NATIONAL GUIDELINES ON UNDERTAKING COMPREHENSIVE ANALYSES OF BENEFITS, COSTS AND UNCERTAINTIES OF STORM DRAINAGE AND FLOOD CONTROL INFRASTRCUTRE IN A CHANGING CLIMATE

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INTRODUCTION

Following more than two years of extensive research and stakeholder engagement, the National Research Council of Canada (NRC) has recently completed the development of a comprehensive resource for practitioners to assist in the development of economic assessments of initiatives aimed at reducing flooding damage to core public infrastructure assets. The overall guidelines which bear the same title as this paper consists of a "main" guideline document supported by several appendices of foundational research, comprising over 700 pages in total.

The guidelines (NRC, 2021) were developed in recognition of the need to harmonize and standardize the assessment of the value of storm drainage and flood control infrastructure initiatives. The benefits provided by these infrastructure initiatives include the value of future avoided damages as well as direct and indirect co-benefits, such as enhanced health, recreational and environmental value. These benefits are compared to the costs associated with the infrastructure initiatives whilst considering the various uncertainties associated therewith, explicitly including those uncertainties associated with a changing climate. While such analyses are not uncommon in Canada, they have generally been limited to large-scale projects or other special situations requiring significant levels of investment and sophistication. In this light, these guidelines are intended to help promote such practices for a broader range of projects and a broader range of jurisdictions with varying degrees of sophistication as well as the quantity and quality of available information relating to their assets.

These guidelines are intended to promote the rational assessment of projects or initiatives, using rigorous analysis through an economic lens such that competing projects or alternatives can be objectively assessed and compared. Concepts such as the time value of money, benefit estimation, life cycle costs, net present value, net benefits, benefit-cost ratios, cost-effectiveness, sensitivity analyses and probabilistic risk assessments are explicitly considered in the guidelines. The application of these concepts is demonstrated through five case studies that span a broad spectrum of project or initiative types as well as scales.

This paper is intended to provide a brief synopsis of the guidelines, and the reader is encouraged to obtain a copy of the complete publicly-available document for additional details.

ORGANIZATION OF THE GUIDELINES

The guidelines are organized into two components: (i) a main body referred to as the Guidelines Document; and (ii) nine appendices consisting of a comprehensive bibliography with over 300 entries followed by a glossary and list of acronyms, the foundational research (discussed further below) and case studies. The Guidelines Document itself provides the reader with brief summaries of the salient findings of the foundational research work, followed by a generalized approach to conducting the economic assessments and relevant information for performing time value of money calculations, estimating benefits and costs as well as assessing uncertainties. As with any such practice, it is evolving in nature and, while the fundamental concepts generally do not change materially over time, the ability to apply these concepts can change as the degree of available information expands and improves. To this end, a brief section dealing with considerations for future work concludes the Guidelines Document.

The extensive foundational research work is summarized as follows (with the relevant appendix titles in bold typeface):

- A **Benefit-Cost Analysis Industry Scan** was undertaken to assess practices across Canada and internationally to identify the state-of-the-art as well as limitations. Included with this work was the review and assessment of several relatively recent applications made to Infrastructure Canada's Disaster Mitigation Adaptation Fund (DMAF) which, in turn, revealed several issues related to the estimation of benefits and application of benefit-cost analyses.

- A thorough review of **Direct & Indirect Long Time Horizon Flood Damages** reports and research studies was undertaken in conjunction with a review of available insurance industry data sets for purposes of estimating benefits (i.e., avoided damages) associated with project or initiatives aimed at reducing flooding. While bottom-up estimation of avoided damages is fairly common, damage estimation considering actual reported losses has not been readily available – insurance industry claim data has been analyzed to support such analysis.

  It is not always sensible or appropriate to apply bottom-up techniques when assessing certain project types or scales. The ability to use insurance industry data allows for top-down assessments and guidance on how this is done is provided in this appendix. Amongst the concepts covered in this portion of the research is that related to the use of damage-probability relationships to derive the Expected Annual Damages (EAD), also referred to as Annual Average Damages (AAD), being an important value in the estimation of the overall present value of damages.

Table 1 provides the results of the assessment of available insurance industry data in relation to the value of sewer back-up. Losses per property may be applied to bottom-up analyses., Aggregate EAD values, to be used in top-down analysis are provided for flood-related losses as well as sewer back-up losses. Additional details are available in the guidelines and its appendices, and it is expected that these values may continue to be refined and updated over time as additional information becomes available.

