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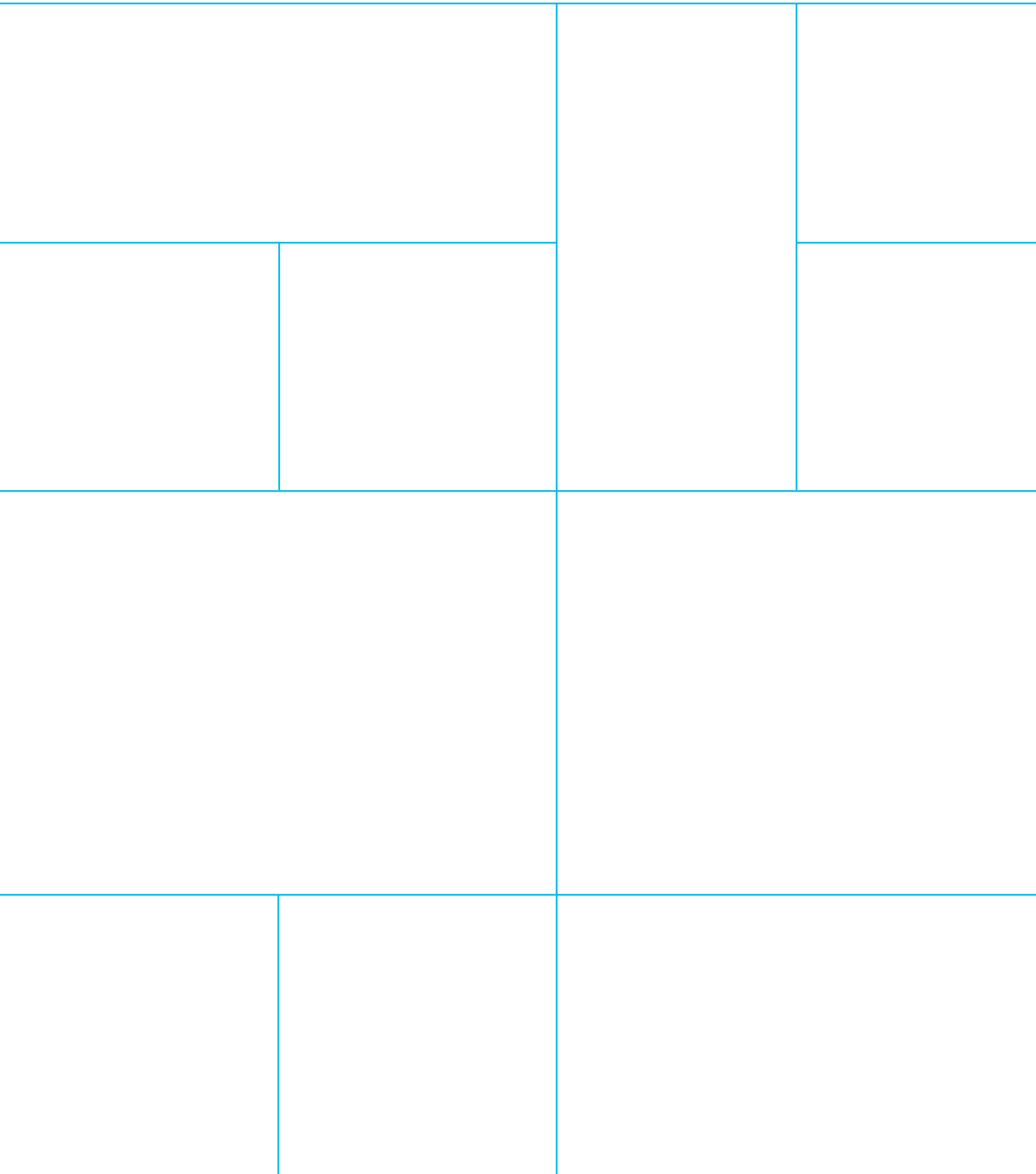
Constructing Ontario's Future

Incorporating Sustainability in Infrastructure ROI

The energy costs of deferred maintenance in municipal water systems



Incorporating Sustainability in Infrastructure ROI

The energy costs of deferred maintenance in municipal water systems

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The Residential and Civil Construction Alliance of Ontario (RCCAO) is an alliance composed of management and labour groups that represent all facets of the construction industry. Its stakeholders stem from residential and civil sectors of the construction industry, creating a unified voice. The RCCAO's goal is to work in cooperation with governments and related stakeholders to offer realistic solutions to a variety of challenges facing the construction industry. For more information please visit www.rccao.com

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Executive Summary

While easily taken for granted, the vital importance of our infrastructure is readily acknowledged when suddenly faced with profound failure. Collapsed sinkholes and bursting watermains can quickly remind us of our dependence on these usually steadfast and silent facilitators of our economic, social and material well-being. Fortunately, failures such as these have thus far not occurred with alarming frequency. But when they do happen, they are often accompanied by a reexamination of the state of these systems and bold pronouncements of a renewed dedication to preserve and maintain our infrastructure.

The danger with such reactive measures, however, is that decisions can be made that are visible and immediate in impact, but not necessarily the wisest and most strategic in the long term. Building and construction policies must be based on effective research that embraces the integration of sustainability principles with engineering systems.

To achieve integration, the Province of Ontario must reconfigure the methods used for evaluating return on investments in infrastructure projects to include more quantitative, formal and creative analysis of sustainability impacts and benefits. Evidence shows that investing in rehabilitation and enhanced project specifications can have positive benefits in terms of waste reduction and enhanced energy use.

In the longer term, the Province needs to establish a strategy and clear policies for planning infrastructure systems. The approach should focus on making the link between life-cycle costs, infrastructure rehabilitation and sustainability, even while holding agencies accountable for the maintenance of their capital facilities.

To that end, this study provides an assessment of the energy savings that could be realized upon fixing leakage in water distribution systems.

With age, watertight pipes deteriorate. Deterioration leads to higher water losses, which must be addressed through higher pumping levels. As a consequence of this diminished performance, we see the rising cost of water distribution pumping. Furthermore, the cycle results in faster rates of obsolescence for both pumps and pipes.

For example, it is estimated that 5-10 billion kilowatt hours (kWh) of power generated each year in the United States is wasted on water that is either lost via leaks or not paid for by customers. The City of Toronto alone spends approximately $2 million per month to energize its water distribution system.

In some provincial systems, confronting and controlling energy inefficiencies could save up to 50 per cent of energy use. If the Province invests rigorously in pipe rehabilitation to bring leakage to an acceptable level of seven per cent, it could realize, on average, $1,500,000 in operational energy savings per month. In addition to the direct cost savings, fixing such leaks and reducing energy consumption diminishes the growth in greenhouse gas (GHG) emissions that contribute to anthropogenic climate change, combats resource depletion and generally shrinks the ecological footprint associated with energy production and consumption.

Electricity generation in Canada is estimated to account for 20 per cent of total GHG emissions. If as a reasonable estimate five per cent of electricity consumption goes to pumping water and utilities experience leakage ranging from 10 to 50 per cent, the opportunity to reduce GHG emissions from curtailing even half of the leakage is significant. If other areas of inefficiency are improved, the benefits of GHG reductions would be higher.

This report recommends that several specific forms of deterioration or poor performance be quantitatively assessed and evaluated, including pipe deterioration, blockages and trapped air, pumping, and energy recovery.

With respect to the larger spectrum of sustainable infrastructure, this report recommends that the Province:

1. Reconfigure the methods used for evaluating return on investments in infrastructure projects to include more quantitative analysis of sustainability impacts and benefits. Evidence shows that investing in rehabilitation and enhanced project specifications can have positive benefits in terms of waste reduction and enhanced energy use.

2. Establish long-term and clear policies for life-cycle planning of infrastructure systems. These should include:

- financing strategies for water and environmental infrastructure;
- optimizing the role of national and local public budgets;
- ensuring access of poor and vulnerable groups to water and sanitation services; and
- mobilizing local capital and financial markets.

In light of the previous analysis, some of the following actions are also worth further consideration:

- improving data collection and analyses;
- incorporating energy-savvy design of utilities;
- broadening the objectives of the *Green Energy and Green Economy Act, 2009* (GEA) to the domain of urban utilities;
- creating a fund for expediting the renewal of energy-wasting facilities;
- investigating new financing tools to help consumers, per the GEA; and
- ramping up the use of advanced technologies.

