STRATEGIC ENVIRONMENTAL ASSESSMENT DESIGN FOR WETLAND ASSESSMENT AND CONSERVATION POLICY DEVELOPMENT IN AN URBAN PLANNING CONTEXT

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ABSTRACT

This research advances Strategic Environmental Assessment (SEA) design and methodology for wetland assessment and policy development within an urban planning context. The thesis is a 'manuscript-style' and consists of three manuscripts, which collectively contribute to the overarching research purpose. The first manuscript presents and demonstrates a spatial framework for the application of SEA in the context of land use change analysis for urban wetland environment. The study aims to meet the needs for a proactive framework to assess and protect wetland areas more efficiently, and advance urban planning and development design. The proposed framework, adopting Geographic Information System and Remote Sensing approaches, presents a temporal evaluation of wetland change and sustainability assessment based on landscape indicator analysis. The results show that despite the recent extremely wet period in the Canadian prairie region, land use change contributed to increasing threats to wetland sustainability in the developing urban environment of the city of Saskatoon from 1985 to 2011.

The second manuscript presents a scenario-based approach to SEA for wetland trends analysis and land use and land cover (LUC) modeling. Alternative future LUC was simulated using remote sensing data and city planning documentation using a Markov chain technique. Two alternatives were developed for LUC change and threats to urban wetland sustainability: a zero alternative that simulated trends in urban development and wetland conservation under a business as usual scenario, in the absence of prescribed planning and zoning actions; and an alternative focused on implementation of current urban development plans, which simulated future LUC to account for prescribed wetland conservation strategies. Results show no improvement in future wetland conditions under Saskatoon's planned growth and wetland conservation scenario versus the business as usual scenario. Results also indicate that a blanket wetland conservation strategy for the city may not be sufficient to overcome the historic trend of

urban wetland loss; and that spatially distributed conservation rates, based on individual wetland water catchment LUC differences, may be more effective in terms of wetland conservation. The results also demonstrate the challenges to applied SEA in a rapidly changing urban context, where data are often sparse and inconsistent across the urban region, and provides potential solutions through LUC classification and prediction tools to help overcome data limitations to support land use planning decisions for wetland conservation.

The third manuscript presents an analytical approach to SEA, bridging strategic level assessment with operational planning and implementation. An expert-based strategic assessment framework was developed and applied to assess the potential implications of alternative wetland conservation policy targets on urban planning goals, and to identify a preferred conservation policy target. Site-specific algorithms, based on wetland area and wetland sustainability, were used to prioritize wetlands for conservation to meet policy targets within urban planning units. Results indicate a preferred wetland conservation policy target beyond which higher targets provided no additional benefit to urban development goals. The use of different implementation strategies, based on wetland area versus wetland sustainability, provides operational guidance and choice for planners to meet policy objectives within neighborhood planning units, but those choices have implications for local land use and wetland sustainability.

Overall, the research contributes to the following aspects of SEA design and methodology: i) scoping processes to define the spatial and temporal context for SEA; ii) baseline assessment for analysis of environmental conditions and changes across space and/or over time; iii) methods to support the identification and evaluation of potential impacts of strategic alternatives; and iv) structured and systematic, quantitative assessment and decision-support tools for SEA that bridge strategic-level assessment with operational planning and implementation.

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LIST OF ABBREVIATIONS

ABI	Area Based Conservation Preference or Priority Index
AHP	Analytic Hierarchy Process
CDED	Canadian Digital Elevation Data
CDP	Current Development Plan
CDR	Surface Reflectance Climate Data Records
DEM	Digital Elevation Model
EA	Environmental Assessment
FPWC	Canadian Federal Policy on Wetland Conservation
GIS	Geographic Information Systems
LiDAR	Light Detection and Ranging
LUC	Land Use and Land Cover
MDPI	Multidisciplinary Digital Publishing Institute
nLCI	normalized Landscape Composite Index
nLI	normalized Landscape Indicator
OMU_{gr}	Output Mapping Unit Granularity
PPP	Policy, Plan, or Program
RE	Relative Error
RS	Remote Sensing
SEA	Strategic Environmental Assessment
STD	Standard Deviation

1 CHAPTER 1: INTRODUCTION

1.1 Research purpose and objectives

Strategic Environmental Assessment (SEA) can be defined as an in-advance evaluation of the potential environmental consequences of a proposed or existing policy, plan, or program (PPP). The primary aim of SEA is to help protect the environment and promote sustainable development (Chaker et al., 2006; Thérivel, 2010). A typical SEA framework consists of several phases, including a scoping phase to define the spatial and temporal context for assessment; a baseline assessment that focuses on the analysis of current conditions and changes across space and/or over time; assessment and evaluation, which identifies and evaluates the potential impacts of alternative PPP actions or opportunities; a management component, where impact mitigation and enhancement measures are identified; and, following PPP implementation, ongoing monitoring of PPP performance and actual environmental outcomes (Government of Canada et al., 2010; Gunn & Noble, 2009; Ramsar Convention Secretariat, 2010; Thérivel, 2010).

