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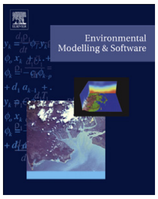

A decision support system for updating and incorporating climate change impacts into rainfall intensity-duration-frequency curves: Review of the stakeholder involvement process

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ABSTRACT

Stakeholder involvement can serve to increase the quality of decision support systems (DSSs) and increase the perceived legitimacy of DSS outputs. Involving those who are ultimately affected by the outputs of DSSs in system design and development also reflects democratic principles. Importantly, stakeholder involvement can help ensure that the outputs of DSSs are used in decision-making processes. However, DSSs often fail due to poor engagement of stakeholder and end-user communities in the development and design of systems. The stakeholder engagement process applied in the development of the Computerized Tool for the Development of Intensity Duration Frequency Curves under Climate Change described here followed many of the tenants of best practices identified in the literature. While the engagement strategy was generally considered successful, over- and under-representation of some stakeholder groups and long term funding issues were weaknesses in the engagement process.

1. Introduction

Environment and water management-related Decision Support Systems (DSSs) and related computer-based information systems frequently experience low uptake (Diez and McIntosh, 2009; Dragan et al., 2003; Giupponi et al., 2007; McCown, 2002; McIntosh et al., 2005; Ochola and Kerkides, 2004; Oliver et al., 2012; Van Delden et al., 2011). McIntosh et al. (2011: 1394) argued the main challenge associated with uptake of DSSs by end-users includes the "… *quantity, quality and appropriateness*" of the involvement of end-users in the DSS development process. Conversely, many authors have identified improved stakeholder engagement as a means of increasing the uptake and application of computer-based systems, including environmental models, computer-based information systems and decision support systems (DSSs) (Baroudi et al., 1986; Diez and McIntosh, 2009; Oxley et al., 2004).

There are numerous reported benefits of the involvement of a variety of stakeholders in the development of DSSs (Diez and McIntosh, 2009; Fiorino, 1990; McIntosh et al., 2011; Oliver et al., 2012). Through participation in the development processes, users are able to affect design of systems to satisfy their needs, develop a sense of ownership, and develop an understanding of how systems can assist them in their work (Barki and Hartwick, 1994). Local stakeholders are likely to have a better understanding of the implications of certain DSS outputs at the local scale (Voinov and Bousquet, 2010). Further, stakeholders are often "… *more likely to be listened to than the scientists who may be perceived as foreign to the problem or the locality*" (Voinov and Bousquet, 2010: 1277), increasing the likelihood that DSSs will be used in local decision-making. Involving individuals in the design of systems and decisions that affect them is also viewed as reflecting democratic values (Kormfacher, 2001; Pretty, 1995), as individuals have a right to be involved in the design of systems and decisions that will ultimately have a direct impact on them (Oliver et al., 2012).

Despite the value and importance of stakeholder participation in DSS development, stakeholders are often not effectively involved in development processes. Reasons for limited involvement include

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lack of stakeholder engagement strategies, lack of funding for stakeholder involvement, improperly defining the scope of stakeholder involvement at the beginning of a project, improperly defining relevant stakeholder groups, mismatches in scale with respect to funding organizations (which may be national) and implementation (typically local scale), defining and involving stakeholders late in the development process, among other barriers (McIntosh et al., 2011; Quinn, 2010).

This paper reviews and critiques the stakeholder engagement process used to support the development of the Computerized Tool for the Development of Intensity Duration Frequency Curves under Climate Change (hereafter referred to as the IDFCC tool). The IDFCC tool is a DSS designed to assist local water management professionals in the updating and adjustment of rainfall intensity-duration-frequency (IDF) curves to account for the potential impacts of climate change on extreme rainfall regimes in Canada. The IDFCC tool was developed to increase the capacity of local water managers to integrate climate change impacts into infrastructure planning, design, operations and maintenance decisions through increasing the availability and applicability of Global Climate Model (GCM) outputs. The tool was designed to be user-friendly, was published on the Internet and is freely accessible to any member of the public. Stakeholder involvement was a key component of the design of the tool.

Part 2 describes the purpose and background of the IDFCC tool, including a description of rainfall IDF curves, their use, and the need for climate change affected IDF curve information in Canada. Part 2 also provides an overview of the IDFCC tool and its user interface. In Part 3, a review of the context and practice of stakeholder involvement in DSS development is provided. Part 4 provides methods for inclusion of stakeholders in the development of the IDFCC tool, and Part 5 provides a discussion of results of the involvement process.

