Decision Making and Investment Planning

Managing Risk

This document is the tenth in a series of best practices that transform complex and technical material into non-technical principles and guidelines for decision making. For titles of other best practices in this and other series, please refer to <*www.infraguide.ca*>.

National Guide to Sustainable Municipal Infrastructure®

NRC · CNRC FCM Federation of Canadian Municipalities Fédération canadienne des municipalités Canadä

Managing Risk

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INTRODUCTION

InfraGuide® – Innovations and Best Practices

Why Canada Needs InfraGuide

Canadian municipalities spend $12 to $15 billion annually on infrastructure but it never seems to be enough. Existing infrastructure is ageing while demand grows for more and better roads, and improved water and sewer systems responding both to higher standards of safety, health and environmental protection as well as population growth. The solution is to change the way we plan, design and manage infrastructure. Only by doing so can municipalities meet new demands within a fiscally responsible and environmentally sustainable framework, while preserving our quality of life.

This is what the *National Guide to Sustainable Municipal Infrastructure (InfraGuide)* seeks to accomplish.

In 2001, the federal government, through its Infrastructure Canada Program (IC) and the National Research Council (NRC), joined forces with the Federation of Canadian Municipalities (FCM) to create the National Guide to Sustainable Municipal Infrastructure (InfraGuide). InfraGuide is both a new, national network of people and a growing collection of published best practice documents for use by decision makers and technical personnel in the public and private sectors. Based on Canadian experience and research, the reports set out the best practices to support sustainable municipal infrastructure decisions and actions in six key areas: decision making and investment planning, potable water, storm and wastewater, municipal roads and sidewalks, environmental protocols, and transit. The best practices are available online and in hard copy.

A Knowledge Network of Excellence

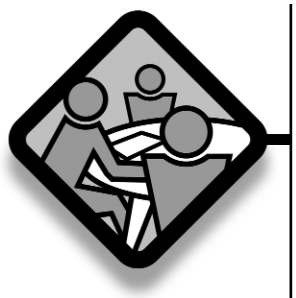
InfraGuide is a national network of experts and a growing collection of best practice publications for core infrastructure, offering the best in Canadian experience and knowledge of core infrastructure. With our founders — the Federation of Canadian Municipalities, the National Research Council and Infrastructure Canada, and our founding member, the Canadian Public Works Association — we help municipalities make informed, smart decisions that sustain our quality of life.

Volunteer technical committees and working groups—with the assistance of consultants and other stakeholders—are responsible for the research and publication of the best practices. This is a system of shared knowledge, shared responsibility and shared benefits. We urge you to become a part of the InfraGuide Network of Excellence. Whether you are a municipal plant operator, a planner or a municipal councillor, your input is critical to the quality of our work.

Please join us.

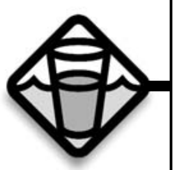
Contact InfraGuide toll-free at **1-866-330-3350** or visit our Web site at ***<www.infraguide.ca>*** for more information. We look forward to working with you.

The InfraGuide Best Practices Focus



Decision Making and Investment Planning

Current funding levels are insufficient to meet infrastructure needs. The net effect is that infrastructure is deteriorating rapidly. Elected officials and senior municipal administrators need a framework for articulating the value of infrastructure planning and maintenance, while balancing social, environmental and economic factors. Decision-making and investment planning best practices transform complex and technical material into non-technical principles and guidelines for decision making, and facilitate the realization of adequate funding over the life cycle of the infrastructure. Examples include protocols for determining costs and benefits associated with desired levels of service; and strategic benchmarks, indicators or reference points for investment policy and planning decisions.

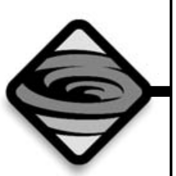


Potable Water

Potable water best practices address various approaches to enhance a municipality's or water utility's ability to manage drinking water delivery in a way that ensures public health and safety at best value and on a sustainable basis. Issues such as water accountability, water use and loss, deterioration and inspection of distribution systems, renewal planning and technologies for rehabilitation of potable water systems and water quality in the distribution systems are examined.

Environmental Protocols

Environmental protocols focus on the interaction of natural systems and their effects on human quality of life in relation to municipal infrastructure delivery. Environmental elements and systems include land (including flora), water, air (including noise and light) and soil. Example practices include how to factor in environmental considerations in establishing the desired level of municipal infrastructure service; and definition of local environmental conditions, challenges and opportunities with respect to municipal infrastructure.



Storm and Wastewater

Ageing buried infrastructure, diminishing financial resources, stricter legislation for effluents, increasing public awareness of environmental impacts due to wastewater and contaminated stormwater are challenges that municipalities have to deal with. Storm and wastewater best practices deal with buried linear infrastructure as well as end of pipe treatment and management issues. Examples include ways to control and reduce inflow and infiltration; how to secure relevant and consistent data sets; how to inspect and assess condition and performance of collections systems; treatment plant optimization; and management of biosolids.

Transit

Urbanization places pressure on an eroding, ageing infrastructure, and raises concerns about declining air and water quality. Transit systems contribute to reducing traffic gridlock and improving road safety. Transit best practices address the need to improve supply, influence demand and make operational improvements with the least environmental impact, while meeting social and business needs.

Municipal Roads and Sidewalks

Sound decision making and preventive maintenance are essential to managing municipal pavement infrastructure cost effectively. Municipal roads and sidewalks best practices address two priorities: front-end planning and decision making to identify and manage pavement infrastructures as a component of the infrastructure system; and a preventive approach to slow the deterioration of existing roadways. Example topics include timely preventative maintenance of municipal roads; construction and rehabilitation of utility boxes; and progressive improvement of asphalt and concrete pavement repair practices.

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Municipal infrastructure is essential to a community's economic well-being and public safety. Given this dependency, a community should be aware of and manage the various risks that can adversely affect the performance of its infrastructure over time. Risk management has the potential to minimize the cost to provide a healthy, safe, affordable, and publicly acceptable service.

In this best practice, risk is referred to as the probability and severity of a particular circumstance or a combination of circumstances that will negatively affect a municipality's ability to meet its objectives. Risk management, therefore, is the analysis and collective actions to be taken to reduce risk to an acceptable level.

This document provides an overview of the risk management process and its value in the development of efficient management programs and corporate policies for sustainable municipal infrastructure assets. It recommends the principles of a best practice to incorporate risk management into an asset management strategy. Risk emanates from uncertainty and is generally considered to encompass both threats and opportunities. *The Guide to the Project Management Body of Knowledge* (PMBoK Guide, 2004), defines risk as *". . . an uncertain event or condition that, if it occurs, has a positive or a negative effect on a project objective . . ."*. As such the potential severity of impact of a risk and the probability of its occurrence are key elements in quantification of risk.

Risk is defined in this best practice as the likely exposure to a threat that negatively impacts the ability of infrastructure assets to meet the objectives of the community it serves. Risk management is a set of activities, procedures, methods and systems used to identify, quantify and mitigate undesirable exposure to loss in capital and/or quality of service so as to meet community objectives.

Every organization should have clearly understood and documented objectives that its infrastructure assets should meet in their performance. Failure to fully meet the objectives results in exposure to risk. Tolerance for risk must be considered in a range of categories and circumstances. Clearly this can vary from one community to another.

Development and implementation of risk management programs require four main steps or phases: 1) risk identification, 2) risk quantification, 3) risk mitigation, and 4) evaluation and feedback. It should be noted that the first step is knowledge based and experience driven, and aims at identifying items, events and/or issues that are perceived to give rise to risk. Various categories of risk, driven by external and internal events along with source of risk analysis are outlined in the best practice for this step. The second step aims at establishing numerical indices for each of the identified risk items, calculated simply as the product of the severity impact and the probability of occurrence associated with the risk item being considered. Risk quantification is also referred to as risk analysis and it may be simple and of limited scope or it may be elaborate and involve simulation techniques. This step is described in Sections 3.1 and 3.2 of this best practice. In the third step, strategies and methods are developed to mitigate the risk, identified and quantified in the previous two steps. This includes doing nothing, particularly in cases where the calculated risk indices are relatively low or deemed acceptable. It should be noted here that what is acceptable for one community may not be so for another. Last step could be viewed a continuous improvement process that benefits from past applications of the risk management program used. A wide range of risk mitigation strategies are described in detail in this best practice.

Risk emanates from uncertainty and is generally considered to encompass both threats and opportunities.

Risk management is a set of activities, procedures, methods and systems used to identify, quantify and mitigate undesirable exposure to loss in capital and/or quality of service so as to meet community objectives.

Executive Summary

Risk management should be an integral part of the decision-making process both at the strategic corporate level and at the tactical operational levels.

Risk management should be an integral part of the decision-making process both at the strategic corporate level and at the tactical operational levels. As such it is used as a useful tool in budget appropriation and allocation and in developing procurement policies as well as in decision taking at the project level, including selection of the most suitable construction methods. Six case studies are included in this best practice to demonstrate the value added in and benefits of integrating risk management principles at the corporate and project levels. This best practice draws from and impacts upon the principles, procedures and methods outlined in a number of InfraGuide Decision Making and Investment Planning (DMIP) best practices, particularly: *Managing Infrastructure Assets* (InfraGuide, 2004), *Developing Levels of Service* (InfraGuide, 2002), *Investment Parameters for Municipal Infrastructure* (InfraGuide, 2004) and *Public Consultation* (InfraGuide, 2005).

1. General

1.1 Introduction

Municipal infrastructure is essential to a community's economic well-being and public safety. Given this dependency, a community should be aware of and manage the various risks that can adversely affect the performance of its infrastructure over time.

Risk is defined as the combination of the probability and severity of a potential circumstance that would negatively affect a municipality's ability to meet its objectives. Risk management is the collective assessment of risk and the actions taken to address risk.

By using a risk management approach, a community can rationally assess the potential risks to its infrastructure and then develop an appropriate course of action to control those risks. Risk management has the potential to minimize the cost to provide a healthy, safe, affordable, and publicly acceptable service. Risk management is only one component of an overall asset management strategy.

It has become widely accepted for communities to develop an asset management program to evaluate their infrastructure in many different ways, including risk management. In doing so, communities can incorporate their tolerance for risk into decisions to rehabilitate or replace existing infrastructure and make new investments. This document recommends the principles to incorporate risk management into an asset management strategy. Further information on parameters to consider when planning for municipal infrastructure investments can be found in the InfraGuide best practice: *Investment Parameters for Municipal Infrastructure* (InfraGuide, 2003).

