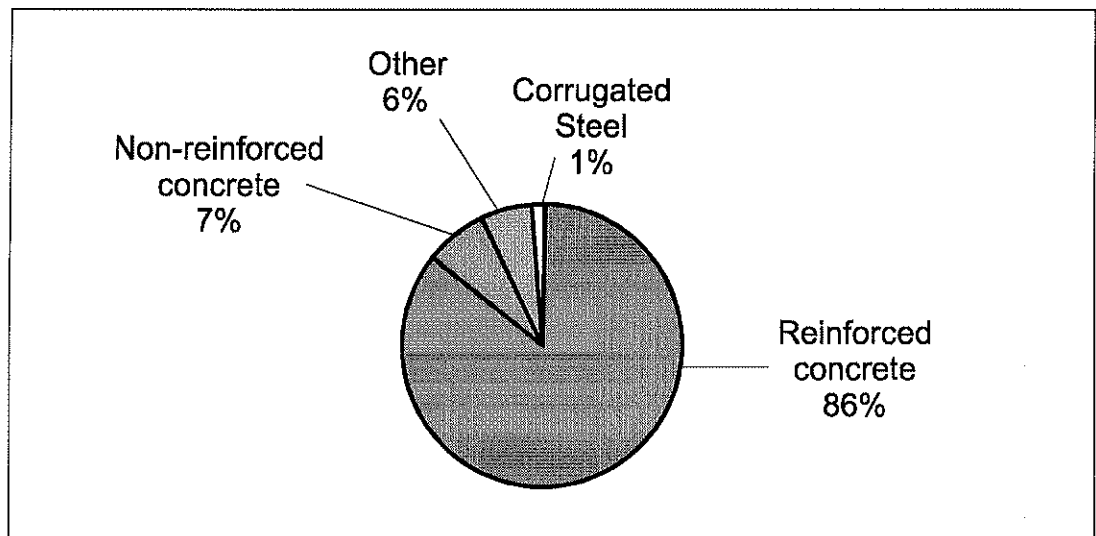


Figure 4. Storm-sewer pipe materials for pipe diameters of 675 - 900 mm (29 cities: 12,480 km of pipe)

Figure 5 shows that 63% of buried sanitary sewer pipe with diameters of 450 to 600 mm is made of concrete. Another 8% is PVC, while 28% is made of other materials. For sewers with diameters between 675 and 900 mm, reinforced and non-reinforced concrete comprise 85% of the systems; other materials make up the remaining 15% (see Figure 6).

The soil types in which the sanitary and storm sewers are installed vary across the country. Most of the pipes are installed in clay soil, but some are buried in soils that are fine-grained, coarse-grained, rocky or high in organic materials.

The concrete pipe materials vary in age from less than 25 years to greater than 75 years.

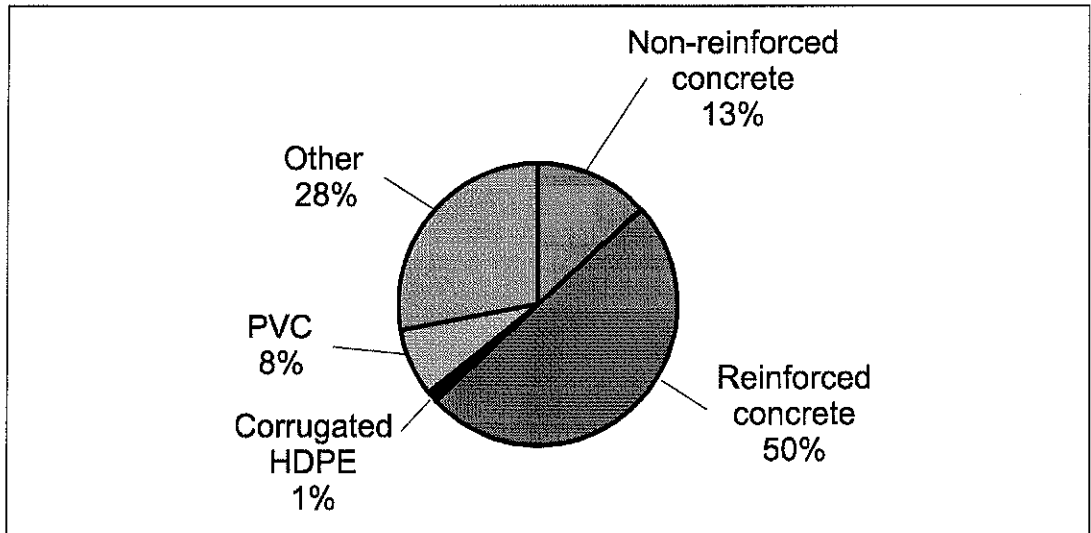


Figure 5. Sanitary-sewer pipe materials for pipe diameters of 450 - 600 mm (23 cities: 13,640 km of pipe)

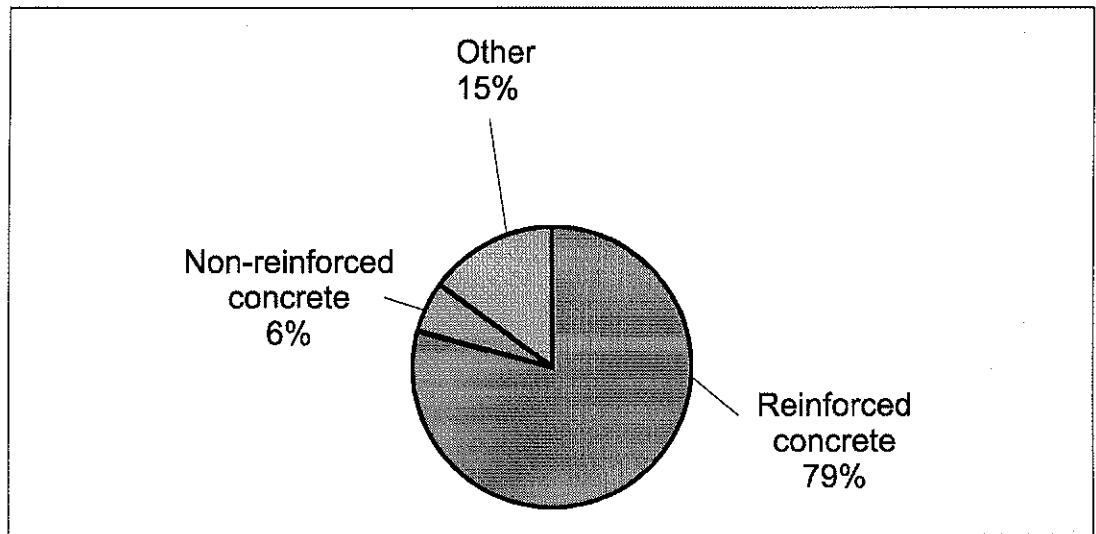


Figure 6. Sanitary-sewer pipe materials for pipe diameters 675 - 900 mm (21 cities: 12,830 km of pipe)

Many cities reported having concrete pipe in the two other age categories specified on the questionnaire, 25 to 50 years and 51 to 75 years. The PVC pipe for both storm and sanitary pipe was less than 25 years old, while steel pipe was less than 50 years of age.

Tables 1 and 2 show that the amount of pipe installed over the past 5 years is quite small,

which may be surprising at first glance. However, this is due to the fact that new installations are primarily under the jurisdiction of subdivision developers, as indicated by numerous respondents. As a consequence, municipal inventory at the time of the questionnaire may not include all materials recently installed by developers.

Table 1. Length of each storm material type for new installations in the last 5 years (22 cities)

Material	Length of Storm Sewer Installed (km)		
	450 - 600 mm	675 - 900 mm	Total Length of Recent Installations (%)
Non-reinforced concrete	11.9	2.3	8.5
Reinforced concrete	85.6	50.6	82.0
Corrugated steel	0.2	0.3	0.3
Corrugated HDPE	0.6	0.1	0.4
PVC	11.5	1.9	8.0
Other	0.8	0.6	0.8
Total	110	56	100

Table 2. Length of each sanitary material type for new installations in the last 5 years (22 cities)

Material	Length of Sanitary Sewer Installed (km)		
	450 - 600 mm	675 - 900 mm	Total Length of Recent Installations (%)
Non-reinforced concrete	5.7	0.3	13.6
Reinforced concrete	22.5	3.0	58.0
Corrugated steel	-	-	-
Corrugated HDPE	0.2	0.1	0.7
PVC	10.7	0.02	24.4
Other	0.7	0.8	3.4
Total	40	4.2	100

In recent years, it appears that cities continue to favour concrete for storm sewer pipe of both diameter categories, followed by PVC (see Table 1). Table 2 shows that reinforced concrete remains the most popular material for sanitary sewer pipe installed in the past 5 years, followed by PVC.

2.2 Provincial Culvert Inventory

Six provincial departments of transportation completed the questionnaires. One other province indicated that most of its pipe is larger than the diameters of interest in the survey. From the six completed questionnaires, the consensus was that provincial governments are, for the most part, not responsible for storm drains. Therefore, provincial information in this report pertains only to culverts. Because one province did not complete the inventory section, the results presented here apply to five provinces. Approximately 230,000 culverts are

being maintained by four transportation departments. These range in length from 6 to 100 metres; the average length is 22.7 m.

From data supplied by two departments, 10% of culverts have diameters in the 450-600-mm range, while 17% are between 675 and 900 mm. Most of the culverts currently in use are constructed of corrugated steel and reinforced concrete. The extremes for the two material types were 60% corrugated steel and 40% reinforced concrete in one province, and 95% corrugated steel and 5% reinforced concrete in another. (The recent installation of corrugated HDPE culvert pipe in Ontario was brought to the attention of the author.)

The corrugated steel and reinforced-concrete culvert pipes are less than 50 years old. In recent installations of culvert, reinforced concrete and corrugated steel was primarily used. Table 3 lists the length of each pipe

Table 3. Length of each material type for new culvert installations in the last 5 years (4 departments)

Material	Length of Culvert Installed (km)	
	450 - 600 mm	675 - 900 mm
Non-reinforced concrete	-	-
Reinforced concrete	2.0	2.5
Corrugated steel	42.3	17.8
Corrugated HDPE	-	-
PVC	-	-
unknown breakdown	120	22.6
Total	164.3	42.9

material for the two diameter groups in two provinces. Two other provinces indicated that information on pipe material is not kept.

Four departments use ribbed PVC pipe material for installations of pipes 450 to 600 mm in diameter. Corrugated aluminum is used by one department, and ribbed HDPE (for erosion control) has been used by another. For the installation of culverts 675 to 900 mm in diameter, ribbed HDPE (for erosion control) and corrugated aluminum are the only two materials used by two provinces.

3. Design

Section 2 of the questionnaire focused on pipe design. Specifically, the survey asked: "How is the choice of pipe material made (who chooses, and is the choice made on life-cycle costing or initial costs), what are the types of standards used for the bedding conditions, and what is the design approach to the pipe system (pipe, trench, backfill)." A further question asked the municipal engineer or technician to indicate the conditions in which each type of pipe material

would be preferred. Another question asked for a ranking of various design parameters in order of relevance for each type of pipe material. However, no distinction was made between "design and specifications" and "specifications only," although municipalities could choose either approach. For this section, 34 cities responded.

3.1 Municipal Storm and Sanitary Pipe Design

The first question asked for the person or organization responsible for the design of the pipe system (pipe and surroundings). The responsibility for the design of the storm sewer pipe system is shown in Table 4.

Table 4 illustrates that the municipality generally establishes the specifications for the storm sewer pipe system. Similarly, the sanitary sewer pipe system specifications are principally established by the municipality, followed by the design consultant and the manufacturer (see Table 5).