TABLE 1 – EVENT AVERAGE SEWER BACK-UP LOSSES (PER PROPERTY) AND INSURED LOSS EAD VALUES (CAD 2018)

Jurisdiction	Event Average Sewer Back-up Loss (for bottom-up analysis)	Flood Loss EAD (for top-down analysis)	Sewer Back-up/Water EAD (for top-down analysis
		(Millions)	(Millions)
Canada	$22,300	$819	$376
Alberta	$19,700	$414	$88.8
British Columbia	$8,440	$16.1	$0.752
Manitoba	$8,870	$14.2	$1.83
New Brunswick	$13,300	$7.32	$2.33
Newfoundland and Labrador	$17,400	$10.2	$1.83
Nova Scotia	$13,900	$18.9	$14.2
Ontario	$18,500	$289	$244
Prince Edward Island	$8,500	$0.222	$0.0085
Québec	$9,890	$90.4	$35.9
Saskatchewan	$18,200	$41.8	$15.0

The aggregate EAD values may be scaled down to a municipal- or project-level to estimate existing damages that could potentially be avoided in the future with the new infrastructure under consideration. Details are provided in the case studies.

The appendix **Climate Change & Flood Damage Considerations** addresses issues related to meteorological uncertainties. Potential changes in climate and meteorology have the potential to significantly affect the shape of future damage-probability relationship. This component of the research thoroughly reviews the available literature and data to give the reader a complete reference to consult. One of the important findings of this work was the need to differentiate between short duration meteorological events (typically less than 1 day and often on the order of hours) and long duration climate that ranges from several days to more typically on the order of months, seasons or years. Urban (pluvial) and sewer surcharge-related flooding, where the majority of damages occur, is typically driven by short-duration rainfall events and therefore, these deserve the appropriate level of focus when considering projects at the more common scales of sewersheds and municipalities. Environment and Climate Change Canada (ECCC) data relating to short-duration rainfall trends was assessed in detail and found to (i) generally not show strong overall signs of change in any direction (i.e., up or down), and (ii) have a significant variation that is location-dependent. These observations regarding short duration rainstorms are also corroborated in the literature (Shephard *et al.,* 2014; ECCC, 2020). Methods for considering future climate conditions are reviewed, albeit with varying degrees of uncertainty, and methods for dealing with such uncertainty are also identified.

- It is important to recognize that intangible benefits also accrue with any interventions that reduce the likelihood and consequence of flooding. Accounting for these additional benefits will have the effect of improving the economic assessment of any intervention. The appendix titled **Post-Flood Event Economic, Legal, Social and Indirect Costs** addresses matters related to reductions in property values, human health impacts, population displacement, disruption of (and stress on) municipal infrastructure services, and legal costs. The appendix titled **Post-Flood Event Environmental Impacts** addresses matters related to flood impacts such as erosion, quality of water in the environment, impacts to flora and fauna and greenhouse gas emissions, among others. It is worth noting that it is often difficult, and sometimes impossible to monetize many of these co-benefits. Nevertheless, the process of identifying and (non-monetarily) quantifying such benefits is helpful in striving for a comprehensive economic assessment and may be incorporated into multi-criteria and/or triple bottom line analyses that can accompany the monetarily-based economic assessments.

- The appendix titled **Life Cycle Costs of Storm Drainage and Flood Control Infrastructure** addresses an area where the industry benefits from a considerable amount of data and experience as such assessments, or at least components thereof, are routinely conducted in relation to project selection, construction cost estimation, construction contracting as well as asset management and financial forecasting. In addition to basic guidance on developing cost streams for time value of money calculations, an abundance of cost estimating data and relationships is also provided to facilitate this component of any economic assessment.

- The overall document concludes with an appendix consisting of five **Case Studies** which demonstrate the application of the various concepts and methods promoted in the guidelines. The case studies are largely developed from actual projects of various types, scales and locations in Canada in order to give the practitioner a sense of how such economic assessments may be approached and conducted.

Although the guidelines are the result of specific, deliberate and thorough research, they are not to be construed as a prescriptive approach. Each opportunity to apply them needs to be assessed based on its own particular circumstances, including the degree of importance (i.e., value of initiative considered and/or risk associated with infrastructure in question, including its criticality), the quantity and quality of available information as well as the level of effort to acquire any additional information and conduct supporting technical analyses (e.g., hydrologic and hydraulic modelling, depth-damage curve development, etc.), amongst other matters. To assist the practitioner in identifying how to approach an analysis, a conceptual model is provided in Figure 1.