1.2 Purpose and Scope

Programs designed to manage public infrastructure should include processes to understand and manage the risk that arises from infrastructure procurement, operation, and deferral of planned investments. There is a range of categories of risk that can prevent the infrastructure assets from delivering the desired levels of service to the public.

This best practice document covers the subject of risk management as it relates to municipal infrastructure. It is intended to outline risk management issues and concepts, and provide a basic process to manage risk to a municipality's assets. The document concludes with case studies that illustrate risk management experiences.

1.3 How to Use This Document

This document complements the other best practices that have been developed for decision-making and investment planning and is one of a number of practices developed by InfraGuide to assist communities deliver sustainable infrastructure. It is recommended that an individual best practice be read and understood in the context of other relevant best practices.

In this best practice, the subject of risk management for municipal infrastructure is discussed in the following sections:

Section 2: Rationale (An overview of risk management)

Section 3: Principles of Risk Management

Section 4: Applications and Limitations

Six case studies are included in the Appendices to outline situations where municipal organizations have experienced serious risk exposure due to inadequate identification and management of risk.

Risk management has the potential to minimize the cost to provide a healthy, safe, affordable, and publicly acceptable service.

1.4 Glossary

Asset Management — The combination of management, financial, economic, engineering, and other practices applied to physical assets with the objective of providing the required level of service in the most cost-effective manner.

Best Practices — State-of-the-art methodologies and technologies for planning, design, construction, management, assessment, maintenance, and rehabilitation that consider local economic, environmental, and social factors.

Capital Cost — Expenditures used to create new assets, rehabilitate, or replace existing assets or increase the performance of existing assets beyond their original design standards or service potential.

Decision Tree — A graphic representation of decisions and their possible consequences (including resource costs and risks) used to create a plan to reach a particular goal.

Indemnify — To compensate for a loss, in whole or in part, by payment, repair, or replacement.

Infrastructure — Refers to those physical basic installations and facilities such as potable water, storm and wastewater, municipal roads and sidewalks, and transit, on which the continuation or growth of a community depends

Levels of Service — Levels of service reflect the social and economic goals of the community and may include any of the following parameters:

- Safety
- Customer satisfaction
- Quality
- Quantity
- Capacity
- Reliability
- Responsiveness
- Environmental acceptability
- Availability
- Cost and affordability

Life Cycle Cost —Costs over the full life cycle of an asset, from planning, design, construction, acquisition, through operation, maintenance and rehabilitation to replacement or reconstruction and to disposal.

Life cycle costing — A method of expressing cost in which both capital costs and operations and maintenance costs that are considered in comparing different alternatives. “Present worth” is one way to express life cycle costs. The present worth represents the current investment that would have to be made at a specific discount (or interest) rate to pay for the initial and future cost of the works.

Maintenance — All actions necessary to retain an asset in as near as practicable to its original condition renewal.

Operation —The active process of using an asset to deliver service, which will consume resources such as manpower, energy, chemicals and materials.

Pareto Rule — A principle derived by Italian economist Vilfredo Pareto that is commonly referred to as the 80/20 rule. The principle is that a small number of causes or issues (20%) are responsible for a large percentage (80%) of effects. In the context of this best practice it suggests that 20% of the assets give rise to 80% of the risk. The principle when employed in management decision-making uses “Pareto Charts” to refine the actual percentages based on experience with the issues.

Probability — The likelihood of an event occurring.

Risk — The combination of the probability and impact severity of a particular circumstance that negatively impacts the ability of infrastructure assets to meet the objectives of the municipality.

Risk Assessment — The analysis of the severity of the potential loss and the probability that the loss will occur, leading to quantification of impacts.

Risk Management — The collective assessment of risks and management actions taken to control them.

Risk Transfer — Having another party accept responsibility to manage a defined risk.

2. Rationale

Background: The Concept of Risk as it Relates to Infrastructure Assets

Risk is the combination of the probability and impact severity of a particular circumstance that negatively impacts the ability of infrastructure assets to meet the objectives of the municipality. Risk management is the collective assessment of risks and management actions taken to control them. It is an essential part of an overall asset management program. Every public organization that owns, operates, or acts as the approving authority for infrastructure assets will be exposed to some degree of risk. There is not, and cannot, be a condition of "zero" risk.

Unforeseen risk will often result in unplanned expense and diversion of resources from planned programs. Risks must be understood, identified, quantified, analyzed, and managed. There are many categories of risk that will be identified in Section 3.1 of this best practice document. This document focuses on risk as an important element of an asset management program.

It is important to understand and document the organizational objectives of the public organization in terms of the service to be delivered to the customer or user of the infrastructure assets. These objectives should be derived for each individual organization, and are described in greater detail later in this document. If the objectives of the organization are not fully understood and documented, it is not possible to quantify the impact of a risk-hazard on the organization. It is therefore paramount that corporate or community goals and strategic alignment and mission objectives of a municipality do not function at cross purposes.

Organizational objectives have a broader *essential* application to the building of asset management programs, and assist to draft, test, and recommend level of service design standards and performance to be delivered by the assets. Organizational objectives must be understood to establish the levels of service that are to be delivered by the assets. The targets for asset condition and performance are directly dependent on the levels of service to be delivered, and the risk associated with the assets is directly related to the condition and performance of the assets. If a temporary loss of service in an area is acceptable, assets can be allowed to deteriorate to a point that represents high probability of failure.

As organizational objectives are derived, the tolerance of the organization for risk should be understood. This will require the categorization of risks and the generic understanding of acceptable levels of risk in a variety of circumstances.

Principles of risk management may be applied at every management level for the purpose of:

- Identifying corporate objectives;
- Determining a strategic/business plan;
- Identifying and evaluating risks;
- Avoiding or eliminating risks where practical; and
- Developing risk mitigation strategies compatible with the community's tolerance to exposure to undesirable outcomes. This may include contractually transferring risks (to some degree to other parties, where possible).

Risk is the combination of the probability and impact severity of a particular circumstance that negatively impacts the ability of infrastructure assets to meet the objectives of the municipality.

3. Principles of Risk Management

3.1 The Risk Management Process

The risk management process for a municipality can range from the simple to the complex depending on the size of its infrastructure portfolio, community needs, and financial resources. Whatever the approach, the risk management process has a logical, chronological sequence of steps, which are illustrated in Figure 3–1. The steps involved in risk management are described in the following sections of this document. Figure 3–1 describes this flow and indicates the section of this document where the process step is described.

3.1.1 Policy Review and Infrastructure Assessment

Overall Policy Review

To implement risk management as part of an asset management strategy, it is essential to develop policies that are understandable, affordable, and acceptable at all critical levels of management, and are supported or formally endorsed by the elected council. The risk management process begins with the review of the applicable municipal policies and standards relating to infrastructure and an assessment of the current physical condition and performance of its infrastructure. Policies will derive from the municipality's corporate objectives, and will include derivation of levels of service, design standards, and a clear understanding of what assets the municipality has responsibility for. The policy review will shape and govern how infrastructure risks will be managed. The review should focus on developing a thorough understanding of the service levels expected of a municipality's existing and future infrastructure. These service levels can include such parameters as reliability, environmental impact sustainability, affordability, and quantification of service. Further information about defining service levels can be found in the InfraGuide best practice: *Developing Levels of Service* (InfraGuide, 2003).

In addition to understanding the policies, design standards, and expected service levels, a municipality must understand, in quantifiable terms, the current physical condition and performance of its infrastructure. Depending on the size of a municipality's infrastructure inventory, the identification, recording and condition assessment can be a significant, though valuable, undertaking. In most cases, a municipality's infrastructure must be classified in some meaningful way, such as age (by decade), material, or condition to enable the risk management process to be effective. Further information on infrastructure asset management can be found in the InfraGuide best practice: *Managing Infrastructure Assets* (InfraGuide, 2004).

Setting Organizational Objectives

Defining and understanding overall objectives is essential to allow the measurement of the impacts of infrastructure failure or compromised performance. It is important that the objectives

Figure 3–1: The Risk Management Process

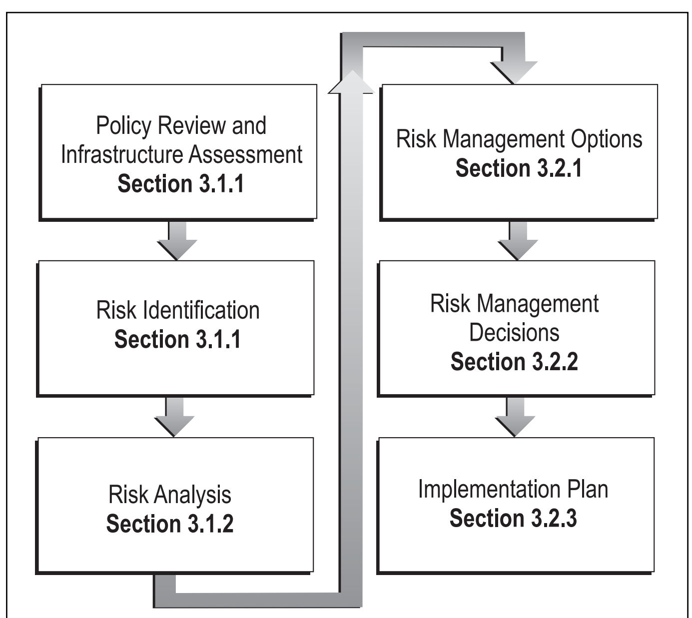

Figure 3–1
The Risk Management Process

The risk management process begins with the review of the applicable municipal policies and standards relating to infrastructure and an assessment of the current physical condition and performance of its infrastructure.

be developed and tested for feasibility, and affordability, and that they meet reasonable public expectations. It is desirable that the objectives be communicated to, and supported by, all levels of management. Ideally they should be understood and endorsed by Council. If not already existing in corporate and community plans, these objectives will be derived for each individual organization and in most cases will include, but not necessarily limited to, the following points, as they may assist in the development of organizational objectives.

- Levels of service, performance objectives and design standards for the assets that are practical, understandable, publicly acceptable, affordable, achievable, and measurable.
- Objectives to Deliver the Commitment to the Principles of Sustainability (financial, environmental, and social — see InfraGuide Sustainable Principles and Guidelines).
- Customer Service and Reliability objectives.
- Clear financial objectives, and a financial strategy to operate and proactively maintain and sustain the assets over their life cycle.
- Compliance with regulatory requirements for performance, reliability, health, safety and environment.

Design standards communicate the intent of an agency in terms of the desired performance and capacity of its infrastructure. They must correspond to the community objectives in terms of the environment, health and safety, and cost.