Introduction

Infrastructure and energy are together the lubrication and motive force for modern society. Though going largely unnoticed, they nevertheless perform an unbelievable number of roles that facilitate human, economic and ecosystem health. Inquiry into this issue is strongly motivated by the unqualified conviction that we can do better in the design and operation of infrastructure, and that such progress will have tremendous economic, environmental, energy and human benefits.

Traditionally infrastructure has been designed at the project level with only passing consideration to the overall performance of the network. Projects were further designed according to short-term business requirements (mainly project direct costs). The fact that these infrastructure systems are being rehabilitated in the midst of congested urban areas requires more rigorous consideration for the impacts of individual projects on local communities.

There is clearly a need for a new paradigm in the design and management of infrastructure systems. We have to incorporate the sustainability impacts of projects into the analysis and decision-making processes. New costs and benefits have to be incorporated into the overall estimation of project feasibility and return on investment (ROI):

Indirect costs: The majority of infrastructure systems are located in urban areas, leading to an ever-increasing importance to indirect costs such as business and traffic costs. For example, if the failure of a water system causes an associated failure in either the transportation system or electrical system, it is imperative that this true cost be factored into the assessment of the reliability and investment into the water system.

The costs to the environment: Real dollars can now be associated with the impacts of an infrastructure project on the environment (whether positive or negative). The ever-increasing costs of energy are changing the equation for ROI in infrastructure systems. Investing in more energy-saving systems is not only good for the environment, but also for the financial bottom line.

Safety and security: Designing infrastructure according to limited business requirements would lead to a minimalist design (elimination of any redundancy). In contrast, addressing interdependency concerns requires embedding adequate redundancy in individual projects to enhance the resilience of the overall network. Not doing so results in increased safety and security impacts with increasing associated costs.

This report aims to develop a roadmap for considering sustainability issues upon making infrastructure funding decisions. The report includes a synthesis of some relevant literature, a set of recommendations and an Ontario-centric case study. The case study looks at the nexus between the quality of water infrastructure systems and energy management. Specifically, the case looks at how much energy savings can be realized by fixing leaky water pipes. To that end, the decision of the Government of Ontario to combine infrastructure and energy under one Ministry is both intriguing and encouraging.

Estimating Infrastructure ROI

Despite the clear positive contribution of infrastructure to the economy, it has been difficult, and sometimes controversial, to estimate the rate of return for public investments in infrastructure. Depending on the method used, estimates as high as 50 per cent and as low as zero have been generated. Economist David Aschauer recently revived the controversy through a set of papers that examined the role of infrastructure in the U.S. economy. He argued that in addition to improving our quality of life, investments in the public sector increase economic growth and boost returns on private investments. Aschauer suggested one of the highest rates of return ever: 50 per cent or higher! The number is of course controversial and is disputed by many. However, few economists disagree about the role of infrastructure in economic growth. In fact, "Many economists speculated that the drop in infrastructure investment could explain the slow growth in productivity in Europe and North America during the 1970s and 1980s. They suggested that more spending on public infrastructure might spark a new 'golden age' of growth and prosperity, like the one North America and Europe experienced in the decades following the Second World War" (Baldwin and Dixon, 2008).

Others, such as Macdonald (2008), point out that "uncertainty around the estimates has proven sufficiently large enough that no economic rate of return is attached to public capital when public sector gross domestic product (GDP) is estimated. Only the depreciation of public capital enters the calculation for GDP in the public sector." Traditionally, many softer returns have been associated with infrastructure—namely enhancements to the quality of life and public health. Aschauer (1990) argues that "better roads reduce accidents, so improving public safety. Water systems have reduced disease. Waste management improves health and reduces unpleasant odours. Infrastructure is thus important not only for the economic benefits it brings, but also because of its impact on, inter alia, health, safety, leisure and general aesthetics" (Baldwin and Dixon, 2008).

For example, a study by the Appalachian Regional Commission (ARC) looked into the indirect economic impacts of public infrastructure investments. While the study focused on small, medium (and sometimes rural) communities, its findings are telling. "The economic impacts were measured either by new jobs and personal income generated from business attraction and expansion, or by existing jobs and personal income retained by saving businesses that would otherwise have been forced to close down or move out. Additional economic impacts on leveraging private sector investment and fiscal impacts on increasing local tax revenues were also documented. For each of these impact measures, the ratio of impacts per dollar of ARC investment and per dollar of total public investment, were assessed. Relative ratios of benefits and costs were also examined" (Brandow et al, 2000).

On average, the study found that the return on every public dollar is $26. That is, considering private sector leverage and income creation, there is a return ratio of 26:1 for each public dollar spent (see the Table below). Interestingly, for water projects, interviews with local community leaders indicated the following additional benefits:

- facilitated growth and increased commercial activity;
- supported expansion of new and existing industries;
- provided incentives for investment by industries reliant on high-quality water;
- addressed environmental concerns about new development;
- encouraged collaboration between municipalities; and
- provided residential amenities such as convenience, cost savings and community preservation.

Benefits realized per Public Dollar

Project Type	Public $ per **Direct** New Jobs	Public $ per **Total** New Jobs	**Total** Income per Public $	Direct Private Investment per Public $
Access Road	$4,266	$2,711	$8.45	$12.03
Business Incubator	$5,466	$3,136	$8.04	$6.68
Industrial Park	$8,494	$4,720	$4.50	$17.95
Water/Sewer-Business	$3,273	$1,634	$12.73	$46.75
Average	**$5,011**	**$2,643**	**$8.11**	**$26.37**

(Source: Brandow et al, 2000)

Infrastructure and Sustainability

Society and the economy are experiencing rapid changes that are pushing for the design of more sustainable and resilient infrastructure systems. In many cases, a new infrastructure project is seen by some as a possible threat to the environment. However, we have to bear in mind that many infrastructure projects do exactly the opposite. Enhancement to transportation systems or a new transit system means reduction of congestion and the associated GHG emissions. Restoration of old sewer lines can mean less effluent is discharged into the environment or leaks into the ground. And, of course, building a better sewage treatment plant means cleaner rivers and lakes.

A related but often ignored case involves leaks in water distribution systems. Leaks and breaks discharge not only water, but lead directly to considerable increases in power costs, or reduced performance, or both. Essentially, they impose an extra consumption upon the system, even though such consumption (unlike frivolous demand) does not even involve the perception of utility for any stakeholder. Although the notion of leaks contributing to energy consumption is logical and has met with implicit recognition, direct attention to this link and assessment of its impact is apparently recent (Colombo, 2004). Perhaps as a harbinger of greater awareness, recognition of the energy cost of leaks is made in the AWWA Water Loss Control Committee's 2003 report *Applying Worldwide BMPs in Water Loss Control*. Referring to the burden imposed by leakage, the committee acknowledges that: "…the additional energy needed to supply leakage unnecessarily taxes energy generating capabilities" (AWWA, 2003, p.75). In fact, the committee estimates that 5-10 billion kWh of power generated each year in the United States is wasted on water that is either lost via leaks or not paid for by customers.

Preoccupation with water loss is nothing new and is perhaps the most obvious cost of leakage since there is a clear relationship between a utility's income and water that fails to reach customers. Numerous studies have attempted to estimate typical water loss figures. Lai (1991) conducted one of the first 'global' surveys that reported water loss (then referred to as "unaccounted-for-water") figures from several different countries and cities and discovered that these varied widely, from a low of nine per cent in Germany to a high of 43 per cent in Malaysia, with most countries falling into the range of 20-30 per cent. Brothers (2001) estimated average water loss in North American networks to be about 20 per cent, most of this being leakage. Growing concern over resource scarcity and water loss, partly confirmed by studies such as these, induced the International Water Association (IWA) to devise clear and unequivocal water audit procedures in order to facilitate system comparison and benchmarking (Alegre et al, 2000; Farley and Trow, 2003), a move also embraced by the American Water Works Association (AWWA, 2003).

