Potential Impacts of Climate Change on Stormwater Management

by
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Abstract
This paper provides an overview of the potential impacts of climate change on stormwater management practices in southern Ontario. A synopsis of the recent (2007) findings of the United Nations Intergovernmental Panel on Climate Change, the IPCC, is presented to illustrate both the anticipated changes in climate, in terms of precipitation, temperature, and event frequency, as well as the uncertainty associated with climate change projections. Although large uncertainties are associated with all climate change projections, the 2007 IPCC results indicate that in southern Ontario over the next century, average annual temperatures will increase more than the global average, total annual precipitation will increase, and the number of dry-days will increase marginally. Therefore, less frequent, more intense rainfall events are a distinct possibility in the near future.

Evaluating the implications of potential climate change on stormwater management requires an understanding of historical stormwater management practices. Prior to about 1970, the principal problem was increased runoff volumes in developing areas and the solution was to rapid drainage. Between 1970 and 1990, downstream flooding and erosion were the key problems and constructed storage was the popular solution, while from 1990 to the present, water quality impacts, as well as flooding and erosion concerns were addressed using a wide range of urban BMPs. For the future, the emphasis appears to be on achieving a post-development water balance that is consistent with pre-development conditions.

Based on anticipated climate change, it is reasonable to assume that pipe diameters and storage volumes will need to increase. However, other externalities and non-climate related issues must be considered as well. For example, aging infrastructure, population growth, and changing public perceptions and expectations may all impact stormwater management to an extent equal or greater than climate change.

In general, existing design criteria and methodology need to be re-examined in light of potential climate change. In many cases, current approaches do not reflect advances in science or best available technology, and therefore climate change should be addressed as one of several uncertainties.

Stormwater design criteria should be explicitly related to uncertainty or risk as is common in other design fields of civil engineering. Furthermore, some consideration to adaptive planning and design, providing some overcapacity for example, may represent a prudent additional measure.

Introduction

On an almost daily basis, media reports highlight the perceived dangers of climate change. We are reminded constantly that the earth's climate is in a state of flux and, according to these reports, the single most important contributing factor is anthropogenic contributions of green house gases. The extent to which our climate will change remains a subject of considerable debate, and the degree to which humans have influenced this change is an equally controversial topic. Importantly, the recently published work of the Inter-Governmental Panel on Climate Change, the IPCC (2007), provides a comprehensive synopsis of expected climate change and concludes that global average temperature will, on average, increase. However considerable spatial variability in this temperature increase is anticipated. Despite the uncertainties surrounding the available opinions, scientific and otherwise, there appears to be consensus among the scientific community in Canada that anthropogenic sources of green house gases will contribute to future increases in the global average temperature.

The principal goals of this paper are to:

- review the findings of the IPCC research and determine the expected climate change for southern Ontario,
- review historical stormwater management practices in southern Ontario and determine the potential impact of climate change on future stormwater management, and to
- develop stormwater management recommendations to address anticipated climate change.

Recent Findings of the IPCC

The intergovernmental Panel on Climate Change, or IPCC, was organized by the World Meteorological Organization (WMO) and the UN in the mid eighties with a mandate to provide member countries with an objective assessment of climate change. The IPCC is not a research organization; rather it is tasked with providing concise interpretations of world-wide research and scientific investigations related to climate change. The IPCC organization includes three main working groups.

- Working Group #1 is tasked with assessing the physical scientific aspects of the climate system and climate change,
- Working Group #2 is tasked with assessment of the vulnerability of socio-economic and natural systems to climate change.
- Working Group #3 is responsible for assessment of options for mitigation of climate change through limiting or preventing greenhouse gas emissions.

With respect to this paper, the recent findings of the Working Group #1 were examined (Climate Change 2007 – The Physical Science Basis). Although the IPCC work provides a global perspective and this review focused on the findings relevant to North America, and southern Ontario in particular. A summary of the relevant IPCC findings is provided below.

Role of Greenhouse Gases

Greenhouse gases play an important role in regulating the earth's climate. In general, greenhouse gases absorb long wave radiation from the earth's surface and reflect it back to the surface or out to space. As such, the earth's temperature is moderated by the presence of greenhouse gases. Greenhouse house gases include a number of

compounds including methane, nitrous oxide and carbon dioxide; however carbon dioxide represents the most significant component. The concentration of atmospheric carbon dioxide has remained reasonably stable over the past 10,000 years, as determined by analysis of polar ice cap and ocean sediment coring (IPCC 2007) as illustrated in Figure 1 below (IPCC, 2007).