Setting Levels of Service and Design Standards

It is not possible to determine the necessary level of performance that must be prescribed by an asset management strategy if the authority responsible for the assets does not determine the level of service to be delivered by the assets. Drafting, testing, and establishing levels of service that are documented, publicly acceptable, affordable, measurable, and understandable is essential to the asset management program. This process requires an extended time frame requiring the input and support of all of the municipal stakeholders.

The process to establish levels of service is the subject of another best practice document: *Developing Levels of Service* (InfraGuide, 2003). Design standards communicate the intent of an agency in terms of the desired performance and capacity of its infrastructure. They must correspond to the community objectives in terms of the environment, health and safety, and cost. Design standards for new infrastructure should document required capacity and performance, and the circumstances within which the level of performance is expected. They can also provide for secondary systems to deal with infrequent high demands. An example of this would be the design of a storm water collection system to convey runoff from rainfall intensities with a 1:5 year statistical return period without surcharging. In more recently applied designs, this collection system is augmented with a major overland flow system capable of handling the runoff from major storms having a 1:100 year return period. This provides a cost-effective way to improve the protection of property and public safety at a relatively low incremental cost.

Design standards that incorporate the most durable materials and excellent construction practices may have a marginally higher initial capital cost while providing a lower life cycle cost, and an associated lower risk of compromised performance. Analysis that considers the incremental cost of increasing capacity beyond regulated standards, can be measured against the probability of an event that causes capacity problems. Designing redundancy into pipe networks to allow "looping" or redirection of service can be a legitimate strategy to address catastrophic failure of a critical line. Design standards should include consideration of ease of inspection and maintenance without extended service disruption.

Understanding the Assets

Risks arising from the operation of the assets cannot be assessed or managed if a policy is not in place to validate asset inventory and determine the general physical condition and performance of the assets. This requires a program to group the assets into representative network sections that are of similar age (by decade), material, and condition.

Critical elements in the network need to be considered separately for risk assessment due to their strategic importance. Put another way, assets need to be understood from both a corporate strategic perspective that is senior-directed and from a "bottom up" operational perspective. A good example of this approach is more explicitly described in InfraGuide best practice *Development of Water Distribution System Renewal Plan* (InfraGuide, 2003).

Appropriate management of risk will depend on the source of the risk. It is useful to identify categories of events, circumstances, and sources of risk that could impact assets in a manner that prevents the organizational objectives from being achieved. Risk can arise from different sources, both external and internal, as described in the following sections.

Categories of Risk

In the risk management field, there are thought to be five (5) general categories of risk. Within each of these categories, a municipality can identify the specific impacts that are applicable to its own infrastructure. These impacts may include financial, environmental, damage to reputation, and penalties from legal or non-compliance with regulations. Categories of risk are:

Events External to the Organization

1. Naturally-Occurring Events, such as fire, storms, floods, earthquakes, and lightning strikes. The timing of these types of events is unknown and uncontrollable but their probability and severity can, to some degree, be statistically predicted for some.
2. External impacts as a result of indirect consequences of *failure by an outside party*. Examples include power failure, material supply failure, spills, industrial discharges, unauthorized sewer downloads, labour strikes and traffic accidents.
3. External aggression, or deliberate acts of vandalism, and/or terrorism that results in destruction of critical assets and potential injury and loss of life.

Events Internal to the Organization

4. The physical deterioration or failure of assets. The condition of the assets and the deterioration to failure can be predicted and determined. This category of risk is the most predictable and manageable.
5. Operational risks arising from the manner in which the assets are designed, managed and operated to meet the organizational objectives. This category includes risks arising from design standards, management policies, operator behavior, and maintenance practices. This category of risk generates policies that clarify internal responsibility, and contractual procedures used to transfer responsibility, and some level of risk, to contractors and service providers.

Within each category, specific risks can be identified that may affect various parts of a municipality's infrastructure. An example of a specific risk in the category of Physical Deterioration, might be ground settlement causing a joint failure of an existing water main, failure of the roadway and storm water surcharging

This implementation step requires the organization to assess each of the five categories of risk and determine their applicability to the local circumstances that exist. Initial thinking should be done on appropriate criteria for risk analysis and risk forecasting for each category of risk. Any other categories of risk unique to the circumstances, or environment, that prevail in the asset location or organization should be similarly assessed.

Natural Events

Examples of naturally occurring events include earthquakes, severe weather, and pandemics. These kinds of events can be reasonably expected over the lifetime of the assets, but the timing and magnitude are unpredictable.

The appropriate level of service for the design of an asset can be based on its resistance to natural events. This applies to earthquake

Assets need to be understood from both a corporate strategic perspective that is senior-directed and from a "bottom up" operational perspective.

loading, wind resistance, snow loading, and rainfall volumes and intensities. Design standards are tested for affordability, and health and safety objectives.

Many communities are obligated to develop emergency response plans to be able to respond as promptly and effectively as possible when these natural events occur. In the case of British Columbia, the lead agency for emergency response for many types of events is the responsibility of the Province. In Ontario, each local municipality must develop and implement an emergency response plan.

Power failures, labour strife, or rail line spills, are examples where the triggering event is unpredictable making it difficult to calculate a probability. However, on the other side of the coin, the severity of the impacts they can impose can be understood and mitigated by certain management and operational practices.

Natural events can have health impacts on the community that relate to the operation of the infrastructure. A recent example is the concern for the spread of the West Nile Virus, by mosquitoes breeding in storm water in treatment ponds, ditches, catch basins and pipe networks. The proactive injection of larvicides into the appurtenances of the storm water collection system has been used successfully to control these kinds of risks. These kinds of strategies should be incorporated in contingency plans and emergency response plans and coordinated with city, provincial and federal health agencies. Information on emergency response planning can be obtained from the Office of Emergency Preparedness, Planning and Training at Health Canada at *<http://www.psepc-sppcc.gc.ca/>.*

External Events Caused by a Third Party

External impacts arising from a failure of service provided by an outside organization are, in many circumstances, similar to natural events. Power failures, labour strife, or rail line spills, are examples where the triggering event is unpredictable making it difficult to calculate a probability. However, on the other side of the coin, the severity of the impacts they can impose can be understood and mitigated by certain management and operational practices.

For example, investment in standby power generators at essential facilities protects the organization from certain ill effects from power failure. The August 13, 2003 blackout in the Northeastern U.S. and Ontario is an example of how communities can be affected by a widespread power outage. First Energy's East Lake plant shut down unexpectedly triggering a series of problems on its transmission line that triggered a cascade effect that caused the cross-border blackout. According to the Anderson Economic Group, the economic cost to government agencies due to overtime wages and emergency services was as high as US$100 million.

Developing a diversity of supply sources for critical materials needed to maintain critical services is also an important way to mitigate impacts caused by a third party. This may involve contingency plans for supply failure. Another example of a management approach is to develop contracts to minimize the likelihood and severity of labour stoppages. In many cases, agencies plan to provide for emergency support in situations that may threaten health and safety. All of these initiatives should of course be cost analyzed and the cost/benefit ratio developed based on the risk reduction achieved.

Risk from Aggression

In managing this category of risk, it is essential to know the strategic importance and criticality of each of the elements of the public infrastructure in the system.

Levels of security and protection can then be designed around various assets. Like any other risk management activity, the measures should be priced against the benefit of preventing negative effects. Obviously, high costs may be tolerable on the most strategically important assets, those that simply cannot be taken out of service, while elaborate security strategies may not be justifiable where assets are less critical or where prompt response is possible to redirect and restore service.

Redundancy designed into critical elements of the most strategically important assets becomes a valid issue for cost benefit analysis. There are a number of recently developed tools for the water and wastewater industries that support detailed, comprehensive vulnerability analyses to identify risks and management responses to reduce them. Emergency response plans are an essential part of risk management for all categories of risk but are particularly important for category 1 and 3 risk.

Aging Infrastructure and Related Deterioration

The potential for infrastructure failure or reduction in level of service can increase depending on age and condition. This risk will arise from the deterioration of assets. The risk begins from the day the assets are commissioned. This category of risk is the most predictable, and the easiest to manage effectively. However, it is also the easiest to overlook or defer, especially during times of scarce finances, when more immediate priorities can be found. This explains the current infrastructure deficit in Canada and other countries.

Risk management for this category of risk requires knowing the representative condition and the historic deterioration rates of the various groups of assets. Condition assessment identifying defects is critical to the management of risks arising out of the deterioration and possible failure of the assets. Every defect presents a hazard leading to potential for failure of the asset, or compromised performance. Knowing the present and projected condition of asset groups and determining their relative criticality will allow organizations to assess and manage risks in an objective and rational way.

Operational Risks

Risk of failure can be affected by asset design, construction and operating procedures. This category of risk offers great opportunities to minimize risk exposure through sound policies and management practices. However, low probability and high consequence from failure are most susceptible to complacency problems. The high consequence part is often forgotten in the equation.

Proactive condition and performance assessment and inspection of assets at regular intervals and operation protocols such as periodic valve and hydrant operations can reduce risk exposure. Preventative maintenance programs to reduce likelihood of failure or reduced performance are also necessary.

3.1.2 Risk Analysis

In the risk analysis stage, the identified risks are assessed in terms of the predictability and probability of an event occurring and affecting a municipality's infrastructure. Next, the potential impact or severity on the infrastructure and the affected objectives related to a particular risk occurring is analyzed. In addition to the scientific probability and severity analysis, an understanding of how stakeholders perceive risk is needed.[1] The perception of risk is often dependent on the needs, issues and concerns of stakeholders. The Canadian Standards Association recommend a comprehensive and systems approach, with particular emphasis on dialogue with stakeholders. It cannot be emphasized enough that stakeholders must be engaged early in any risk management process. If this is left until later, there is greater potential for conflict, and risk communication becomes ineffective when decisions already made have to be defended with stakeholders. Further information on public consultation and stakeholder involvement can be found in the InfraGuide best practice: *Public Consultation* (InfraGuide, 2005).

In terms of technical analysis of risk, a common approach is to define a range of possible outcomes to ensure that all have been captured and to standardize the outcomes enabling all of the stakeholders to participate in risk management discussions and decisions. In addition, a range of numerical values can be assigned to each of the defined outcomes. These values can be used to calculate a number for a particular risk, which can be compared relative to other risks affecting a municipality's infrastructure.

The perception of risk is often dependant on the needs, issues and concerns of stakeholders. The Canadian Standards Association recommend a comprehensive and systems approach, with particular emphasis on dialogue with stakeholders. It cannot be emphasized enough that stakeholders must be engaged early in any risk management process.

