Automated GIS routine for Strategic Environmental Assessment: a spatiotemporal analysis of urban and wetland change

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Abstract

Urban development is one of the recognized drivers of wetland lost. Strategic Environmental Assessment (SEA) can serve as an effective framework for evaluation of potential effects of urban growth to wetland habitats. This automated GIS routine provides a unified tool for the baseline assessment component of SEA, particularly for landscape based temporal analysis of wetland/urban change. Application of the routine to the Saskatoon growth sectors in the period of 1985-2011 revealed the change of spatial wetland patterns and overall decreasing of wetland sustainability.

Background and Relevance

Wetland habitats support a large number of species and provide a living environment for water birds, amphibians, fish, as well as other vertebrates, invertebrates, and aquatic and terrestrial flora. Wetlands also serve as flood control areas, support ecosystems in terms of water quality improvement, nutrient cycling, and carbon sequestration (Bartzen et al., 2010). Only about 5 to 8 percent of the Earth's land surface is covered by wetlands (about 14 percent of land cover in Canada); this area continues to decrease mostly due to land use change, agricultural activities and, in recent years, urban growth and associated regional development activities (Mitsch and Gosselink, 2007; Noble et al., 2011). In the Canadian context, the primary causes of wetland loss are as follows: first, many of the development activities and land uses that affect wetlands are not subject to regulatory-based environmental assessment requirements, including urban development and land conversion (Noble et al., 2011), and, second, there is limited science-based guidance and environmental assessment methodology for wetland impact assessments (Breaux et al., 2005; Noble et al., 2011). McInnes (2010) identified the need for more intelligent planning and design, including the development of more proactive frameworks to assess and protect wetland habitat and services more efficiently.

Strategic Environmental Assessment (SEA) can serve as a potential methodological framework for assessing land use disturbances to wetlands (see Gunn and Noble, 2009 for example). Having such a framework in place well before proposed development is critical to sustainable environmental management (Creasy, 2002). Noble et al. (2011) argue that standardized procedures are required to guide wetland assessment and decision making.

Arguably, Geographic Information Systems (GIS) can combine data management and spatial-temporal analysis and serve as a support tool for SEA. GIS techniques can serve as a cost-effective applied tool for wetland assessment in terms of the evaluation of

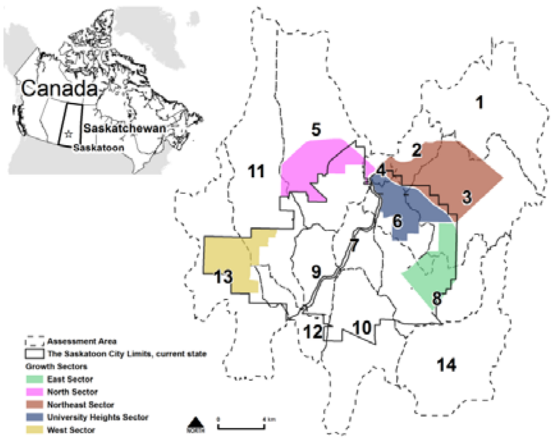

Figure 1. The City of Saskatoon growth sectors and Assessment Areas

wetland habitat from past to current conditions (Atkinson and Canter, 2011; Töyrä and Pietroniro, 2005).

The introduced automated routine was prepared as a standardized component of SEA baseline assessment: a GIS support scheme for a spatial framework of landscape based temporal analysis of wetland/urban change (Sizo at al., 2014). The main objective of this project was to embody the framework in a GIS environment by using remote sensing, watershed analysis, overlay analysis, and other GIS and RS methods as a quantitative and qualitative basis for the estimation of wetland/urban land use change.

The automated GIS routine was applied to Saskatoon growth and neighborhood development sectors (Fig.1), as they were identified by the Future Growth Study (City of Saskatoon, 2000) and the Official Community Plan Bylaw No. 8769 (City of Saskatoon, 2009), for analysis of temporal tendency of wetland and urban areas change at the landscape level.

Methods and Data

Atkinson and Canter (2011) describe the utility of GIS for environmental assessment in terms of its ability to store, manipulate, analyze, and display large sets of complex geographically referenced data and contend that GIS is well suited to spatial applications of this nature and complexity.