The sharp rise in atmospheric carbon dioxide illustrated in Figure 1 during the last 100 years or so, rising from about 280 ppm to over 380 ppm, an increase of over 35%, is believed to be the result of anthropogenic sources. This relatively rapid increase in atmospheric greenhouse gases is the driving force behind most climate change forecasts. Although similar changes in atmospheric carbon dioxide concentrations have occurred, between 18,000 and 10,000 years ago for example, the time required for such a change is considerable longer. Interestingly, the rise in atmospheric carbon dioxide that began roughly 18,000 years ago is coincident with the recession of the last ice age and a general global warming. However, other factors are important with respect to ice ages, such as the natural changes in both the earth's angle of rotation and the minor axis of the earth's orbit around the sun. Climate change is not a new phenomenon, but the recent change in atmospheric carbon dioxide concentration is unprecedented and, as demonstrated by IPCC's report, is likely to result in climate change.

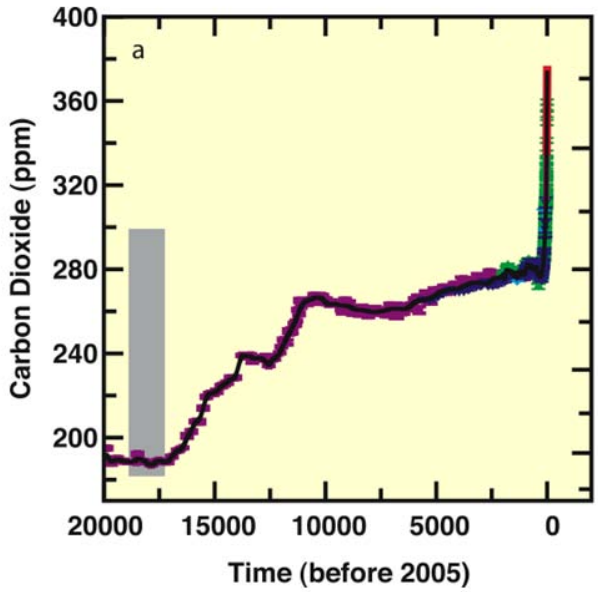

Figure 1. Historic Atmospheric CO_2 Levels
(IPCC Working Group 1: Climate Change 2007 – The Physical Science Basis)

Trends in Temperature

The IPCC publication provides a synthesis of the results from numerous scientific contributors and identifies probable changes in precipitation and temperature, both spatially and temporally. Generally, the climate change forecasts extend to the year 2,100, and the spatial resolution is reasonably coarse, with North America being split into four distinct regions. The region identified as Eastern North America, or ENA, extends from central Ontario to as far south as Florida. Figure 2 illustrates the IPCC summary of predicted increases in temperature for the area referred to as ENA. As illustrated, average annual temperatures for this area are expected to rise between 2 and 5 C^o. Clearly, some considerable uncertainty is associated with the forecast and, as illustrated in Figure 2, uncertainty increases with time.

All forecasts presented in the IPCC document are qualified as being either likely (greater than a 66% probability) or very likely (greater than 90 % probability). In addition to the predicted average annual temperature increase, IPCC (2007) provides the following predications with respect to temperature in the ENA area.

- The annual mean warming is *likely* to exceed the global mean warming.
- Seasonally, warming is *likely* to be largest in winter.
- Minimum winter temperatures are *likely* to increase.

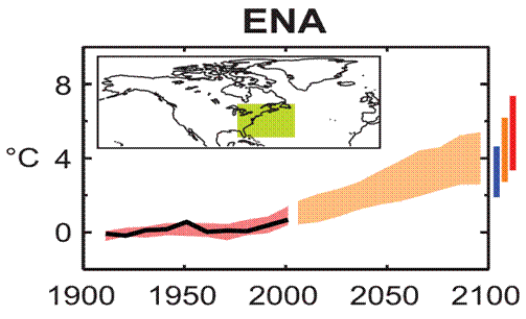

Figure 2. Predicted Changes in Average Annual Temperature for Eastern North America
(IPCC Working Group 1: Climate Change 2007 – The Physical Science Basis)

Increases in temperature will impact precipitation, as discussed below and winter snow pack, which in turn may have consequences on urban drainage systems.

