Adapting to Climate Change - An Open Data Platform for Cumulative Environmental Analysis and Management

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Technical Report CS-2015-06

Abstract. The frequency of extreme weather events has accelerated, an apparent outcome of progressive climate change. Excess water is a significant consequence of these events and is now the leading cause of insurance claims for infrastructure and property damage.

Governments recognize that plans for growth must reflect communities' needs, strengths and opportunities while balancing the ***cumulative effects*** of economic growth with environmental concerns. Legislation must incorporate the cumulative effects of economic growth with adaptation to weather events to protect the environment and citizens, while ensuring that products of growth such as buildings and infrastructure are resilient. For such a process to be effective it will be necessary for the private sector to develop and operate cumulative effect decision support software (CEDSS) tools and to work closely with all levels of government including watershed management authorities (WMAs) that supply environmental data. Such cooperation and sharing will require a new ***Open Data*** information-sharing platform managed by the private sector. This paper outlines that platform, its operation and possible governance model.

Keywords: climate change, open data, environmental analysis, cumulative effects, software platform

1 Introduction

The frequency of extreme weather events has accelerated over the last decade. Although excess water is one of the significant impacts of these weather events and is the leading cause of insurance claims for infrastructure and property damage [10, 11], lack of water can be just as problematic. Prolonged periods of drought can limit our access to drinking water and impair agricultural production, while also changing the landscape ecosystem, encouraging invasive species and putting terrestrial species at risk.

Economic development such as construction of buildings and infrastructure, and resource development modifies the landscape and its response to extreme weather. Economic development is ***cumulative***, as changes in one area will at a minimum impact adjacent areas if not further afield. Thus, planning for adaptation to weather events must recognize these ***cumulative effects*** [4, 12].

Many governments acknowledge that plans for growth must reflect the needs, strengths and opportunities of the communities involved while balancing economic needs with environmental concerns [5, 6]. The essential element of balancing the economy with environmental issues must be embodied in legislation that governs how the land is developed. Such statutes must reconcile environmental concerns and the ***cumulative effects*** of economic development to:

- Protect the environment; and
- Ensure that the products of growth such as buildings, infrastructure and resource development
  - are durable and resilient to the impacts of climate change; and
  - have sustainable environmental impact.

For such a process to be effective it will be necessary for the private sector to develop and operate cumulative effects decision support software (CEDSS) tools and to work closely with all levels of government, including watershed management organizations (WMAs) and other parties that supply environmental data. Such cooperation and sharing will require a new **Open Data** information-sharing platform managed by the private sector but with the full cooperation of the public sector and associated NGOs in supplying and maintaining appropriate **Open Data**. This paper outlines such an information platform, its operation, a governance model and benefits to both the public and private sectors.

2 Why an Open Data Platform?

Currently the private sector works with data from government and WMAs, so why is there a need for an Open Data platform to assess environmental impacts and propose remediation solutions? To answer this question we should first examine the process that is currently followed and discover its deficiencies. Then we can illustrate a new form of cooperation between the public and private sector that will be far more effective in addressing issues related to the interactions between the cumulative effects of economic growth and the environment.

2.1 Current Processes for Environmental Impact Analysis

How is environmental impact analysis conducted currently? The following steps outline the process for a specific geographic area.

1. Identify the modelling procedures that are required.
2. Find or develop the modelling tools to implement the procedures.
3. Acquire the necessary mapping and environmental data from all the different government agencies and WMAs for the analysis and simulation.
4. Do the analysis and simulation and prepare a report.

What happens to the tools and data that have been gathered and generated for the analysis and simulation relating to a specific land use change, development or infrastructure plan? Typically a report is produced and the data used to generate the report are stored in a computer system or a desk drawer. The next time a similar analysis or simulation is required the process is repeated, all the data are assembled again and the raw results of the original analysis and simulation are not accessible. Thinking of the cost of repeating all these operations, it is clear there must be a better way. In addition, because the results of previous analysis and simulations are not available it is impossible to show the cumulative effects when projects changing the environmental landscape build upon one another.