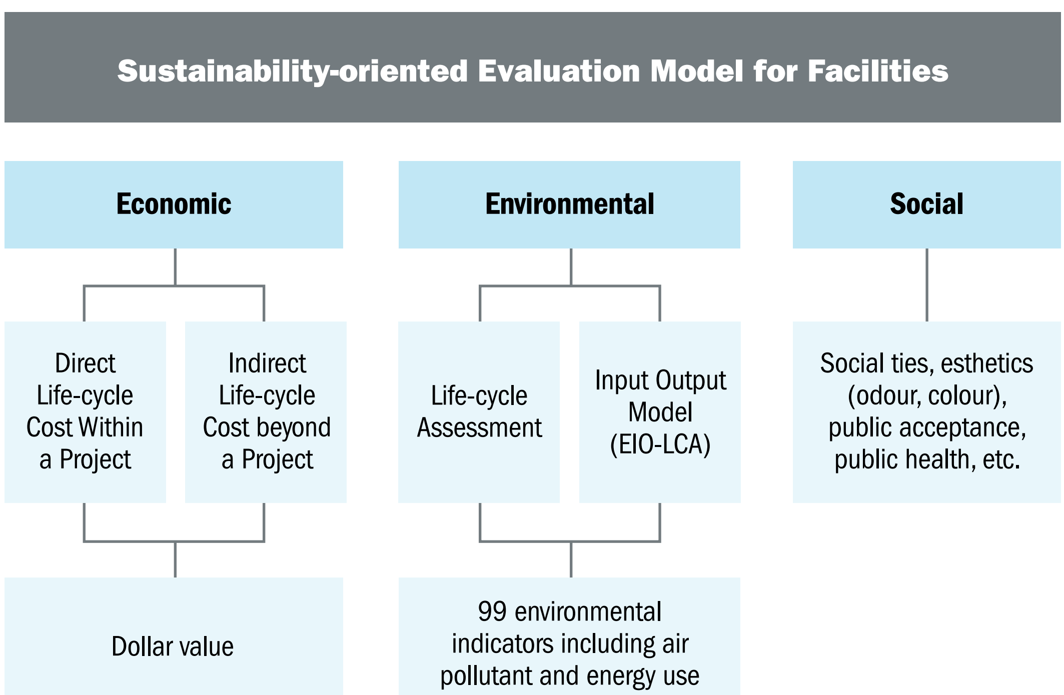
The question that our society faces now is a pressing one: how can we evaluate the feasibility of construction projects or options considering their life cycle and sustainability impact? Traditionally, feasibility studies of construction facilities, especially large-scale infrastructure systems, have focused on optimizing direct cost and immediate needs. With sustainability moving to the centre of public decision-making, we need to evaluate the feasibility of construction facilities beyond the limited direct cost consideration. We have to amend our evaluation models to incorporate the variety of tools available to us. Appendix A on page 26 summarizes these tools.

Public decision making has to be based on two paradigms. First, life-cycle analysis—we have to consider the life-cycle cost of the facility. Second, sustainability—incorporating the environmental and social benefits as well as impacts in the evaluation process. The evaluation has to optimize three aspects: economic, environmental, and social:

- The economic dimension includes direct and indirect life-cycle costs, which can be expressed in dollar values. Direct cost is usually defined as the life-cycle cost of a project including upfront capital investment, regular operation and maintenance expenses, rehabilitation costs, renewal costs, risk costs, and sometimes disposal costs.

- The environmental impact can be considered by environmental life cycle assessment (LCA) over the whole life of an infrastructure, from raw material acquisition, through to construction, transportation, use, and disposal. LCA consists of three specific methods: process-based LCA, environmental input/output LCA (EIO-LCA), and hybrid LCA. The process-based LCA utilizes the hard data to calculate environmental impacts. However, this method has some limitations including expensive and time-consuming workloads, arbitrary boundaries, and difficulty in assembling data. In order to overcome these limitations, environmental input/output model can be used to utilize economic input/output table to trace environmental effects through all the economic sectors.

- We can use some new techniques to evaluate some of the social benefits and impacts of infrastructure projects (see Appendix A, page 26).



Energy, Leaks and Infrastructure Investment

As a case in point, this report investigated the nexus between water distribution systems (WDS) and energy use. Specifically, the report investigates how much energy savings can be realized by fixing leaks. This section is an attempt to showcase that investments in infrastructure—especially in the rehabilitation of underperforming systems, can be a positive contribution to both the economic and environmental bottom lines.

The problem of leaks in water distribution systems has generated significant interest due to the financial cost borne by utilities, potential risks to public health and environmental burden associated with wasted energy. In recent years, such concerns have led to the introduction of stricter penalties against water authorities for ignoring leakage and have provided the necessary incentives for the investment in better leak detection technology and enhanced leak reduction strategies.

The Essential Variable Relating Energy to System Performance

The energy requirements associated with supply water arise primarily from the need to pump the water to move it effectively from its source to its destination. Thus, understanding the relationship between the key pump variables is a prerequisite for making better decisions and better trade-offs in system design, rehabilitation and operation. This section reviews these essential relationships.

A pump essentially moves water from its suction side at low pressure, to its discharge side at higher pressure. The difference in energy levels between the discharge and suction side, for any given rate of flow, is summarized by the "total dynamic head" (TDH, H) of the pump, measured as an equivalent height of a water column. The expression for the power required by a pump is related to the product of the TDH (in metres of water) and the discharge "Q" through it (in cubic meters of water per second):

$$P= (s\ Q\ H)/n$$

in which "s" is the unit weight of water (about 10 kilonewtons, or kN, per cubic metre), "n" is the efficiency, and "P" is the power in kilowatts (kW).

The power is converted to energy, and then to a cost, by taking into account the supply duration (and sometimes the time of use) of the power. Essentially, the energy used is the integral of the power over a convenient time period (such as a month) and then converted to standard electrical units like kilowatts. If we redefine "H" and "n" to be monthly average values, this operation effectively turns the discharge into a volume of water pumped "V" (in cubic metres), and thus converts power into energy:

$$E= (s\ V\ H)/n$$

This would normally be expressed in kilojoules (kJ), but if we divide by 3,600, we obtain an energy value in standard electrical units of kilowatt hours (kWh).

To map this into typical variables of consequence is now straightforward. If we assume for argument that the average per capita water demand in Ontario is of the order of 300 litres per day (L/day), then one million users would use 300 megalitres (ML) of water for every day (equivalent to 120 full Olympic pools or about 800 regular community pools), or about 9,100 ML per month, assuming 30.4 days in the average month. If we provisionally assume that the average monthly pumping efficiency is 0.75, and that the most basic system requires a pumping head of at least 50 metres, then meeting the basic water supply needs of a million people for a month would require, by direct substitution, about 1,650,000 kWh of electricity. This "base level" electricity would cost about $165,000 per month, assuming the average cost of electricity, including distribution and debt retirement, is about $0.10/kWh.

To better judge this relationship we need to consider the issue of head in more detail. The head "H" a pump needs to supply must take into account the sum of three primary factors: (i) the head required at the delivery point, (ii) the elevation gain between the point of supply and the highest delivery point in the system, and (iii) the friction losses taking place in the entire pipe network between the supply and delivery points. The net result is that pumps often have to supply many times the basic 50 m head assumed above, particularly in large systems built at the shores of a lake, as is the case in the Greater Toronto Area (GTA). It should be noted that larger heads are often not supply system wide, but rather large municipal systems are often split into pressure zones that effectively sub-divide the head requirements of some segments from others. Taking all this into account, a realistic estimate of monthly energy costs is likely in the order of $400,000 per million of population. With 12 million inhabitants, the total monthly energy cost of Ontario's water distribution systems is close to $5 million.

The beauty of these basic relationships is that they so clearly establish the key variables that must be controlled in any conservation approach. The real essence of conservation is to keep both the head and flow requirements as low as is practical. This can be achieved through pressure management (not being as generous to exceed pressure requirements and managing transmission head losses) and by all forms of demand management. At the household level, demand is potentially managed through strategic use of water saving devices like low volume toilets and efficient shower heads. But within the municipal system, demand can be managed as well, and one of the most effective means is through the control of unwanted leakage losses.

It is worthwhile pointing out that head and discharge, particularly within a built system, are not independent quantities. Because friction losses are inevitably a power flow relationship of discharge, demand management—either at the household or through leakage control—has a huge double benefit. Not only does it directly manage the volume term in the energy expression, but it acts through the lower losses to make pressure management approaches more effective and economical. This is one of the key reasons why this report targets leakage.

Point of Departure

The argument, in summary:

- First, deterioration leads to fewer watertight pipes and higher water losses.
- Second, greater water loss must be addressed through higher pumping levels.
- As a consequece of this diminished performance, water distribution pumping costs rise.
- Furthermore, this cycle tends to result in faster rates of obsolescence of both pipes and pumps.

One must recognize that there is an inevitable trade-off between energy savings and performance, particularly in terms of water delivery pressure. In particular, if performance is fixed at a standard (reasonable minimal) value, energy losses can be expected to increase between 1.3 and 1.8 times the percentage water loss. The overall water losses in the world are huge, and even in Ontario they are substantial. A search unearths interesting data, as is compactly summarized in the leakage table for Ontario.