Trends in Precipitation

Global average changes in temperature, arising from significant increases in atmospheric green house gases, result in changes in precipitation. However, the impact on precipitation varies spatially, both in terms of total precipitation and intensity. Forecasts of precipitation changes are based, in part, averaging the results of several global climate models, or GCMs, that provide numerical approximations of atmospheric and oceanic circulation. The sophistication and complexity of GCMs has increased over the years and a brief illustration of increased model resolution is provided in Figure 3 (IPCC 2007). As illustrated in Figure 3, model complexity has increased significantly over the past 20 years, and presumably model capabilities have improved with corresponding improvements in reliability of model predictions.

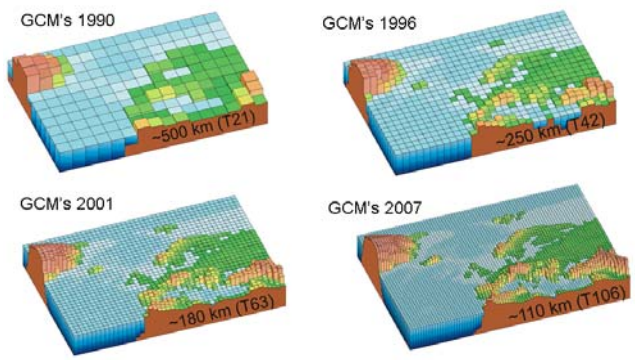

Figure 3. Changes in GCM Resolution over the Past 20 Years
(IPCC Working Group 1: Climate Change 2007 – The Physical Science Basis)

With respect to changes in precipitation in North America, Figure 4 presents the IPCC summary of expected changes in precipitation intensity over the next 100 years. In this illustration, precipitation intensity (the ration of annual precipitation to number of wet days) is expressed in normalized standard deviation units, rather than an absolute rate. Figure 4 was developed using the results of numerous GCMs developed and operated by independent scientific agencies. The areas of Figure 4 covered with dots represents areas where more than 50 % of the numerical models were in agreement. Rigorous quantification of the expected change is not the focus here; rather, the goal is to determine the expected direction of change. As indicated on Figure 4, most of the GCMs were in reasonable agreement regarding expected change in southern Ontario, and the ratio of annual precipitation to number of wet days is expected to increase.

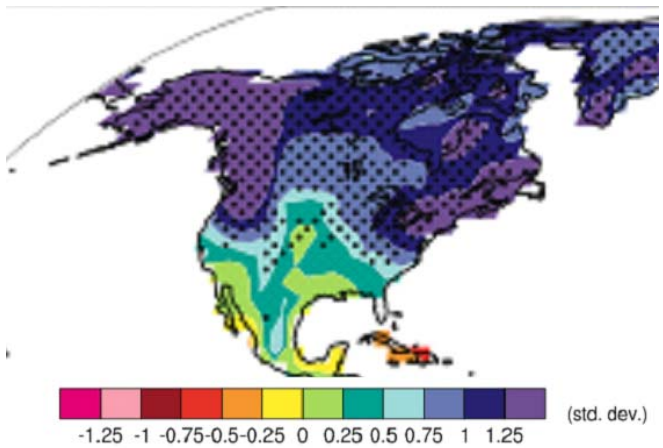

Figure 4. Expected Changes in the Ratio of Annual Precipitation to Number of Wet Days in the Year 2100

(IPCC Working Group 1: Climate Change 2007 – The Physical Science Basis)

A similar illustration prepared by IPCC examining the expected change in the average number of drought days per year, over the next 100 years, is provided in Figure 5. As illustrated, little change is expected in the number of drought days per year in southern Ontario. In addition, the IPCC publication indicates that annual mean precipitation in Canada will very likely increase.