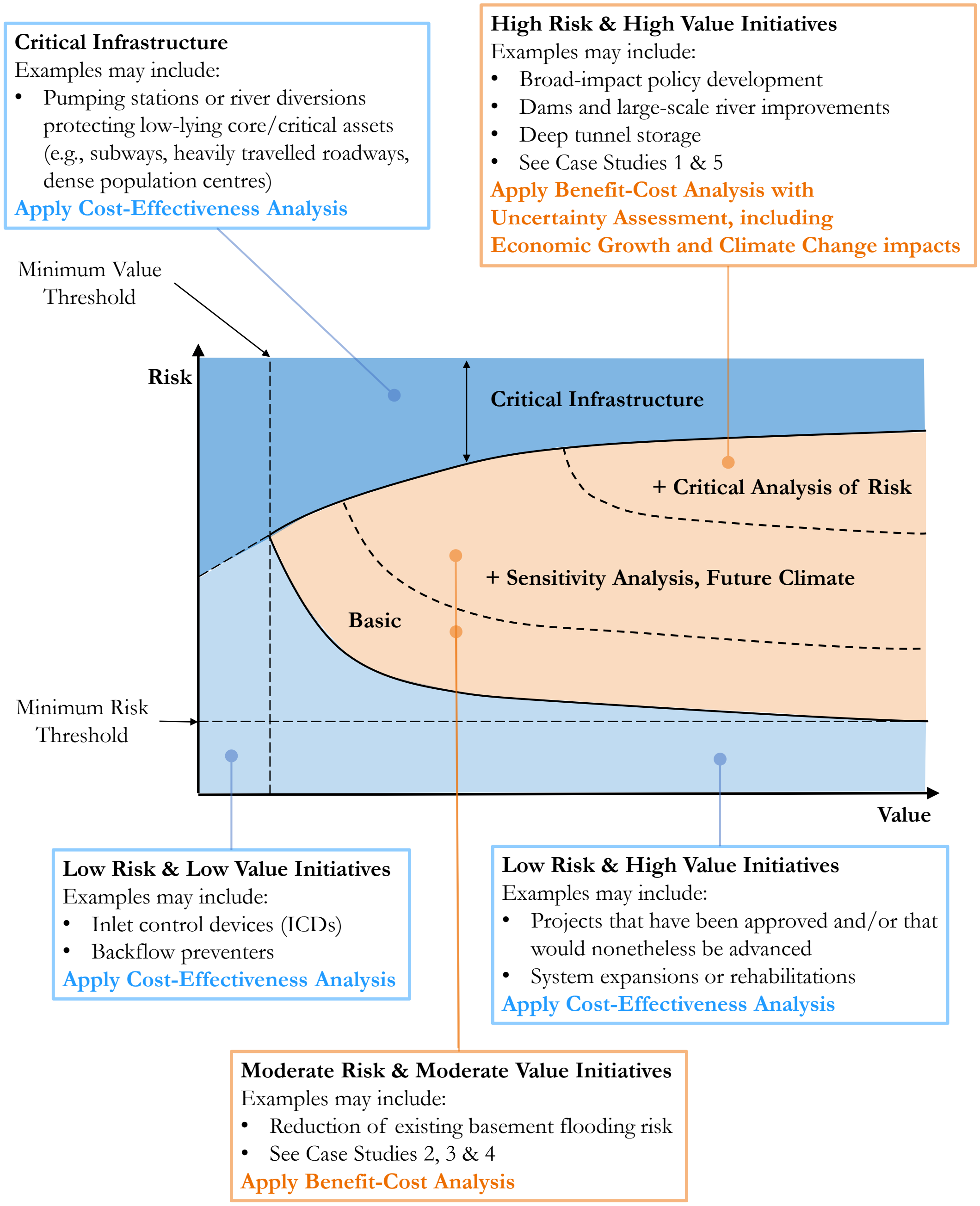

FIGURE 1: CONCEPTUAL MODEL TO IDENTIFY ANALYSIS METHODS TO CONSIDER WITH EXAMPLE APPLICATIONS

EXPECTED ANNUAL DAMAGES (EAD)

As noted earlier, the main benefit of any flood-control measure is the value of the damages this measure is expected to avoid over the duration of its service life. The high uncertainty that is inherent in estimating future damages necessitates a probabilistic approach, where damage from a flooding event is associated with the probability of occurrence of this event. This is illustrated graphically in Figure 2, and involves determining the area beneath each of the damage-probability curves (i.e., both the existing curve and the future, after the improvement project, curve) to arrive at the area between these curves.