It can be argued that the boundaries for the economic analysis are usually far too small; that is, actual costs to society are MUCH greater than they are to the water system alone. Broken pipes often cause electrical and traffic problems and push many additional costs onto homeowners. Broken and leaky pipes and dysfunctional systems create water quality and health risks that are real but difficult to quantify. Finally, we have a strong tendency to bury pipes and take them for granted. Yet these investments and the delivery system they represent have enormous implications for the operating expenses of cities and industries, influence the quality of life and health of all city dwellers, and strongly determine the vitality of life in urban centres. Overall, we neglect water pipes to our peril and to our great disadvantage.

Energy Loss Due to Leaks

Electricity costs for pumping comprise the major portion of most system's operating budgets. Because water is relatively "heavy"—with a density of 1,000 kilograms per cubic metre (kg/m^3)—and must often be transmitted long distances, sometimes across terrain with significant topographic variation, this is not surprising. A potentially illustrative measure of a system's energy burden might be the fraction of total electricity consumption that goes to pumping water. Although not a widely published statistic, and in many cases difficult to evaluate, consideration of what estimates are available may prove enlightening.

One dated estimate claims that pumping water accounts for seven per cent of total electricity consumption in the U.S. (Brailey and Jacobs, 1980). Figures for the fraction of world power consumption for pumping water differ and are not readily available. One study indicates two to three per cent of total global energy production and seven per cent of total electricity consumption is allocated to pumping water (Watergy, 2004). The American Water Works Association Water Loss Control Committee indicates that 2-10 per cent of the power consumed in a given country is by water utilities (AWWA, 2003). Because of the large energy input needed to treat and distribute potable water, a thorough understanding of the nature and causes of energy loss in WDS is warranted and overdue, a statement no less true for Toronto or London as for Mexico City or Sao Paulo.

In addition to water loss, leaks are costly in terms of energy consumption. Colombo and Karney (2002) raised this issue as part of a preliminary evaluation of the relative importance of energy waste via leakage. Further recognition of the energy cost of leaks was made in the AWWA Water Loss Control Committee's 2003 report which acknowledged that "the additional energy needed to supply leakage unnecessarily taxes energy generating capabilities" (AWWA, 2003).

An early mention of the leak-energy link was by Cole (1912) who noted that the City of Chicago was burning twice as much coal as needed to supply customers due to substantial losses (about 50 per cent). Though anecdotal, his observations were empirical and essentially constituted an informal example of the first approach. Colombo and Karney (2002) addressed estimation of leakage's energy impact from the other direction by developing and evaluating key relationships (leak size, system roughness and leak location) assuming knowledge of idealized leaks in simple hypothetical systems and assuming equivalent service/delivery conditions between leak and non-leak scenarios. They extended this analysis to systems with storage (Colombo and Karney, 2005). Bounds and Kahler (2006[i]) performed analyses for a large-scale water network and found that leak management could save 14 per cent of its electrical power consumption.

These contributions have not directly attached dollar values to the energy waste associated with leakage because they have concentrated on hypothetical systems with idealized characteristics and cannot necessarily be extrapolated to real networks. While helpful for understanding leak-energy physics, it is the top-down auditing approach that is more likely to assist a given utility in ascribing a monetary value to the energy burden of leaks. This would typically begin with a system-wide water audit in order to account for the different sources of non-revenue water (water that does not reach users and for which no customer is billed; referred to as unaccounted-for-water, UFW, in older parlance). This includes water used for street cleaning, park irrigation, fire fighting, sewer rehabilitation, illegal connections, accounting errors, meter inaccuracies etc., as well as water lost through leaks and breaks. Leakage is often a major component of non-revenue water. Thus, a good estimate of UFW is a good start to establishing how much water is lost via leakage. Some data about UFW for select Ontario cities is presented in the table on the next page.

Extended Impacts Of Leaks

The determination of performance extends beyond the traditionally simplistic confines of hydraulic "satisfaction" and financial cost, but also covers environmental and social externalities. Some of these externalities may be beneficial and could include the economic benefits that water supply infrastructure can bring to a community or the public health benefits of a reliable water supply to a hospital. Thus, the total cost of the system includes not only the financial cost of manufacturing and maintaining the infrastructure, but also encompasses the health effects of poor water quality, the environmental impact of energy consumption and inefficiency, water loss due to leaks, disruptions and associated service losses due to breaks, and a variety of other burdens associated with the system and its operation.

UFW Percent of Total Production in Each City

City	Percent of Total Production	Year
Toronto	14% [ii]	2007
Ottawa	22%-28%[iii] Another exact datum is 25.9%[iv]	2006
London	8%[v]	2008
Guelph	13%[vi]	2008
Windsor	24.5%-25.5%[vii]	2008
Vaughan	10.1%[viii]	2006
Kingston	At least 38%[ix]	2002
Barrie	3.2%[ix]	2006
Port Colborne	30%[ix]	2006
Niagara Falls	28%[ix]	2006
Thorold	25%[ix]	2006
Chatham Kent	17%[ix]	2006

There are also some data for Ontario and Canada; that is, 16 per cent (2008) unaccounted for water in Ontario [ii], and 20 per cent (2004) in Canada [iii].

Pipe breaks differ from leaks in that they require immediate attention. Thus, while they usually only persist for short duration, they involve a large energy investment associated with repair operations. Apart from the obvious energy charge for excavation, replacing pipe segments entails a certain energy investment in terms of the embodied energy that goes into pipe manufacture. Moreover, emergency pipe repair usually spells traffic delays with the attendant emissions of GHGs from idling motor vehicles.

In addition to introducing a troublesome potential to contaminate WDS and compromise public health, abandoned water mains may create their own energy burden upon system operation. Derelict pipes can promote energy loss if they remain "live" (that is, if they are still connected to the system via an open link) and contain leaks. Such conduits can also be susceptible to breaks like any other pipe that remains in normal service. Typically, these forgotten branches in the system result from cancelled real estate developments, changes in land use, and poor record keeping on the part of utilities and contractors (in the case of service connections).

The potential for leaks to admit contaminated water during hydraulic transients is yet another cost of leakage which has also been a key subject of inquiry. Funk et al (1999) assessed the intrusion risk by evaluating the possible volume of intruding groundwater given transient duration and severity (minimum waterhammer pressure). As part of the AWWARF study *Pathogen Intrusion into the Distribution System* (Kirmeyer et al, 2001), Karim et al (2003) collected and tested soil and water samples in the immediate vicinity of water mains at eight locations in six U.S. states and found that often these soils contain potentially harmful bacteria and pathogens such as coliforms (detected in 58 per cent and 70 per cent of water and soil samples, respectively) and fecal coliform bacteria (detected in 43 per cent of the water and 50 per cent of the soil samples).

How Much Can Be Saved by Investing in Pipe Rehabilitation?

Reducing energy use diminishes the growth in greenhouse gas emissions that contribute to anthropogenic climate change, combats resource depletion and generally shrinks the ecological footprint associated with energy production and consumption. Electricity generation in Canada is estimated to account for 20 per cent of total GHG emissions. If five per cent of electricity consumption goes to pumping water and utilities experience leakage ranging from 10 to 50 per cent, the opportunity to reduce GHG emissions from curtailing even half of the leakage is significant when placed in the context of Canada's Kyoto commitments. If other areas of inefficiency are also improved, the benefits of GHG reductions would be even higher.

Premature capacity expansion of both the water and electricity supply systems can be avoided or delayed, helping to secure a reliable supply of both to Canadians while easing the financial pressure on Canadian municipalities. The rehabilitation budget for water and sewer pipes in the City of Toronto alone is approximately $500 million per year. Clearly, even small savings or delayed expenditures for repair and rehabilitation of WDS will yield valuable financial benefits.

The City of Toronto alone spends approximately $2 million per month to operate its water distribution system. There is a clear potential for savings on the part of Canadian municipalities and quick paybacks are foreseeable for modest investments in leak management. One can easily estimate that at least 20 per cent could be saved if the system could be made significantly more water-tight, say by reducing the leakage rate to a reasonable seven per cent. For the remainder of the province, leakage rates are, on average, higher but water usage (and energy) is correspondingly decreased. With total energy bills for the municipal supply of water to be in the neighborhood of $5 million a month, and taking into account system topology, structure and capacity, a concerted effort to reduce leakage is likely to yield a minimum of 20 per cent savings (with 40 per cent savings being a real possibility). In fact, for some systems, up to 50 per cent of energy use may be reduced by confronting and controlling the various sources of energy inefficiency, rendering the preceding example of savings especially conservative.