Table 4. Pipe specification/design responsibility for storm sewer systems (34 cities: 30,910 km of pipe)

Pipe Material	Municipality (%)	Design Consultant (%)	Manufacturer (%)
Non-reinforced concrete	60	30	10
Reinforced concrete	64	27	9
Corrugated steel	58	33	8
Corrugated HDPE	55	30	15
PVC	67	28	6

Table 5. Pipe specification/design responsibility for sanitary sewer systems (34 cities: 30,910 km of pipe)

Pipe Material	Municipality (%)	Design Consultant (%)	Manufacturer (%)
Non-reinforced concrete	64	29	7
Reinforced concrete	68	27	5
Corrugated steel	65	25	10
Corrugated HDPE	50	35	15
PVC	68	27	5

Table 6 shows that the municipality also tends to choose the pipe material for both storm and sanitary sewer systems.

Table 6. Selection of pipe material (34 cities: 30,910 km of pipe)

Organization	Selection of Pipe Material (%)
Municipality	62
Contractor	14
Design consultant	24

Table 7 shows that for pipes with diameters between 450 and 600 mm, concrete products are commonly selected when depth of burial is the prime consideration. The main criterion for choosing corrugated steel (CSP) is the purpose of the pipe, i.e., culvert, outfall. Soil conditions are the chief reasons for using corrugated HDPE and PVC pipes.

Table 7. Conditions/criteria governing the choice of material for pipes 450 - 600 mm in diameter (30 cities: 30,120 km of pipe)

Pipe Material	Design Condition/Criteria
Non-reinforced concrete	<ul style="list-style-type: none"> • burial depth (5) • groundwater condition (2) • purpose of pipe (2) • economic consideration • only material in that size
Reinforced concrete	<ul style="list-style-type: none"> • burial depth (14) • purpose of pipe (3) • preferred for use in all conditions (3) • groundwater condition (2) • all applications except soft ground (2) • soil conditions (2) • economic consideration • if pipe diameter greater than 380 mm • only material in that size

For the larger-diameter group (675 to 900 mm), the leading reasons, behind the choice of each material, are similar to those of the smaller pipes. For example, burial depth is the primary consideration for using reinforced-concrete (RCP) material, while non-reinforced concrete (NRCP) is used when burial depth and pipe size are the main considerations. The design factors for the use of corrugated steel are soil conditions and the purpose of the pipe. Soil conditions are also important criteria for the use of corrugated HDPE and PVC pipes (for more details, see Table 8).

Location appears to influence the design standards in use. For example, as shown in Table 9, ASTM standards are used in the western, Prairie and maritime provinces. Ontario and Quebec use their own pipe bedding standards, while British Columbia is the only province where design engineering standards are used in conjunction with ASTM and municipal standards.

Table 7 continued

Pipe Material	Design Condition/Criteria
Corrugated steel	<ul style="list-style-type: none"> • purpose of pipe (6) • soil conditions (3) • burial depth (2) • groundwater conditions
Corrugated HDPE	<ul style="list-style-type: none"> • soil conditions (3) • groundwater condition (2) • no experience • purpose of pipe
PVC	<ul style="list-style-type: none"> • soil conditions (6) • purpose of pipe (5) • prefer in all conditions (5) • burial depth (2) • groundwater condition (2) • economic (2) • specific construction conditions (2) • availability • handling

Note: The number of cities recording each specific consideration is shown in parentheses.

Table 8. Conditions/criteria governing the choice of material for pipes 675 - 900 mm in diameter (30 cities: 30,120 km of pipe)

Pipe Material	Design Conditions/Criteria
Non-reinforced concrete	<ul style="list-style-type: none"> • burial depth (3) • pipe size (not used if diameter greater than 600 mm) (3) • economic consideration • soil conditions
Reinforced concrete	<ul style="list-style-type: none"> • burial depth (14) • preferred for use in all conditions (8) • soil conditions (4) • purpose of pipe (3) • size of pipe (2) • economic consideration • cold weather installation • groundwater condition
Corrugated steel	<ul style="list-style-type: none"> • soil conditions (5) • purpose of pipe (5) • burial depth (3) • pipe size • groundwater condition
Corrugated HDPE	<ul style="list-style-type: none"> • soil conditions (3) • burial depth • no experience
PVC	<ul style="list-style-type: none"> • soil conditions (5) • purpose of pipe (4) • all conditions (4) • pipe size (3) • burial depth (3) • groundwater condition (2) • availability • handling

Note: The number of cities recording each specific consideration is shown in parentheses.

Table 9. Design standards used for the bedding condition (32 cities: 30,870 km of pipe)

Province	Design Standards
British Columbia	ASTM, Design engineering standards, Municipal
Alberta	ASTM, CSA
Saskatchewan	ASTM, CSA
Manitoba	ASTM, Manufacturer
Ontario	Provincial (OPSS), Municipal
Quebec	Provincial (BNQ)
New Brunswick	ASTM
Prince Edward Island	ASTM

Of the 35 municipalities that indicated a method for choosing the type of pipe material, 55% said they considered initial cost, and 34% said they conducted a life-cycle analysis (LCA). Three cities, one each in the western, central and eastern regions, were contacted by phone to clarify how they did their LCAs. All three said they included the initial cost of the pipe and the expected cost of servicing in their

LCA. One city also compares the present value of reconstruction costs for each potential material.

Table 10 illustrates that similar design parameters are relevant for reinforced-concrete and PVC pipe. Traffic loading was ranked as most relevant for concrete pipes followed by hydraulic flow and backfill selection. The cities that chose PVC pipe ranked hydraulic flow to be most pertinent, followed by traffic loading and finally backfill selection. Corrosion was most relevant for corrugated steel pipe.

For pipes with diameters between 675 and 900 mm, compaction was a relevant factor, especially for flexible pipes (see Table 11). Compaction ranked second among the four main design parameters, behind hydraulic flow for corrugated steel and HDPE. It ranked third for PVC pipe. Traffic loading was again considered the most relevant parameter in the design of a concrete pipe.

Table 10. Most relevant design parameters for storm and sanitary sewer pipe 450 - 600 mm in diameter (29 cities: 30,215 km of pipe)

Ranking	Material				
	NRCP	RCP	CSP	HDPE	PVC
1	traffic loading	traffic loading	corrosion	hydraulic flow	hydraulic flow
2	backfill selection	hydraulic flow	hydraulic flow	compaction	traffic loading
3	compaction	backfill selection	compaction	backfill selection	backfill selection
4	hydraulic flow	compaction	traffic loading	traffic loading	compaction

Note: NRCP is the abbreviation for non-reinforced concrete pipe, RCP for reinforced concrete pipe, CSP for corrugated steel pipe, HDPE for high density polyethylene pipe and PVC for polyvinylchloride pipe.

Table 11. Most relevant design parameters for storm and sanitary sewer pipe 675 - 900 mm in diameter (29 cities: 29,715 km of pipe)

Ranking	Material				
	NRCP	RCP	CSP	HDPE	PVC
1	traffic loading	traffic loading	hydraulic flow	hydraulic flow	hydraulic flow
2	backfill selection	hydraulic flow	compaction	compaction	traffic loading
3	compaction	backfill selection	corrosion	backfill selection	compaction
4	frost loading	compaction	traffic loading	traffic loading	backfill selection

3.2 Provincial Culvert Design

As with the municipalities, the provincial government plays the lead role in determining the design specification for culverts (see Table 12).

Table 12. Specification/design responsibility for culvert pipe (6 provinces)

Pipe Material (%)	Ministry Consultant (%)	Design (%)
Non-reinforced concrete	83.3	16.7
Reinforced concrete	90	10
Corrugated steel	91.7	8.3
Corrugated HDPE	75	25
PVC	83.3	16.7

Note: Manufacturers play no role in the specification and design for culvert pipe.

Similarly, the province tends to choose the material for the culverts (see Table 13).

Table 13. Selection of pipe material (6 provinces)

Organization	Selection of Pipe Material (%)
Department	75
Contractor	16.7
Design consultant	8.3

Five provinces responded to questions regarding the conditions for the use of particular types of pipe (see Table 14). One province indicated that the cost was the only factor governing the selection of culvert material.

Table 14 indicates that the purpose of the pipe, the soil and environmental conditions, burial depth and construction conditions are among the factors taken into consideration.

Table 14. Conditions/criteria governing the selection of culvert pipe material (5 provinces)

Pipe Material	Culvert Diameter (mm)	
	450 - 600	675 - 900
Non-reinforced concrete	<ul style="list-style-type: none"> • burial depth, groundwater level, soil conditions, pipe purpose 	<ul style="list-style-type: none"> • burial depth, groundwater level, soil conditions, pipe purpose
Reinforced concrete	<ul style="list-style-type: none"> • soil conditions (2) • cold weather construction, burial depth, groundwater level, pipe purpose 	<ul style="list-style-type: none"> • cold weather construction, soil conditions, high traffic volume, high fill embankment
Corrugated steel	<ul style="list-style-type: none"> • soil conditions (2) • pipe purpose (2) • burial depth, groundwater level, field crossings, cold weather construction, deep installation 	<ul style="list-style-type: none"> • pipe purpose, cold weather construction, deep installation, low traffic volume, soil/environmental conditions
Corrugated HDPE	<ul style="list-style-type: none"> • corrosive or aggressive soil conditions 	---
PVC	<ul style="list-style-type: none"> • corrosive or aggressive soil conditions 	<ul style="list-style-type: none"> • corrosive environments

As with the municipal standards for bedding conditions of storm and sanitary pipe, geography appears to play a role for culverts. For example, Table 15 shows that ASTM standards are used in the western and Prairie provinces, and also in the far eastern province of Newfoundland. The central provinces (Ontario and Quebec) and Nova Scotia in the east, use their own provincial standards for the bedding of culvert pipe. British Columbia uses AASHTO, CSA and manufacturers' standards.

Table 15. Design standards used for the bedding conditions (6 provinces)

Province	Design Standards
British Columbia	ASTM, AASHTO, CSA, Manufacturers'
Saskatchewan	ASTM
Manitoba	ASTM
Ontario	Provincial (OPSS)
Quebec	Provincial (BNQ)
Nova Scotia	Provincial
Newfoundland	ASTM

The responses for the most relevant parameters in the design of culverts were largely the same for both diameter groups. However, for corrugated steel pipes, 675 to 900 mm in diameter, the parameters in italics in Table 16 were reported as sharing third priority with traffic loading.

Question 13 dealt with whether the choice of culvert pipe material was based on initial or

life-cycle costs. Three said that they base their decisions on initial costs, and one, on life-cycle costs. Another province stated that the decision was based on neither method, and the sixth allows the contractor to make the decision.

4 Installation

The survey included questions regarding the ease or difficulty of installation, installation cost, the number and type of damaged pipes, the shape of the trench, the types of problems encountered during installation, and the opportunity to suggest methods to improve on the installation of various pipe materials. Other questions pertained to ranking the various types of pipe material with respect to ease of joining, the inspection procedures specified for installation, and the person who conducts the inspections. A final question asked whether non-shrinkable fill is used by the municipality or province.