2.2 New Ways to Gather, Maintain and Analyze Environmental Data

The issues just described give rise to a number of questions including:

- Can mapping and environmental data from the different government agencies and WMAs be assembled and stored in an accessible Open Data platform?
- Can an accessible suite of analysis and simulation software tools often called cumulative effects decision support software (CEDSS) be provided?
- Can results from previous analyses be captured so that future analyses can build upon previous results showing cumulative effects?

If we could answer these questions positively, then we could ensure that current cumulative data and the tools representing the latest available science and engineering practice are being used in environmental analysis and modelling. Current government policies and existing information technologies can support this wide accessibility of existing data, cumulative data and CEDSS tools. In fact answering the first question alone would reduce the cost of any analysis and simulation exercise by eliminating repetitive data gathering.

Governments and agencies such as WMAs are adopting Open Data policies. Open Data is based on the concept that certain data should be freely available to everyone to use and republish as they wish, without restrictions from copyright, patents or other mechanisms of control. However, republishing does imply citing the original source, not only to give credit, but to ensure that the data has not been modified or the results misrepresented [2].

Current technologies such as web-based and mobile cloud computing services provide the ability to access both Open Data and the latest CEDSS tools. Instead of each organization assembling data and acquiring software tools such as CEDSSs, organizations can access a common pool of data and tools. Users of a web-based cloud system will also be able to store the results of running a CEDSS in the cloud system. Thus, the next uses based on the same geographic area will have access to the latest results and will be able to show the cumulative effects of economic development.

2.3 Challenges to Governance and Operation

Building such a web-based cloud system is technically feasible and would provide substantial benefits to any organization that needs to model and understand specific environmental behaviour. However, this is a new model of operation and requires answers to several key questions including:

- How will the web-based and mobile cloud system be operated?
- How will policies be set for the operation of this cloud system?
- Who will supply and maintain the Open Data?
- Who will supply and maintain the CEDSS software tools?
- What is the pricing model for the services provided?
- How does a web-based and mobile cloud system scale so as to become operational for a significant portion of a geographic area?

The answers to many of these questions require different modes of operation involving both the private and public sectors. Business is likely to supply the software tools and build and operate the web-based and mobile cloud infrastructure, while governments and NGOs such as WMAs, will supply the data and ensure that the results are properly applied by the parties involved.

The next sections of this paper explore how this web-based and mobile cloud system might be started and grow into a viable, sustainable operation. The paper starts by describing the architecture of the CEDSS web-based and mobile cloud and then its initial operation. Then the paper presents a partial road map for growth of the operation into wider jurisdictions.

3 Making Environmental Data Accessible

Making data easy to store and maintain while making it accessible is critical. Could we find a way to:

- assemble and store accessible mapping and environmental data; and
- accumulate results from previous simulations to show cumulative effects?

Such an approach would reduce the cost of any analysis and simulation with CEDSS tools and make it easier for organizations with fewer financial resources to participate.

Fortunately, the Internet and Web provide connectivity for access and the new cloud structures provide accessible, scalable and inexpensive processing and storage. Mapping and environmental data can be stored so that it is accessible through an Open Data storage mechanism. Not only maps and data collected from direct measurement of the environment, but also the results of running CEDSS tools would be accessible. Future studies could cumulatively build on the results of current work.

Instead of each organization assembling data and acquiring software tools such as CEDSSs, organizations can access a common pool of data and tools. Members of each organization will have to understand the data, keep the data current, and be able to use the tools, but will no longer have to maintain the database and the software. This maintenance will be performed for the cloud system by the "cloud staff."

The remainder of this section provides a detailled description of how such an Open Data platform could be structured.