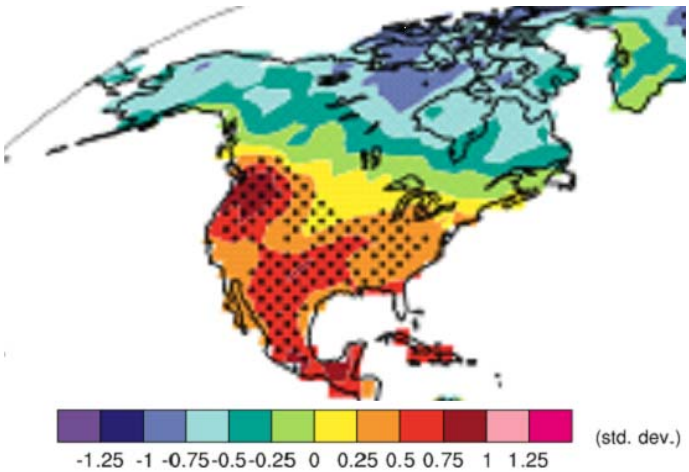

Figure 5. Expected Changes in the Average Number of Drought Days Per Year 2100

(IPCC Working Group 1: Climate Change 2007 – The Physical Science Basis)

The combination of increased ratio of precipitation to number of wet days, (Figure 4), little change in the number of drought days (Figure 5) and an expected increase in

annual precipitation indicate that frequency of relatively intense rainfall may increase. This general conclusion provides a basis for moving forward and considering the implications of expected climate change in southern Ontario on stormwater infrastructure. Importantly, this result is approximate and no specific information has been derived with respect to expected changes in intensity-duration-frequency, IDF, curves, commonly used for design purposes. Indeed, the results summarized by the IPCC are not sufficient for defining changes to IDF curves. The level of model uncertainty, and the resolution of the numerical tools, is not adequate to support detailed predictions regarding IDF curves. However, general trends, such as the expected increase in more intense precipitation events are generally supported by the IPCC summary reports.

Stormwater Management - Historical Perspective

The urban infrastructure in place in Canada today, and for the foreseeable future, reflects the approaches to managing urban stormwater over the last 100 years. Furthermore, the approach adopted today is likely to be utilized for the next decade or more because of the inertia in urban water resources policy and management.

The history of stormwater management in Canada is characterized by three eras in which both the 'problem' and the 'solution', in terms of stormwater infrastructure, varied. The existing stormwater infrastructure reflects this history so that some municipalities with nineteenth century neighbourhoods still have combined sewers and, at the other extreme, new developments in some municipalities have urban stormwater best management practices (BMPs) such as extended detention ponds. The majority of urban stormwater infrastructure lies between these extremes and is dominated by storm sewers.

- **The Storm Sewer Era (~1880-1970)**
  From about 1880-1970, the solution to the problem of increased volumes and flows of urban stormwater was the provision of a sewer network which transported stormwater from upstream urbanized areas to downstream receiving waters—creeks, rivers, lakes and oceans. Design criteria included prescribing a design rainfall input of specified return period, usually in the range of 2-10 years (occasionally up to 25 years), and a procedure (the rational method[1]) for computing the peak flow resulting from this rainfall over a duration equal to the time of concentration. Pipes were sized to convey these peak flows. The benefits of the storm sewer solution included minimal local flooding except under extreme storm conditions. However, as urban areas grew significantly, the costs of large collector sewers and erosion control measures increased. Generally, the cost of pollution of receiving waters was not recognized over most of the storm sewer era.

- **The Stormwater Management Era (~1970-1990)**
  Through the 1970s and 1980s, increased volumes and flows were treated via two additional means: a) stormwater ponds within or at the downstream end of the storm sewer network and, b) explicit consideration of the major system to convey flows which exceed the capacity of the minor system (pipes and ponds). Design criteria included the prescription of a design storm input for each of the minor and major systems and a restriction on post-development flows - in general, these could not exceed pre-development flows under design storm conditions. Specified return periods were typically 2–10 years for the minor system and 100 years for

the major system. Design procedures included the use of urban runoff models with design storm inputs for computing the flow at any time and point in the system. Pipes and ponds were sized to convey and store these flows. Relative to the *storm sewer era*, stormwater management solutions minimized local and downstream flooding, reduced the cost of sewers in many cases and provided waterfront property around the stormwater ponds. However, long-term costs, including those for pond maintenance and erosion control downstream of the ponds, remained. Although pollution of receiving waters was generally recognized in this era, the cost was not explicitly considered in the design process.