It is, however, safe to assume that a 30 per cent energy savings can be achieved. This totals to a $1.5 million per month in energy savings alone.

Cumulative Effect of Energy Waste

The estimate of $1.5 million/month is very conservative. While this could be seen as a significant waste in energy, one can only realize the true significance when the analysis is conducted on a long-term basis. Leaks are long-term phenomena: as such, one has to consider their impacts on a longer life cycle. The Table below shows a sample, hypothetical scenario. It is assumed that the leakage level in 2009 in Ontario is 100 per cent (i.e. it is the basis for the analysis). It is also assumed that the annual deterioration level increased by two per cent over the last 10 years. In other words, if the leakage rate is for example 40 per cent in 2009 in a municipality (close to the Kingston levels), it was 39.2 per cent in 2008. Or if the leakage rate is at 10 per cent in another municipality in 2009, it was 9.8 per cent in 2008. The scenario further assumes that the energy costs in 2009 are the basis and further assuming that it has been increasing at two per cent over the last 10 years. The cumulative wasted energy due to deferring maintenance amounts to $161 million over the last 10 years. That is, had Ontario spent the same amount of money on maintenance of leaky pipes at one point (ten years ago) instead of distributing the same amount of money over 10 years, the savings in energy alone, could have reached over $160 million (provided the pervious assumptions). In other words, the energy costs (not the total cost) of "deferring" maintenance is about $160 million over the last 10 years.

Year	Energy Cost	Deterioration Level	Energy Cost
2009	1	1	18
2008	0.98	0.98	17.3
2007	0.96	0.96	16.6
2006	0.94	0.94	15.9
2005	0.92	0.92	15.2
2004	0.9	0.9	14.6
2003	0.88	0.88	13.9
2002	0.86	0.86	13.3
2001	0.84	0.84	12.7
2000	0.82	0.82	12.1
1999	0.8	0.8	11.5
		Total (interest free)	**161.2**

Policy Recommendations

By prioritizing overall resource efficiency, and targeting those investments that have the greatest return (informally, "bang for the buck"), this proposal seeks nothing less than a major shift in infrastructure development and management, system performance, economic and resource efficiency, and a strategic deployment of new investment. The aim is to put Ontario communities at the forefront of the world as exemplary systems. Government needs to define and implement a policy of performance-based service delivery. The vision should link land-use and environmental planning with economic development and infrastructure investment. The vision and the plan should serve as a basis for planning and programming multi-sectoral infrastructure investments. What is important is to start the process of integrated planning. As U.S. President Dwight Eisenhower once said, "plans are nothing, planning is everything" (Dowall and Whittington 2003).

Two fundamental macro recommendations are presented to Province of Ontario:

1. Reconfigure the methods used for evaluating return on investments in infrastructure projects to include more quantitative analysis of sustainability impacts and benefits. Evidence shows that investing in rehabilitation and enhanced project specifications can have positive benefits in terms of waste reduction and enhanced energy use.
2. Establish long-term and clear policies for life-cycle planning of infrastructure systems. These should include
   - financing strategies for water and environmental infrastructure
   - optimizing the role of national and local public budgets
   - ensuring access of poor and vulnerable groups to water and sanitation services
   - mobilizing local capital and financial markets

To this end, an analysis by the U.S. Congressional Budget Office found that "State decision-makers and policy analysts are far too preoccupied with first costs. Instead, the state needs to develop a more holistic approach of assessing its capital outlay decisions. The approach should focus on lifecycle costs; that is, the total costs of building, operating, and maintaining a capital asset. The life-cycle approach looks beyond procurement costs and considers ongoing maintenance expenses. These charges should be included as part of the budget for the facility. Funding for maintenance needs to be encumbered when an asset is put in place. The state needs to hold agencies accountable for the maintenance of their capital facilities. At a minimum, this requires much better reporting of facilities' condition. Agencies should be required to report deferred maintenance backlogs and to develop five-year plans for eliminating deferred maintenance. The state needs to fund these plans" (Dowall and Whittington 2003).

In the same vein, the American Society of Civil Engineers (ASCE) emphasizes the need for clear and sustainable funding from the government for infrastructure—especially water and wastewater systems, as they are crucial to the preservation of our environment (ASCE 2006). "Clean and safe water is no less a national priority than are national defense, an adequate system of interstate highways, and a safe and efficient aviation system. These latter infrastructure programs enjoy sustainable, long-term federal grant programs; under current policy, water and wastewater infrastructure do not." In addition, ASCE supports the establishment of a "federal capital budget to create a mechanism to help reduce the constant conflict between short- and long-term needs. The current federal budget process does not differentiate between expenditures for current consumption and long-term investment. This causes major inefficiencies in the planning, design and construction process for long-term investments."

Changes are needed in the way the Province manages its water distribution systems. Taking all factors into account, the overall potential to save the electrical energy associating with pumping water is enormous, likely representing a potential savings of perhaps half of the electricity currently being used for pumping water, based on current delivery constraints and service levels within supply and distribution networks. However, it is also quite likely that, should these measures be systematically implemented, the savings would be shared or split between energy savings and improvements to the performance of the delivery systems. However, the net result would be that Ontario would end up having cheaper systems that perform better, and that is surely an objective that justifies first greater consideration but also significant investment and diligence assessment.

The current investment strategy has to consider the enormous returns in saved energy as part of the assessment of the cost/benefits of projects—especially rehabilitation projects. Any energy management strategy that is currently being contemplated should examine the possibility of energy savings (and even recovery) by fixing under-performing pipes first. Furthermore, any new construction has to contemplate using more advanced technologies and approaches for the design and construction of pipe systems. This, of course, can only be implemented effectively within a clear and accountable asset management strategy.

The following is a quick review of some international practices that could be of relevance in shaping a long term strategy/culture for energy conservation in water utilities in Ontario.

Denmark: Since the 1980s, the City of Copenhagen has introduced a general policy to replace one per cent in length of their network annually. In essence, this means that the life cycle of any pipe is capped at 100 years.

Australia: Hunter Water, a publicly-held, private-like water management corporation, is another good example. The company has a policy of replacing or repairing water services between the water main and meter—even though they are not required to do so legally. This program costs $600,000 each year but results in savings of about 305 megalitres per year. The program is relatively cost effective and addresses a very visible form of leakage. The rationale for the program is the lack of strong incentives for owners to repair leaking services; if Hunter Water ceased its current program, it is likely that the level of leakage would increase significantly. Also, there are overall efficiencies achieved through coordinating this work through a single agency, on behalf of the community. Within the water main replacement program, about five kilometres of pipes are replaced per year. Hunter Water currently replaces failed sections of water main based on an economic evaluation model. Under this model the economic, social and environmental value of lost water is included in the assessment. The program has an estimated savings of 20 megalitres per year (Hunter Water 2007).

Action Items

This report recommends several specific forms of deterioration or poor performance be quantitatively assessed and evaluated, including the following:

Pipe deterioration: Deteriorated pipes are more prone to leaks and exhibit higher levels of energy loss due to higher levels of friction. Greater friction losses from aging pipes that become rough are the single largest mode of energy loss in WDS operation. The Province has to establish clear performance measures and assessment policies to detect and fix deterioration in pipes appropriately, adequately and in a timely manner

Blockages and trapped air: Air in pipes is often poorly managed. It may cause blockage and increased energy loss due to increased friction losses. It could also result in reduced performance levels and unpredictable or erratic operation. While the acceptable level is two per cent, air contents of 5 or 10 per cent have been observed and are not uncommon. Air can have an unpredictable affect when hydraulic transients are experienced, in some cases attenuating them by reducing wave speed and in others exacerbating them by inducing strong and sudden flow changes at blockage points. A more complete understanding of transient effects and better monitoring of the pipe system are both needed to avoid such damaging consequences and to make wise infrastructure choices.

Pumping: Pump stations are often poorly configured and maintained. Modern control approaches, variable speed drives and well-structured maintenance programs could dramatically improve the performance and expense of pump operations. Unfortunately, such guidelines frequently remain ignored. The Province has to adopt a systematic asset management program to assure the highest level of operation at pumping stations. This plan should include rigorous system inspection, timely replacement and better education and training of operating staff.