3.1 The Structure of the Cloud

The authors' organizations are cooperating to design, implement and deploy an initial version of a web-based and mobile cloud for environmental impact analysis called an Integrated Science and Watershed Management System (ISWMS^{TM}). A version of the system is shown as three layers (Open Data & Other Data Sources; Science & Engineering; and Human Interface) in Figure 1.

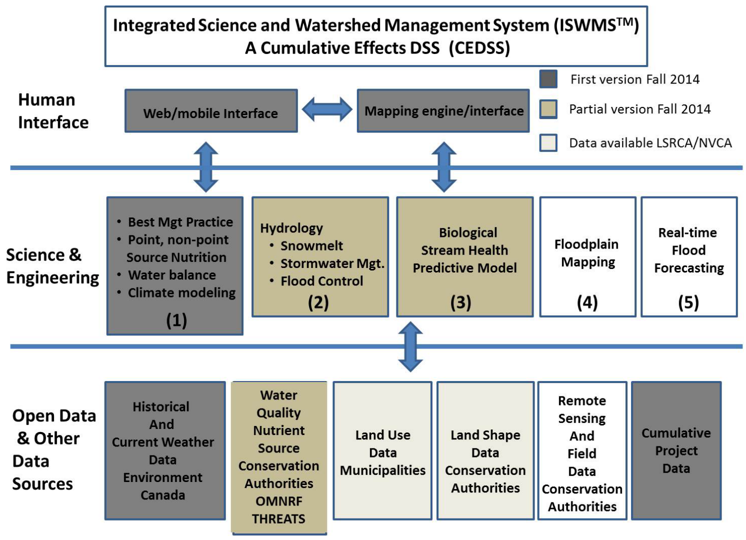

Fig. 1. ISWMS^{TM}- architectural layers and components.

Open Data & Other Data Sources Layer The Open Data layer indicates the sources of data, much of which will come from governments and NGOs such as WMAs. Current weather data comes from the Federal government, while a significant amount of water quality data comes from provincial or state governments while gathered by local WMAs. Present and future land use data is typically provided by municipalities, while drainage characteristics such as catchment and stream delineation are derived from digital elevation maps. Remote sensing and field data may come from WMAs, university researchers, professional consultants or government and cumulative data from previous studies.

An Open Data layer will provide multiple advantages:

- Data will not have to be gathered every time there is a requirement to analyze or model aspects of the land or water such as a watershed, it will be accessible through the Open Data layer;
- Projects will be able to build upon the results of previous analysis and modelling runs, thus able to anticipate cumulative effects of development; and
- Costs of "understanding" and managing interactions with the environment should be significantly lower and more precise because of the direct availability of data and the ability to accumulate results.

The issue with the Open Data layer is to organize and index the data to provide easy access and ensure that the data is current. This is a significant but manageable problem that can be addressed. Once the data is accessible, then CEDSS tools can be provided by the private sector.

Science & Engineering Layer The Science & Engineering layer in Figure 1 shows the CEDSS tools that have been developed or are under development by the authors' organizations. Many of these tools have become mainstream in the last decade and so are relatively new to the environmental management community. Of course the software platform in Figure 1 is an open platform and CEDSS tools from other suppliers can be added as they become available.

Box (1) summarizes the functionality of the CANWET™(CANadian Watershed Evaluation Tool) [9]. Since 2004, versions of CANWET™have been used in Ontario, Canada to:

- Develop the Lake Simcoe Protection Plan [7];
- Complete Tier 1 and 2 water budget/water taking and other source water protection related projects;
- Identify new infrastructure solutions and sustainable community planning policies associated with Ontario's Places to Grow Act [6];
- Prepare regional Official Plan directives, such as the County of Simcoe's Infrastructure Visioning Strategy [8]; and
- Complete project related climate change impact assessments.

This part of the diagram, Box (1) in Figure 1, represents CANWET™5, which is a web-based cloud version.

Box (2) in Figure 1 shows the first version of the ISWMSFF™(Integrated Stormwater Management and Flood Forecasting tool) that is being upgraded to a web-based cloud application with added functionality.