A set of tools, which incorporated GIS and remote sensing techniques, were developed to support calculation of landscape based, temporal wetland/urban change and to facilitate spatial and temporal data collection, creation, management, analysis, transformation, and application. The automated routine was designed in the Esri ArcGIS environment, using Python scripting and visual programming. See Fig.2 for the GIS based automated routine workflow.

Minimum hydrological unit. Watershed analysis was applied for delineation of water catchments encompassing the city's growth areas. A water catchment unit was chosen as the smallest ecologically meaningful unit for the regional scale assessment (see Duinker and Greig (2006). Further, the study area was adjusted to the calculated boundary of the water catchments. The adjusted area is referred to as the assessment area (Fig. 1).

Data, classification, and accuracy assessment. Three Landsat 5 TM Surface Reflectance Climate Data Records datasets (USGS, 2013) were used as RS sources, acquired 11 May 1985, 28 April 2006, and 19 May 2011. The selection of RS data was based on image quality, availability, and seasonality. Preference was given to spring images, as suggested by Dahl and Watmough (2007) for wetland identification in Canada prairie region.

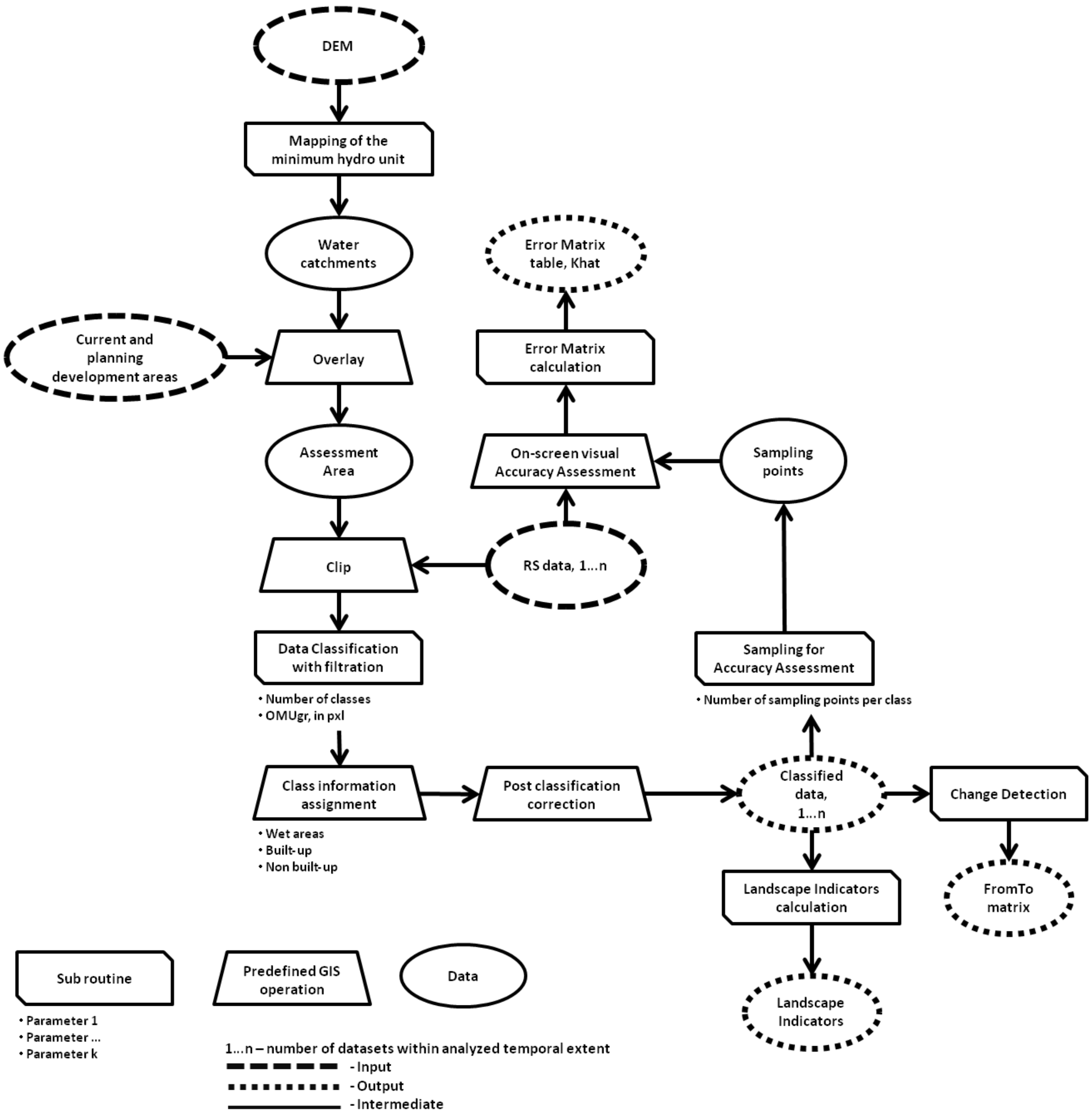

Figure 2. The GIS based automated routine workflow

The post classification comparison method was used for land use change extraction in the form of a change detection table. The unsupervised classification method was applied for the RS data classification. The following classes were identified: (i) wetlands, or "wet areas," defined as open water and saturated areas, without taking in account the soils' morphological properties (Gala and Melesse, 2012); (ii) urban area, defined as "built-up areas with various structures (e.g., housing units, schools)" (MacGregor-Fors, 2011); (iii) all other area that was not identified as wet area or built-up area, was classified as non built-up area. The accuracy assessment resulted in overall accuracy of 92.4% for 1985, 93.6% for 2006, and 92.0% for 2011, and Khat coefficients of 0.884, 0.903, and 0.878 respectively.

Landscape indicators. Environmental assessment must consider potential effects from a proposed development, including direct and indirect effects. However, identification of all individual sources of stress from development on wetland habitats may not be neither achievable nor practical. Therefore, Noble et al. (2011) suggest evaluation of the sustainability of wetlands rather than the individual sources of stress directly. In this way, the sustainability of wetland habitats may be described based on landscape indicators, which concern the linkages between spatial patterns of land use or disturbances and ecological processes (Canter and Atkinson, 2011).