Energy recovery: In many cases, pressure must be dissipated through pressure reducing valves (PRVs), especially near pressure zone boundaries to prevent undesirably large pressures in other parts of a system. Recent improvements in microturbine and distributed power generation technology are promising to greatly facilitate energy recovery in places where hitherto energy would automatically be dissipated with a PRV (Zhang and Karney, 2003).

In light of the previous analysis, some of the following actions are worth further consideration:

1. Improving data collection and analysis: With energy jumping into the forefront of most major policies, it is important that energy consumption and conservation become a major element in the performance assessment/measures applied to municipalities. The analysis in this report was hampered by the lack of clear or consistent data. We had to make conservative estimates to conduct our analysis. It is proposed that the Province conduct a thorough analysis to figure out means to find, report and track the exact numbers, upon which sound policies can be built. In fact, one of the main objectives of *Green Energy and Green Economy Act, 2009* (GEA) is "Setting electricity conservation targets for local utilities and helping them to deliver effective programs to households and businesses."

2. Incorporating energy-savvy design of utilities: It is important to support new design approaches that have energy conservation at its core. For example, Appendix A provides a summary of water pipe designs that take into consideration energy impacts. The Province should encourage and spread such practices through training programs, seminars and manuals.

3. Broadening objectives of the GEA: From support for savings and better managed household energy expenditures (through a series of conservation measures) to the domain of urban utilities. The province should educate and encourage municipalities to include energy consumption and conservation as part of the decision criteria in capital budgeting plans.

4. Creating a fund for expediting the renewal of energy-wasting facilities. This is not only good as a means for renewing outdated facilities or for saving energy and the associated negative impacts on the environment, it is also good for the bottom line. As shown in the study, a minimum of $61 million could have been saved if the same maintenance activities and expenditures were not deferred (in other words if all maintenance work over the last 10 years ago was done at once 10 years ago, or in a more expeditious manner.) In hindsight, Ontario could have realized a positive ROI if it had borrowed the money ten years ago, provided that the interest payments did not exceed $160 million.

5. Investigating new financing tools to help consumers, per the GEA: One could argue that the same still applies for the next 10 years. Ontario can safely borrow money to expedite the maintenance of leaky pipes (over the next 10 years) provided that the interest does not exceed $150 million. Or, in a more progressive scenario, Ontario could lump all its next 10-year investments in repairs now and realize at least an additional $150 million in returns in addition to the regular returns realized in public utility investments, i.e. shutting the dripping energy leaks faster is more beneficial than the piecemeal approach.

6. Ramping up the use of advanced technologies: One of the most promising and possibility effective and long-lasting initiatives to be funded is the use of remote sensor and telemetry technologies for ongoing monitoring and analysis of source, transmission, and distribution facilities. Remote sensors and monitoring software can alert operators to leaks, fluctuations in pressure, problems with equipment integrity, and other concerns. Environment Canada data suggests that "Up to 30 per cent of the total water entering supply-line systems is lost to leaking pipes. In most cases, if unaccounted for water in a municipal system exceeds 10 to 15 per cent, a leak detection and repair program is cost-effective. For example, studies have shown that for every dollar spent in communities with leak detection programs, up to $3 can be saved." In addition to helping to detect leaks, these investment programs 1) promote long-term asset management of what can be considered "permanent assets," 2) provide sources of data for other system activities, 3) enable us to move to better knowledge-enabled management of water systems that will facilitate greater investment efficiency.

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Appendix A: Estimating the Sustainability Costs and Investments

The assessment of environmental and social (E&S) costs associated with highway construction/rehabilitation operations is faced with several challenges:

- **Lack of clear definitions:** There is no clear and agreed upon definition of the E&S costs. This could be attributed to the subjectivity of the domain itself and the fact that this is an evolving domain of interest to decision makers.
- **Ambiguity in identifying relevant costs:** There is no standard means to identify which costs are applicable to each project. There is also no clear means to link specific project tasks to certain environmental/social impacts.
- **Unclear boundaries:** There is no agreement about the geographical extent of the E&S impacts of highway construction. While some researchers have considered the macro/global impacts, others have only considered the micro/immediate impacts.
- **Inconsistent estimation methods:** Some methods use socioeconomic approaches, while others use pure technical/engineering approaches. There is a clear inconsistency in the methods used by researchers and practitioners to estimate these costs. This is not simply due to the subjectivity of the domain, but is also a reflection of the disagreement about the extent of the impacts of a highway project on the surrounding environment.

A set of relevant methods/approaches have been used to estimate E&S costs. The schema classifies these methods into 6 major classes as shown in the Table below (compiled from Tsunokawa and Hoban, 1997; Dixon and Hufschimidt, 1986; Gilpin, 2000; King and Mazzotta, 2004). Table 1 (page 29) also lists E&S costs where each method could be applied.

Direct Estimation Method: This method is used to evaluate costs that are fairly explicit and can be estimated based on available data. This method is mainly used to evaluate costs on the local-level—for example, the cost to change the layout of a highway, or the cost to stabilize slopes. With some judgment calls, this approach can also be used to estimate less tangible costs such as damage to fisheries and/or wetlands.

Shadow Project Method: This method is also used to estimate costs on the local level. It is used to estimate less tangible issues, such as impacts on habitat, local heritage and the value of recreational spaces. The method compares the impacts of the current project with a hypothetical (shadow) project that can produce less impacts.

Economic Valuation Approach: This approach is used in assessing the economic impacts of highways. It uses three production changes that evaluate the economic losses and gains associated with highway construction:

- **Change in Productivity Approach:** Direct value changes in output of economic assets due to wasted time or a reduction in productivity.

- **Opportunity Cost Approach:** The lost market value of a physical asset, such as a house, due to proximity to a highway.
- **The Lost Earnings Approach:** Reduction in people's output and subsequent loss of earnings.

Input/Output Analysis: This approach deals with the macro impacts/costs of highways on the economy and the environment. The economic input-output analysis accounts for all of the direct and indirect inputs in producing a product or service by using the input-output matrices of a national economy. The environmental input-output analysis complements the economic input-output by linking economic data with resources as an input and environmental degradation as an output. The approach depends on calculating the embodied energy of the road construction and then converting it into environmental load (Horvath and Hendrickson 1998; Hendrickson and Horvath 2000; Matthews et al. 2001; Park et al. 2003; Treloar et al. 2004). The environmental cost can thus be determined by multiplying the environmental load (emission values) with its unit damage cost.

Surrogate Market Approach: This is an indirect method of estimation, which is used when the direct estimation of economic impacts is impossible. The most commonly used techniques are:

- **The Hedonic Pricing Approach:** This method is also referred to as the property valuation approach because it is used to estimate the change in property value resulting from adverse environmental impacts such as noise, air pollution, quality of surrounding environment, property access etc. The basic premise is that, if the quality and character of a house (with a similar cost of construction) are kept constant, then the difference in market price is due to the surrounding environment. However, other controlling factors also exist, such as proximity to better schools, shopping centers, recreational facilities, entertainment, law and order situations, like having good neighbours and a better neighborhood reputation (Gilpin 2000).
- **The Travel Cost Approach:** This method considers the costs and time spent by system users in accessing areas of interests (ecosystem, landscape, cultural heritage etc.) (Friedrich and Bickel 2001). "Travel costs from each concentric zone around the site are used as a surrogate for price, the quantity being determined by actually counting the number of visitors from each zone" (Gilpin 2000).
- **Wage Differential Approach:** This approach is very similar to the Hedonic Pricing Method; as "it uses wage differentials in place of property prices as a guide to the values that people assign to environmental qualities, and workers are assumed to be able to choose freely between jobs in different areas at wages that will maximize utility for them" (Gilpin 2000). Wage differential approach can also be defined as the "Estimation of willingness of workers to tradeoff wages for improved environmental quality" (Dixon and Hufschmidt 1986).