- **The Urban Stormwater BMP Era (~1990-2007)**
  Since about 1990, concerns over the residual problems associated with stormwater management, and especially deteriorating water quality, have led some jurisdictions into the urban stormwater best management practices (BMP) era where the problem is expanded to include the quality as well as the quantity of stormwater. The solution is extended to include a wide range of urban stormwater BMPs such as extended detention ponds, infiltration basins and trenches, porous pavement, sand filters, water quality inlets and use of vegetation. Additional benefits of the BMP solution (over the stormwater management solution) include reduced erosion and improved water quality in receiving waters; however, these are offset somewhat by additional maintenance costs.

- **Future Directions (~2008 – 2050)**
  As illustrated above, stormwater management over the past 130 years has not been static; there is no reason to expect that the "ultimate solution" has been attained. Emerging approaches as of 2008 include attempts to preserve the water balance and stormwater reuse.

Implications of Climate Change

- **General**
  The sensitivity of urban stormwater infrastructure to changes in climate depends in part on the magnitude of the expected change. The sensitivity is also a function of the type of infrastructure: transmission structures (e.g., gutters, ditches, pipes, streets, channels, swales, urban creeks, and streams), management structures for quantity control (e.g., roof tops, ponds, urban lakes, and infiltration devices), storage structures for quality control, and CSO abatement structures.

- **New SWM Infrastructure**
  The scope of almost all elements of any stormwater management system should expand with increased rainfall. However, even with certain knowledge of increased rainfall, there can be no guarantee that this knowledge will be incorporated into stormwater management or storm sewer guidelines issued by provincial or municipal government agencies. There has been and continues to be a great deal of inertia in urban stormwater policy and design. It remains a challenge to encourage all Canadian provinces and municipalities to use the existing historical rainfall database in their design guidelines, let alone accommodate potential shifts in climate.

- **Maintenance of Existing Stormwater Management Infrastructure**
  Additional maintenance of existing infrastructure may be necessary should the rainfall regime over the service life of the structure become more severe than that for which the structure was designed. For both quantity and quality control type storage structures, modest increases in rainfall severity (e.g. 15 %) may force more frequent maintenance. However, given the limited experience and information available, it would be difficult to quantify the expected increase and associated costs. Similar comments apply to the increase in maintenance for CSO abatement structures, although it is possible that the performance of CSO facilities could decrease, perhaps to a level that CSO objectives are not met. Overall, uncertainties notwithstanding, the maintenance of existing stormwater infrastructure is expected to be relatively insensitive to the impacts of modest changes in climate.

- **Retrofitting of Existing Infrastructure**
  Retrofit is the alteration of existing infrastructure to meet revised design criteria as a result of increased flows and/or revised policies and guidelines. For example, a storm sewer system may need to be retrofitted to meet new stormwater management guidelines or quality standards for receiving waters. Relative to new infrastructure and maintenance, more uncertainty exists for retrofits, where the unknown magnitude of potential increases in rainfall and unit impact is compounded by uncertainty related to the number of units to be retrofit. This last item is much more difficult to predict than the number of units of new infrastructure.

  In view of changing criteria for stormwater infrastructure, and the difficulty of retrofitting underground infrastructure, it seems rather unlikely that what might be regarded as one more step in the evolution of design criteria—climate change—would result in any significant amount of retrofitting. However, when retrofitting is carried out for other reasons, the potential impacts of climate change could and should be incorporated into the design criteria. In many cases, this would involve detailed modelling of the existing system and the proposed retrofits.

- **Externalities**
  Not all of the costs of urban infrastructure are borne by municipal governments. Individual property owners and insurance agencies incur occasional repair costs due to flooding (both ponding and shoreline) and erosion. In addition, provincial agencies have spent large amounts of money on flood and erosion control projects to protect both private and public property. The frequency of events that overload the system causing such flooding and erosion damage may rise with increased rainfall. How frequently such events would occur, if at all, in the lifetime of an average property owner would depend on the event return periods for specific as-built drainage systems.