4.1 Municipal Storm and Sanitary Pipe Installation

Table 17 shows the perception of the municipal engineer or technician regarding the relative ease of installation of each pipe material in the two diameter groups. The results were determined by adding up the rankings given by each city for each material (with 1 being the easiest and 5 the most difficult), and calculating an average for the cities that responded. Thus, the lower the figure in Table 17, the easier the installation is perceived to be. The municipal

Table 16. Most relevant design parameters for culvert pipe (six provinces)

Ranking	Material				
	NRCP	RCP	CSP	HDPE	PVC
1	traffic loading	hydraulic flow	hydraulic flow	hydraulic flow	hydraulic flow
2	hydraulic flow	corrosion	corrosion	corrosion	traffic loading/ corrosion
3	corrosion	traffic loading	traffic loading <i>/compaction /backfill selection</i>	-	-
4	<i>groundwater conditions</i>	<i>groundwater conditions</i>	<i>groundwater conditions</i>	-	<i>backfill selection</i>

engineers feel that PVC is the easiest material to install for pipe with diameters between 450 and 600 mm, followed by corrugated HDPE and reinforced concrete. For pipe with diameters between 675 and 900 mm, PVC is again perceived to be the easiest to install, followed by reinforced concrete, then corrugated HDPE. It should be pointed out that the amount of corrugated HDPE pipe currently in place is very small compared to the amounts of PVC and reinforced-concrete pipe (see Figures 3 to 6 for details).

Table 17. Relative ease of installation (32 cities: 30,925 km of pipe)

Pipe Material	Pipe Diameter (mm)	
	450 - 600	675 - 900
Non-reinforced concrete	2.7	2.6
Reinforced concrete	2.4	2.2
Corrugated steel	3.3	3.2
Corrugated HDPE	2.1	2.8
PVC	1.2	1.3

Table 18 lists the reasons why pipes with diameters of 450 to 600 mm are perceived to be easy to install, while Table 19 shows where difficulties are encountered. Similar lists for pipes 675 to 900 mm in diameter are found in Tables 19 and 20. The number of cities that indicated each reason is included in brackets in the table.

From Table 18, the three main reasons for ease of installation are light weight and handling ease, longer pipe lengths and ease of joint installation. A few cities gave reasons for the ease of installation of rigid pipe products, which are designated by a double asterisk in Table 18.

Table 18. Reasons for ease of installation of pipes 450 - 600 mm in diameter (32 cities: 30,925 km of pipe)

Ranking	Reasons
1	<ul style="list-style-type: none"> • light weight/handling (31) • fewer joints • shallow depth • bedding • bedding requirement * • rugged material • experience • solid **
2	<ul style="list-style-type: none"> • longer pipe length (11) • ease of joint installation (5) • ease to cut (5) • light weight (3) • availability of components (2) • heavy equipment not needed • backfill • exterior smoothness • weather conditions • durable **
3	<ul style="list-style-type: none"> • ease of joint installation (10) • ease/ability to cut (3) • light weight/handling ease (2) • longer lengths • local knowledge • aligning ease • gaskets • easier lateral location • private services • better seal at joint • testing success • bedding • durable **

Note: * reinforced-concrete pipe and ** rigid pipe products.

Table 19. Reasons for installation difficulty with pipes 450 - 600 mm in diameter (32 cities: 30,925 km of pipe)

Ranking	Reasons
1	<ul style="list-style-type: none"> • pipe weight/handling (29) • assembly more complicated (1) • couplings (1) • joint installation difficult (2) • bedding requirement (2) • cold weather gasket placement (1) • local knowledge • lack availability of components • bedding and backfill sensitive *
2	<ul style="list-style-type: none"> • shorter lengths (8) ** • difficulty of joint installation (4) - frozen material in spigot • difficult to maneuver (4) • lower standard of compaction • backfill • heavier weight • difficulty inserting saddles • ease of fit • exterior roughness • easier damaged (2) * • bedding/compaction is critical * • ease of fit • ability to pass pressure test
3	<ul style="list-style-type: none"> • difficulty adjusting/cutting (6) • difficulty jointing (5) • partially frozen bedding • pipe ends not round • gaskets • testing success • fewer installation precautions • difficulty backfilling • bedding needs to be more accurate *

Notes: * flexible pipe products, ** rigid pipe products

The three main reasons for installation difficulty are pipe weight and handling, short pipe lengths problems adjusting or cutting the pipe. The cities that indicated that flexible pipe products were more difficult to install have their reasons followed by an asterisk.

Table 20. Reasons for installation ease with pipes 675 - 900 mm in diameter (31 cities: 29,625 km of pipe)

Ranking	Reasons
1	<ul style="list-style-type: none"> • light weight/handling ease (18) • local knowledge • aligning easier • longer lengths • shallow depth • bedding • rugged material ** • not highly compaction sensitive ** • only material available in this diameter ** • solid ** • durable **
2	<ul style="list-style-type: none"> • longer lengths (8) • ease of joint installation (7) • light weight (3) • availability components • ease in inserting saddles • internal gaskets • exterior smoothness • ease to cut (2) • backfilling less strict (2) ** • shorter pipe (backhoe backfilling **)
3	<ul style="list-style-type: none"> • ease of joint installation (6) • light weight/handling ease • ease/ability to cut (4) • longer lengths • heavy equipment not needed • easier lateral location • private services • better seal at joint • testing success • bedding **

Notes: ** rigid pipe products

Among 675 - 900 mm diameter pipes, many of the same factors were cited as contributing to the ease of installation.

Again, for pipes with diameters between 675 and 900 mm, the three main reasons for installation difficulty are the same as those for the smaller pipes.

Table 21. Reasons for installation difficulty with pipes 675 - 900 mm in diameter (31 cities: 29,625 km of pipe)

Ranking	Reasons
1	<ul style="list-style-type: none"> • pipe weight/handling (15) • local knowledge • assembly more complicated • couplings • joint installation difficult (2) • bedding • cold weather gasket placement • unavailable components • aligning problems
2	<ul style="list-style-type: none"> • shorter lengths (5) * • difficulty of joint installation (2) - frozen material in spigot • difficulty adjusting/cutting (2) • backfill (2) and compaction • heavier weight (1) • difficulty inserting saddles • ease of fit • exterior roughness • more easily damaged (2) * • bedding/compaction is critical * • ease of fit
3	<ul style="list-style-type: none"> • difficulty adjusting/cutting (4) • difficulty jointing (3) • need heavy equipment for installation • partially frozen bedding • pipe joints not as good • difficulty with lateral connections • gaskets roll • testing success • fewer installation precautions • difficulty backfilling • bedding needs to be more accurate *

Note: * flexible pipe products

Questions dealing with recent installation costs, the number of pipes rejected or damaged during transport, storage and installation, and the types of damage experienced, yielded inconclusive results. The intent was to determine whether the choice of pipe material within a particular city was based on the installation cost of the material. Of the few cities that responded to this question, most provided costs for only one material. Comparisons cannot be drawn because of the statistically insignificant data.

The shape of the trench used for pipe installation appears to be related to the particular situation,

such as soil type and pipe depth. Municipalities indicated the use of all three trench shapes listed in the questionnaire (boxed, sloped and combination boxed/slope), but the combination boxed/sloped was used most often.

Suggestions provided by cities to improve the installation of pipe products are listed in Table 22. The most common proposal for reinforced-concrete pipe was to adjust the weight of the pipe to enable installation without heavy equipment. For PVC pipe, two cities suggested improving the backfill selection and compaction practices to eliminate or reduce pipe floating and displacement.

Table 22. Suggestions to improve installation (10 cities: 13,860 km of pipe)

Pipe Material	Suggestion
Non-reinforced concrete	<ul style="list-style-type: none"> • lifting/handling systems • cleanliness of joints • sufficient trench width to facilitate uniform bedding
Reinforced concrete	<ul style="list-style-type: none"> • weight (install without heavy equipment) (2) • improved seals for installation • rough gasket surface • cleanliness of joints • sufficient trench width to facilitate uniform bedding • deeper "rib" area in spigot to keep gaskets in • embankment problems
Corrugated steel	<ul style="list-style-type: none"> • cleanliness of joints • selection of appropriate bedding • more choices on special fittings (angles)
Corrugated HDPE	<ul style="list-style-type: none"> • excess friction on bedding during jointing operations • cleanliness of joints • avoid installing in cold temperatures • care during transportation • pipe material not suited for placement under asphalt roads with heavy traffic
PVC	<ul style="list-style-type: none"> • ensure backfill/compacted properly • floating and displacement concerns (2) • existing ground conditions (peat bogs, and stone, etc.) • ensure cleanliness of joints • select appropriate bedding • when in service problem getting camera through pipe

Cities were requested to report any problems with installation at temperatures below -10°C. Some of the problems experienced for reinforced-concrete pipe include stiff rubber gaskets. Two of the more common problems with PVC pipe were brittleness (brittle fracture) and the pipe freezing to the ground. Table 23 lists the reported experiences.

Table 23. Problems with cold-weather installation (13 cities: 15,540 km of pipe)

Pipe Material	Cold-Weather Installation
Non-reinforced concrete	<ul style="list-style-type: none"> stiff rubber gaskets cracking
Reinforced concrete	<ul style="list-style-type: none"> stiff rubber gaskets (2) shrinkage cracking gaskets pop off when pipe doesn't seat properly icing joints
Corrugated steel	—
Corrugated HDPE	<ul style="list-style-type: none"> fragile material in cold weather (2) broken rib (rib HDPE)
PVC	<ul style="list-style-type: none"> brittle (6) freezes to ground if not supported by blocking (2) prone to breakage problems with smaller diameter pipe very fragile material joint problems

There are numerous inspection procedures that follow the installation of the various storm and sewer pipes. These include:

- compaction testing on bedding and backfill (9)
- CCTV (video) inspection (8)
- inspection for proper joints (7)
- inspection for proper bedding (6)
- inspection for pipe deflection (3), alignment (3), grade (3), backfill (3), elevation (3), in conformance with Ontario Provincial Specification Standards (OPSS), manufacturers' and city specifications (3)

- complete inspection procedure (2), air test (2), inspection after the pipe has been put in place to verify depth (2)
- inspection of stock-piled pipe and rejection of broken and cracked lengths (1)

The number in brackets indicates the number of cities that registered the comment in their response. The most frequent response was compaction testing on bedding and backfill. The item "in conformance with OPSS, manufacturer and city specifications" may include the provision for compaction specifications on bedding and backfill, but since it most likely contains other specifications and procedures, the three municipalities that indicated this item were not included in the total for compaction testing on bedding and backfill.

Question 25 asked who performed inspections of storm and sanitary pipe. For the responding cities, 56% use municipal staff, 40% use contractors and the remainder engage consultants to perform the inspection of newly installed systems.

There is currently little use of unshrinkable fill. Fifty-one percent of responding cities do not use it in any installations, and 46% use it in fewer than 20% of all possible applications. Only 3% indicated the use of unshrinkable fill in 20 to 40% of their installations.

4.2 Provincial Culvert Installation

Five departments of transportation commented on the relative ease of installation of different culvert pipe materials (see Table 24). The rankings for this question were determined in the same manner as those for municipalities in Table 17. The closer the value to one, the easier it seemed to install the material.

Table 25 shows that the reasons for ease of installation are the same for both pipes regardless of diameter. One exception involves bedding control for pipes with diameters of 675 to 900 mm.

Table 24. Relative ease of installation (5 provinces)

Pipe Material	Pipe Diameter (mm)	
	450 - 600	675 - 900
Non-reinforced concrete	3.7	3.6
Reinforced concrete	3.2	2.6
Corrugated steel	1.4	1.6
Corrugated HDPE	3.0	2.0
PVC	3.7	4.0

Table 26 lists the primary reasons for the difficulty of installing pipe of both diameters. The weight of the pipe, concerns about the bedding/compaction requirements and the joining or coupling of the pipe are the main concerns.

Five of the departments of transportation commented on the relative cost of installing each pipe material within each diameter group. However, it does not appear from the responses that one type of culvert material (rigid or flexible) is consistently more expensive than another, when all other variables are the same.