The scoping, baseline assessment, and assessment and evaluation phases of SEA are arguably the most important data-, information-, and methodology-intense phases of the process and have a significant impact on the quality of SEA results and its ultimate contribution to more sustainable PPP outcomes (Fischer, 2007; Hilding-Rydevik & Bjarnadóttir, 2007; Thérivel et al., 2004; Wright, 2007). Although SEA has advanced considerably since being established in the late 1980s, SEA continues to be limited by the availability (or lack thereof) of analytical-based approaches for the assessment of the potential environmental effects from PPPs and, in particular, methodological guidance and practical directions for spatially explicit and context-oriented SEA application (Geneletti, 2015; Noble et al., 2012). The purpose of this research is to advance empirical understanding of SEA design and applied methodology, specifically in the context of urban planning and wetland conservation.

SEA for urban planning requires a broad understanding of the relationship between wetland loss and development pressures for the effective management of the current and future impacts of urban growth on wetlands, including an understanding of site-specific spatial and temporal trends and patterns of wetland change (Office of the Deputy Prime Minister 2005; Bartzen et al. 2010; Li et al. 2012). Noble et al. (2012) reported that the methods used in SEA are restrictive and limited to a number of common qualitative-based approaches; analytical-based, quantitative assessment methods are lacking. Belcáková and Nelson (2006) identified the need to develop supporting procedural and methodological frameworks for SEA in spatial planning, including the development of more practical frameworks for more intelligent urban planning and design to assess and protect wetland habitat and services more efficiently (McInnes, 2010).

Scenario-based approaches are acknowledged as good-practice in impact assessment methodology; they produce future visions of land use with and without planned urban development actions or initiatives (Bonder & Cherp, 2000; European Parliament and Council, 2003; Schmidt et al., 2005). Furthermore, they are recognized as a means to help overcome the challenges associated with predicting future outcomes under uncertain spatial planning conditions (Duinker & Greig, 2007; Geneletti, 2012; Noble, 2008; Peterson et al., 2003; Zhu et al., 2011). It can be argued that a variety of modeling approaches that are applicable to land use analysis currently exist (Sohl et al., 2010; Verburg et al., 2004), as well as a number of available scenario-based approaches (Duinker & Greig, 2007; Peterson et al., 2003; Zhu et al., 2011). However, there is a need for contextualized methodology in SEA to support scenario development and land use modeling (Bragagnolo & Geneletti, 2013; Ma et al., 2012; Mozumder & Tripathi, 2014), particularly within the context of urban planning and wetland conservation.

In response, this research develops and demonstrates an operable SEA framework and offers decision support tools for urban and regional land use planning, which support the exploration of opportunities for wetland conservation. This is achieved within the context of the Saskatoon urban region, Saskatchewan, Canada. The objectives of this research are to:

- identify methods for SEA evaluation in the context of urban growth planning and wetland conservation;
- develop an applied methodological approach for SEA to support decision making and sustainable planning in the context of wetlands in urban development;
- demonstrate the SEA methodology within the context of wetland conservation policy and planning in the Saskatoon growth region.

1.2 Literature Review

The chapter provides a background information about wetlands, wetland loss, and define a usage of term 'wetlands' in the current research. Next, Canadian wetland policy described in brief along with a summary of current environmental assessment practices in a wetland context, including SEA. Then, SEA framework is shortly described, highlighting known shortcomings and identified limitations in SEA implementation in Canada. The chapter ends by a conclusion that summarize identified research gaps.

1.2.1 Wetlands

Wetlands are complex and dynamic ecosystems and many definitions for wetlands have been introduced over the years. How a wetland is defined depends on the particular geographic region, specific area of research or application, and different aspects of wetlands considered relevant to a situation (Mitsch & Gosselink, 2007). In the current research, following the National Wetlands Working Group (1997), a wetland is defined as a "land that is saturated with water long enough

to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment." This research also adopts the term 'wet area,' describing open water and saturated areas. The term 'wet area' is used for the purpose of facilitating the use of Remote Sensing (RS) tools and RS classification in this research, without taking into account the soil's morphological properties (Gala & Melesse, 2012). The implications of this approach are discussed later in the thesis.