Results

The GIS routine provides users with a repeatable and flexible modeling tool with the opportunity to modify input parameters and re-run analysis as needed, or as new data becomes available. The routine was applied to the Saskatoon growth regions to perform spatiotemporal analysis of wetland/urban land use change at the landscape level. The following landscape indicators were calculated for each catchment of the assessment area: total wet area, average wet area size, number of wet areas, wet areas density, total built-up area, built-up area to total water catchment area ratio, wet area to total water catchment area ratio, and wet areas to built-up ratio (see Fig. 3 and Fig. 4).

Analysis revealed change in wetland spatial patterns. Generally for the assessment area, the wetland area decreased from 1985 to 2006 and increased from 2006 to 2011. Most likely, the wetland area increase was caused by an abnormal wetness period in the Canadian prairie region that started in 2010 (Chun and Wheater, 2012). The absolute number of wet areas has notably decreased since 1985; the trend shows a decrease in the number of wetland density with an increase in average size. Considering all landscape indicators, the overall trend shows declining wetland sustainability. This suggests an overall decline in the capacity of wetlands to maintain their ecological functions.

Conclusions

Wetland areas continue to decrease across the world, including Canada, due to land conversion, agriculture activity, and, most recently, urban development. Our review identified a need for intelligent and standardized urban planning for conservation of wetland habitats. SEA can serve as a proactive framework for assessing a proposed activity and its potential effect on wetlands. In turn, GIS and RS techniques can support workflow and data maintenance such a SEA framework.

In response to these needs, the current project proposed a GIS based automated routine to support the baseline assessment component of SEA, particularly for landscape based temporal analysis of wetland/urban change. It was successfully applied to the Saskatoon growth regions. The analysis showed a change in wetland spatial patterns, which indicates a decline of wetland sustainability and its capacity to maintain their functions and services in the Saskatoon growth regions.