Box (3) in Figure 1 shows the possibility of using Predictive Models for Biological Stream Health through measurements of water course shape, fish and plant populations, and benthic data. The Flowing Water Information System (FWIS) [1], a joint project of the Ontario Ministry of Natural Resources and Forestry, Ontario's Conservation Authorities, the University of Waterloo Computer Systems Group and the Centre for Community Mapping contains this data for Ontario. The THREATS software (The Healthy River Ecosystem AssessmenT System) [3] also captures information about stream health and is available to be integrated into the layer.

Boxes (4) and (5) in Figure 1 identify significant problems that we have encountered. We do not have accurate floodplain maps considering the extreme weather events that are occurring more frequently. These floodplain maps could be developed using digital elevation mapping acquired by Lidar[4]-equipped aircraft. The system could use available in-stream/river bathymetry data. Alternatively, blue-green spectrum Lidar technology, capable of penetrating the reflective water surface, may be used to develop bathymetric data for river channels, which can then be integrated with terrestrial elevation data. Real-time flood forecasting is another area where significant progress could be made, based on analyzing snowmelt and weather data, thereby anticipating the next Spring floods such as those that occurred in Muskoka and Calgary in Canada in 2013. Once accurate floodplain maps are created they can be used to model opportunities for flood mitigation using low impact development techniques.

Human Interface Layer The Human Interface layer in Figure 1 allows the user of ISWMS™ to view the results of modelling and analysis using tables, graphs and charts. The mapping engine/interface provides the ability to outline the area to be studied and to visualize the results related to a map. The Web/mobile interface incorporates the maps as well as reports and graphical presentation of the results. The mobile version could also be used for data collection in the field.

3.2 Summary

Many of the components needed to create ISWMS™ are available and in a form to be deployed as a web-based cloud system. What is needed is a restricted deployment to investigate and answer the questions in Section 2.3.

4 The Initial Operation of the Cloud

Where can we deploy the ISWMS™ CEDSS Platform in Section 3.1 to refine the related concepts? Since the consortium building the platform is based in Ontario, Canada it would be appropriate to choose two pilot sites in that province. Two choices could be:

[4] Lidar is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. Lidar is used to make high-resolution digital elevation maps.

1. The South Georgian Bay/Lake Simcoe Source Water Protection Region, including the Lake Simcoe Basin, Nottawasaga River Basin (to the west of Lake Simcoe) and Severn-Sound Basin (draining into Georgian Bay); and
2. The Six Nations Community near Brantford, Ontario.

The Lake Simcoe and Nottawasaga River and Severn Sound Basins study would focus on improvements to stormwater management and source water protection plans, while the Six Nations project would provide an opportunity to investigate flooding and related source water protection, which is also a paramount issue for remote First Nations communities.

4.1 South Georgian Bay/Lake Simcoe Source Water Protection

The Lake Simcoe, Nottawasaga River and Severn-Sound watersheds are shown in the map in Figure 2. CANWET™has now been used extensively in these three watersheds to evaluate in-stream assimilative capacity, set nutrient targets and determine the potential for use of rural and urban management practices to achieve these targets. These existing models will be added to the platform and brought into the CANWET™web-based environment such that subscribers will be able to view simulation results and evaluate scenario changes.

The Lake Simcoe Region Conservation Authority (LSRCA) and the Nottawasaga Valley Conservation Authority (NVCA) have expressed strong interest in using the new (5th) version of CANWET™as a means of evaluating and managing nutrient loads, assessing probable climate change impacts and targeting mitigation efforts to key contributing sources. Both watersheds are experiencing significant development and growth pressures from the communities of Barrie, Orillia, Newmarket, Aurora, Bradford-West Gwillimbury, Innisfil, New Tecumseth, Springwater and Oro-Medonte. These stresses on the watersheds need to be balanced with environmental concerns and economic benefits derived from the natural environment. Creating a standardized and science-based approach to quantifying impacts and mitigation approaches is essential to a sustainable, long-term management approach that achieves results and recognizes the cumulative effects of economic development in Ontario.