1. Risk Management: *Guideline for Decision-Makers*, Canadian Standards Association, CAN/CSA-Q850-97

3. Principles of Risk Management

3.1 The Risk Management Process

Table 3–1
Examples of Methodology for Source of Risk Analysis Category 4 — Physical Deterioration Risks

Table 3—2
Severity Analysis

This is particularly useful in identifying priority risk areas within the overall infrastructure portfolio.

This is an exercise in building a series of matrices, or charts, that describe the hazards and include severity and probability evaluations. A hazard is defined as something that has the potential to cause harm. This is distinct from risk, which combines the severity and probability of a hazard. In other words, hazard ignores probability. Examples are provided in the following sections in Tables 3–1, 3–2 and 3–3 to illustrate the methodology.

Source of Risk Analysis

Risk analysis begins by building a matrix for each category of risk that considers the source of the risk, the hazard that arises from the source, the impact of the hazard if it occurs and the organizational objective that is compromised if the hazard occurs. An example of a matrix for the category of risk arising from aging infrastructure and related deterioration is shown in Table 3–1.

Severity Analysis

When defects, hazards, and impacts are defined for a category or defined group of assets, the next step is to estimate the severity of each impact and the degree in each case to which organizational objectives would be compromised should the hazard occur.

Another matrix simplifies the explanation of severity analysis. (Table 3–2, below, is a simplified example.) This matrix takes into account severity levels from impacts that

Table 3–1: Examples of Methodology for Source of Risk Analysis Category 4 — Physical Deterioration Risks

Source of Risk (Defects)	Hazards	Potential Impacts	Organisational Objectives Compromised
Sewer-pipe longitudinal and transverse cracking	Structural failure — pipe collapse	■ Sewer backup ■ Basement flooding ■ Road closure ■ Service interruptions	■ Reliable customer service ■ Protect health and safety ■ Prevent property damage
Cast-iron water-main joint failure	Surface settling and loss of water	■ Service interruption and washouts ■ Excessive operating costs	■ Reliable customer service ■ Fire and health protection ■ Prevent property damage and personal injury ■ Provide efficient operation

Table 3–2: Severity Analysis

Organizational Objective	Severity Level			
	Catastrophic (10)	Critical (7)	Moderate (4)	Negligible (1)
Reliable Customer Service	Extensive sewer backups with large numbers of customers affected for extended period of time	Smaller number of customers affected by backups; some mitigation bypass pumping	No backups into basements, but bypass pumping into storm systems	Brief sewer surcharging; no backups; no overflows
Health and Safety	Death or serious injury among large numbers of customers or service workers	Severe injuries or health hazards among workers or customers	Minor injuries or illness among service workers only; no impact on customers	No injuries or illness among customers or service workers
Environmental Protection	Severe and irreversible contamination of environmentally sensitive areas	Significant but reversible environmental impacts on limited areas	Brief, easily reversible contamination of small areas; manageable cleanup costs	Impacts lasting less than 1 day; only very small areas involved

range from negligible to catastrophic, and weights them accordingly. For each category of assets, a distinct set of organizational objectives should be carefully thought out and severity levels established by thoughtful analysis of potential impacts. In practice the matrix will contain more than three organizational objectives. Users are encouraged to adapt their own categories and ratings to be sure that they are appropriately based on experience in the organization.

Probability Analysis

The last step in asset condition risk analysis involves probability related to the condition. How likely is a hazard to occur and produce the corresponding effects over a defined time period? The probability analysis should be customized for each category of assets to recognize the specific and detailed knowledge of the operating agency, particularly its tracking of history and frequency of failures in the delivery system.

In assigning values to probability levels, the framework illustrated in Table 3–3 can be applied when it is adapted to local circumstances. The appropriate period is critical in considering any risk because time is a major factor in the probability term. In other words, the likelihood of an event increases as the time period extends.

The relative frequency of probability can be shown as:

$$Pr(A) = m/N$$

N = the number of times the event repeats itself
m = the number of times the event A occurs in those
N repetitions

This defines Pr(A) well. As N becomes very large in principle, the ratio m/N becomes increasingly constant and therefore more predictable. Measures can be put in place. The quantification of the level of risk that prevails is a matter of multiplying probability and severity to reduce the frequency of these events.

Another way of saying this is with the probability calculation set out below. The accuracy of this depends on a well thought out or documented series of event possibilities:

$$P\text{ (event)} = \frac{\text{The Number of ways a specific event can be generated}}{\text{Total number of possible events}}$$

These calculations can be exploited in a variety of ways to come up with probabilities of practical value.

A higher than tolerable level of risk can occur even if the probability of the occurrence is low but the severity of impact high. Alternatively a high level of risk will also occur if the probability of the occurrence is high and the severity only low to moderate.

If severity and probability are estimated using the type of matrix analysis illustrated above, the two considerations can be used to compare the severity and probability to derive some form of "Index of Risk" as described in the section below.

A higher than tolerable level of risk can occur even if the probability of the occurrence is low but the severity of impact high. Alternatively a high level of risk will also occur if the probability of the occurrence is high and the severity only low to moderate.

Table 3–3: Application of Framework to Local Circumstances

Likelihood		Probability Level
Frequent	10	Will occur more than 4 times over next 2 to 5 years
Likely	8	Will occur 2 to 4 times over next 2 to 5 years
Occasional	6	Will occur once over next 2 to 5 years
Seldom	3	May occur once over next 2 to 5 years
Unlikely	1	Unlikely to occur over next 5 years

Figure 3–2
Example of a Method for Establishing a Asset Risk Index

3.2 Quantification of Risk Levels

The previous sections presented the categories of risk as well as a brief description of how risks are analyzed. This section will present a methodology to quantify risk levels.

Municipalities have a multitude of assets of various types and functions and a multitude of impacts on organizational objectives. Individual major assets, or groups of assets with similar attributes, in a network should be initially categorized as to their strategic importance, impact of failure on objectives, and vulnerability to any of the categories of risk previously presented.

Risk management then reduces to a process to determine for any event in any category of risk, the severity of the effects on the objectives and the probability of the event occurring. Severity and probability are used to define the level of risk, following which appropriate measures to control the risk to acceptable levels can be determined.

Severity and probability are used to define the level of risk, following which appropriate measures to control the risk to acceptable levels can be determined.

Matrices to determine severity and probability can be derived by judgement within the utility. It is possible to derive, in some cases subjectively, severity and probability levels for any event that can be contemplated in any category of risk.

There are a variety of matrices that are used to combine severity and probability to quantify risk levels. One large Canadian municipality simply multiplies severity levels by probability levels to establish a numerical index of risk.

Implementation requires building a meaningful, understandable relationship that combines probability and severity to produce an index that enables risk levels to be compared. Figure 3–2 provides an example chart describing a numerical index of risk (hereafter called an *Asset Risk Index* (ARI). Practitioners are encouraged to adapt their own categories and ratings from a table such as Figure 3–2 shown below to make sure the ratings make sense based on the particular experience of the municipality in question.

The scale of severity can be logarithmic if the probabilities and likelihoods are set up on exponential scales. Events producing an Asset Risk Index (ARI) outcome greater than the risk tolerance level should be the subject of a cost benefit analysis of actions to reduce the severity and/or probability levels. The above example was developed by CH2M HILL,

Figure 3–2: Example of a Method for Establishing a Asset Risk Index

Probability		Frequent		Likely		Occasional			Seldom		Unlikely
	Probability Level	10	9	8	7	6	5	4	3	2	1
Severity	Severity Level										
Catastrophic	10	100	77	60	47	36	28	22	17	13	10
	9	77	60	47	36	28	22	17	13	10	8
	8	60	47	36	28	22	17	13	10	8	6
Critical	7	47	36	28	22	17	13	10	8	6	5
	6	36	28	22	17	13	10	8	6	5	4
	5	28	22	17	13	10	8	6	5	4	3
Moderate	4	22	17	13	10	8	6	5	4	3	2
	3	17	13	10	8	6	5	4	3	2	2
	2	13	10	8	6	5	4	3	2	2	1
Negligible	1	10	8	6	5	4	3	2	2	1	1

in which the changes of grey tone from light grey to white and from white to dark grey represent the risk tolerance levels of an individual community. Different grey tone zones trigger different reactions: light grey—do nothing; white—prioritize a review; and dark grey—immediate action. While this model has been successfully applied, there are many other options that can be used to achieve the objective of quantifying one risk relative to another. However, any method used should provide an index that will respond to mitigation options and the risk reduction to be achieved and should enable the establishment of priorities.

3.2.1 Risk Management Options

When risks have been identified and quantified in some way, options to manage the risks must be considered and evaluated. There are five basic options. These are to avoid, abate, retain, transfer or share risks. In considering the options, the municipality will evaluate them in terms of criteria such as cost, availability, requirements, and general advantages and disadvantages.

Risk Avoidance

Risk avoidance means opting to avoid the risk, or not proceed with a specific task, activity or project associated a particular risk. For example, following the review of a proposal, a municipality determines that the commitment to a certain project outcome or service is associated with a risk that is not acceptable, and the project does not proceed. Risk avoidance is a business and policy decision, and sometimes can be very good strategy when the option is available. The cost of this option to the organization is not receiving the intended benefit of a proposed infrastructure project.

Risk Abatement

Risk abatement (mitigation) consists of a series of proactive steps that will prevent or minimize the effect of a hazard compromising the organizational objectives, resulting in a loss. These mitigation steps reduce the loss potential by reducing the probability and/or the severity of the hazard if it occurs. Risk mitigation is used in conjunction with a range of other risk management strategies. Examples related to the mitigation of asset deterioration include: improved regular proactive maintenance, better asset inspection, engaging only the most qualified contractors to build or rehabilitate the asset, and the choice of higher quality materials in building the asset. The cost of this option to the organization is the amount expended to undertake proactive steps, such as the following:

- Reduction or elimination of asset defects by rehabilitation or replacement.
- Improvements in operational practices and policies.
- Creating redundancy.
- Enhancing emergency response plans.
- Enhancing security measures.
- Revising procurement and contracting procedures.

The options then evolve to a greater level of detail for each group of assets, depending on their strategic importance, and the category of risk being reduced.

An example of this would be a sanitary sewer serving 3,000 homes which is determined to be under capacity resulting in a high probability of flooding with severe effects. Therefore this is a very high risk. Detailed options for replacement, diverting tributary area, or twinning with a new sewer can all be defined and priced and the risk reduction determined. A similar sewer having inadequate capacity serving three unpopulated warehouses gives a reduced severity and a lower risk. In fact, the lower risk may be deemed tolerable given the cost of abatement. A further example of an operating practice would be establishment of valve operation procedures associated with their routine maintenance to minimize damage to valves and minimize service disruption due to valve failure.

External risk from the occurrence of natural events is often mitigated by *asset redundancy*.