Wetland are recognized as among the most productive environments in the world. They support biological diversity, water quality, nutrient cycling, flood mitigation, and carbon sequestration. Innumerable species, including rare and sensitive species, depend on wetland environments: birds, mammals, amphibians, fish, and invertebrates (Bartzen et al., 2010). Despite the significance of wetlands, total global wetland area is decreasing more rapidly than any other type of ecosystem (Davidson & Finlayson, 2007). Only about 5 to 8 percent of the earth's land surface is covered by wetlands, and only 14 percent of the land surface in Canada is wetland (Canada Committee on Ecological Land Classification, 1988; Noble et al., 2011). Wetland loss is continuing globally and close to 50 percent of original wetlands has been completely lost; in the context of Canada's Prairie pothole region it is reported 71 percent loss, and a 40 percent loss in Saskatchewan with half of the remaining wetlands considered at risk (Huel, 2000; Mitsch & Gosselink, 2007).

Wetland loss may occur for several reasons: hydrological modification, coastal development, pollution, salinization, eutrophication, sedimentation, forestry, mosquito control, infilling for buildings or for solid waste disposal, mining for natural resources, and/or because of invasive species. Most of these are driven by, or associated with, land use change and human-induced surface disturbance (Bartzen et al., 2010). In Canada, the permanent threat of wetland

area loss and degradation is a subject of "industrial development, expansion of ports, construction of hydro-electric reservoirs and facilities, urban expansion, fluctuating water levels (especially in the Great Lakes Basin) and agriculture" (Rubec & Hanson, 2009). Wetland areas have become significantly affected as a result of urbanization. Ehrenfeld (2000), for example, identifies several likely effects of the urban environment on wetlands (both direct and indirect), including changes in hydrology, geomorphology, and ecology.

1.2.2 Wetland policy and assessment practice

According to Rubec & Hanson (2009), the Canadian Federal Policy on Wetland Conservation (FPWC) is intended to ensure wetland conservation, mitigation of environmental impacts on wetland area, and to sustain wetland functions. The key points of this policy are: "(i) no net loss of wetland functions on federal lands and waters and in areas affected by federal programs through the mitigation of impacts of development related to these wetlands, (ii) no further loss of wetland area where wetland loss has been severe, and (iii) enhancement and rehabilitation of wetlands in areas where the continuing loss or degradation of wetlands has reached critical levels." The FPWC applies to federal land, all activities on it, and all programs, expenditures, and decisions under federal jurisdictions. In addition, many provincial governments and municipalities in Canada have adopted policy for wetland conservation and management (Rubec & Hanson, 2009). For example, Alberta Wetland Policy applies to all natural wetlands in the province and is seen as a tool and knowledge system for wetland management and decision-making processes (Alberta Government, 2013). In Saskatchewan, provincial wetland policy is intended to provide overarching principles to development land and water management strategies for wetland conservation and sustainable use (Huel, 2000; Saskatchewan Watershed Authority, 2002). At the municipality level, for example, recently adopted the City of Saskatoon wetland

policy brings the concern of wetland conservation to the City's development plans, focusing on the responsible integration of wetlands into the urban environment (City of Saskatoon, 2013). However, despite numerous policy and regulatory initiatives in Canada, there is a lack of standardized or formal approaches for the proper mitigation of the environmental impacts on wetlands from projects and land-use decisions (Nielsen et al., 2012; Rubec & Hanson, 2009). Additionally, the majority of wetlands in Canada are on privately owned agriculture land (Neuman & Belcher, 2011), which makes both federal and provincial wetland protection policy practically ineffective, as well as for 'urban' wetlands in municipal owned areas.

Currently, the tool most often applied to wetland impact assessment in Canada is project based Environmental Assessment (EA). However, Noble et al. (2011) argue that a considerable number of proposed activities, which potentially affect wetlands both directly or indirectly, including urban growth expansion, are either not classified as significant enough to trigger EA or are not subject to formal EA regulation. When an EA is conducted, "assessments are often 'screening-type' assessments, designed for routine projects with seemingly predictable impacts," and EA is often conducted perfunctorily, spatially and temporally restrictive, without including indirect impacts and/or small or seasonal wetlands (Noble et al., 2011). The authors note that a major issue in wetland assessment is the lack of guidance and environmental assessment methods for wetland impacts for the in-advance stage of proposed activities, particularly for developments that occur at the regional or landscape level, such as those associated with road infrastructure or urban growth and development planning.