Contingent Valuation: Also known as "hypothetical valuation", this approach is used in the absence of information about people's preferences or when there is absolutely no direct way of allocating cost value on less tangible items (like visual impact). This method sets up a hypothetical market through questionnaires or other sampling techniques for soliciting expert input (Friedrich and Bickel 2001). This approach is basically comprised of a survey of Willingness To Pay (WTP) for benefits or willingness to accept (WTA) as compensation for tolerating annoyances. Experience shows the value of WTA to be several times greater than WTP. This approach has several forms (Gilpin 2000):

- **Bidding Game:** Individuals are directly asked how much they are ready to pay to enjoy or preserve a particular environmental feature. The surveyor could ask for a single bid, or an open-ended bid, and get individual WTP or minimum WTA values.
- **Convergent Direct Questioning:** Each individual is given two values, a high value (which is likely to exceed any reasonable WTP) and a low value (which certainly would be paid). The individual is given some reasonable value to find his/her WTP. If the individual's response is yes, then the value is increased until the response turns into no. If the individual response is no for the first given value, then the amount is decreased until the response turns into yes.
- **Trade-off Game:** Each individual is given two items: a certain amount of money, and an environmental feature. The individual is then asked to choose between the items. The point of indifference defines the value of the environmental feature.
- **Costless Choice or Moneyless Choices:** This approach is similar to the Trade-off Game. However, specified commodities are used instead of money. This could be suitable for individuals with better economies. The point of indifference will identify the almost equivalent commodity to the environmental good, and the current market price of the commodity chosen will give the economic value of the environmental good.
- **Priority Evaluation Method:** An individual is given a hypothetical sum of money to spend on conventional goods and environmental amenities at assumed prices. Because the individuals' choice is constrained by the limited budget, it will reflect true preferences. Marginal value can then be estimated from these findings.
- **Delphi Technique:** The concept of the Delphi technique is to arrive at an economic value of environmental assets by asking experts' opinions. The technique consists of a series of questionnaires through successive rounds of continuous refinements until the group agrees on a certain value. Experts' knowledge and background, and proficiency in the use of this technique play an important role, and can affect the quality of outcome to a high extent.

TABLE 1: Evaluation Models

Method		Applicability of Valuation Technique
Direct Estimation Approach		• Air pollution • Encroachment on [1]ANSI's • Impact on fisheries • Cost of erosion protection and water purification services of wetlands • Water/soil contamination (cost to treat drinking water contaminated by highway runoff) • Valuing noise protection (by measuring the cost of building barrier wall)
		• Property losses, cleaning or painting structural surfaces spoiled by air pollution. • Plantation, agricultural land, wetland.
Shadow Project Approach		• Habitat area degradation • Impact on fisheries • Cost of supplying alternate recreational facilities
Input-Output Analysis		• Macro impacts on the economy • Macro impacts on the environment
Economic Valuation Approach	Change in Productivity Approach	• Impact on water supply or impact on ground water recharge or discharge area • Effect on agricultural output, on fisheries, or on benefits of wetland • Impact on waterways • Loss in local businesses • Encroachment on ANSI's • Water and soil contamination • Impact on cultural heritage
	Opportunity Cost Approach	• Soil contamination and erosion, and water course contamination • Encroachment on ANSI's • Impact on cultural heritage • Impact on fisheries • Species degradation or species loss • Effect on agricultural land and wetland • Impact of uncontrolled highway runoff
	Lost Earning Approach	• Health hazard • Businesses' losses
Surrogate Market Technique	Hedonic Price Method	• Overall environmental quality (air pollution, water pollution, noise pollution, odour) • Living condition (housing quality) • Visual impact • Noise valuation
	Travel Cost Approach	• Restriction of access (increased transportation cost and travel time) • Visual impact • Elimination of existing recreation site • Change in environmental quality at a recreational site • Improved access to recreational site
	Wage Differential Approach	• Health impact • Visual impact
Contingent Valuation Approach		• Overall environmental quality (air pollution, water pollution, noise pollution, odour) • Living condition (housing quality) • Visual impact • Reduced water quality • Water and soil contamination • Impact on community structure

[1] The term ANSI's stands for Areas of Natural and Scientific Interest, and is adopted from the Environmental Assessment Term of Reference document of Mid-Peninsula Transportation Corridor prepared by MTO (Ontario Ministry of Transportation).

Appendix B: Water Leakage Issues and Background

Because water and energy are basic requirements of life, and their use figures so prominently in contemporary society, it is no wonder that one may appropriately perceive both the water supply and energy networks as the bedrock of civil infrastructure. While easily taken for granted, their vital importance is readily acknowledged when suddenly faced with a profound failure. News events can quickly remind us of our dependence on these usually steadfast and silent facilitators of our economic, social and material well being. Fortunately, acute and celebrated failures such as these have not hitherto occurred with alarming frequency, but when they do happen, they are often accompanied by a soul searching re-examination of the state of these systems and bold pronouncements of a renewed dedication to preserve and maintain our infrastructure. The danger with such reactive measures, though, is that decisions can be made that are visible and immediate in impact, and not necessarily those that are the wisest and most strategic in the long term.

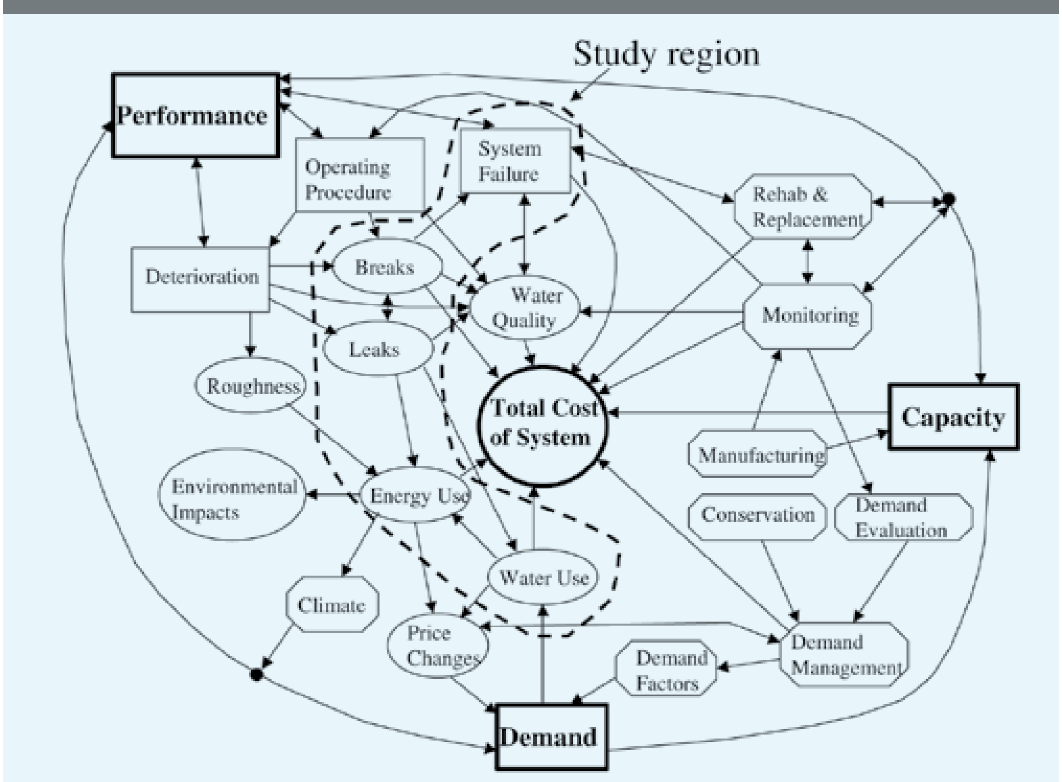
In general, Canadian municipal water distribution systems (WDS) provide a high level of service with amazing regularity. This being the case, is there reason for any serious concern? Curiously, while spectacular failures occasionally push matters to the forefront, it is the day-to-day operation of such infrastructure that may entail the greatest economic, social and environmental burdens. Ongoing inefficiency has a greater impact on total water and energy resource use as well as the financial burden of operating the infrastructure than do infrequent, but large events. Unwanted consequences associated with wasted energy in these systems include needless emissions of greenhouse gases (GHGs) which are responsible for encouraging anthropogenic climate change and other atmospheric pollutants that induce smog, ozone depletion, and acid precipitation. Occupational hazards related to the production, generation and use of energy such as coal mine explosions, oil spills and the compromised health of workers in the energy sector are indirectly increased in some measure when more energy is used and wasted. As infrastructure ages and deterioration introduces new sources of energy inefficiency while exacerbating old ones, the already tight fiscal resources of most Canadian municipalities are put under further pressure. At the moment, for example, provinces are grappling with the problem of underfunded health care and educational systems. Money lost due to poorly performing infrastructure, and inadequately planned infrastructure investment, entails an opportunity cost since these funds could be applied elsewhere, either for more effective infrastructure renewal and repair or other endeavours that serve a higher societal interest like public assistance, education or support for culture.