The responses to questions about the number and percentage of failures that occurred during transportation, storage and installation, about the shape of the trench, and about the percent deviation in trench width were inadequate for further analysis.

Respondents were also asked for suggestions to improve the installation of culvert pipes. For reinforced-concrete culvert pipe, suggestions included better training for those responsible for the installation and improving the jointing

Table 25. Reasons for installation ease (5 provinces)

Ranking	Reasons for Ease	
	450 - 600 mm	675 - 900 mm
1	<ul style="list-style-type: none"> weight/handling ease (4) easy connection 	<ul style="list-style-type: none"> weight/handling ease (4) easy connection
2	<ul style="list-style-type: none"> light weight (2) flexible, stiffness, not backfill-sensitive, coupling ease 	<ul style="list-style-type: none"> light weight (2) flexible, stiffness, not backfill sensitive, coupling ease
3	<ul style="list-style-type: none"> easy coupling/joining (2) contractor experience, requires less preparatory work 	<ul style="list-style-type: none"> easy coupling/joining (2) contractor experience, requires less preparatory work, less bedding control

Table 26. Reasons for installation difficulty (5 provinces)

Ranking	Reasons for Difficulty	
	450 - 600 mm	675 - 900 mm
1	<ul style="list-style-type: none"> heavy/handling difficulty (2) tends to float during initial backfilling, compaction sensitive, more preparatory work is involved 	<ul style="list-style-type: none"> heavy (2) more preparatory work is involved, compaction sensitive, damage sensitive
2	<ul style="list-style-type: none"> heavy (2) easy to damage (2) transportation of pipe to work area 	<ul style="list-style-type: none"> easy to damage, transportation of pipe to work area, required experienced labor, heavy, backfilling sensitive
3	<ul style="list-style-type: none"> jointing difficulty (2), punctures unravel easily, more equipment required to handle pipe 	<ul style="list-style-type: none"> bedding-sensitive (2) joints unravel easily, if damaged

systems. For corrugated steel culvert pipe, it was proposed that equipment used for compaction be improved. One province indicated that the problems depended on the area, environment, material and pipe location.

Few problems were associated with cold-weather installations. One province, however, reported that corrugated steel culvert pipe split or tore during cold-weather installation. Another province tries to avoid cold-weather installations. The remaining four provinces did not respond to this question.

Provincial staff were also asked to rank the culvert pipe material with respect to the ease of pipe joining. Table 27 shows the results for this question. Note that in some cases, department staff commented on materials that they themselves do not use.

Table 27. Relative ease of pipe joining (4 provinces)

Culvert Pipe Material	Ranking
Non-reinforced concrete	2.3
Reinforced concrete	4.0
Corrugated steel	3.3
Corrugated HDPE	1.0
PVC	1.7

Four departments of transportation indicated that they specify inspection procedures for pipe installation. Some of these procedures include joining, settlement, trench width, bedding depth and materials, invert elevations, backfill materials (2), compaction methods and density (2), and compliance with OPSS. All provinces that specify installation inspections have their own staff perform them.

Finally, only one province currently uses unshrinkable fills.

5 Performance

In the last section of the questionnaire, information on perception about the performance of different pipe materials was collected. The global lack of knowledge about

the present condition of underground infrastructure can be traced to the poor understanding of the performance of various components of the infrastructure. Most responding cities/provinces were unable to reply adequately to questions on the grounds that pertinent data are not recorded or retained.

Section 5.1 summarizes the information that was obtained, and the statistics that should help to put the results into perspective.

5.1 Municipal Storm and Sanitary Pipe Performance

Respondents were asked whether a rating system or criteria are in place to assess the condition of storm and sanitary sewer systems. Of the responding cities, 32% have a rating system or criteria. However, 68% have no systematic approach to assessing the condition of their infrastructure.

Routine in-service inspections are performed by 64% of the cities who responded to this question (35 cities: 30,800 km of pipe). Although many cities expressed intentions to establish rehabilitation schedules for storm and sanitary sewer systems, few cities now actively conduct inspections.

Of the 23 cities that indicated routine inspections of their systems, all use CCTV inspection techniques. External visual inspections are used by eight cities. The frequency of inspection, however, varies. Some follow a predetermined maintenance/inspection cycle, while others said their entire sewer systems are CCTV-inspected every 5 to 10 years. The frequency of visual inspections varied from yearly to "when possible."

Question 29 inquired how rehabilitation techniques were chosen. The factors that are taken into account are (28 cities: 30,595 km of pipe):

- cost of replacement (life cycle, cost effectiveness) (12)
- pipe defect (6)
- pipe burial depth (3)

- pipe location (2)
- pipe condition, pipe material, individual project basis, sizing infiltration, runoff factor, etc.
- impact analysis, cost analysis in conjunction with other work (road reconstruction), engineer's choice, request for proposal
- assessment of the advantages and the risks, cost of rehabilitation vs. cost of excavation (social costs), past method, based on site and material (matrix)

Table 28 lists the rehabilitation techniques used by various cities for each type of pipe material for the two diameter groups. The selection of rehabilitation techniques seems to be independent of pipe diameter. For both diameter groups, non-reinforced concrete, reinforced concrete and corrugated steel have "excavate and replace" as the leading method, followed by internal liners. Corrugated HDPE and PVC also have "excavate and replace" as their preferred rehabilitation method, followed by a consideration of all other methods for both diameter groups.

Table 28. Type of rehabilitation technique (26 cities: 23,260 km of pipe)

Pipe Material	Pipe Diameter (mm)	
	450 – 600 ^a	675 – 900 ^b
Non-reinforced concrete (a = 790.1 km; 26.2%) (b = 85.6 km; 4.2%)	<ul style="list-style-type: none"> • excavate and replace (14) • internal liners (6) • all considered (2) • grout sealing (2) • spot repairs • u-line sleeves 	<ul style="list-style-type: none"> • excavate and replace (12) • internal liners (4) • all considered (2) • grout sealing (2) • spot repairs
Reinforced concrete (a = 1988.6 km; 65.8%) (b = 1885.3 km; 98.9%)	<ul style="list-style-type: none"> • excavate and replace (21) • liner (7) • grout sealing (5) • internal sleeves (2) • all considered, depends on problem, no failures, spot repairs, reaming root process, Insituform to repair punctures in the interior lining 	<ul style="list-style-type: none"> • excavate and replace (19) • internal liners (8) • grout sealing (4) • all considered (2) • depends on problem, no failures, spot repair, repair punctures
Corrugated steel (a = 28.5 km; 0.9%) (b = 21.5 km; 1.1%)	<ul style="list-style-type: none"> • excavate and replace (13) • internal liners (3) • grout sealing, all considered 	<ul style="list-style-type: none"> • excavate and replace (11) • internal liners (3) • grout sealing, all considered
Corrugated hdpe (a = 16.9 km; 0.6%) (b = 3.8 km; 0.2%)	<ul style="list-style-type: none"> • excavate and replace (4) • all considered (2) • grout sealing 	<ul style="list-style-type: none"> • excavate and replace (4) • all considered (2) • grout sealing
PVC (a = 196.5 km; 6.5%) (b = 11.6 km; 0.6%)	<ul style="list-style-type: none"> • excavate and replace (9) • all considered (2) • internal liners (2) • grout sealing (2) 	<ul style="list-style-type: none"> • excavate and replace (9) • all considered (2) • all considered (2) • grout sealing (2)

Note that the length of each pipe material and percentage corresponding to those responding cities, for the two diameter groups, is included in brackets under each type of pipe material. The diameter groups are identified by "a" for 450 - 600 mm and "b" for 675 - 900 mm.

The responses to Questions 31a and 31b on the number of repairs and replacements for each pipe material were not adequate enough to evaluate. The numbers were either not kept or not recorded, or the responses were expressed in inconsistent units.

The types of in-service distresses/failures for each pipe material and diameter group are given in Table 29. For both diameter groups, cracking is the prominent type of distress for non-reinforced concrete, and joint separation is the most frequent distress type for reinforced concrete. Material degradation is the type of distress most often encountered for corrugated

steel for both diameter groups. Joint separation and bending are the two most encountered in-service distresses for PVC pipe. There were no reported in-service types of distress for corrugated HDPE pipe. Note that no definition for failure was provided in the questionnaires; thus, it was understood to mean defect or distress in a general sense.

Table 30 shows that bedding is perceived as the primary cause of distress of non-reinforced concrete pipe with diameters between 450 and 600 mm. For pipe with diameters between 675 and 900 mm, the causes of in-service distress were believed to be acid corrosion, bedding

Table 29. Type of in-service distresses/failures requiring repair/replacement

Pipe Material	Pipe Diameters (mm)	
	450 - 600 ^a (20 cities; 17,090 km)	675 - 900 ^b (16 cities; 16,830 km)
Non-reinforced concrete (a = 656.1 km; 25.1%) (b = 283.2 km; 16.4%)	<ul style="list-style-type: none"> • cracks (9) • collapse (7) • material degradation (4) • joint separation (4) • splits (3) • holes, infiltration, sumps, buckling 	<ul style="list-style-type: none"> • cracks (5) • collapse (5) • material degradation (3) • infiltration, joint failures
Reinforced concrete (a = 1757.1 km; 67.3%) (b = 1419.3 km; 82.1%)	<ul style="list-style-type: none"> • joint separation (10) • cracks (8) • collapse (4) • holes (4) • material degradation (2) • splits (2) • infiltration (2) • sagging (2) • large deformations, buckling, roots 	<ul style="list-style-type: none"> • joint separation (7) • cracks (5) • collapse (3) • material degradation (2) • buckling (2) • sagging (2) • sumps, holes, infiltration
Corrugated steel (a = 25.1 km; 1.0%) (b = 17.3 km; 1.0%)	<ul style="list-style-type: none"> • material degradation (4) • large deformation (3) • holes (2) • collapse (2) • splits 	<ul style="list-style-type: none"> • material degradation (3) • deformation (2) • collapse, holes
Corrugated hdpe (a = 15.6 km; 0.6%) (b = 3.5 km; 0.2%)	—	—
PVC (a = 157.9 km; 6%) (b = 6.0 km; 0.3%)	<ul style="list-style-type: none"> • joint separation (2) • bending (2) • buckling, deformation, sumps 	<ul style="list-style-type: none"> • bending (2) • buckling, deformation

Note that the length of each pipe material and percentage corresponding to those responding cities, for the two diameter groups, is included in brackets under each type of pipe material. The diameter groups are identified by “a” for 450 - 600 mm and “b” for 675 - 900 mm.

and infiltration. Bedding and infiltration were the two most frequently cited causes of in-service distress of reinforced-concrete pipe for both diameter groups. Municipal engineers suspect that metal corrosion is the leading cause of corrugated steel pipe distress, for diameters between 450 and 600 mm, while bedding and improper compaction were blamed for distresses/failures in PVC pipe.

In response to a question on the perceived performance of storm and sanitary pipe material joints, Table 31 lists each pipe material and its ranking. As in previous tables, the value closest to one represents the best performance.