When risks have been identified and quantified in some way, options to manage the risks must be considered and evaluated. There are five basic options. These are to avoid, abate, retain, transfer or share risks.

Critical assets are defined as elements whereby public safety or essential services to critical customers could be seriously impacted by failure. This would include emergency access routes, as well as utility services to hospitals, 911 call centers, and emergency shelters.

This is the building of an additional asset to permit services to continue in the event of a single asset failure. Investment in asset redundancy is undertaken where it can be demonstrated as affordable and appropriate. This would likely be the case for particular infrastructure defined to be critical. Critical assets are defined as elements whereby public safety or essential services to critical customers could be seriously impacted by failure. This would include emergency access routes, as well as utility services to hospitals, 911 call centers, and emergency shelters.

Asset redundancy is also considered in cases of new infrastructure where a municipality considers investing in redundant capacity in order to avoid the risk of future high cost to accommodate changes in growth. In effect, this means investing in more capacity to allow for uncertainty in growth rate. Caution needs to be taken to ensure that there is an equitable division between the present user and future growth. Also, there have been failures arising from oversized sewers not meeting minimum velocity requirements due to insufficient flow.

Risk Retention

Risk retention may be applied when it is not possible or cost-effective to avoid, abate, or transfer the risk. For instance, if an evaluation of the economic loss exposure determines that the risk can be safely absorbed then it makes sense to retain the risk. Another consideration in retaining a risk is when the probability or severity of loss is so high that to transfer the risk would cost almost as much as the cost of the worst loss that could ever occur. In other words, if there is a high probability of loss, it may be best to retain the risk in lieu of transferring it.

Risk transfer

Risk transfer is shifting the risk burden to a third party, usually the private sector. This is done in several ways, but is usually done through conventional insurance as a risk transfer mechanism, or through the use of contract indemnification provisions. When transferring risk through contract mechanisms, it is a recognized good practice to assign the risk to the party that is best able to control and manage the risk at the least cost to the project. It is essential in any decision to transfer risk to attempt to derive a cost/benefit ratio for the risk transfer. For example, a contractor may build large contingency funding and/or insurance premiums into a tender if he must indemnify an asset owner for a risk that in his judgement has a high probability of occurring or a large financial impact if it does occur, especially where he has no ability to mitigate or control the risk The asset owner should do an independent probability/severity analysis for specific risks that might be transferred to a contractor, and determine if the benefit of indemnification represents good value for the cost of that indemnification under the contract. This consideration is particularly important for risks that may not be fully insurable or only insurable at a very high premium cost.

Sharing the Risk or Risk Allocation

Sharing the risk burden with third parties is usually based on a business decision when the cost of doing a project is too large and/or the benefits are shared by a number of organizations/parties and needs to spread the economic risks and benefits with another organization.

Risk Management Decisions

Each organization must determine its own tolerance for risk and derive the levels of risk that will stimulate actions to reduce the risk level.

Decisions on what management actions need to be taken to address risks are based on risk tolerance, cost, public policy, stakeholder concerns, and the importance of a particular infrastructure asset. Generally the decision process can be described as follows:

- Develop alternative solutions to eliminate or reduce the situation that creates the hazards;
- Analyze the cost of reducing or eliminating the risk; and
- Develop an action plan that has the best cost benefit ratio and is affordable considering the resources available.

It is appropriate to develop some policies that define the tolerance for risk in each category of assets, and for each group of assets within the categories. The strategic importance of the asset is critical to this implementation stage. A critical water supply line serving a huge population and critical facilities must be managed with a very low probability that the service will ever be compromised.

In any circumstance that exposes the organization to a high level of risk, cost effective decisions should be implemented that are affordable and manage risks to tolerable levels. It is a straightforward process to determine the cost of risk management. Table 3–4 indicates a few examples and determinable costs in each category of risk.

Table 3–4: Managing Risk in Decision Making

Category of Risk	Risk Management Options	Activities	Considerations
Naturally Occurring	Risk Reduction Risk Abatement Risk Retention	■ Increase asset performance/capacity ■ Add redundancy to Network ■ Enhance Emergency Response ■ Accept risk if combined probability and severity are low	■ Capital costs and operating costs
Physical Deterioration	Risk Reduction Risk Abatement Risk Transfer Risk Retention Risk Avoidance	■ Asset Rehabilitation ■ Asset replacement ■ Add redundancy ■ Institute inspection procedures ■ Privatize system ■ Add utility asset charge to account for repair/ replacement cost ■ Establish a policy of avoiding ownership (for example natural streams, or drainage swales)	
Non-performance	Risk Reduction Risk Abatement Risk Transfer Eliminate non-essential services	■ Enhance inspection and monitoring ■ Create redundancy ■ Revise contracting procedures ■ Optimize operations	■ Increased operating costs ■ Capital costs and operating impacts ■ Minor administrative costs
External Impacts: ■ Supplier interruptions ■ Labour dispute	Risk Reduction Risk Retention Risk Transfer Risk Abatement	■ Redundancy of supply ■ Select most reliable suppliers ■ Secure labour contracts ■ Selective contracting out ■ Non-essential services can be interupted without detrimental harm ■ Contract language with appropriate non-performance penalty ■ Investment in training or storage	■ Minimal incremental costs ■ May have minor added costs ■ Minor administrative costs and enhanced labour costs
Aggression: Vandalism and Terrorism	Risk Reduction Risk Abatement Risk Transfer Risk Retention	■ Security Enhancements ■ Redundancy within the network ■ Emergency preparedness plans ■ Contract out security ■ Insurance ■ Probability and severity too low to warrant actions	■ Operating costs ■ Capital costs ■ Enhanced operating costs Local agreements with major suppliers and contractors who will offer their resources in an emergency situation.

In any circumstance that exposes the organization to a high level of risk, cost effective decisions should be implemented that are affordable and manage risks to tolerable levels.

3.2.3 Implementation of a Risk Management Program

Monitoring the Program

When decisions are made to implement the risk management options with the best cost/benefit ratios, and to achieve tolerable risk levels, the entire risk management program and implementation of the action plan should be monitored continually and reviewed on an annual basis to verify the effectiveness of the investments. Questions that need to be addressed include the following:

- Have risk levels changed appropriately as expected?
- Has the cost of risk abatement been as expected?
- Were decisions made in accordance with policy?
- Does the policy still make sense?

The second half of the risk reduction analysis is more difficult and more subjective. For any risk reduction strategy it is necessary to quantify the benefit arising from the costs. It is therefore appropriate for any strategy to revisit the effects of the chosen mitigation option on both probability and severity related to the event that is being mitigated. When both probability and severity have been re-calculated, a new ARI can be determined and a judgement made of the value of the risk management costs.

It is appropriate for any strategy to revisit the effects of the chosen mitigation option on both probability and severity related to the event that is being mitigated.

In building a program of sustainable asset management that incorporates risk management as one of the key determinants for prioritization of actions, a few key principles are critical:

- Understand the assets; incorporate them into groups of similar age, condition and performance.
- Determine the strategic importance of each asset group, and of very critical individual assets within the group. Generally speaking the most critical and important assets present the greatest severity of impact when analyzed.

If the assets have been proactively maintained over the life of the assets, it will be possible to determine the small percentage of critical assets that represent the greatest exposure to risk. By determining the ARI for each group of assets and for the most strategically important assets within each group, it is possible to determine that most of the exposure to risk comes from a small percentage of the asset inventory. The Pareto rule that suggests 80% of the risk will arise from 20% of the assets has some application here, though Pareto charts can be built to refine the 80/20 ratio to real scenarios for each asset inventory.

Implementing Guidelines to Transfer Risk

Municipal organizations customarily contract out design and construction services, and increasingly, are considering contracting utility or other types of operations to private sector service providers. This decision may offer cost advantages and leverages a greater production capacity over the option to engage the municipality's own forces. Contracting also offers the opportunity to transfer risk to a third party.

The "hold harmless" clause is a contract provision that transfers liability from one party to another, an agreement that one party will assume the other's liability arising under or because of the contract. Such clauses are frequently found in typical municipal leases, construction contracts, and easement agreements. There are three major types of hold harmless clauses.

- The clarification of liability defines how the parties will each assume their own legal responsibility or will make only a small or reasonable transfer of responsibility from one party to the other.
- The moderate transfer of liability occurs when one party assumes all legal liability except for the negligence of the other (this is considered the standard agreement).
- The most extreme transfer of liability occurs when one party assumes all legal liability regardless of who is at fault or negligent.

In contracting out construction, or service delivery to the private sector, there is a popular tendency to draft contracts that are intended to have the contractor assume all risks with no limitation, and hold the municipality or utility harmless. This is an understandable approach given the time and effort that may be needed to quantify and allocate the various types of risk, and the desire to simplify contracts. Proper indemnification and insurance language in leases, purchase agreements, service agreements, and contracts enable public entities to protect themselves from unnecessary exposure to risk and liability, particularly when the public entity does not have direct control over the activities of a third-party service provider. Municipalities are obligated to shift the legal and financial responsibility for losses or potential losses caused by the actions of a third party to the third party, whenever reasonably possible. This transfer of risk may occur through a variety of means including, appropriate language in leases, purchase and service agreements, and contracts. The transfer of risk is made formally, in writing and may include indemnification agreements, insurance requirements, and required provision of certificates of insurance (with the municipality named as an "Additional Insured").

However, this risk transfer from a public agency to a private contractor comes at a price, and unlimited liability may be either unaffordable or impractical to achieve. There may not even be a market for this kind of risk transfer, or the market may be severely restricted by the small number of private sector firms that are willing to accept terms of unlimited liability. Even the largest contractors and insurers have finite assets.

Losses from a single occurrence may be self-assumed in this manner, provided that consideration is given to all ramifications of the occurrence in its various aspects, including direct property damage, loss of use, additional expenses to continue operations, and liability to employees and others. Taking into account insurance premiums, anticipated losses, services provided or purchased, can optimize the level of self-retention of risk.

Many public utilities and municipalities have chosen to build self-insurance reserve funds that earn interest, reduce premiums, and protect against all but the most disastrous circumstances. To attempt to assign unlimited liability to the contractor or service provider is impractical and cannot succeed in practice.

The above discussion focused on risks of economic loss. When considering transferring risks, impacts on other objectives (such as, public perception and confidence in the organization, customer service, environmental protection and other tangible and intangible objectives taken into account.