2. IDFCC tool background and description

2.1. IDFCC tool: purpose and background

Rainfall IDF curve information describes the frequency of extreme rainfall events for a variety of durations and intensities (see Fig. 1). Rainfall IDF curves are used for a number of water management applications in Canada, including the design of major and minor stormwater management systems, sewers, detention ponds, culverts, bridges, dams, pumping stations, roads, and master drainage planning, among other applications (CSA, 2012; Watt and Marsalek, 2013).

A key feature of IDF curves used throughout Canada is that they have been developed based on the assumption of stationarity and do not account for the impacts of climate variability and change on extreme rainfall regimes (see Cheng and AghaKouchak, 2014; Milley et al., 2008). This assumption results in the creation of risk associated with increasing frequency of failure of water management infrastructure under changing climate conditions.

Climate change will result in intensification of the global hydrologic cycle, causing increased intensity of wet and dry extremes and accompanying floods and droughts (Bush et al., 2014). From 1948 to, 2012, annual mean temperatures in Canada have increased by 1.7 °C (Environment Canada, 2013). While observed trends in extreme rainfall in Canada have been unclear (Bush et al., 2014; CSA, 2012), the need for information on the impacts of climate change on IDF curves is well established (CSA, 2012). Indeed, many studies have suggested that climate change will have considerable impacts on extreme rainfall and associated stormwater management and urban flooding in Canada in the future (Carmin et al., 2012; Eum and Simonovic, 2011; Lemmen et al., 2008; Mailhot et al., 2012, 2010, 2007a,b; Mailhot and Duchesne, 2010; Mladjic et al., 2011; Nguyn et al., 2007; Peck et al., 2012; Prodanovic and Simonovic, 2007). Further, statistically significant trends in extreme rainfall frequencies have been observed in the United States, including regions directly bordering Canada (CSA, 2012; Walsh et al., 2014).

There has been a notable increase in damages associated with extreme rainfall events in urban municipalities (Insurance Bureau of Canada, 2015a, b). As a result, several provincial and municipal strategies and policies have identified a need to accommodate the impacts of climate change in infrastructure planning to limit risk of natural hazards, including risks associated with changing frequency and intensity of extreme rainfall events (British Columbia Ministry of Environment, 2010; City of Vancouver, 2012; City of Windsor, 2012; Environmental Commissioner of Ontario, 2014; Expert Panel on Climate Change Adaptation, 2009; Fisher, 2011; Government of Quebec, 2012; Halifax Regional Municipality, 2013; New Brunswick Environment and Local Government, 2014; Ontario Ministry of Environment, 2011a; Ontario Ministry of Municipal Affairs and Housing, 2014: 30).

Highlighting some of the potential impacts of extreme rainfall events, some of Canada's large, urban centres have been particularly negatively affected by extreme rainfall-related flooding. For example, extreme rainfall events in the Greater Toronto Area in 2013 and 2005 resulted in roughly $1 billion and $732 million in insured losses respectively (2014 CAD—Insurance Bureau of Canada (2015a)). Many other urban municipalities across the country, including Calgary, Saskatoon, Winnipeg, London, Burlington, Ottawa, Montreal and Moncton have also been affected by extreme rainfall events causing flood damages in recent years (Sandink et al., 2015).

Despite the clear need to adapt to changing precipitation regimes associated with climate change, accessibility of data and information to assess adaptation options and availability of technical resources to implement adaptation options has been identified as a barrier to climate change adaptation (Crabbe and Robin, 2006; Environmental Commissioner of Ontario, 2015; Measham et al., 2011; Moser and Ekstrom, 2010). Further, much of the work on accounting for the impacts of climate change on design standards has been conducted in the academic arena; however, academics focus on publishing research findings under a rigorous peer review process, limiting the availability of research to practitioners. An important additional barrier is uncertainty associated with future climate projections, creating difficulty in application of results (Lemmen et al., 2008; Upadhyaya et al., 2014).

2.2. IDFCC tool: description

This section briefly outlines the IDFCC tool, including tool use, functionality and capabilities. For complete information on using the tool and background methods used to generate IDF curves based on historical and GCM data, see Schardong et al. (2015) and Srivastav et al. (2015).

2.2.1. User interface

The IDFCC tool provides an accessible user interface, based on the Google Maps™ GIS system (Fig. 2). The IDFCC tool provides visualizations of outputs in the form of tables, equations and interactive graphs (Figs. 3 and 4).

2.2.2. Tool use

Tool use is illustrated in Fig. 5. Users have the option of selecting one of the 567 pre-loaded EC hydro-meteorological stations with at least 10 years of data and creating and entering data for their own "user created" stations. After selecting a relevant station, users may