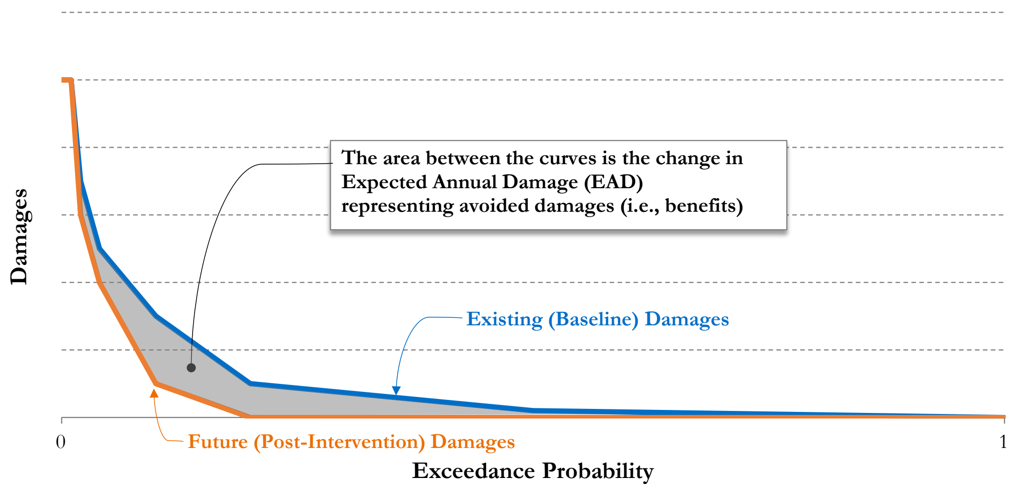

FIGURE 2: CONCEPTUAL CALCULATION OF EXPECTED ANNUAL DAMAGES (EAD) AVOIDED AS A RESULT OF IMPROVEMENT PROJECT

While this calculation seems straightforward enough, it could be complicated by the fact that many relevant factors are not necessarily stationary over time. Matters such as economic growth, representing the real (rather than nominal) value of the properties and assets that are impacted by flooding that can be expected to grow over time as the overall wealth of the society increases. Further, climate change as well as increased urbanization may potentially change the character of the relationship between damage and probability. Changes in the value of assets at risk of flooding (i.e., economic growth) will have the effect of shifting the damage-probability curve vertically (i.e., positive growth will result in an upward shift), while changes in climate, assumed to be represented by changes in rainfall intensities for different return periods (or probabilities of occurrence) will result in a horizontal shift (i.e., increasing rainfall intensities will result in a shift to the right). The combined impact of these changes, as well as how EAD may change over time as a result thereof, is illustrated in Figure 3.