Table 30. Perceived causes of in-service distresses/failures

Pipe Material	Pipe Diameters (mm)	
	450 - 600 ^a (20 cities: 17,090 km)	675 - 900 ^b (16 cities: 16,100 km)
Non-reinforced concrete (a = 656.1 km; 25.1%) (b = 283.2 km; 16.4%)	<ul style="list-style-type: none"> • bedding (6) • infiltration (3) • acid corrosion (3) • compaction (2) • installation/handling, frost loading, sulfate attack 	<ul style="list-style-type: none"> • acid corrosion (3) • bedding (2) • infiltration (2) • sulfate attack, compaction
Reinforced concrete a = 1757.1 km; 67.3%) (b = 1419.3 km; 82.1%)	<ul style="list-style-type: none"> • bedding (9) • infiltration (8) • compaction (5) • voids (2) • sulfate attack (2) • foundation settling (2) • frost loading, slope movement, holes, cracks, joint fails, acid corrosion, overloading, roots, joint opening, installation/handling 	<ul style="list-style-type: none"> • bedding (4) • infiltration (4) • compaction (3) • voids (3) • foundation settling (2) • collapse, sulfate attack, acid corrosion
Corrugated steel (a = 25.1 km; 1.0%) (b = 17.3 km; 1.0%)	<ul style="list-style-type: none"> • metal corrosion (4) • compaction (2) • bedding, holes, compaction, overloading 	<ul style="list-style-type: none"> • holes, compaction, metal corrosion, foundation settling
Corrugated HDPE (a = 15.6 km; 0.6%) (b = 3.5 km; 0.2%)	—	—
PVC (a = 157.9 km; 6%) (b = 6.0 km; 0.3%)	<ul style="list-style-type: none"> • bedding (2) • compaction, deformation, bending 	<ul style="list-style-type: none"> • compaction

Note that the length of each pipe material and percentage corresponding to those responding cities, for the two diameter groups, is included in brackets under each type of pipe material. The diameter groups are identified by "a" for 450 - 600 mm and "b" for 675 - 900 mm.

Table 31. Ranking of joint performance (27 cities: 24,200 km of pipe)

Pipe Material	Ranking of Joint Performance
Non-reinforced concrete	3.2
Reinforced concrete	2.6
Corrugated steel	4.2
Corrugated HDPE	2.3
PVC	1.1

Note: Values listed are averages of the rankings (1- best, 5- worst) provided by municipalities.

The closer the number to 1, the better the joint performance is perceived to be.

A final question asked for circumstances in which types of pipe within the same backfill affect the performance of surface facilities such as roads, manholes and catchbasins. There has so far been insufficient response to evaluate.

5.2 Provincial Culvert Performance

The questionnaire revealed that none of the six responding provinces has a rating system to assess the condition of culverts.

Four of six provinces perform routine visual inspections, the only inspection technique currently in use.

On selecting rehabilitation techniques, two provinces said they replace a pipe section. Four others make the choice based on:

- past experience and discussions with pipe manufacturers
- consultant's opinion or department recommendation
- economics
- ad hoc requirements

Table 32 shows the types of rehabilitation techniques used for culvert pipe for both diameter groups. The more popular methods are "excavate and replace" and installing internal liners and sleeves.

A question concerning the number of failures and replacements was answered by none of the respondents.

However, four provinces provided responses to questions about the types and causes of in-service distresses and failures. These are summarized in Tables 33 and 34. Also included in the tables is the total length of each type of culvert pipe material currently in each province's inventory.

Table 32. Type of rehabilitation techniques for culvert pipe (6 provinces)

Pipe Material	Pipe Diameters (mm)	
	450 - 600	675 - 900
Non-reinforced concrete	<ul style="list-style-type: none"> • excavate and replace (2) • internal liners/sleeves (2) • grout sealing 	<ul style="list-style-type: none"> • internal liners/sleeves (3) • excavate and replace (2) • grout sealing (2)
Reinforced concrete	<ul style="list-style-type: none"> • excavate and replace (4) • internal liners/sleeves (3) • grout sealing 	<ul style="list-style-type: none"> • excavate and replace (4) • internal liners/sleeves (4) • grout sealing (2)
Corrugated steel	<ul style="list-style-type: none"> • excavate and replace (5) • internal liners/sleeves (2) • grout sealing 	<ul style="list-style-type: none"> • excavate and replace (5) • internal liner/sleeves (3) • grout sealing (2)
Corrugated hdpe	<ul style="list-style-type: none"> • no response 	<ul style="list-style-type: none"> • no response
PVC	<ul style="list-style-type: none"> • no response 	<ul style="list-style-type: none"> • no response

For concrete products, no two provinces listed the same types of distress. The most common types of failure/distress of corrugated steel pipe appear to be collapse and material degradation. Other causes of distress/failure are listed in Table 34. Again, four provinces provided responses.

As Table 34 shows, provincial engineers believe the primary causes of in-service failures are compaction, bedding and metal corrosion.

With only three of the six provinces responding, the results for the ranking of joint performance are not statistically relevant.

Table 33. Types of in-service culvert distresses/failures requiring repair/replacement

Pipe Material	Pipe Diameters (mm)	
	450 - 600 ^a (4 provinces)	675 - 900 ^b (4 provinces)
Non-reinforced concrete	<ul style="list-style-type: none"> • splits, cracks, joint separation, holes 	<ul style="list-style-type: none"> • collapse, joint separation, splits, cracks
Reinforced concrete (a = 2 km) (b = 2.5 km)	<ul style="list-style-type: none"> • splits, cracks, joint separation, holes 	<ul style="list-style-type: none"> • no response
Corrugated steel (a = 42.3 km) (b = 17.8 km)	<ul style="list-style-type: none"> • collapse (4) • material degradation (3) • holes (2) • structural failures, splits, sumps, excessive deformation, buckling 	<ul style="list-style-type: none"> • material degradation (4) • collapse (3) • buckling (2) • holes, excessive deformation, splits
Corrugated hdpe	<ul style="list-style-type: none"> • no response 	<ul style="list-style-type: none"> • no response
PVC	<ul style="list-style-type: none"> • no response 	<ul style="list-style-type: none"> • no response

Note: There are 120 km of pipe with diameters of 450 - 600 mm, and 22.6 km of pipe with diameter ranges of 675 - 900 mm that are of unknown composition; see Table 3.

Table 34. Causes of in-service culvert distresses/failures

Pipe Material	Pipe Diameters (mm)	
	450 - 600 ^a (4 provinces)	675 - 900 ^b (4 provinces)
Non-reinforced concrete	<ul style="list-style-type: none"> • compaction, bedding 	<ul style="list-style-type: none"> • compaction, bedding
Reinforced concrete (a = 2 km) (b = 2.5 km)	<ul style="list-style-type: none"> • compaction, bedding 	<ul style="list-style-type: none"> • compaction, bedding
Corrugated steel (a = 42.3 km) (b = 17.8 km)	<ul style="list-style-type: none"> • metal corrosion (4) • bedding (4) • compaction (3) • infiltration (2) 	<ul style="list-style-type: none"> • metal corrosion (3) • compaction (3) • bedding (3) • infiltration
Corrugated hdpe	<ul style="list-style-type: none"> • no response 	<ul style="list-style-type: none"> • no response
PVC	<ul style="list-style-type: none"> • no response 	<ul style="list-style-type: none"> • no response

Note: There are 120 km of pipe with diameters of 450 - 600 mm, and 22.6 km of pipe with diameter ranges of 675 - 900 mm that are of unknown composition; see Table 3.

6 Summary

The cross-Canada survey of the extent and performance of provincial and municipal sewer and drainage infrastructure has yielded some important findings.

Most of the storm and sanitary sewer pipe in Canada, within the specified diameter range of 450 to 900 mm, is a concrete product (either non-reinforced or reinforced), while most of the culvert pipe is corrugated steel. The concrete pipe ranges from just installed to over 75 years of service, while the PVC pipe is less than 25 years old.

In general, the municipal and provincial governments are responsible for selecting the pipe material system. The choice of bedding condition standard is influenced by the location of the city or province.

The conditions used for selecting the type of storm and sanitary sewer pipe vary with the type of material, not the diameter. For example, concrete pipe products are selected when burial depth is a concern, while the choice of steel is based on the purpose of the pipe and the soil conditions. Finally, soil conditions most frequently governed the use of HDPE and PVC pipe. For culvert pipe, an assortment of conditions is listed for each pipe material.

Design parameters, meanwhile, were applied according to whether pipes are rigid or flexible. For example, for concrete pipe (both reinforced and non-reinforced), traffic loading was identified as the most relevant design parameter for both diameter groups. For corrugated steel

pipe, corrosion was identified for the 450-600-mm diameter range, while hydraulic flow was the most relevant parameter for pipes 675 to 900 mm in diameter. Hydraulic flow was also the most relevant parameter listed for HDPE and PVC for both diameter groups. For culvert pipe, traffic loading was the most relevant design parameter where the pipe was made from non-reinforced concrete. Hydraulic flow was the most relevant parameter for all other types of materials.

Respondents generally felt that PVC pipe provides the greatest installation ease for storm and sanitary sewer applications because of its light weight and handling ease, long length and ease of joint installation. Corrugated steel pipe holds the same distinction for culverts, again because of its light weight and ease of pipe joining.

The survey further found that the most popular basics for choosing rehabilitation techniques was the cost of replacement (life-cycle cost), followed by the type of defect. Excavation and replacement was the most common technique of repairing all types of pipes and culverts, followed by the installation of liners.

The survey appears to have succeeded in documenting the inventory, design and installation procedures of sewer and drainage pipes and culverts. The performance section, however, was not well answered. The resultant lack of information solidifies a need for research in this area. One possibility would be to conduct case studies to gauge the performance of various pipe materials throughout the course of their service lives.



Appendix



DURABILITY AND PERFORMANCE COMPARISON OF CONCRETE, PVC, CORRUGATED STEEL AND CORRUGATED HDPE PIPES IN THE DIAMETER RANGE 450-900 mm (18-36 ")

STORM, SANITARY AND COMBINED SEWER PIPES

Please complete the following and return to Shelley McDonald, Infrastructure Laboratory, Building M-20, Montreal Road, IRC/NRC, Ottawa, Ontario, K1A 0R6. The fax number is (613) 954-5984.