The activities involved in the design, construction, operation and maintenance of WDS form a network of interrelated processes that could be thought of as a labyrinth, perhaps such as that depicted in Figure 1. Although even a cursory description of the contents of Figure 1 is beyond the limitations of this report, a few elements deserve brief mention here. As presented, the labyrinth is anchored by three fundamental components. The demand for water establishes the need for the system in the first place and is itself derived from a variety of factors including basic life necessity, socio-economic influences and climate. The quantification of this demand determines how much, and what kind of, capacity is required, directly influencing decisions about investments in pipes, pumps, reservoirs and treatment plants. The capacity of the system is determined by physical attributes of the infrastructure (pipes, tanks, reservoirs, pumps) and incorporates installed, reserve, pumping and treatment capacities. Current capacity reflects past investments and deteriorations while future capacity reflects current system augmentation and rehabilitation decisions. The fit between demand and capacity defines overall performance.

Energy Loss Mechanisms

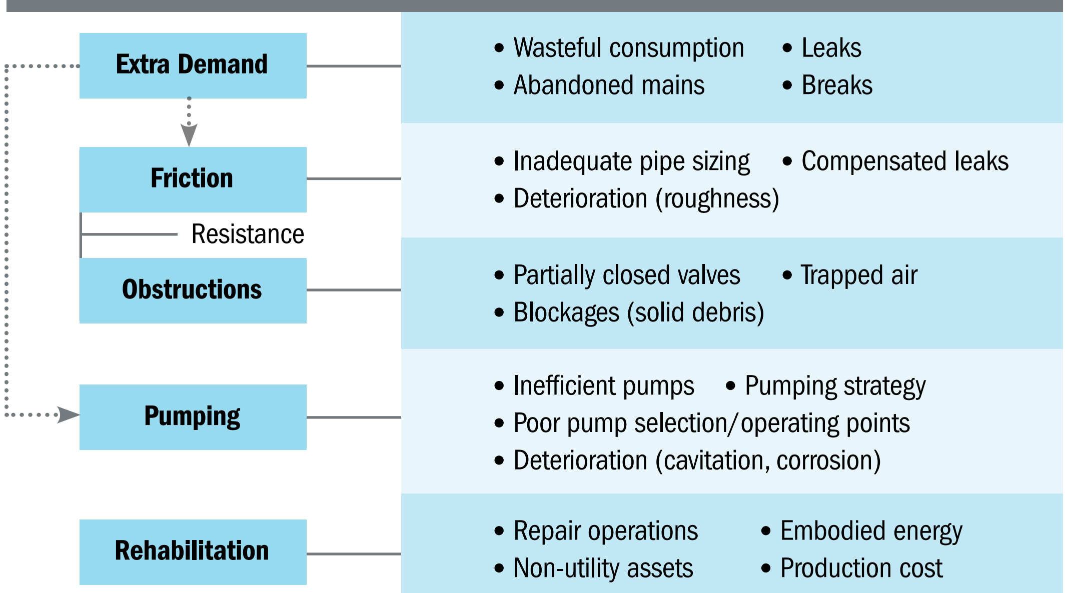
There are several energy loss mechanisms in water distribution systems (WDS). Some mechanisms, like friction and pump selection, are well recognized and have been studied extensively, while others, such as breaks, most types of blockage, repair and replacement operations, and leaks have been inadequately characterized, as have been the interaction of the various subsystems. These less well-appreciated sources of energy loss need to be better understood, with each source of inefficiency being placed into relative context (see Figure 2).

Fig. 1: The Labyrinth of Water Distribution Systems (from Colombo and Karney, 2003)



Deterioration: Deteriorated pipes lead to emergency repairs, wasted water via leaks and breaks, higher friction losses and thus higher pumping costs, and water quality deterioration. Greater friction losses due to aging pipes that become rough are the single largest mode of energy loss in WDS operation. When leaks exist, and customer service is maintained as in a leak free scenario, there is an inevitable compensatory pumping that is required since pumps must feed not only the leak but the original demand as well. Therefore, a larger flow must be transmitted by the system upstream of the leakage location meaning that greater friction losses must be overcome in that portion of the network. In general, the percentage increase in energy use exhibits a greater than 1:1 relationship with leakage as percentage of system demand (Colombo and Karney, 2002).

Fig. 2: Chief Modes of Energy Loss and Inefficiency in WDS



Blockages and trapped air: Obstructions include blockages caused by solid debris as with soil intrusion, immobilized or inadvertently set valves and trapped air. Valves can remain immobilized by infrequent use or lack of "exercising" and can be locked into a partially or completely closed position due to corrosion or accumulation of extraneous debris in the valve seating. Occasionally work crews or system controllers may unintentionally leave a valve at an improper position, forgetting this fact when system operations change or maintenance is finished.

Air in pipes is often poorly managed. It leads to blockage, increased friction losses, greater energy costs, deteriorated performance, and unpredictable or erratic operation. Virtually no system is without some air. The typical estimate for an "air free" system is an air content of about 2 per cent (in a two-kilometre pipe of any diameter this is about 30 metres of air in the column). Air contents of 5–10% have been observed and are not uncommon. Air enters WDS via several mechanisms such as during the filling and draining associated with installation and repair operations, through valves and leaks when low pressures are experienced, as dissolved air, at certain intakes and from transient protection devices such as air chambers. Air can have an unpredictable affect when hydraulic transients are experienced, in some cases attenuating them by reducing wave speed and in others exacerbating them by inducing strong and sudden flow changes at blockage points.

Pumping: Pump stations are often poorly configured and maintained. Modern control approaches, variable speed drives and well-structured maintenance programs could dramatically improve the performance and expense of pump operations. Much research has already been directed to the issues of pump selection and operation and there are already useful guidelines for making effective pump choices. Unfortunately, such guidelines remain frequently ignored. This is in part because system operators must adapt them to specific circumstances and may not recognize how such generalizations translate into individual system specifics. Pumping strategies are typically geared toward taking advantage of time-of-day electricity pricing. Curiously, the lowest financial cost does not always mean the lowest energy use (and hence environmental burden) if the electricity price structure encourages most of the pumping activity in a few short hours per day, incurring greater friction losses (Colombo and Karney, 2005). There is a need to educate system operators about the potential discrepancy between minimum financial expenditure for electricity and minimum energy use and to introduce this trade-off into the decision support framework.

Rehabilitation: As part of emergency repair or routine maintenance, entails certain flows of materials and energy. Some of these are mentioned above in the discussion of breaks. Other aspects of emergency repair include the reparation of damage to nonutility assets such as when a pipe burst floods shops and homes. The rerouting of water through other pipes during the servicing of some part of the system can lead to greater friction losses as fewer conduits carry the same flow through the network. This leads to a temporary alteration of production costs and the energy input regime during the time of rehabilitation.

Energy Recovery: Another peculiar yet intriguing facet of the discussion is the possibility of recovering energy that would otherwise be lost or dissipated. Most systems are divided into pressure zones that exist in order to account for topographical variation over which a network must transport water and are a key tool of pressure management. It occurs, not infrequently, that pressure must be dissipated through pressure reducing valves (PRVs), especially near pressure zone demarcations or downstream of customers situated at high elevations in order to prevent undesirably large pressures in other parts of a system. Recent improvements in microturbine and distributed power generation technology have already opened the door to potentially economic energy recovery in places where hitherto energy would automatically be dissipated with a PRV (Zhang and Karney, 2003). Any energy management strategy that is currently being contemplated should examine the possibility of energy recovery wherever system topology currently necessitates the wasting of energy via PRVs.

Endnotes

[i] Bounds, Peter; Kahler, Jens; Ulanicki, Bogumil (2006). "Efficient energy management of a large-scale water supply system." Civil Engineering and Environmental Systems Volume: 23, Issue: 3, September 1, pp. 209 – 220

[ii] Water efficiency plan (chapter 2) http://www.toronto.ca/watereff/plan.htm

[iii] "Water efficiency plan of City of Ottawa," http://ottawa.ca/calendar/ottawa/citycouncil/pec/2006/02-14/ACS2006-PWS-UTL-0001-EN.htm

[iv] Ontario Sewer and Watermain Construction Association (OSWCA) report (2007.9), "A study of the status of full cost recovery and sustainability of Ontario Municipal Water and Wastewater System" http://www.oswca.org/public/news_and_information/media_room/news_releases/?item=13

[v] Pat McNally, 2009 Water Budget to Board of Control of London (2009), http://ww.london.ca'council/meetingpackages.htm

[vi] City of Guelph Wastewater Treatment Master Plan (2008), guelph.ca/uploads/ET_Group/wastewater/WWTMP/GuelphWWTMP_PAC2_Presentation.pdf

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