Joint and several liabilities is a major issue in some provinces. This intent of introducing such a clause in contracts and agreements is to ensure that all parties to the contract share their portion of liability. This becomes particularly important when major developments take place. Such developments will involve the developer, architect, engineers and contractors. Municipalities must also be involved in zoning, permit and inspection services. All participants in these projects have their professional roles to play and legal duties to perform. Liability arises where there is a claim for damages arising out of an alleged failed duty. Often times the developer or contractor is no longer in business and the municipality assumes the lion's share where payment is ordered. Nevertheless, up to this point, joint and several responsibilities clearly have a role to play in risk transfer.

Municipalities are obligated to shift the legal and financial responsibility for losses or potential losses caused by the actions of a third party to the third party, whenever reasonably possible.

3.2.4 Self-Insurance Reserve

A self-insurance reserve fund is a valuable risk management tool. Most municipalities will receive claims against them for various alleged failed duties and responsibilities. An assessment of the success or failure to defend such a claim (including legal costs of doing so) and associated settlement costs will either have been made by an adjuster appointed by the municipality's liability insurer or directly by the municipality, where a large self-insured retention is applicable. An amount should be put aside either a) as a total estimated settlement amount if under the self-insured retention level or b) the total amount of self-insured retention if the claim is anticipated to settle at over this amount. As municipalities operate with tight annual budgetary restraints, to casually put aside public funds is not generally feasible. However, most sizable claims against a municipality will take in excess of a year to settle so advance 'warning' is given for the future year or years and these amounts can be transferred to the self-insurance reserve fund.

Additionally, a reserve fund serves to accommodate other unforeseen situations. For example no one could have forecast the September 11 World Trade Centre horror or its impact on the insurance market. Apart from the unnecessary loss of life, the economic impact, at the very least, could be described as dramatic. From the liability insurance perspective, premiums in most municipalities rose by as high as sixty percent. How was this to be funded?

On a more local level, some provinces have a relatively high probability of experiencing major events such as earthquakes. For example British Columbia experiences an average of 800 earthquakes each year—albeit most in the northern offshore island areas that are less inhabited. Nevertheless, it is generally understood (and mathematically supported by a 10 percent probability of a seismic 7 event occurring within the next 20 years) that such an event will have a catastrophic impact on any built-up area. Most risk transfer insurance policies have a large deductible, calculated not only as a fixed dollar amount but also a percentage of the amount claimed. It will take considerable sums of money to fully reestablish a municipality after such a loss. Self-insurance reserve funds will obviously help with this.

These are some of the operational risks that support establishing and maintaining a self-insurance reserve fund. Of course it should also be remembered that such a reserve is interest bearing, thus increasing the amount available to cover major losses.

4. Applications and Limitations

4.1 Applications

The best practices recommended in this document are examples of a very broad range of risk management practices that exist across the industry. Those chosen for inclusion in this document are thought to be most applicable to the management of risk arising from the design, construction, operation, and rehabilitation of infrastructure assets which support the provision of municipal services in transportation, potable water, wastewater and stormwater.

Obviously the risk management practices adopted will depend on the characteristics of the individual municipality, particularly the extent of its infrastructure inventory and the sophistication of its condition assessment technology. The best practices for a very small town will not be the same as those adopted in a large urban city, though the principles may be the same for both applications.

A risk management practice for infrastructure assets should be coordinated with, and preferably be an integral part of, an overall risk management program for all categories of risk to which the municipality is exposed. A consistent approach to the development and understanding of risk tolerance in individual municipalities will bear on the application of the best practices in this document.

4.2 Limitations

The unilateral transfer of unlimited liability to transfer all risks is not recommended as a sound business practice. The contractors insurance, and margin to assume risk may be more costly to the municipality than the acceptance of certain levels of risk that the public agency could share or continue to assume. At the very least the municipality could attempt to reasonably determine the cost of "hold harmless" agreements against the benefit to the agency. A more appropriate policy would be to retain those risks that can be self-assumed from current resources without seriously affecting the financial viability of the organization, if this is the most economically practical means of meeting such obligations.

If the risk is of a catastrophic nature, or beyond the capacity of the organization to absorb, then insurance can be considered. The procurement of insurance should be limited to availability of coverage at reasonable cost, and be subject to the practicality of adopting programs of self-insurance, or self-assumption, in whole or in part, consistent with the probable frequency, severity and impact of losses on the financial stability of the municipality.

In adopting risk management practices related to infrastructure, the individual characteristics of the municipality must be taken into account. It is essential to begin the process by establishing organizational objectives that will vary over a wide range for municipal organizations. They will all have infrastructure of varying age and stages in the life cycle. They will all place different, somewhat subjective, strategic importance on various asset elements, and each will have varying tolerance for risk. At a minimum, the best practices in this document should assist in a better understanding of risk and provide guidance in managing risk to tolerable and understandable levels.

No risk management practice can produce zero risk. The principles in this best practice document should assist in understanding levels of risk and documenting a logical program that manages the levels of risk that the individual organization can tolerate.

Limitations arise in risk management programs based on the resources available and the affordability of risk reduction options.

A consistent approach to the development and understanding of risk tolerance in individual municipalities will bear on the application of the best practices in this document.

Appendix A: Case Studies

Introduction to Case Studies

Presented here are six cases, which describe and demonstrate different aspects of risk management as presented in this document. Case studies were selected to illustrate situations that have revealed unintended consequences or expose relatively unique situations either at corporate (cases 1–4) or project (cases 5–6) level.

Case 1: Procurement of a Utility Operator—Lake Huron and Elgin Area Primary Water System Joint Boards of Management

The Lake Huron and Elgin Area Primary Water System Joint Boards of Management approved a competitive process for the future operation and maintenance of the water utility. When proposals were received, one of the proponents was disqualified because they failed to comply with the indemnification provision in the contract. This clause required the operator to provide an indemnification to be essentially unlimited, extending to a parent company. The company indicated that it was impossible for them to comply with the indemnity provision due to conditions imposed on them by their parent company and as a result were disqualified.

This is a case where the Regional authority wanted to make sure that the contractor did not use limitations to remove it from any obligations arising from claims or damages. What they did was to attempt to transfer all related risk to the private owner. The magnitude of that risk, given that it involved the supply and delivery of drinking water, was potentially so large that the indemnity needed to be guaranteed by the parent company. With no defined limit, the parent company could not quantify or insure the risk it was taking on and simply did not agree to comply with the condition.

Virtually any public body seeking assistance from the private sector requests the private sector assume responsibility for its actions and indemnify the public body in some form. Engineering and construction bonds and an array of insurance requirements are the more common examples of this. Most of these agreements have minimum levels set for liability insurance but they must all indemnify the municipality. In this case, the cost of the risk can be priced readily by the purchase of available insurance products. When looking to transfer undefined risk to the private sector, pricing the risk according to insurance premiums is not possible—and the private contractor needs to evaluate and price the risk himself or herself. Many firms are not suited to doing this and will need to report potential liability in their accounting practices and impose financial limits set by their shareholders.

The approach taken by the London authority is clearly understandable given the potential result on the public's health by a failure of the operator to perform.

However, the result is to either restrict the market place for qualified bidders, or higher prices than what the authority is willing to pay. Therefore, an alternative course of action can be considered. Experience with Public-Private-Partnerships has demonstrated that what the goal is not risk transfer but the effective management of risk. This requires a more explicit analysis of risk than is traditionally done for municipal procurement of services.

The authority could determine the approximate probability and severity of a range of failure scenarios and then apply an appropriate cost of risk mitigation, avoidance or transfer. For more common types of contracts where the degree of risk is more easily quantifiable, there are well-established mechanisms to ensure the municipality is reasonably protected and can immediately rectify problems if the contractor fails to respond. The earlier mentioned insurance and bonds coupled with things like irrevocable letters of credit that the municipality can draw funds from are common examples. For less common and more uncertain types of contracts, a specific analysis needs to be done.

For the less quantifiable risks, such as the operation of a water utility, the municipality or government could transfer a specified minimum amount of liability that the contractor would need to assume as part of their operations. This would be sufficient to avoid the authority having to deal with frequent public service issues, and the more common and frequent claims and damages. Many types of risk could be readily mitigated through contractual terms and performance monitoring. Except in cases of gross negligence, events that exceed this amount could then be self-insured by the authority.

Self-insurance against more catastrophic risk could be addressed through dedicated contingency funds. Landfill sites that are in the private sector have contingency funds for catastrophes set up where the users of the site through a portion of the tipping fees provide a pool of money to rectify problems. Most are site specific but they could be pooled and accumulated and used to rectify environmental damage. A similar pool of funds derived from a minor raw water withdrawal fee, or assimilation fee in the case of wastewater may facilitate the accumulation of funds to offset potential loss from low probability catastrophic events regardless of the operator.

Unlimited liability guaranteeing payment under any circumstance cannot be adequately addressed in the private market place and is difficult to put in place in an operations contract. Successful municipal contracts require a clear definition of how the risk and cost is to be shared. Often contracts are developed without the time to do an acceptable analysis of risk and must impose a greater transfer than the authority would otherwise being willing to pay for.

Case 2: Water Damage to Buildings — Greater Vancouver Region

Beginning in the mid 1990s, widespread and extensive water damage was found on numerous buildings in Southwestern British Columbia. The “leaky condo syndrome” as it is now commonly known involved the catastrophic failure of the building envelope allowing water to enter the envelope leading to rot and decay. This has affected condominiums, detached homes, schools and hospitals. The Barrett Commission, initiated in 1998 to make recommendations concerning the quality of condominium construction, estimated that the total cost for re-mediation is between $750 and $800 Million with each building averaging $750,000.

Although the affected buildings in the majority of cases were not municipal assets, Municipalities became involved in claims made by homeowners seeking restitution of damages. Municipalities provide inspection of buildings for compliance to building permits and building codes not for quality control of design and construction decisions. Improper permitting and inspection and failures to ensure compliance with the building bylaws and building code by individual municipal authorities have been alleged to having contributed to the building envelope failure problem. Typical allegations against municipalities in claims arising from building envelope failures include:

- Claims for breach of the duty of care to use reasonable skill and care in performing inspections and issuing permits;
- Negligent failure to ensure compliance with the Building Code and local bylaws;
- Negligent failure to ensure the habitability and Building Code compliance before issuing occupancy permits.

Typically the municipal inspector visits the construction site, on average, five times, and spends approximately 3–5 days. The number and nature of building inspections will vary among municipalities, based on the direction provided by City Councils and the complexity of the project. However, in general, most municipalities carry out, some or all, of the following field inspections:

- Formwork — to inspect the foundation formwork before any concrete is poured.
- Sheathing — to inspect the exterior wood sheathing and window installation.
- Framing — to inspect, as part of the framing, the application of building paper, flashing, stucco wire, and stucco stops.
- Insulation — to inspect the insulation and vapour barrier.
- Plumbing and wiring inspections.
- Final — to inspect the finished building, including caulking and sealant.