Name of Municipality: _____

Address: _____

Name of Respondent: _____

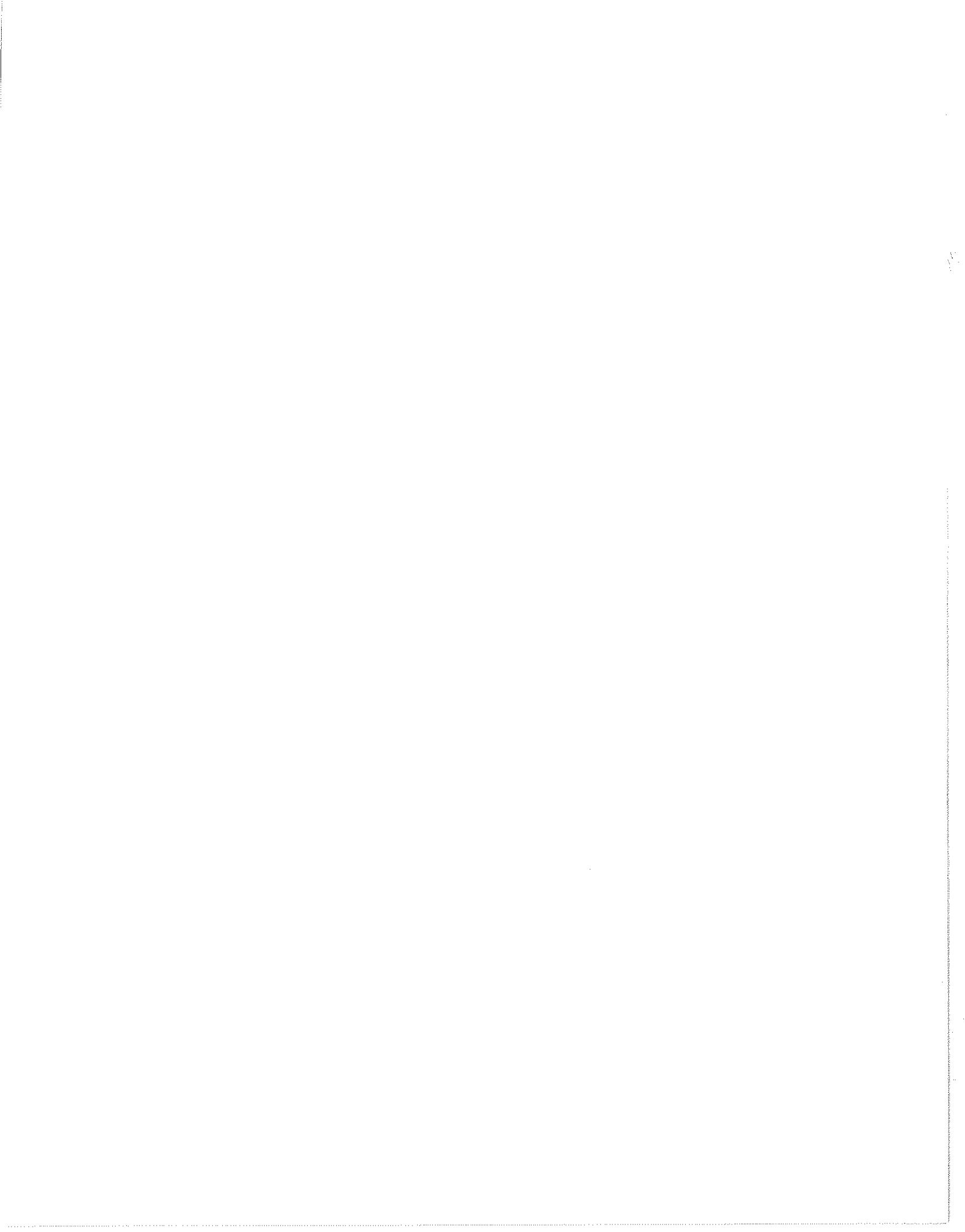
Title of Respondent: _____

Phone/Fax Number: _____

Total Municipal Population: _____

In order to maintain confidentiality of each municipality response, the results of the questionnaire will be reported in aggregate terms. For example, results will be reported according to population groups greater than 100,000, between 50,000 and 100,000 and less than 50,000.

Thank you for your co-operation.



A) Inventory

1a. Do you have an inventory information system in place?

yes no

1b. If yes, please specify the type.

2a. What is the total length of storm pipe?

_____ km

2b. What is the total length of separated sanitary pipe?

_____ km

2c. What is the total length of combined sewer pipe?

_____ km

3. Please indicate, the approximate percentage of storm, sanitary and combined sewer pipe constructed in the various soil types indicated. The categories are < 25, 25-50, 51-75, > 75 %.

	Storm	Sanitary	Combined
Clay	_____	_____	_____
Fine grained (silt, fine sand)	_____	_____	_____
Coarse grained (sand, gravel)	_____	_____	_____
Rock	_____	_____	_____
Other (till, organic soil, etc.)	_____	_____	_____

4. What percentage or length of storm, sanitary and combined sewer pipe which have a diameter in the range...

	Storm	Sanitary	Combined
< 450 mm (< 18 ")	_____	_____	_____
450 - 600 mm (18-24 ")	_____	_____	_____
600 - 900 mm (24-36 ")	_____	_____	_____
> 900 mm (> 36 ")	_____	_____	_____

% km

5a. For the pipes in the diameter range 450 - 600 mm (18-24 "), what percentage of storm, sanitary and combined sewer pipe are constructed of the indicated materials?

	Storm	Sanitary	Combined
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____
Other	_____	_____	_____

%

5b. For the pipes in the diameter range 675 - 900 mm (27-36"), what percentage of storm, sanitary and combined sewer pipe are constructed of the indicated materials?

	Storm	Sanitary	Combined
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____
Other	_____	_____	_____
<input type="checkbox"/> %			

6a. For each pipe material, what is the average age of the storm, sanitary, combined sewer pipe in the 450 - 600 mm (18-24") diameter range? The age groups to choose from are < 25, 25-50, 51-75, > 75 years.

	Storm	Sanitary	Combined
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

6b. For each pipe material, what is the average age of the storm, sanitary, combined sewer pipe in the 675 - 900 mm (27-36") diameter range? The age groups to choose from are < 25, 25-50, 51-75, > 75 years.

	Storm	Sanitary	Combined
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

7a. In the past 5 years, for pipes with diameters between 450 - 600 mm (18-24"), what was the total length of each pipe material installed for storm and sanitary sewer pipe?

	Storm	Sanitary
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

7b. In the past 5 years, for pipes with diameters between 675 - 900 mm (27-36"), what was the total length of each pipe material installed for storm and sanitary sewer pipe?

	Storm	Sanitary
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

8a. In the past 5 years, have you used ribbed plastics or any other new pipe materials for 450 - 600 mm (18-24") storm and sanitary sewer pipe?

Material type	Purpose
_____	_____
_____	_____
_____	_____

8b. In the past 5 years, have you used ribbed plastics or any other new pipe materials for 675 - 900 mm (27-36 ") storm and sanitary sewer pipe?

Material type	Purpose
_____	_____
_____	_____
_____	_____

B) Design

Please note, all questions listed in this section pertain to pipes with diameters between 450 - 900 mm (18 - 36 ") only, unless otherwise indicated.

9. Who establishes the design specifications of each pipe system? The pipe system includes the pipe material, size and class as well as the trench design. Please use MU for Municipality, MA for Manufacturer and DE for Design Consultant.

	Storm	Sanitary
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

10. Who selects the pipe material used for installation?

Municipality	_____
Contractor	_____
Design consultant	_____

11a. Are there conditions in which one type of pipe with a diameter between 450 - 600 mm (18 - 24") is preferred over another? If so, what are the conditions? For example; burial depth, ground water level, cold weather construction, corrosive and/or aggressive soil conditions, purpose of pipe.

Non-reinforced Concrete	_____
Reinforced Concrete	_____
Corrugated Steel	_____
Corrugated HDPE	_____
PVC	_____

11b. Are there conditions in which one type of pipe with a diameter between 675 - 900 mm (27 - 36") is preferred over another? If so, what are the conditions? For example; burial depth, ground water level, cold weather construction, corrosive and/or aggressive soil conditions, purpose of pipe.

Non-reinforced Concrete _____
 Reinforced Concrete _____
 Corrugated Steel _____
 Corrugated HDPE _____
 PVC _____

12. What standards are followed for the bedding conditions for each pipe material for the two diameter groups listed? For example, ASTM, OPSS, ASCE, BNQ, etc.

	450 - 600 mm	675 - 900 mm
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

13a. Is the choice of pipe material based on initial cost (IC) or life-cycle cost analysis (LCA)?

IC LCA

13b. If life-cycle cost analysis is part of the design, who performs the analysis?

Design Consultant _____
 Owner _____

14a. In your opinion, what are the most relevant parameters for the design of a pipe with a diameter between 450 - 600 mm (18 - 24 ") of a particular material? Please rank the below listed parameters in relation to each pipe material from 1-9 with 1 being the most relevant. Hydraulic flow (HF), corrosion (CR), traffic loading (TL), frost loading (FL), abrasion resistance (AR), ground water conditions (GWC), compaction (CM), backfill selection ((BS), etc.

Ranking/ Material	Non-reinforced Concrete	Reinforced Concrete	Corrugated Steel	Corrugated HDPE	PVC
1					
2					
3					
4					
5					
6					
7					
8					
9					

14b. In your opinion, what are the most relevant parameters for the design of a pipe with a diameter between 675 - 900 mm (27 - 36 ") of a particular material? Please rank the below listed parameters in relation to each pipe material from 1-9 with 1 being the most relevant. Hydraulic flow (HF), corrosion (CR), traffic loading (TL), frost loading (FL), abrasion resistance (AR), ground water conditions (GWC), compaction (CM), backfill selection ((BS), etc.

Ranking/ Material	Non-reinforced Concrete	Reinforced Concrete	Corrugated Steel	Corrugated HDPE	PVC
1					
2					
3					
4					
5					
6					
7					
8					
9					

C) Installation

Please note, all questions listed in this section, unless otherwise indicated pertain to pipes with diameters between 450 - 900 mm (18 - 36 ") only.

15a. Please rank the following types of storm and sanitary sewer pipe materials with diameters between 450 - 600 mm (18 - 24 ") with respect to the ease of installation (1-easiest, 5-most difficult, n/a-not applicable or no experience).

Non-reinforced Concrete _____
 Reinforced Concrete _____
 Corrugated Steel _____
 Corrugated HDPE _____
 PVC _____

15b. For the pipe most easily installed, please give 3 reasons for the relative ease of installation.

1. _____
 2. _____
 3. _____

15c. For the pipe most difficult to install, please give 3 reasons for the difficulty of installation.

1. _____
 2. _____
 3. _____

16a. Please rank the following types of storm and sanitary sewer pipe materials with diameters between 675 - 900 mm (27 - 36 ") with respect to the ease of installation (1-easiest, 5-most difficult, n/a-not applicable or no experience).

Non-reinforced Concrete _____
 Reinforced Concrete _____
 Corrugated Steel _____
 Corrugated HDPE _____
 PVC _____

16b. For the pipe most easily installed, please give 3 reasons for the relative ease of installation.

1. _____
 2. _____
 3. _____

16c. For the pipe most difficult to install, please give 3 reasons for the difficulty of installation.

1. _____
2. _____
3. _____

17. What was the most recent installation cost for the pipes listed for each diameter group (\$/unit length)?

	450 - 600 mm	675 - 900 mm
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

\$/m \$/ft

18a. In the last 5 years, what was the percentage of pipes between 450 - 600 mm (18 - 24 ") rejected or damaged during transport (TR), storage (ST) and installation (IN)? Please respond for each pipe material listed.

	TR	ST	IN
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

18b. What types of damage were experienced for each pipe material, diameter between 450 - 600 mm (18 - 24 ")? For example, dents, cracks, splits, broken ribs, etc.

	TR	ST	IN
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

19a. In the last 5 years, what was the percentage of pipes between 675 - 900 mm (27 - 36 ") rejected or damaged during transport (TR), storage (ST) and installation (IN)? Please respond for each pipe material listed.

	TR	ST	IN
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

19b. What types of damage were experienced for each pipe material, diameter between 675 - 900 mm (27 - 36 ")? For example, dents, cracks, splits, broken ribs, etc.

	TR	ST	IN
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

20a. Based on past experience, what was the average percent deviation in the trench width from that specified during installation for the three diameters listed?

	450mm	600mm	900mm
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

20b. What was the shape of the trench for the installation of storm and sanitary sewer pipe with diameters between 450 - 600 mm (18 - 24 ")? Please circle the most appropriate shape.



20c. What was the shape of the trench for the installation of storm and sanitary sewer pipe with diameters between 675 - 900 mm (27 - 36 ")? Please circle the most appropriate shape.



21a. Have you experienced any problems during storm and sanitary sewer installation?

yes

no

21b. If so, what would you suggest in order to improve the installation of the various types of pipe materials?

Non-reinforced Concrete	_____
Reinforced Concrete	_____
Corrugated Steel	_____
Corrugated HDPE	_____
PVC	_____

22. Have you experienced any problems in handling pipe materials in cold temperatures (air temperatures below - 10 °C)? If so, please briefly describe the problems encountered.

Non-reinforced Concrete	_____
Reinforced Concrete	_____
Corrugated Steel	_____
Corrugated HDPE	_____
PVC	_____

23. Please rank the following types of storm and sanitary sewer pipe materials with respect to the ease of pipe joining (1-easiest, 5-most difficult, n/a-not applicable or no experience).