As such, there is a need for a systematic and proactive approach for wetland EA, and SEA may serve as an appropriate methodological framework for assessing such broad landscape level effects on wetland environments. SEA is applied at the early stages of the decision making

process, has a strategic scope, and offers more possibilities for adopting alternative development approaches and mitigation measures than does project-specific EA (Seht, 1999). The Ramsar Convention Secretariat (2010), for example, recommends SEA as a holistic approach for wetland conservation and wise use.

1.2.3 Strategic Environmental Assessment

SEA is intended to play a role in decision making before the implementation of a PPP (European Parliament and Council, 2001; João, 2007). In this regard, SEA is a tool or a set of tools for improving strategic actions through the decision making process, that includes public involvement and stakeholder participation and aims to achieve environmental protection and sustainability. SEA is intended to identify the best option in terms of meeting the PPP's demand and minimization of environmental damage and is focused on minimization of negative impacts, optimization of positive impacts, and compensation of loss of valuable features and benefits. SEA serves to identify the limits of strategic actions in terms of possible irreversible damage from environmental impacts; SEA is a flexible process, which includes different methodologies that vary from a context, stage, and PPP level (Nilsson et al., 2005; Partidário, 2000).

There are many qualitative and quantitative tools (descriptive, analytical, and consultative) available for application in different stages of SEA (Fischer, 2007; Thérivel, 2010). However, Noble (2009) found considerable variability in the practical, specific, and case oriented implementation of SEA across Canada. A lack of understanding of SEA's role in decision-making, a limitation in tested methodology and methodological guidance, and a lack of the demonstration of SEA value for PPP development were found (Noble, 2009). In the context of SEA implementation in regional planning in Canada, Gunn & Noble (2009) report a lack of future-oriented approaches and decision-making support beyond project level EA, with focus on

"describing the current state of the environment, rather than on trends, scenario building, and discerning desirable futures." The majority of frameworks and approaches for assessing impacts to wetlands have similarly been reactive, focused on project-specific permitting and mitigation guidelines (Westbrook & Noble, 2013).

1.2.4 Conclusion

In principle, SEA has the potential to provide a framework to support urban wetland sustainability-based policy and planning decisions (Nielsen et al., 2012; Ramsar Convention Secretariat, 2010). However, broad strategic level principles in SEA are not always translated into operational practices through the decision making process (Fischer, 2003; White & Noble, 2013). It is important that strategies steer implementation (Emmelin & Nilsson, 2006) and that strategic directions emerging from SEA are accompanied by practical direction for 'on-the-ground' PPP implementation (Acharibasam & Noble, 2014). There is a need for further methods development in SEA, particularly quantitative-based methods that translate broad strategic principles and objectives in SEA into more specific, operational plans and practices (Fischer, 2003; Noble, 2009; White & Noble, 2013).

1.3 Thesis structure

The research is presented in a manuscript-style thesis, which consists of three parts, each prepared as a stand-alone manuscript. Collectively, the manuscripts contribute to the overarching research purpose to advance current understanding of SEA design and applied methodology in the context of urban growth planning and wetland habitat conservation. Manuscripts are presented as single thesis chapters, following this Introduction section (Chapter 1).

The first manuscript (Chapter 2), "Strategic environmental assessment framework for landscape-based, temporal analysis of wetland change in urban environments," contributes to the design of the scoping and baseline assessment stages of SEA. The manuscript focuses on a spatial scoping and historical analysis of environmental baselines, set within the Saskatoon urban development context. The manuscript proposes a spatial framework for trends evaluation of wetland change and sustainability assessment based on landscape indicator analysis, adopting Geographic Information System (GIS) and RS tools and applications.

The second manuscript (Chapter 3), "Futures analysis of urban land use and wetland change in Saskatoon, Canada: An application in strategic environmental assessment," contributes to the baseline assessment and assessment and evaluation stages of SEA. The manuscript focuses on a spatio-temporal analysis and future simulation of environmental baselines as data support for land use planning decision making. The manuscript develops and presents a scenario-based approach for wetland future trends analysis and land use and land cover modeling in an urban environment, utilizing a Markov chain technique for future simulation.

The third manuscript (Chapter 4), "A strategic environmental assessment approach to wetland conservation policy development and implementation in an urban context," contributes to the assessment and evaluation stage of SEA. The manuscript focuses first on the evaluation of alternative wetland conservation policy options for Saskatoon, based on strategic urban planning goals, and second on translating broad strategic policy direction to site-specific wetland conservation planning priorities.

