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A new watershed assessment framework for Nova Scotia: A high-level, integrated approach for regions without a dense network of monitoring stations

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SUMMARY

High-level, integrated watershed assessments are a basic requirement for freshwater planning, as they create regional summaries of multiple environmental stressors for the prioritization of watershed conservation, restoration, monitoring, and mitigation. There is a heightened need for a high-level, integrated watershed assessment in Nova Scotia as it faces pressing watershed issues relating to acidification, soil erosion, acid rock drainage, eutrophication, and water withdrawals related to potential shale gas development. But because of the relative sparseness of the on-the-ground effects-based data, for example on water quality or fish assemblages, previously created approaches for integrated watershed assessment cannot be used. In a government/university collaboration, we developed a new approach that relies solely on easier-to-collect and more available exposure-based variables to perform the first high-level watershed assessment in Nova Scotia. In this assessment, a total of 295 watershed units were studied. We used Geographic Information Systems (GIS) to map and analyze 13 stressor variables that represent risks to aquatic environment (e.g., road/stream crossing density, acid rock drainage risk, surface water withdrawals, human land use, and dam density). We developed a model to link stressors with impacts to aquatic systems to serve as a basis for a watershed threat ranking system. Resource management activities performed by government and other stakeholders were also included in this analysis. Our assessment identifies the most threatened watersheds, enables informed comparisons among watersheds, and indicates where to focus resource management and monitoring efforts. Stakeholder communication tools produced by the NSWAP include a watershed atlas to communicate the assessment results to a broader audience, including policy makers and public stakeholders. This new framework for high-level watershed assessments provides a resource for other regions that also have limited availability of effects-based data, an important consideration as expanding human activities impact water resources in less densely monitored regions.

1. Introduction

Across Canada, ground-based aquatic monitoring faces reduced capacity from job cuts and government program cutbacks (for example, Beeby, 2012; Scoffield, 2012; Nature Editorial: Death of evidence, 2012; Fitzpatrick, 2011; Hoag, 2013). These cutbacks highlight the need for complementary watershed assessments that are high-level, i.e., regional or provincial scale, and integrated, i.e., including multiple stressors, to guide on-the-ground aquatic monitoring and to support effective watershed management. Here we describe the first high-level integrated watershed assessment for Nova Scotia (NS[1]), a 55,284 km^2 province in Canada that has a large number of small watersheds that drain directly to the Atlantic Ocean.

High-level planning that compares watersheds at regional scales is an essential part of effective management of aquatic

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[1] *Abbreviations*: NS – Nova Scotia; NSWAP – Nova Scotia Watershed Assessment Program.

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systems (Nel et al., 2009; Wang and Yang, 2012; Detenbeck et al., 2000; Burton et al., 2012), especially for regions which face complex types of development that occurs in a distributed pattern across regions and which can change quickly, such as for shale gas (Rahm and Riha, 2012). High-level watershed assessments also need to be integrated, i.e., to consider multiple stressors in order to examine cumulative effects (Burton et al., 2012); in recent decades, new geospatial databases have facilitated the inclusion of multiple stressors (USEPA, 2012), in contrast with earlier single-chemical approaches (Burton et al., 2012).

The utility of high-level integrated watershed assessments are three-fold. First, they create a regional picture of threats to aquatic ecosystems (Bryce et al., 1999) needed to compare threats among watersheds (Graham et al., 1991). This picture identifies the major sources of stress and where they occur, and provides information needed to identify high priority watersheds in order to focus limited protection, mitigation, and restoration resources (Mattson and Angermeier, 2007; Detenbeck et al., 2005; Linke et al., 2007; Mollot and Bilby, 2008). Threats posed by nonpoint source stressors such as road development and land cover change are well-described in high-level assessments, because these impacts are not easily monitored or detected from point in-stream monitoring sites (Detenbeck et al., 2000; Graham et al., 1991; Hunsaker et al., 1990). For example, in the United States, high-level watershed assessments serve multiple goals in the USEPA Clean Water Act for water quality monitoring, including assessment of regional conditions and identification of impaired water bodies (Detenbeck et al., 2005).

Second, these assessments are useful tools to improve ground-based monitoring by guiding site location based on gaps in coverage, selection of metrics and monitoring variables, and aiding the interpretation of results. The assessments also place unmonitored watersheds into context by projecting probability of impairment in unmonitored watersheds (Detenbeck et al., 2005).