Non-reinforced Concrete _____
Reinforced Concrete _____
Corrugated Steel _____
Corrugated HDPE _____
PVC _____

24a. Do you specify inspection procedures for pipe installation?

No Yes

24b. If so, what do they include?

24c. If not, who does?

25. Who does the inspection?

Municipal staff _____
Contractor _____
Consultant _____
other _____

26. How often is unshrinkable fill (or controlled low strength material) used for backfilling? Please check one.

0 % 20 % 40 % 60 % 80 % 100 %

D) Performance

Please note, all questions listed in this section, unless indicated otherwise, pertain to pipes with diameters between 450 - 900 mm (18 - 36 ") only.

27. Do you have a rating system/criteria set up for assessing the condition of storm and sanitary sewer pipe?

No Yes (PLEASE SEND A COPY)

28a. Are routine inspections performed?

No Yes

28b. If so, what type and at what frequency?

External visual _____
Internal closed circuit television _____
Sonar systems _____
X-ray _____
Cut-out section _____
other _____

29. How is the choice of rehabilitation technique made?

30a. What types of rehabilitation techniques are performed for the pipe materials listed for pipe diameters between 450 - 600 mm (18 - 24 ")? For example excavate and replace, grout sealing, liners, internal sleeves, etc.

Non-reinforced Concrete _____
 Reinforced Concrete _____
 Corrugated Steel _____
 Corrugated HDPE _____
 PVC _____

30b. What types of rehabilitation techniques are performed for the pipe materials listed for pipe diameters between 675 - 900 mm (27 - 36 ")? For example excavate and replace, grout sealing, liners, internal sleeves, etc.

Non-reinforced Concrete _____
 Reinforced Concrete _____
 Corrugated Steel _____
 Corrugated HDPE _____
 PVC _____

31a. In the past 5 years, what was the total number of repairs for each pipe material for each diameter listed?

	450 mm	600 mm	900 mm
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

#/km

31b. In the past 5 years, what was the total number of replacements for each pipe material?

	450 mm	600 mm	900 mm
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

#/km

32a. What were the top 3 types of in-service failures requiring repair/replacement for each pipe material for pipe diameters between 450 - 600 mm (18 - 24 ")? Failure types include: collapse, splits, cracks, bending failure, unravelling, joint separation, material degradation, buckling, large deformation, holes, sumps. Please list the most predominant failure type first.

Non-reinforced Concrete _____

 Reinforced Concrete _____

 Corrugated Steel _____

 Corrugated HDPE _____

 PVC _____

32b. What were the causes of the inservice failures for each pipe material for pipe diameters between 450 - 600 mm (18 - 24 ")? Failure causes include: bedding, compaction, infiltration, voids, sulfate attack, acid corrosion, metal corrosion, abrasion, biological attack.

Non-reinforced Concrete _____

 Reinforced Concrete _____

 Corrugated Steel _____

 Corrugated HDPE _____

 PVC _____

33a. What were the top 3 types of in-service failures requiring repair/replacement for each pipe material for pipe diameters between 675 - 900 mm (27 - 36 ")? Failure types include: collapse, splits, cracks, bending failure, unravelling, joint separation, material degradation, buckling, large deformation, holes, sumps. Please list the most predominant failure type first.

Non-reinforced Concrete _____

 Reinforced Concrete _____

 Corrugated Steel _____

 Corrugated HDPE _____

 PVC _____

33b. What were the causes of the inservice failures for each pipe material for pipe diameters between 675 - 900 mm (27 - 36 ")? Failure causes include: bedding, compaction, infiltration, voids, sulfate attack, acid corrosion, metal corrosion, abrasion, biological attack.

Non-reinforced Concrete _____

 Reinforced Concrete _____

 Corrugated Steel _____

 Corrugated HDPE _____

 PVC _____

34. Please rank the following types of storm and sanitary sewer pipe materials with respect to joint performance (1-easiest, 5-most difficult, n/a-not applicable or no experience).

Non-reinforced Concrete _____
 Reinforced Concrete _____
 Corrugated Steel _____
 Corrugated HDPE _____
 PVC _____

35. In your experience, can a particular pipe material over another (within the same backfill) affect the performance of surface facilities (roads, manholes and catchbasins)?

No Yes

If yes, please indicate the pipe type:

THANK YOU FOR YOUR COOPERATION

Please indicate the address where the \$ 100 cheque should be sent.

DURABILITY AND PERFORMANCE COMPARISON OF CONCRETE, PVC, CORRUGATED STEEL AND CORRUGATED HDPE PIPES IN THE DIAMETER RANGE 450-900 mm (18-36 ")

STORM DRAINS AND CULVERTS

Please complete the following and return to Shelley McDonald, Infrastructure Laboratory, Building M-20, Montreal Road, IRC/NRC, Ottawa, Ontario, K1A 0R6. The fax number is (613) 954-5984.

Name of Ministry: _____

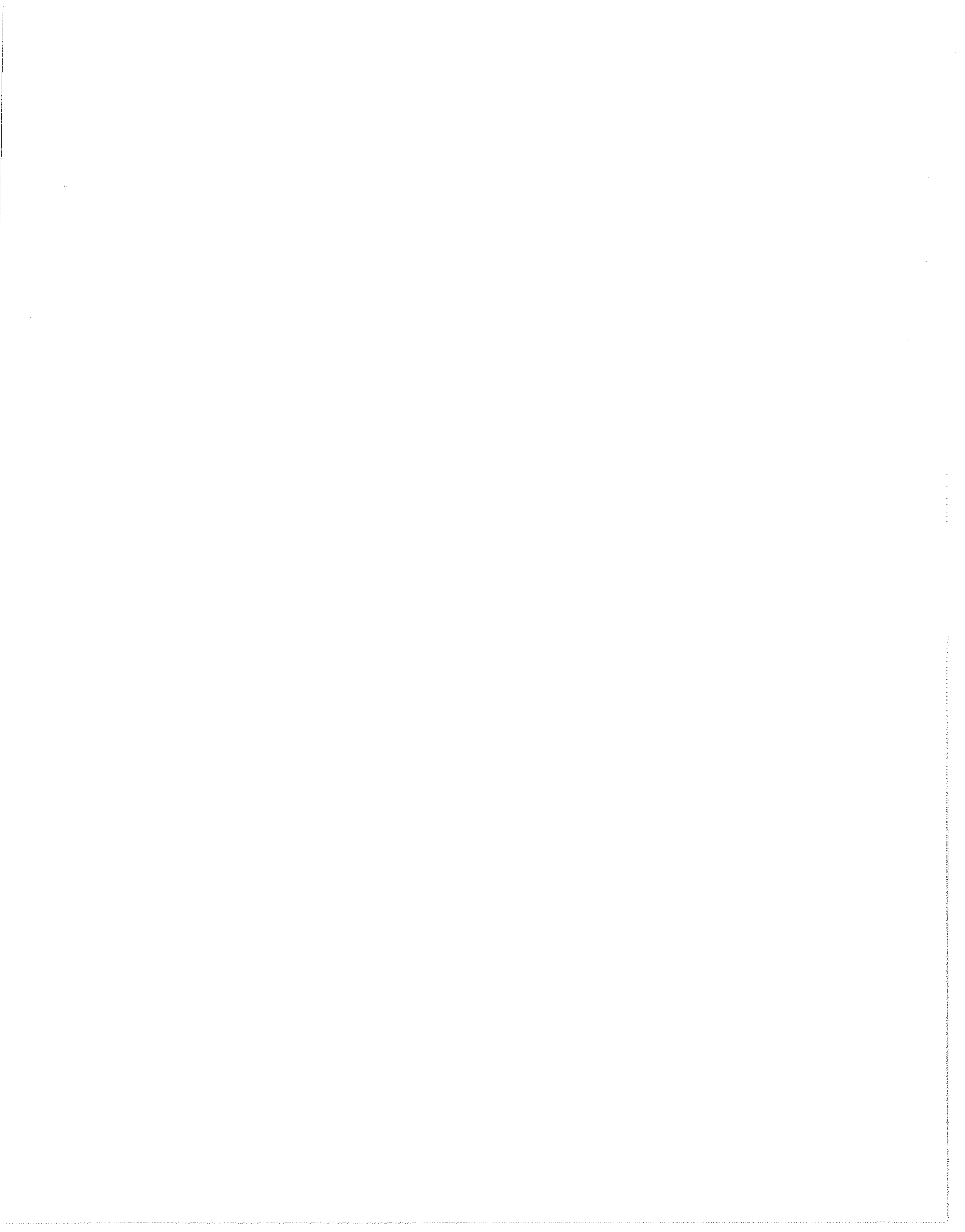
Address: _____

Name of Respondent: _____

Title of Respondent: _____

Phone/Fax Number: _____

Thank you for your co-operation.



A) Inventory

1a. Do you have an inventory information system in place?

yes no

1b. If yes, please specify the type.

2a. What is the total length of storm pipe under your ministry's jurisdiction?

_____ km

2b. What is the total number of culverts under your ministry's jurisdiction?

2c. What is the average, minimum and maximum length of culvert under your ministry's jurisdiction?

average length	minimum length	maximum length
_____	_____	_____

3. Please indicate, the approximate percentage of storm drain and culvert constructed in the various soil types indicated. The categories are < 25, 25-50, 51-75, > 75 %.

	Storm drain	Culvert
Clay	_____	_____
Fine grained (silt, fine sand)	_____	_____
Coarse grained (sand, gravel)	_____	_____
Rock	_____	_____
Other (till, organic soil, etc.)	_____	_____

4. What percentage or length of storm drain and culvert which have a diameter in the range...

	Storm drain	Culvert
< 450 mm (< 18 ")	_____	_____
450 - 600 mm (18-24 ")	_____	_____
600 - 900 mm (24-36 ")	_____	_____
> 900 mm (> 36 ")	_____	_____

% km

5a. For the pipes in the diameter range 450 - 600 mm (18-24 "), what percentage of storm drain and culvert pipe are constructed of the indicated materials?

	Storm drain	Culvert
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____
Other	_____	_____

5b. For the pipes in the diameter range 675 - 900 mm (27-36"), what percentage of storm drain and culvert pipe are constructed of the indicated materials?

	Storm drain	Culvert
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____
Other	_____	_____

6a. For each pipe material, what is the average age of the storm drain and culvert pipe in the 450 - 600 mm (18-24") diameter range? The age groups to choose from are < 25, 25-50, 51-75, > 75 years.

	Storm drain	Culvert
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

6b. For each pipe material, what is the average age of the storm drain and culvert pipe in the 675 - 900 mm (27-36") diameter range? The age groups to choose from are < 25, 25-50, 51-75, > 75 years.

	Storm drain	Culvert
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

7a. In the past 5 years, for pipes with diameters from 450 - 600 mm (18-24"), what was the total length of each pipe material installed for storm drain and culvert pipe?

	Storm drain	Culvert
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

7b. In the past 5 years, for pipes with diameters from 675 - 900 mm (27-36"), what was the total length of each pipe material installed for storm drain and culvert pipe?

	Storm drain	Culvert
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

8a. In the past 5 years, have you used ribbed plastics or any other new pipe materials for 450 - 600 mm (18-24") storm drain and culvert pipe?

Material type	Purpose
_____	_____
_____	_____
_____	_____

8b. In the past 5 years, have you used ribbed plastics or any other new pipe materials for 675 - 900 mm (27-36 ") storm drain and culvert pipe?

Material type	Purpose
_____	_____
_____	_____
_____	_____

B) Design

Please note, all questions listed in this section pertain to pipes with diameters from 450 - 900 mm (18 - 36 ") only, unless otherwise indicated.