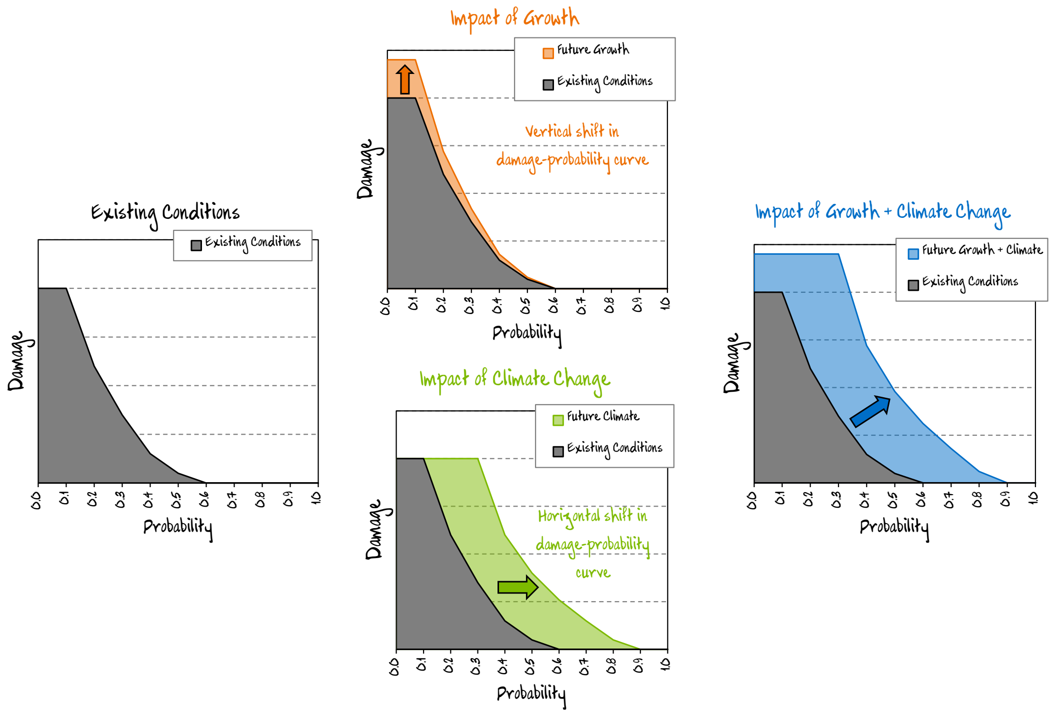

FIGURE 3: CONCEPTUALIZATION OF IMPACTS OF ECONOMIC GROWTH AND POTENTIAL CLIMATE CHANGE ON FUTURE DAMAGE ASSESSMENT

ASSESSING UNCERTAINTY

A good forecaster is not smarter than everyone else,
he merely has his ignorance better organized.
- Anonymous

It is extremely important to acknowledge, understand and explicitly consider the uncertainties inherent in any analysis, particularly given the scale of investment and potential damage implications associated with storm drainage and flood control infrastructure. Ignoring these uncertainties may result in significant under- or over-investment, yielding poor returns on investment and depriving society of value by wasting resources that could otherwise be deployed for other, more valuable, infrastructure improvements. The impact of neglecting to account for uncertainty is magnified by the extremely long service life of these infrastructure assets – typically in the order of 75-100 years.

Uncertainties exist in relation to the estimation of baseline benefits and costs, as well as in relation to potential changes in the benefits of avoided damages associated with economic growth and potential climate change impacts. Additionally, the assumptions applied for the time value of money calculations, including the discount rate and time horizon, may play meaningful roles in changing the economic outlook of a project.

The guidelines identify various methods for assessing uncertainty, including the relatively simple application of sensitivity analysis and, as a subset thereof, stress tests. Both of these types of analyses have been adopted by various jurisdictions to help identify vulnerabilities in existing or proposed infrastructure systems and allow for the allocation of additional costs and efforts only where they are most needed. A more sophisticated method of dealing with uncertainty covered in the guidelines include the application of the probabilistically-based Monte Carlo analysis, where probability distributions for each of the uncertainty-bearing parameters can be developed and applied to produce a probability distribution for the output (e.g., benefit-cost ratio or other outcome sought through the analysis).

The guidelines also contain a discussion of Real Options Analysis, which is expected to be particularly relevant to the intended audience given the potential scale of investment required for certain projects aimed at reducing flooding. This approach focuses on adaptability and incorporates the ability to incorporate information as it becomes available to help decide on the appropriate next step. It limits possible over-investment that may result from high uncertainty, which in turn leads to over-estimation of the severity of future conditions, whilst not constraining the ability to implement the investment when supported by the then available evidence. This approach bears a strong resemblance to the Observational Method of the American Society of Civil Engineers (ASCE) in relation to the adaptive design and risk management of infrastructure for climate resiliency (ASCE, 2018). It is a practical approach and is typically practiced in a less formal manner, although there is merit in formalizing (and documenting) such assessment processes to promote a comprehensive consideration of influencing matters as well as for purposes of communications, both when the analyses are occurring periodically over time, as well as across time periods. The *Canada in a Changing Climate: National Issues* report (Government of Canada, 2021) identifies Real Options Analysis as one main approach for accommodating uncertainty in the economic appraisal of adaptation actions.

CONCLUSIONS

The development of a national set of guidelines to undertake comprehensive economic assessments of storm drainage and flood control infrastructure is intended to promote, advance and to some extent harmonize and standardize such practices across Canada and at various levels of implementation. The guidelines, supported by extensive foundational research, represent a comprehensive reference for practitioners in assessing the value of initiatives that may be considered, including the consideration of uncertainties (including those related to potential climate change impacts), such that competing projects and project alternatives can be objectively and rationally assessed so as to inform decisions and promote the judicious allocation of investment capital. In many ways, these guidelines represent somewhat of a renaissance of the application of classical engineering economics in relation to matters that are of current relevance and in light of the vast (and growing) amount of information and tools available to inform these assessments.

BILBIOGRAPHY

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