Third, high-level integrated assessments typically assemble watershed information from a number of sources and agencies into one accessible location (Kapo and Burton, 2006), and, as a result, provide a clear picture of information gaps. Map products from these assessments promote clear visual communication of important watershed information and foster public education (USEPA, 2012). Tools from the assessments are used by a range of end-users, including watershed managers, policy makers, communities, regulatory agencies, as well as researchers. In order to be effective, high-level watershed assessment and planning needs to be cost-effective, strategic, structured, rapid and scientifically defensible (Nel et al., 2009; Meixler and Bain, 2010).

In general, there is no widely-accepted single approach for high-level integrated watershed assessments to quantify threats to watersheds at regional scales (Wang and Yang, 2012). Further, most high-level, integrated watershed assessments have been developed in regions with relatively abundant on-the-ground monitoring networks, including widespread geomorphological, aquatic population and water chemistry data to monitor the effects of stressors on the watershed (following USEPA, 2012). The USEPA has recently summarized a number of high-level integrated watershed assessments being conducted in the USA; common themes for these approaches include the reliance on existing data, rather than the collection of new data, multi-agency involvement, use of geographic information systems (GIS), and an aquatic focus (USEPA, 2012).

Variables in high-level integrated watershed assessments used to map the frequency and severity of anthropogenic impact (Graham et al., 1991; Hunsaker et al., 1990) can be classed into two types: exposure-based or effects-based (Detenbeck et al., 2000). Exposure-based variables are typically map-based stressor variables that are often nonchemical in nature or related to nonpoint sources, such as regional patterns of water withdrawals, land use development on erodible soils, and road networks. In contrast, effects-based variables measure the localized effects of anthropogenic impacts on the ground, and include data on fish communities (e.g., Wang et al., 2011; Paukert et al., 2011), water chemistry, water flow, and channel morphology (Kapo and Burton, 2006). Both types of variables have advantages and disadvantages for their use in high-level, integrated watershed assessments. Effects-based variables are essential information for change detection but are generally more expensive to collect, require time series data to be able to detect change and have more uncertainty with regards to spatial and temporal representativeness. Exposure-based variables provide essential information for attribution of any changes observed and are generally more available and cheaper to obtain, but by definition do not provide direct information on change to aquatic habitats. Most high-level integrated assessments use a combination of the two types of variables in their watershed assessments (USEPA, 2012) according to data availability, which differs among regions (Mattson and Angermeier, 2007).

The Province of Nova Scotia has been in need of tools provided by high-level, integrated watershed assessments. In addition to land use changes, the province faces complex, regional-scale stressors such as chronic acidification, groundwater nitrate contamination in agricultural areas, climate change, and possible shale gas development. For example, parts of Nova Scotia were among the most heavily acidified in North America and Europe at the end of the last century, and no improvement has been observed following emission reductions (Clair et al., 2011). Mercury levels in Nova Scotia are among the highest in Canada (Depew et al., 2013). Acid rock drainage creates high acidity in some Nova Scotian rivers that cause fish kills, disrupts public water supplies, contaminates private wells and damages engineering works (Fox, 1999). Nova Scotia has over 300 years of land cover change, dam construction, and road development. Currently several major aquatic populations in Nova Scotia face high risk of extirpation such as the three Atlantic Salmon populations in Nova Scotia that are either listed, or recommended to be listed, as endangered; the major threats to these populations have been identified as chronic acidification and in-stream habitat stressors, such as riparian deforestation and dams (DFO, 2013). However, high-level, integrated watershed assessment approaches such as those outlined in USEPA (2012) cannot be used in Nova Scotia because of the relative paucity of provincial-scale on-the-ground effects-based information, such as morphological assessments, water quality monitoring stations and fish population studies. We have developed a new approach that relies only on more readily-available exposure-variables that are linked to presumed aquatic health impairments in a conceptual model.

Following the release of Nova Scotia's first water resource strategy "Water for Life" in 2010 (Nova Scotia Environment, 2010) we initiated the university/government led Nova Scotia Watershed Assessment Program (NSWAP) in 2011. The Water for Life strategy explicitly recognizes the need for a provincial-scale assessment and identification of priority watersheds, defined as watersheds which need to be studied further due to their estimated higher levels of impacts and stressors (Nova Scotia Environment, 2010).

The primary objectives of the NSWAP are to conduct a high-level integrated watershed assessment for the province by (1) developing and calculating a suite of indices that quantify regional-scale, nonpoint source anthropogenic stressors and threats to freshwater resources of Nova Scotia on a watershed basis, (2) identifying patterns of watershed stressors and priority watersheds for additional assessment or management measures based on threat severity, with comparison to the distribution of current management