9. Who establishes the design specifications of each pipe system? The pipe system includes the pipe material, size and class as well as the trench design. Please use MI for Ministry, MA for Manufacturer and DE for Design Consultant.

	Storm drain	Culvert
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

10. Who selects the pipe material used for installation?

Ministry	_____
Contractor	_____
Design consultant	_____

11a. Are there conditions in which one type of pipe with a diameter from 450 - 600 mm (18 - 24") is preferred over another? If so, what are the conditions? For example; burial depth, ground water level, cold weather construction, corrosive and/or aggressive soil conditions, purpose of pipe.

Non-reinforced Concrete	_____
Reinforced Concrete	_____
Corrugated Steel	_____
Corrugated HDPE	_____
PVC	_____

11b. Are there conditions in which one type of pipe with a diameter from 675 - 900 mm (27 - 36") is preferred over another? If so, what are the conditions? For example; burial depth, ground water level, cold weather construction, corrosive and/or aggressive soil conditions, purpose of pipe.

Non-reinforced Concrete _____
 Reinforced Concrete _____
 Corrugated Steel _____
 Corrugated HDPE _____
 PVC _____

12. What standards are followed for the bedding conditions for each pipe material for the two diameter groups listed? For example, ASTM, OPSS, ASCE, BNQ, etc.

	450 - 600 mm	675 - 900 mm
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

13a. Is the choice of pipe material based on initial cost (IC) or life-cycle cost analysis (LCA)?

IC LCA

13b. If life-cycle cost analysis is part of the design, who performs the analysis?

Design Consultant _____
 Owner _____

14a. In your opinion, what are the most relevant parameters for the design of a pipe with a diameter from 450 - 600 mm (18 - 24 ") of a particular material? Please rank the below listed parameters in relation to each pipe material from 1-9 with 1 being the most relevant. Hydraulic flow (HF), corrosion (CR), traffic loading (TL), frost loading (FL), abrasion resistance (AR), ground water conditions (GWC), compaction (CM), backfill selection ((BS).
If in your opinion, an important factor has been omitted, please feel free to identify that factor and place it in the appropriate box.

Ranking/ Material	Non-reinforced Concrete	Reinforced Concrete	Corrugated Steel	Corrugated HDPE	PVC
1					
2					
3					
4					
5					
6					
7					
8					
9					

14b. In your opinion, what are the most relevant parameters for the design of a pipe with a diameter from 675 - 900 mm (27 - 36 ") of a particular material? Please rank the below listed parameters in relation to each pipe material from 1-9 with 1 being the most relevant. Hydraulic flow (HF), corrosion (CR), traffic loading (TL), frost loading (FL), abrasion resistance (AR), ground water conditions (GWC), compaction (CM), backfill selection ((BS).

If in your opinion, an important factor has been omitted, please feel free to identify that factor and place it in the appropriate box.

Ranking/ Material	Non-reinforced Concrete	Reinforced Concrete	Corrugated Steel	Corrugated HDPE	PVC
1					
2					
3					
4					
5					
6					
7					
8					
9					

C) Installation

Please note, all questions listed in this section, unless otherwise indicated pertain to pipes with diameters from 450 - 900 mm (18 - 36 ") only. Please understand there is a difference between ease of handling and installation.

15a. Please rank the following types of storm drain and culvert pipe materials with diameters from 450 - 600 mm (18 - 24 ") with respect to the ease of installation (1-easiest, 5-most difficult, n/a-not applicable or no experience).

Non-reinforced Concrete _____
 Reinforced Concrete _____
 Corrugated Steel _____
 Corrugated HDPE _____
 PVC _____

15b. For the pipe most easily installed, please give 3 reasons for the relative ease of installation.

1. _____
 2. _____
 3. _____

15c. For the pipe most difficult to install, please give 3 reasons for the difficulty of installation.

1. _____
 2. _____
 3. _____

16a. Please rank the following types of storm drain and culvert pipe materials with diameters from 675 - 900 mm (27 - 36 ") with respect to the ease of installation (1-easiest, 5-most difficult, n/a-not applicable or no experience).

Non-reinforced Concrete _____
 Reinforced Concrete _____
 Corrugated Steel _____
 Corrugated HDPE _____
 PVC _____

16b. For the pipe most easily installed, please give 3 reasons for the relative ease of installation.

1. _____
 2. _____
 3. _____

16c. For the pipe most difficult to install, please give 3 reasons for the difficulty of installation.

1. _____
 2. _____
 3. _____

17. What was the most recent installation cost for the pipes listed for each diameter group (\$/unit length)?

Please be consistent with the variables included for each installation cost for each pipe material (include the same variables for each cost).

	450 - 600 mm	675 - 900 mm
Non-reinforced Concrete	_____	_____
Reinforced Concrete	_____	_____
Corrugated Steel	_____	_____
Corrugated HDPE	_____	_____
PVC	_____	_____

\$/m \$/ft

18a. In the last 5 years, what was the percentage of pipes from 450 - 600 mm (18 - 24 ") rejected or damaged during transport (TR), storage (ST) and installation (IN)? Please respond for each pipe material listed.

	TR	ST	IN
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

18b. What types of damage were experienced for each pipe material, diameter from 450 - 600 mm (18 - 24 ")? For example, dents, cracks, splits, broken ribs, etc.

	TR	ST	IN
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

19a. In the last 5 years, what was the percentage of pipes from 675 - 900 mm (27 - 36 ") rejected or damaged during transport (TR), storage (ST) and installation (IN)? Please respond for each pipe material listed.

	TR	ST	IN
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

19b. What types of damage were experienced for each pipe material, diameter from 675 - 900 mm (27 - 36 ")? For example, dents, cracks, splits, broken ribs, etc.

	TR	ST	IN
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

20a. Based on past experience, what was the average percent deviation in the trench width from that specified during installation for the three diameters listed?

	450 mm	600 mm	900 mm
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____

20b. What was the shape of the trench for the installation of storm drain and culvert pipe with diameters from 450 - 600 mm (18 - 24 ")? Please circle the most appropriate shape.



20c. What was the shape of the trench for the installation of storm drain and culvert pipe with diameters from 675 - 900 mm (27 - 36 ")? Please circle the most appropriate shape.



21a. Have you experienced any problems during storm drain and culvert pipe installation?

yes

no

21b. If so, what would you suggest in order to improve the installation of the various types of pipe materials?

Non-reinforced Concrete	_____
Reinforced Concrete	_____
Corrugated Steel	_____
Corrugated HDPE	_____
PVC	_____

22. Have you experienced any problems in handling pipe materials in cold temperatures (air temperatures below - 10 °C)? If so, please briefly describe the problems encountered.

Non-reinforced Concrete _____
Reinforced Concrete _____
Corrugated Steel _____
Corrugated HDPE _____
PVC _____

23. Please rank the following types of storm drain and culvert pipe materials with respect to the ease of pipe joining (1-easiest, 5-most difficult, n/a-not applicable or no experience).

Non-reinforced Concrete _____
Reinforced Concrete _____
Corrugated Steel _____
Corrugated HDPE _____
PVC _____

24a. Do you specify inspection procedures for pipe installation?

No Yes

24b. If so, what do they include?

24c. If not, who does?

25. Who does the inspection?

Ministry staff _____
Contractor _____
Consultant _____
other _____

26. How often is unshrinkable fill (or controlled low strength material) used for backfilling? Please check one.

0 % 20 % 40 % 60 % 80 % 100 %

D) Performance

Please note, all questions listed in this section, unless indicated otherwise, pertain to pipes with diameters from 450 - 900 mm (18 - 36 ") only.

27. Do you have a rating system/criteria set up for assessing the in-service condition of storm drain and culvert pipe?

No

Yes (PLEASE SEND A COPY)

28a. Are routine inspections performed?

No

Yes

28b. If so, what type and at what frequency?

External visual _____

Internal closed circuit television _____

Sonar systems _____

X-ray _____

Cut-out section _____

other _____

29. How is the choice of rehabilitation technique made?

30a. What types of rehabilitation techniques are performed for the pipe materials listed for pipe diameters from 450 - 600 mm (18 - 24 ")? For example excavate and replace, grout sealing, liners, internal sleeves, etc.

Non-reinforced Concrete _____

Reinforced Concrete _____

Corrugated Steel _____

Corrugated HDPE _____

PVC _____

30b. What types of rehabilitation techniques are performed for the pipe materials listed for pipe diameters from 675 - 900 mm (27 - 36 ")? For example excavate and replace, grout sealing, liners, internal sleeves, etc.

Non-reinforced Concrete _____

Reinforced Concrete _____

Corrugated Steel _____

Corrugated HDPE _____

PVC _____

31a. In the past 5 years, what was the total number of repairs for each pipe material for each diameter listed?

	450 mm	600 mm	900 mm
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____
	<input type="checkbox"/> #	<input type="checkbox"/> #/km	

31b. In the past 5 years, what was the total number of replacements for each pipe material?

	450 mm	600 mm	900 mm
Non-reinforced Concrete	_____	_____	_____
Reinforced Concrete	_____	_____	_____
Corrugated Steel	_____	_____	_____
Corrugated HDPE	_____	_____	_____
PVC	_____	_____	_____
	<input type="checkbox"/> #	<input type="checkbox"/> #/km	

32a. What were the top 3 types of in-service failures requiring repair/replacement for each pipe material for pipe diameters from 450 - 600 mm (18 - 24")? Failure types include: collapse, splits, cracks, bending failure, unravelling, joint separation, material degradation, buckling, excessive deformation, holes, sumps. Please list the most predominant failure type first.

Non-reinforced Concrete	_____
Reinforced Concrete	_____
Corrugated Steel	_____
Corrugated HDPE	_____
PVC	_____

32b. What were the causes of the in-service failures for each pipe material for pipe diameters from 450 - 600 mm (18 - 24")? Failure causes include: bedding, compaction, infiltration, voids, sulfate attack, acid corrosion, metal corrosion, abrasion, biological attack.

Non-reinforced Concrete	_____
Reinforced Concrete	_____
Corrugated Steel	_____
Corrugated HDPE	_____
PVC	_____

33a. What were the top 3 types of in-service failures requiring repair/replacement for each pipe material for pipe diameters from 675 - 900 mm (27 - 36 ")? Failure types include: collapse, splits, cracks, bending failure, unravelling, joint separation, material degradation, buckling, excessive deformation, holes, sumps. Please list the most predominant failure type first.

Non-reinforced Concrete _____

 Reinforced Concrete _____

 Corrugated Steel _____

 Corrugated HDPE _____

 PVC _____

33b. What were the causes of the in-service failures for each pipe material for pipe diameters from 675 - 900 mm (27 - 36 ")? Failure causes include: bedding, compaction, infiltration, voids, sulfate attack, acid corrosion, metal corrosion, abrasion, biological attack.

Non-reinforced Concrete _____

 Reinforced Concrete _____

 Corrugated Steel _____

 Corrugated HDPE _____

 PVC _____

34. Please rank the following types of storm drain and culvert pipe materials with respect to joint performance (1-easiest, 5-most difficult, n/a-not applicable or no experience).

Non-reinforced Concrete _____
 Reinforced Concrete _____
 Corrugated Steel _____
 Corrugated HDPE _____
 PVC _____

35. In your experience, can a particular pipe material over another (within the same backfill) or associated installation procedures affect the performance of surface facilities (roads, manholes and catchbasins)?

No Yes

If yes, please indicate the circumstances of these problems:

 (if any qualitative information is available, please send a copy)

THANK YOU FOR YOUR COOPERATION

Please indicate the address where the \$ 100 cheque should be sent.