  Environmental impacts are considered in the selection and design of urban stormwater systems, but more as a ‘fuzzy’ constraint than a cost and thus essentially remain external. These impacts could become more severe under conditions of increased rainfall. Stream morphology for undeveloped, developing and fully developed urban areas, may also change and hence affect existing outfall structures and potential pond locations. In addition, some of the impacts listed

above are temperature-dependent and could be exacerbated under warmer conditions. For example, an important issue in some locations is the temperature regime of stormwater ponds and receiving waters and the resulting implications for water quality. Changes in this temperature regime resulting from climate change may influence pond sizing, design or location. Other environmental impacts relate to loadings of particular contaminants and human activities that are sensitive to climate—for example the use of road salts for winter highway maintenance (Environment Canada and Health Canada 2000).

- **Impacts of Non-climatic Factors**
  The current state of stormwater infrastructure in Canada, in terms of type (pipes, ponds, BMPs), adequacy, age, and maintenance history, is extremely varied, as are estimates of future states. Climate change could be viewed as just one more source of uncertainty. However, it is a very important one because the pipes being put in the ground today will likely still be in service 100 years from now. Other factors that may have impacts of similar or greater magnitude than climate change include the following:
  - a long-term trend in the deterioration of existing infrastructure through benign neglect and the possibility that funding priorities may change and possibly reverse this trend;
  - population growth and the requirement for urban stormwater infrastructure to meet the standards of the day;
  - new models for financing urban infrastructure (see Cameron *et al.* 1999);
  - new provincial standards for licensing stormwater loadings;
  - new models for water pricing;
  - evolving public attitudes toward the natural environment;
  - changing public expectations with respect to performance of the built environment; and
  - increased influence (and responsibility) of local municipal government relative to senior levels of government.

Assessments of potential climate change impacts ultimately need to consider the evolution of these non-climatic factors and their role in exacerbating or ameliorating the effects of climate change alone.

Strategies to Address Climate Change Impacts
Planning and Design

- **Examine Design Criteria and Methodology**
  Design return periods have not changed in many years and may not reflect current or future risk of damage. Also, in many cases, methodology does not reflect advances in science or best available technology. The implications are that designs based on a stationary climate may be far from optimal. It would be prudent, there fore to critically review existing design criteria and methodologies before considering adjustments for climate change.

- **Climate Change Viewed as an Additional Uncertainty**
  The potential impacts of climate change could be viewed as one of several uncertainties. Other uncertainties include future population growth, new standards, new financing models, changing public expectations, evolving attitudes towards the natural environment.

- **Relate Design Criteria to Uncertainty**
  In other civil engineering fields, design criteria are explicitly related to uncertainty (e.g. safety factors). However, in stormwater management, design criteria are fixed regardless of uncertainty level. Valid question are "Why?" and "Is this state of affairs appropriate?" Considering only the design return period, a more defensible approach would be to state a minimum value for use where all uncertainties (including climate change) were essentially zero and then a series of safety factors, with increasing values for increasing uncertainty. The base case and the safety factors would be determined through a comprehensive risk analysis.

- **Consider Adaptive Planning and Design**
  Insofar as possible, flexibility should be maintained in both the planning and design stages of the work so as to minimize uncertainty due to all sources. This approach will facilitate revision of design criteria as situations evolve and the revision of plans as design criteria and methodology evolve. Finally, some overcapacity should be provided as a hedge against increased rainfall.

Summary

1. Relatively large increases in atmospheric carbon dioxide will result in an increase in the global annual mean average temperature. As a result, in southern Ontario, more intense, less frequent rainfall events are likely.
2. The type of urban stormwater infrastructure in Canada has evolved from combined sewers to separate storm sewers to (sewer + ponds) to (sewers + ponds + a wide range of urban stormwater BMPs). As a result, the existing urban stormwater infrastructure in Canada generally includes a range of systems from combined sewers to BMPs, with the former being more prevalent in older (pre 1945) districts and the latter in new subdivisions/districts.
3. The most probable hydrometeorological impact of climate change relevant to urban stormwater infrastructure is an increase in the magnitude and frequency of heavy rainfalls. For existing systems, this increased rainfall will produce increased storm runoff and an increase in negative environmental impacts.
4. Implications of climate change should be addressed in system configuration and type, design of new infrastructure, retrofit of existing systems and maintenance.
5. Uncertainties due to non-climatic factors, externalities and climate change should all be considered in stormwater management and design.
6. Strategies to reduce adverse impacts of climate change include examination of design criteria/methodologies, treating climate change as one uncertainty, relating design criteria to uncertainty and adaptive planning and design.

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