The final thesis section is the "Conclusion" (Chapter 5), which summarizes the research conclusions and discusses the results obtained in the research. Each manuscript chapter starts

with a Preface that briefly outlines the manuscript's focus, its relevance to the research purpose and objectives, and the manuscript publication status.

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2 CHAPTER 2: STRATEGIC ENVIRONMENTAL ASSESSMENT FRAMEWORK FOR LANDSCAPE-BASED, TEMPORAL ANALYSIS OF WETLAND CHANGE IN URBAN ENVIRONMENTS

2.1 Preface

Chapter 2 represents the first part of the research. This part defines the spatial and temporal scope of the research and presents a baseline assessment framework for a historical evaluation of wetland change and wetland sustainability. This work was led by Anton Sizo under the supervision of Bram Noble and Scott Bell. The data were collected and analyzed by Anton Sizo, and reviewed by Bram Noble and Scott Bell. All authors were equally involved in the writing of the manuscript for publishing. Anton Sizo generated all maps and figures. The Chapter manuscript has been submitted for publication and is under review in the journal Environmental Management, co-authored by Dr. Bram Noble (second author) and Dr. Scott Bell (third author). All authors read and approved the final manuscript. The manuscript citation is provided below. Since its submission, the Chapter manuscript has undergone spelling and syntax correction and minor changes in sections 2.3 and 2.6.

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2.2 Introduction

Wetlands are ecologically productive lands and provide important services such as wildlife habitat, carbon sequestration, and flood control; they are also amongst the most threatened ecosystems (Mitsch & Gosselink, 2007). A wetland is land that is saturated with water long

enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity, which are adapted to a wet environment (National Wetlands Working Group, 1997). Most wetland loss is driven by, or associated with, land use change due to human-induced surface disturbance (Bartzen et al., 2010). The majority of wetland loss since the early 1800s has been attributed to drainage from agricultural land conversion; in more recent years, disturbances associated with urban growth have caused incremental, yet cumulatively significant, stress to wetland sustainability (Nielsen et al., 2012). In the 20th century, for example, the world's urban population increased from 14% to 50% of the total global population distribution; during that period urbanization was responsible for 58% of total wetland loss (Ehrenfeld, 2000; Li et al., 2010). Understanding the relationship between wetland loss and development pressures, in particular spatial and temporal patterns and trends in wetland change due to urban land use, is crucial to effective urban wetland conservation and restoration programs (Bartzen et al., 2010), and to understanding, planning for, and managing the current and future effects of urban growth on wetland environments (Li et al., 2012; Office of the Deputy Prime Minister, 2005). The majority of frameworks and approaches for assessing impacts to wetlands, however, have been reactive, focused on project-specific permitting and mitigation guidelines (Westbrook & Noble, 2013).

Wetland sustainability, within the context of land use planning, refers to the maintenance of a wetland environment over the long-term, ensuring "the greatest continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations" (Ramsar Convention Secretariat, 2010b). Sustaining wetlands in urban environments requires a more proactive approach than the current project-specific permitting and mitigation practice, focused at the strategic level of policy development and spatial planning.

Strategic Environmental Assessment (SEA), the evaluation of the potential environmental consequences of policy and planning initiatives, has the potential to provide a framework for the assessment and management of urban land use impacts to wetlands in support of sustainability-based policy and planning decisions (Geneletti, 2012; Gunn & Noble, 2009; Li et al., 2012). The purpose of SEA is to help understand the context of a proposed policy, plan or strategy, to identify problems and environmental and sustainable options that will help achieve strategic objectives (Partidário, 2007). Currently in place in some 60 countries (Tetlow & Hanusch, 2012), SEA should be advanced enough for practical application with sufficient methods and techniques to support urban planning for wetland sustainability (Thérivel, 2010). However, Noble et al. (2012) identified the lack of direction for selecting the best methodological design for specific SEA application, and report the methods used in SEA to be restrictive and limited to a number of common qualitative-based approaches; analytical-based, quantitative assessment methods were lacking. They also report that much of the methodological guidance available for SEA internationally is too generic for specific application, and argued for "more systematic methodologies with guidance on methods selection at different SEA tiers and in different contexts, perhaps even sector-based guidance, along with practical tools, models and examples…" (Noble et al., 2012). Belcáková and Nelson (2006) similarly identified the need to emphasize the added value of SEA to spatial planning, but also noted the need to develop supporting procedural and methodological frameworks, criteria, and indicators.