The introduced routine does have limitations. The routine tracked land use change only between three classes: wet areas, built-up, and non built-up (other); only RS data was used for change detection, and eight selected landscape indicators were used for temporal trend description. However, for particular needs, the RS classification scheme can be enlarged and wet areas can be split into wetland classes, which, in turn, will amplify analysis by including wetland type diversity information as a landscape indicator. The flexibility of the routine design allows making adjustment for future analysis needs.

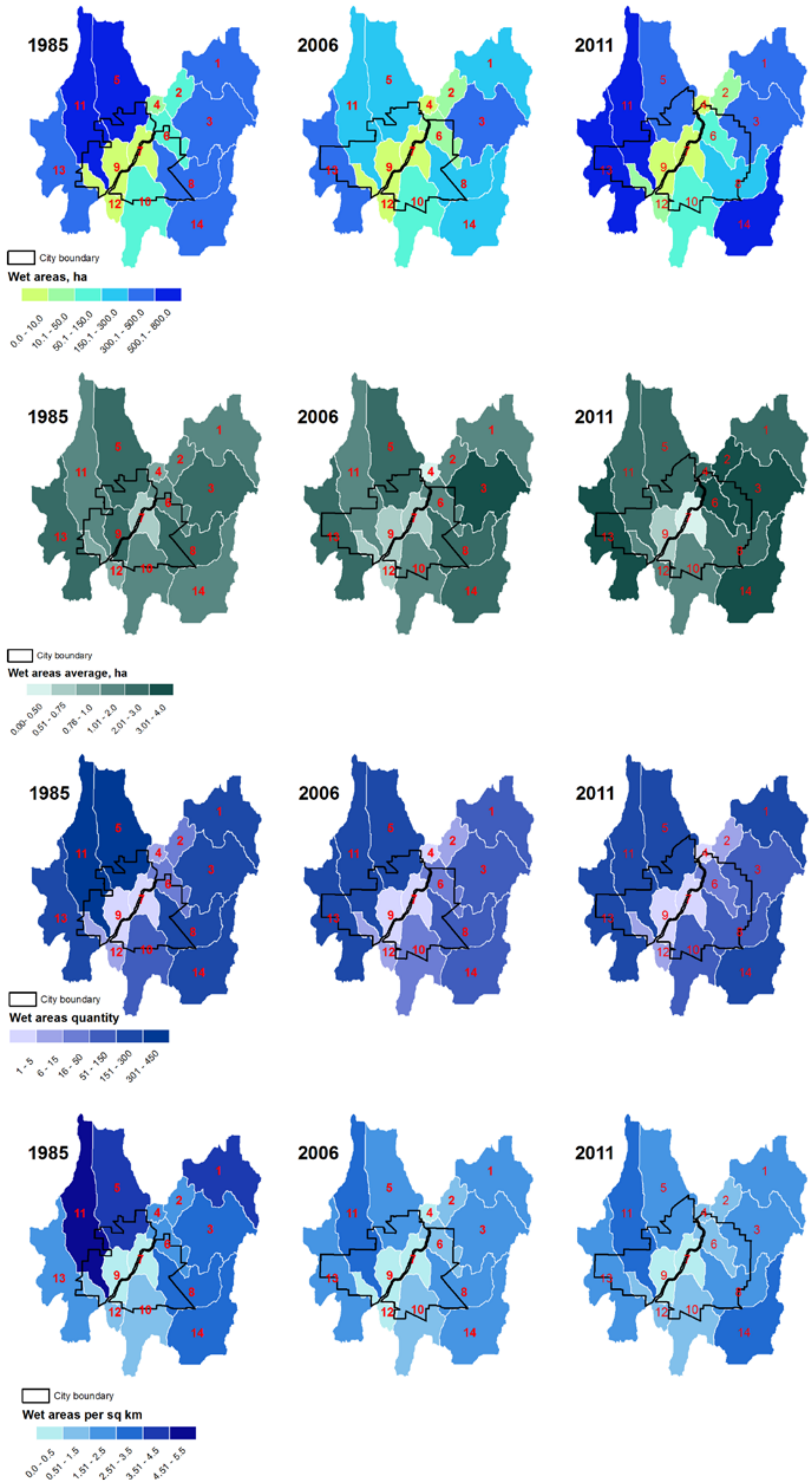

Figure 3. Landscape indicators

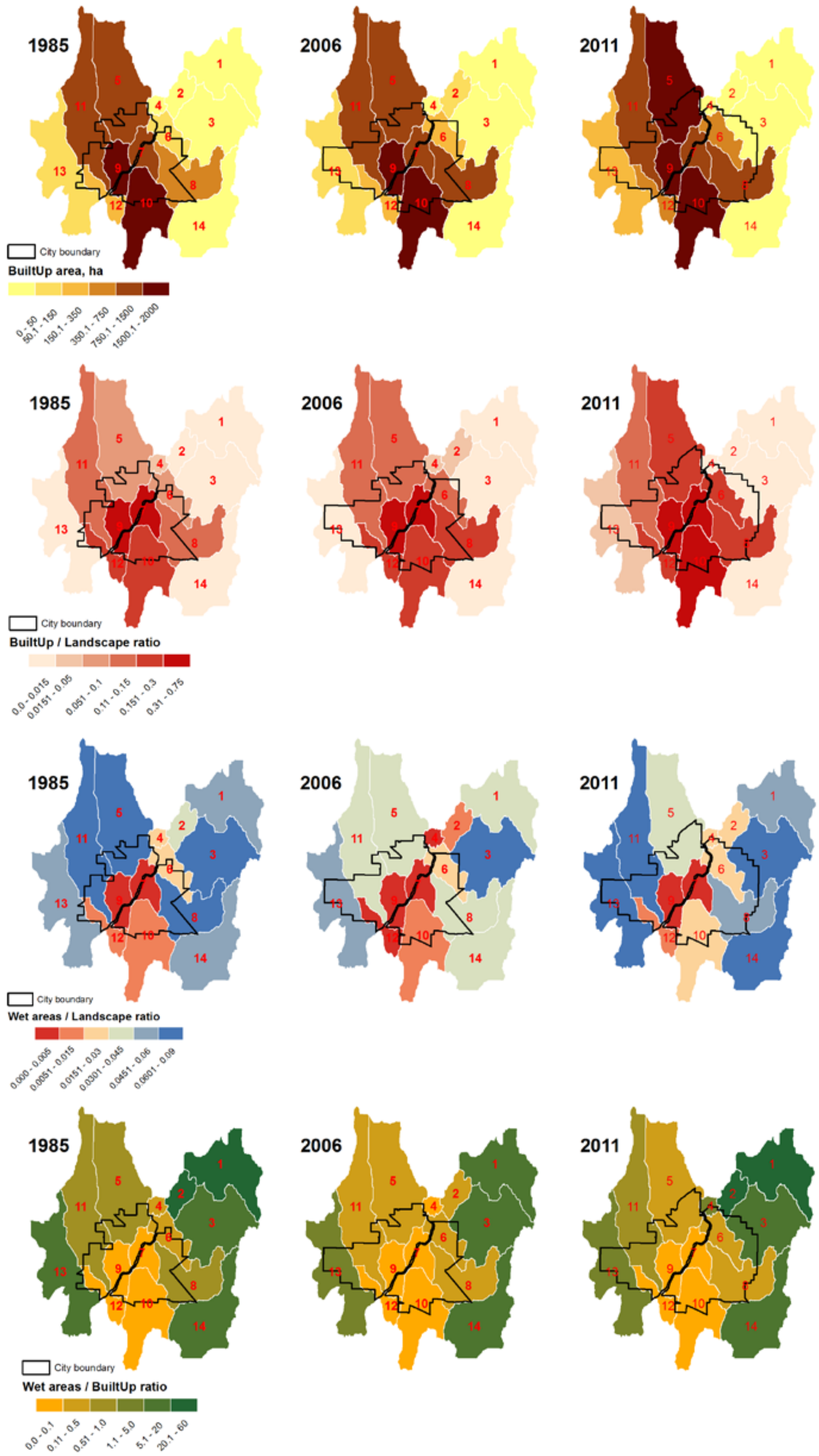

Figure 4. Landscape indicators, cont.

Acknowledgements

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