According to the Barrett Commission, the role of the municipal government is widely misunderstood and part of this is due to the fact that municipalities have not communicated why inspections are done and what their role is. It is the role of the municipality to enforce the standard of the applicable Building Code, which is established to protect the health and safety of the occupant, not to guarantee the quality of construction. The building inspection, by necessity, has to be an audit function with municipal inspectors relying on a sample of reviews at particular stages in construction to find out if the building is in compliance with building code.

Municipalities can be liable on a "joint and several" basis, for inspection activity that has not been properly carried out. In cases where there remains no developer due to bankruptcy, or an architect or engineer with "deep pockets", a municipality could be held financially responsible for all the costs related to a successful judgment. The Barrett Commission found the joint and several liability of a municipality to be onerous and recommended removing this from the municipal act in favour of proportionate liability.

The Barrett Commission report recommends, "*That municipal councils review their building permit process with a view to enhancing the inspection of work, related to an effective building envelope, and that inspectors become more conversant with the role and effectiveness of building science issues related to the building envelope.*"

The faulty condominium construction problem is really a failure of the market to correctly reflect the quality of construction. This is a case where municipalities did not foresee the extent of exposure they may have to the condominium building failures. Although a new home warranty was in place, it did not provide adequate coverage for the resulting widespread damage.

Municipal inspectors are viewed by the homeowner as being in a position of protecting the public against the effects of non-compliant construction and poor workmanship. However, municipalities view themselves as providing inspection services for code compliance only. The developer, architect and engineer remain responsible for the quality of construction.

When a claim is made and there remains no other solvent player remaining, the courts turn to the municipal government for the full restitution regardless of the proportionate share. With the knowledge of this risk at hand, municipalities could probably temper this exposure through:

- Information to homeowners about the role of the municipal inspector in assessing building quality as opposed to confirming compliance with Building Code for health and safety issues only;
- Investment in Municipal Inspectors towards being more aware of common construction and materials quality issues;
- Maintaining the policy of not doing inspection for building quality. Instead, the municipality could opt to pressuring the Building industry and the provincial government to put in place a mandatory warranty program to check and confirm construction for building quality, and do their part to educate and advise consumers.

Case 3: Acceptance of New Infrastructure Standards by the City of Surrey—East Clayton Neighbourhood Concept Plan

In 2001, The City of Surrey adopted the East Clayton Neighbourhood Concept Plan. This plan covered an area of about 250 hectares and outlined the servicing, land use, densities, and road network for a new community within Surrey. Surrey is the largest municipality in the Greater Vancouver Region with a population of 360,000 and a land area extending from the Fraser River to the US border. It is a fast growing community within one of the fastest growing urban areas in Canada.

The East Clayton community was envisioned as a sustainable community planned from the very beginning to reflect principles of a sustainable community. These principles ranged from mixture of housing types, pedestrian friendly neighbourhood, narrower streets, and promotion of natural drainage systems to reduce the impact on natural streams. Council approved the application of the principles to the development of the plan in 1996 and an extensive planning effort to define the community and its services was underway.

It was quickly determined that the drainage servicing for the East Clayton area was constrained by the negative impact of increased runoff on agricultural lowlands below the urbanized areas, and the potential negative impact of increased impervious area on valuable salmon habitat, for which Surrey has a rich heritage. Therefore, the storm drainage servicing required the implementation of alternative servicing standards to promote infiltration, reduce direct runoff, and control the impact of impervious surfaces. This is not a unique situation in the lower mainland and many agencies and industry representatives became interested in how the East Clayton development project would deal with this difficult issue. Could new storm drainage standards be applied to East Clayton that could be promoted to deal with the same issue in other areas?

The East Clayton plan became known as the Headwaters Project intended to demonstrate an example of a sustainable urban community on the ground. Funding support was received from the Real Estate Foundation of BC, Environment Canada, the BC Ministry of Municipal Affairs, BC Ministry of Agriculture, CMHC and many others.

Implementing new drainage servicing standards to a large new community introduced a potentially, significant risk to the City of Surrey. Firstly, many of the innovations being promoted had not been applied with sufficient site-specific experience. Secondly, the City management was of the opinion that the municipality was taking on too high a risk by accepting alternative standards from developers without some kind of guarantee that if the systems failed to perform that the municipality was adequately protected, and that some recourse was available to rectify any defects.

Although the plan was approved by City council in 2001 with some conditions, there was great difficulty in finding a way to pilot new standards without the municipality taking on an unacceptable level of risk. The approval of the concept plan included a provision that the initial infiltration systems for the initial development sites would be monitored and the results confirmed before standards could be adopted elsewhere. Also, grants were received to pay the additional cost of infrastructure to account for the possibility that the infiltration system would fail to perform. These were reasonable and understandable steps to take in view of the uncertainty involved.

Municipalities are increasingly adopting sustainable development principles as a matter of policy in their growth plans. However, there remains a significant hurdle to overcome in terms of promoting innovation in developing, and actually implementing new technology to advance these policies into practice. For East Clayton, despite tremendous policy advances towards more sustainable community design, it remained difficult for the City to ultimately take responsibility for the approval for the new infrastructure design. Instead, a more rigorous and collective risk assessment of the system design would likely have more clearly demonstrated the probability and impact of failure to management and developers, and a more efficient decision could have been made in terms of the design and acceptance of the new standard.

Proposed innovation technologies could also be directed to the Canadian Infrastructure Technology Assessment Centre (CITAC) at the National Research Council Canada in Ottawa. To reduce the risks and uncertainty of trying a new technology, CITAC offers an objective third party technical assessment of new innovative technologies that have not yet been made into standards. Paid for by the manufacturer/proponent the CITAC assessment develops a testing methodology and performance criteria to determine the suitability of the technology for its intended use. The evaluation involves the determination of the technical issues and concerns from the municipal and provincial owners and operators of the infrastructure systems and developing lab and field evaluation protocols to demonstrate how the technology will perform in response to those issues. The evaluation looks at constructability, functional performance, quality control, maintenance, safety and environmental issues. In the end a final CITAC Evaluation Report will include a description of the technology, CITAC's expert opinion on the usage and any limitations of the technology and the performance results. CITAC reports are freely available at *<http://irc.nrc-cnrc.gc.ca/ccmc/citac_intro_e.shtml>.*

Case 4: City of Edmonton — Implementation of a Risk Model To Minimize Failures and Determine Strategic Investment

Many Canadian cities, like Edmonton, have limited revenues to address aging infrastructure. In response to this situation, Edmonton has undertaken the development and implementation of innovative infrastructure management tools and processes. The purpose of the tools and processes are to address the 'infrastructure gap', the funding required to address infrastructure needs and the funding available to do so. The most recent long range financial plan shows that more than $1.5 billion will be required over the next ten years just to address the existing needs, including 'backlog' of projects and deferred rehabilitation. The risk assessment model is a strategic tool currently in development that has shown promise in providing a quantitative method to measure the risk of underfunding and/or not reinvesting in the existing infrastructure.

Since 2003, the City of Edmonton has used this risk assessment model (based on a combination of macro lifecycle analysis and standard risk analysis modeling) to identify which infrastructure areas are most in need, and the time and amount the funding needed. The risk assessment distinguished the City's most "critical" assets (where failure is presently occurring or imminent) and in doing so, provided insight into infrastructure areas in which investment should take place immediately to minimize failure and corresponding impacts. The approach can also be used to develop funding strategies. At the same time, the City is able to identify the investment needed to attain various levels of service.

The challenge was to develop a uniform risk model that dealt with all types of assets. In 2002, the City of Edmonton began the process of rating existing infrastructure in terms of physical condition, demand/capacity and functionality to compare disparate infrastructure assets. This standardized rating system provided a strategic perspective of the state and condition of the City's infrastructure and also provided one level of input into the risk assessment model.

One of the first steps in the development of the complex risk model was to examine infrastructure assets owned and/or operated by particular infrastructure areas and then classify these assets into groups with similar performance characteristics. Staff with expertise and working knowledge specific to those areas developed deterioration curves. These curves were used to reflect and model current conditions, the natural aging process, the actual use and performance history as well as the rehabilitation strategy applicable to that asset.

Risk associated with a given infrastructure element was then measured using a number of indicators including; portion of assets deemed to be critical (i.e. expected to fail), impact of failure of an asset, expected mode of failure, overall condition, portion of the asset in poor condition, condition severity, and others. Impacts of asset failures were measured in five dimensions consistent with the organization's values described in the City of Edmonton's Municipal Development Plan. These areas of impacts are safety and public health, growth, environment, preservation of the infrastructure and services to people. In accumulating the overall impact of an asset's failure to the organization, the five areas of impact were weighted based on their significance as determined by an internal committee comprised of high-level managers (Infrastructure Management Committee). As a final step, a "severity" indicator (an analytical combination of expected assets in critical condition, and the impacts of failure of those assets) was estimated for each asset group. This represents the level of exposure to risk the City faces as a result of the asset's condition.

Sidewalks are one of the assets listed under the infrastructure area referred to as 'Road Right-of-Way" and can be used as an example to demonstrate a high level perspective of the risk modeling process. In 2002, the sidewalk inventory consisted of over 3,600 kilometres with a replacement value of $550 million and is anticipated to increase to over 4,400 kilometres in 10 years time. Based upon the standardized 5-point rating system, approximately 14% of the sidewalks in 2002 were in D (poor) and F (very poor) condition. Using the deterioration curves and forecasted rehabilitation funding, the assets in D and F condition in five and ten years timeframes increased to 19% and 20% respectively. Theoretically, not every asset in D or F condition will fail and mathematical probabilities are used to determine the portion of assets deemed to be 'critical'. The 'critical' assets are expressed as a dollar value and this increased from $5.4 million to $7.0 million over five years and to $8.1 million over ten years.

The impact values, referred to in Section 3.2 of this best practice as risk indices, are defined by a scale ranging from negligible (1) to disastrous (1000). The impact of failure of sidewalks does not generally involve multiple deaths or injuries, long-term (decades) impact, nor long-term disruption to the organization and the impacts as determined by experienced practitioners rated very low on the impact scale. A summation of the product of the impact values and the likelihood of that failure occurring provides an overall impact value. In addition, the expected number of units failing is calculated using a Poisson distribution. Using all of these factors, a risk severity for an asset is calculated and mapped on an exponential scale of 1 to 1000. The risk severity for sidewalks, using 2002 data, was determined to be 204. After five years, the severity increased to 251 and to 281 after ten years. Because the severity values are exponential, even a small increase is significant. A graph of severity versus replacement values was plotted for 80% of the City of Edmonton assets and any assets with a severity of over 200 were determined to be in a higher risk category and required further investigation. This would indicate that the proposed rehabilitation funding for sidewalks over the next ten years may be inadequate to maintain sidewalks in an acceptable condition and potentially poses an unacceptable risk.