In the initial version, the ISWMS™CEDSS platform will offer a common modelling dataset with ready-to-use calibrated base models. Because of the development pressures in the proposed pilot area basins, it is anticipated that multiple users will use the system to test scenarios such as municipal Low Impact Development (LID), floodway infrastructure changes, private land development, insurance and financial institution flood risk analysis, and/or urban and rural agricultural Best Management Practices (BMPs) changes. These users, as part of the agreement to participate, will consent to "publish" proposed and completed watershed changes thus creating a cumulative database for future modelling. Thus, each application of the base model can reflect up-to-date conditions plus pending proposals or master plans. Note that they will not be asked to publish detailed plans, but just the impacts of those plans.

Fig. 2. Southern Georgian Bay Lake Simcoe Source Water Protection Area.

4.2 Six Nations - Watershed Management/Source Water Protection

The second proposed pilot area is the Six Nations community shown in the map in Figure 3. The community encompasses 183.20 sq. km with a network of waterways including between 50-70 drainage catchments and two main watercourses.

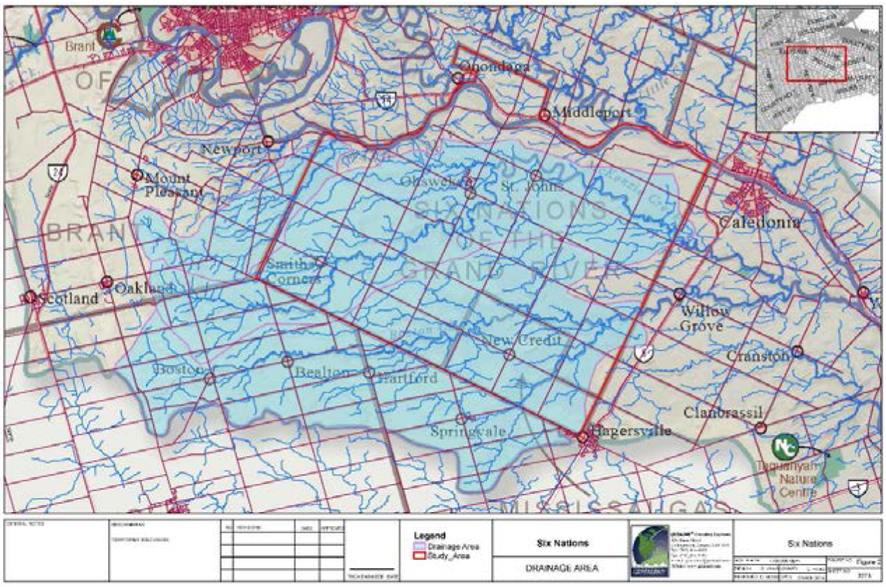

Fig. 3. Six Nations Community in Southwestern Ontario.

The Six Nations community wants to develop a science-based stormwater management and flood mitigation strategy that includes calibrating computer models with field survey data collected by Sixth Nations members and using state-of-the-art digital mapping and satellite data. The CEDSS tools from this project can be used for long-term watershed oversight, source water protection and flood forecasting. This second demonstration project could establish the groundwork for source water protection in remote First Nations communities.

4.3 Governance and Growth

By setting up these pilot projects, we should be able to implement a first attempt at answering the operational questions in Section 2.3. This project is not exclusive; other organizations and businesses will be encouraged to use and add both data and software tools.

An operational and growth advisory group will be established with representatives from Provincial ministries, Federal agencies and local agencies such as municipalities and WMAs, First Nations, climate change and adaptation specialists, environmental engineering firms, the development and insurance industries. The operational and growth advisory group will be responsible for the development of an operational plan. The initial project should take two (2) years to complete. However, results and partial deployments should start being available after the first year of operation.