In this paper, we propose and demonstrate a methodological framework and spatial tools for SEA application to support urban planning for wetland conservation. The SEA process consists of several stages, including a scoping process to define the spatial and temporal context for assessment; a baseline assessment focused on analysis of conditions and changes across

space and/or over time; identification and evaluation of the potential impacts of alternative planning actions; development and implementation of impact mitigation and enhancement measures; and ongoing monitoring of plan performance and environmental outcomes (Government of Canada et al., 2010; Gunn & Noble, 2009; Ramsar Convention Secretariat, 2010a; Thérivel, 2010). Our focus is on advancing a spatial support framework for scoping and baseline assessment in SEA – the most important and information-intense phases of SEA to help ensure the sustainability of wetlands in support of urban planning, and that have a significant effect on the quality of SEA results (Fischer, 2007; Hilding-Rydevik & Bjarnadóttir, 2007; Thérivel et al., 2004; Wright, 2007).

The section that follows provides a brief review of applications of spatial methods and tools for scoping and baseline analysis in urban wetland contexts. This is followed by a methodological framework and approach for scoping and baseline assessment in SEA, based on landscape-based, temporal analysis of wetland-urban environmental change using Geographic Information Systems (GIS) and Remote Sensing (RS) tools. The framework and approach are then demonstrated based on an application to the urban wetland environment in Saskatoon, Canada. The paper concludes with a discussion of lessons and opportunities for advancing spatial frameworks and methodology for SEA. Although used within the context of urban wetland conservation, we suggest that the framework is broadly applicable to other regions and land uses, including agriculture and industrial activities.

2.3 Spatial solutions for scoping and baseline analysis

The use of GIS and RS tools is now common practice in environmental assessment and is promoted as a unifying instrument in SEA, from establishing baseline data to impact evaluation and information presentation for decision making (Antunes et al., 2001; González et al., 2011).

Atkinson and Canter (2011), for example, describe the utility of GIS for environmental assessment in terms of its ability to store, manipulate, analyze, and display large sets of complex and geographically referenced data; they contend that GIS is well-suited to spatial applications of the nature and complexity associated with environmental assessment. Gontier (2007) similarly suggested that GIS can prove useful in the delineation of spatial and temporal scales for environmental assessments, specifically for ecological impacts, and Noble (2008) demonstrated the potential of GIS to support SEA, from simple operations such as spatial analysis and overlays (see González et al., 2011) to more complex trend analysis and extrapolation in baseline assessments and scenario analysis.

Several different GIS and RS-based techniques have been developed for identification and analysis of ecological impacts in urban areas, including impacts to wetlands. For example, Sarvestani et al (2011) used GIS and RS tools along with ancillary data to analyze city growth patterns and the impact of urban sprawl in Shiraz, Iran. The authors integrate multispectral data, 3D topographic maps, field data, and census data in the analysis. Jiang et al. (2012) performed a spatial-temporal analysis of wetland area change with further statistical analysis of driving factors and the relative contributions of those factors to urban wetland change in Beijing, China. Gala and Melesse (2012) integrated spectral images (Landsat ETM+), radar images (Radarsat-1 SAR), and terrain information into a mapping tool for wetlands within the Prairie Pothole Region of Central Canada and used the tool to analyze regional and temporal changes in wetland areas. Serran and Creed (2015) used Light Detection and Ranging (LiDAR) data based Digital Elevation Model (DEM) and object-based techniques for mapping wetlands, including small (<1 ha), and estimating wetland loss in the Prairie Pothole Region of Canada.

Despite the range of GIS and RS methods and tools available for environmental assessment application, particularly for identifying and managing the effects of land use disturbances to wetlands, more work is required to ensure that such techniques are optimized in a spatially-specific and contextualized methodology to provide reliable results for SEA and for land use and development decisions (e.g. Belcáková & Nelson, 2006; González, 2012; Noble et al., 2012). Part of the challenge is that although GIS and RS tools are common in environmental assessment practice, they are generally used in a more descriptive than strategic way – focused primarily on features mapping versus analyzing regional conditions, spatial or temporal change, and indicators to support decisions about land use and development. Below, we propose a SEA methodological framework for assessing urban land use impacts to wetland sustainability using GIS and RS tools. Our focus is on scoping practices and baseline assessment. The framework is developed based on SEA principles and a review of current literature and frameworks focused on spatial tools in impact assessment with an emphasis on wetland and land use change assessment.

2.4 Spatial support framework for SEA of urban wetlands using GIS and RS tools

The proposed SEA framework for scoping and baseline analysis of urban land use impacts to wetlands consists of five stages: (i) assessment area delineation, (ii) landscape indicators identification, (iii) data selection and classification, (iv) change analysis, and (v) landscape change analysis (Figure 2-1). Each stage is discussed briefly below, followed by an application of the framework.