The results of the risk model were validated through a comparison with the results from a separate 18-month study of the City of Edmonton sidewalks performed by Dr. Ralph Haas from the University of Waterloo. Dr. Haas and his colleagues developed a life cycle investment strategy for the City of Edmonton sidewalks and analyzed over 30 years of detailed records. The results from the detailed analysis compared favorably to the results of the "macro-level" risk model developed through a combination of subjective estimates and the newly developed theoretical components of the process. In effect, the University of Waterloo study confirmed the validity of the risk assessment of the City.

To date, the risk assessment model has only been applied to the physical condition component of the assets and specifically addressed the risk associated with the physical deterioration of the infrastructure. Preliminary results indicate that problems are starting to emerge at the "local neighborhood level" (i.e. residential roads, sidewalks, residential light poles, local sanitary sewers, service connections, etc.) and in the recreational and emergency response assets (i.e. pools, arenas, ambulance, fire stations, etc.). The risk analysis determined the total amount of funding, over and above the funding already dedicated to rehabilitation, required to bring those assets deemed critical now, or within the next 10 years, to a manageable level. It was also determined that a significant amount of funding would be required just to keep all the assets at a minimum average condition.

The next phase of risk assessment modeling, to be completed by the end of 2005, is to evaluate risk in the demand/capacity and functionality areas. This will address such issues as the ability of assets to meet service and program delivery needs. The final product of the risk analysis will be the integration of the asset classifications to construct a tool to assist decision makers in the identification of priority areas and the optimization of investments.

Case 5: City of Ottawa — The Construction of the Lynwood Collector Sewer and the Impacts on the Surrounding Community

In the mid-1970s, it became necessary to construct a major sanitary sewer collector in the western region of the city of Ottawa. This sewer had a diameter of approximately 2.5 meters and a depth to invert of approximately 16 meters.

Because of soil conditions (sensitive soft clay) near the surface, it was felt that tunneling was the lowest cost option for construction. The actual tunneling operation however was in a layer of permeable granular materials below the soft clay and well below the water table. It was the original intent to do minimal de-watering in the immediate area of tunneling and build the concrete tunnel structure under compressed air.

The successful contractor however claimed to substantiate an alternative technique to draw the water table down temporarily using very high volume deep wells allowing the tunnel to be constructed in relatively dry conditions. It was felt that the short term de-watering would not produce damaging vertical movements in the soils around and above the tunnel. This recommendation proved later to be incorrect and led to disastrous results.

The water table was lowered several meters by massive pumping and the tunnel was constructed. Following the construction, major surface settlements occurred. The settlements produced widespread massive damage from settlement cracking to hundreds of homes in the areas adjacent to the sewer alignment, with resulting long term litigation and ultimate settlement of damage claims by the (Regional) municipality, the contractors and the engineers. The cause of the settlement was determined to be the drying of the clay zone above the granular zone, and the volume reduction in the granular zone itself. In the long term the water table did not return to its original level when measured some 10 years later.

The disastrous result was produced by an incorrect assessment of the risks arising from the proposed construction technique. Both the probability and severity of settlements arising from the de-watering operation were underestimated. The assumption that the water table would quickly return to its original level proved to be false. Testing of assumptions and potential uncertainty would have given a greater understanding of the risk. A higher cost construction method with much less de-watering would have produced a much lower overall project cost. Instead the result was widespread dissatisfaction of the homeowners, and lengthy and costly litigation that lasted for over a decade.

Case 6: City of Edmonton — The Design and Construction of the 23rd Avenue Storage Tunnel for Interchange Storm Drainage[2]

As a result of the existing congestion, excessive delays, safety concerns and access management issues, and in combination with a projected increase in traffic demand along the Calgary Trail/Gateway Boulevard corridor, the 23rd Avenue intersection has been identified as a priority for a grade-separated interchange. A storage tunnel has been recommended in the 23 Avenue Interchange Concept Planning Study for the purpose of stormwater management and the Design and Construction Section of Drainage Services was commissioned to undertake the project. This project will be carried out in a design-build format and, due to time constraints, the tunnel will be constructed by a fast track construction method. The construction will commence at the conclusion of the preliminary design and detailed design will be carried out at the same time as construction.

Previous geotechnical investigations and analysis for the proposed area of the storage tunnel indicated the presence of a sand filled pre-glacial channel that is not conducive to conventional tunneling techniques. Therefore, in accordance with the ISO 9001 system procedures of the Design and Construction Section, a formal risk assessment was conducted to reduce the overall risk to Drainage Services through the identification and management of the risks.

The first risk analysis workshop was organized to identify the risk factors specific to this tunnel project. Risk factors relevant to all the technically feasible alternatives were examined and five credible alternatives were screened for further analysis after this workshop. The five alternatives were:

- Alternative 1: Shallow vertical alignment using Earth Pressure Balance (EPB) machine.
- Alternative 4a: Shallow vertical alignment using City Tunnel Boring Machine (TBM).
- Alternative 5: Conceptual design alignment using specialized EPB.
- Alternative 11a: Conceptual design alignment using both City TBM and EPB.
- Super Shallow: Highest vertical alignment based on the design constraint using City TBM.

Upon further analysis, the following conclusions were made:

- Alternative 1 uses EPB for the boring and is on the same vertical alignment as Alternative 4a. Therefore, Alternative 1 is considered as a mitigation measure for Alternative 4a and thus will not be evaluated further.
- Alternative 11a was eliminated from further evaluation due to the combined risks in obtaining the EPB machine and in using the City's TBM in the same project.

The three remaining options, Alternatives 4a, 5 and Super Shallow, were then evaluated in further detail. Another workshop was conducted to quantify the risk factors and to select the preferred alternatives. Risk quantification was done based on the assessment of likelihood and the magnitude of impact from such risk. The severity of the risk factor is the product of likelihood and magnitude.

Because of the nature of the project in this case, the only viable alternatives involve a risk severity score in the range of "intolerable". Normally, a municipality would prefer to only look at alternatives that do not require extreme risk management measures. This necessitates significant risk transfer measurements that are judged to be highly reliable.

2. AbouRizk, Simaan, 2005. "Risk and Uncertainty" Construction Research Forum. University of Alberta, Edmonton, Alberta.

Additional meetings were conducted to choose between the remaining two preferred alternatives and to develop a risk mitigation plan. Option 5 depended on the availability of the EPB machine and was thus considered unfavourable. Option 4a was eventually recommended as the preferred alternative due to the availability of equipment and previous experience in tunnelling through sand layers.

Upon the completion of the initial risk assessment, the field investigation program confirmed the presence of contaminated soil in the proposed alignment of the storage tunnel. Elevated benzene concentrations were found in the groundwater samples, soil samples and air samples. The groundwater and soil samples indicated that an aqueous phase plume was present within the sand layer on the site at a depth of approximately 11 m below ground surface. Therefore, a special review meeting was conducted to develop mitigation plans for working in the contaminated area. The review meeting included experts in the fields of tunnel construction, geotechnical and environmental engineering, and occupational health and safety. Table A–1 is an example of a risk factor and the mitigation plan developed from the risk review meeting.

Table A–1: Example of a risk factor and the mitigation plan

Risk Factor [1]: Encountering contaminated soil will cause delays, cost escalations and safety issues.
Risk Quantification Likelihood = 150 Magnitude = 50 Severity = 7500
Mitigation [2]
General Discussion ■ Consider an open pit at the contaminated sand location (adds $0.5M to cost, delays schedule). ■ Increase ventilation and monitoring, air injection. ■ Exploration shaft in the affected location. ■ Start extracting this area right away. ■ Ask company responsible for contamination of the site to pick up the costs. Initiate the process to put them on notice. ■ Raise tunnel elevation as much as possible to minimize exposure.
Specific Action Plan ■ General: ● Concentrations of Benzene to create explosions in the tunnel are very low. ● Main concern with Benzene at this level of concentration is not explosions; it is the health effects on workers. This risk can be best handled through engineered air. ■ Reducing uncertainty: ● Get air samples from shaft and from wells already in place. Test them for BTEX (benzene, toluene, ethylbenzene, and xzylene) to get the information required for proper evaluation. ● Continue monitoring groundwater to verify the level. ● Need to confirm the classification for this tunnel work site. There are different requirements for different tunnel classifications (such as intrinsically safe). ■ Dealing with Benzene: ● Continuous monitoring. ● Give workers gas masks. ● Engineered air circulation to dilute. ● Investigate the requirements for electrical and power systems to be in a gaseous tunnel. ● Consider sinking another shaft before the contaminated area to prevent circulated air from going back into the entry shaft.

Notes:

1. Risk Factor was identified from the initial risk assessment based on a brain-storming session from participants (some factors were developed based on previous risk assessment sessions on similar projects).
2. Mitigation was developed as per the risk review meeting from consensus among the experts in the meeting.

References

AbouRizk, Simaan, 2005. *Risk and Uncertainty* Construction Research Forum. University of Alberta, Edmonton, Alberta.

Association of Metropolitan Sewerage Agencies (AMSA), 2002. *Managing Public Infrastructure Assets to Minimize Cost and Maximize Performance.* Washington D.C. Web site: *<info@amsa-cleanwater.org>.*

Boghosian, David G. and Davison, J. Murray, 1999. *The Law of Municipal Liability in Canada*. Toronto, Ontario. Butterworths.

Canadian Mortgage and Housing Corporation (CMHC), 2003. *Re-Sale of Leaky Condos: Did the Buyer Know?* Technical Series 03–108. Montréal, Quebec.

Canadian Standards Association (CSA), *Risk Management: Guideline for Decision-Makers*, CAN/CSA–Q850–97, Ottawa, Ontario.

National Guide to Sustainable Municipal Infrastructure (InfraGuide), 2003a. Decision Making and Financial Planning best practices: *Developing Levels of Service*. Ottawa, Ontario.

——— (InfraGuide), 2003b. *Developing a Water Distribution System Renewal Plan*, Ottawa, Ontario

——— (InfraGuide), 2003c. *Investment Parameters for Municipal Infrastructure*, Ottawa, Ontario.

——— (InfraGuide), 2005. *Public Consultation*, Ottawa, Ontario.

Project Management Institute (PMI), 2004. *A Guide to the Project Management Body of Knowledge*, Project Management Institute, Upper Darby, PA, U.S.A.

Notes