5 Governance and Operations

There are multiple factors at work in setting up the environment in Figure 1.

– Current mapping and environmental data is primarily captured by governments and WMAs and their mandate will always make them a significant factor in data collection. However, this is likely to change as more intensive land development and land use occur. The private sector will require data more quickly than in the past as there will be a pressing need to adapt plans to climate change and also to follow the latest environmental laws and guidelines. Thus the data gathering cycle will need to be shortened.
– Once mapping and environmental data are collected they need to be assembled and organized into meaningful data sets.
– A large number of the CEDSS tools will be developed and operated by private sector engineering and consulting firms as most of the tasks undertaken will not be directly related to government.
– Development of the Open Data store and the CEDSS tools will require advanced software technologies.

Based on these observations there needs to be a partnership between the public and private sectors to construct and oversee the operation of the platform outlined in Figure 1.

Although the details need to be determined, the partnership should have two basic components.

1. Governments and NGOs will still continue to collect and supply mapping and environmental data according to their mandate. This data will be augmented by the private sector where needed.
2. The private sector will:
   (a) Construct and operate the Open Data store; and
   (b) Develop and operate the analysis and simulation software tools.

6 Growth of the Cloud - Provincial ISWMS™CEDSS Platform Operations Road Map

Once proven through testing within the LSRCA and NVCA watersheds and the Six Nations community the ISWMS™CEDSS platform will be made available for application across broader jurisdictions.

6.1 ISWMS^{TM}CEDSS platform Deployment Schedule

The ISWMS^{TM}CEDSS platform will be developed in stages. The first part of the platform will include the fifth version of the CANWET^{TM}(called CANWET 5) a web-based cloud version. Then the ISWMS^{TM}CEDSS platform will add the following functions.

- Flood Warning, Flood Forecasting and Flood Damage Assessments tools;
- Hydrologic Analysis for Watershed Planning and Water Resources Design;
- Integrated Water Balance with Nutrient/Sediment/Pathogen/Bacteria Loadings and In-stream Temperature and Dissolved Oxygen Modelling;
- Instream and Lake/Reservoir Routing Capabilities (Quantity and Quality);
- Groundwater (Shallow System) Modelling;
- Predictive Modelling of Urban and Rural BMP Effectiveness;
- Predictive Modelling of Urban Low Impact Development (LID) Options;
- Canadian Climate Change Impact Modelling; and
- Integration of a Rainfall-Snowmelt/Canadian Climate Change Impact Tool.

CANWET 5 and other tools need access to large amounts of Open Data to function. Much of the initial data for CANWET 5 has been developed for earlier studies within the LSRCA and NVCA watersheds. Providing a better automated framework for accessing and maintaining databases of Open Data will be a high priority task within this entire project.

Future additions to the initial ISWMS^{TM}CEDSS platform will include:

- Watershed Health Database (Canada) and Cumulative Stress Assessment Tool and includes THREATS [3] and FWIS [1];
- Flood Hazard Identification and Flood Plain Mapping;
- Ecosystem Services Platform;
- Watershed Nutrient Trading and Offsetting Management Tool; and
- Reservoir and Lake Capacity Modelling Tool

Of course both other private and public sector organizations will be encouraged to participate by providing software tools and data.

7 Conclusions

This paper describes a cloud-based cumulative effects decision support system (CEDSS) for environmental impact analysis and management using both Web-based and mobile systems and based on Open Data. The Open Data will be provided by federal, provincial and municipal governments, WMAs, business and research organizations. The Open Data will be accessible by all participants. The CEDSS tools to manipulate the data for purposes of sustainable management may be openly available, open source or proprietary in nature and organizations and businesses will be encouraged to add to this toolkit.

The entire cloud platform will be operated by the private sector while ensuring that both the public and private sectors' objectives are met. It is proposed that the initial version of the cloud platform will be applied in the South Georgian Bay/Lake Simcoe Source Water Protection Region and Six Nations territory watersheds, as initial case studies.

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