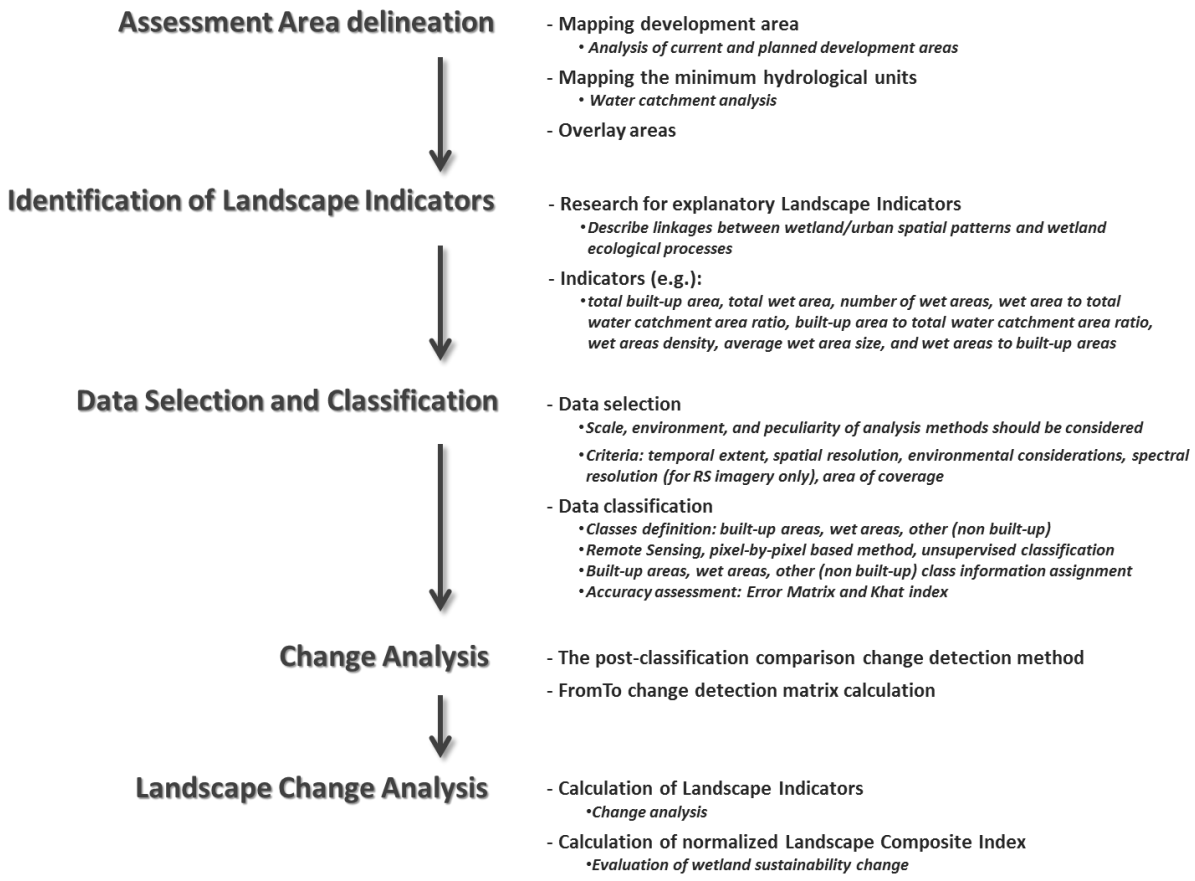

Figure 2-1 SEA scoping and environmental baseline support framework for temporal analysis of wetland and urban area change

2.4.1 Assessment area delineation

The first stage of the framework is the delineation of an appropriate spatial scale and scope for assessing impacts to wetlands in an urban environment. Selection of a proper scale and assessment boundary are key in the quality, granularity, and relevance of SEA output to decision making (João, 2007). Thérivel and Ross (2007) report that effective management of development impacts has not occurred as often as it should, in part because of the poor treatment of scale issues. They argue that scale matters in creating an ability to manage environmental impacts, explaining that when the scale of assessment is inclusive the ability to manage impacts caused by many individual activities across a landscape is enhanced. In the context of wetlands, Mitsch and

Gosselink (2000) report that variations in the spatial scale of an assessment may alter the estimation of wetland values. As such, delineation of the assessment area for SEA should consider the spatial scale of the primary components of concern – in this case, sustainable wetland management in an urban environment (MacDonald, 2000).

That being said, and despite the recognized importance of adopting ecological or functional scales, environmental assessment applications are often tempered by the administrative boundaries that form the basis of planning decisions (Gontier, 2007). Rather than adjust ecological boundaries to fit administrative boundaries, or adjust often-rigid administrative boundaries to fit ecological ones, we suggest adjusting the spatial scale used in technical analyses undertaken to support planning and administrative decisions about land use to the next closest ecologically meaningful scale (see Duinker and Greig, 2006); which, in the context of urban wetlands, is a water catchment. A wetland water catchment represents the minimum hydrological unit in terms of the ability of a wetland to maintain its functioning over the long-term (Committee on Mitigating Wetland Losses et al., 2001; Ehrenfeld, 2000), and it is the recommended spatial scale for analyses of urban land use when concerned about the sustainability of urban wetlands (see Ramsar Convention Secretariat, 2012). GIS-based watershed delineation for water catchments can be used to estimate wetland ecological catchment boundaries (see Tarboton, 1997; Tarboton & Ames, 2001; Maidment, 2002). In focusing on this minimum hydrological unit, the implications for wetlands of urban land use decisions at the administrative or planning unit can be understood within a meaningful ecological context.

2.4.2 Identification of landscape indicators

Second, there is a need to identify the potential effects to wetlands from land use development, including direct and indirect effects. However, identification of all individual sources of stress from urban land uses on wetlands may neither be practical nor achievable. Noble et al. (2011) suggest focusing instead on the evaluation of the sustainability of wetlands based on proxies or indicators of cumulative stress, rather than the evaluation of individual sources of direct stress to wetlands per se. In this way, the sustainability of wetlands, or cumulative risks due to urban land uses, can be understood using landscape indicators, which consider the linkages between spatial patterns of land cover / land use and ecological processes (Canter & Atkinson, 2011) and provide reliable information for decision making (Donnelly et al., 2007). Numerous indicators related to wetland functions exist to assess and monitor threats to wetlands (see Brooks et al., 2006; Canter & Atkinson, 2011). These include, for example, several landscape indicators that have been shown to provide insight to the sustainability of wetlands within a water catchment (Mitsch & Gosselink, 2000; Schweiger et al., 2002; Wang et al., 2008), namely: total built-up area, built-up area to total water catchment area ratio, total wet area, number of wet areas, wet areas density, wet area to total water catchment area ratio, average wet area size, and wet areas to built-up area ratio (Table 2-1). Supporting data for such indicators may be available through RS imagery, validated by aerial photos or ground truthing, or available through urban land use planning documents, such as five-year plans, neighborhood plans, or annual land use planning and permitting updates.

Table 2-1 Adopted landscape indicators for measuring wetland sustainability

Indicator	Definition	Metric	Description and relation to wetland functions
Total built-up area	Area identified or predicted as a built-up land use.	Area, e.g. ha	The majority of impacts from urban development are related to construction and industrial activity, and can be summarized as a 'disturbance factors,' or 'surface disturbances' (see Noble et al., 2011; Westbrook & Noble, 2013). Surface disturbances can serve as a measurement of wildlife disturbance and of cumulative stress to wetland ecosystem health (Gunn & Noble, 2009; Hegmann et al., 1999). An increase in total built-up area and the ratio between built-up area and water catchment area indicates a potential threat to the sustainability of wetland functions.
Ratio between built-up area and water catchment area	A rate between identified or predicted built-up area and delineated water catchment.	Ratio, e.g. %	
Wetland area	Area identified or predicted as a wetland	Area, e.g. ha	*Wetland area* is a major indicator for wetland habitat evaluation, as it is possible to assume that the loss or degradation of wetlands area negatively affects the ability of wetlands to carry out their function within the region (Dahl & Watmough, 2007). A decrease in wetland area indicates a potential negative effect to the ability of wetlands to maintain their functions within a water catchment.
Wetland numbers	Number of wetlands within the water catchment.	Units	*Wetland numbers* within a water catchment and *wetland density* are indicators of the degree of fragmentation of a landscape type (Wang et al., 2008). Relatively high wetland numbers and density are indicative of the potential ability of wetlands to benefit hydrological conditions of a region and provide more efficient wildlife habitat (Schweiger et al., 2002).
Wetland density	Rate between wetland numbers and area of the respective water catchment.	Units per area	
Ratio between wetland area and total water catchment area	Ratio of identified or predicted wetland area to delineated water catchment.	Ratio, e.g. %	The *ratio between wetland area and total water catchment area* can serve as a threshold, which, according to Mitsch and Gosselink (2000), should be 3-7% (average 5%) of wetland area in a temperate-zone watershed for an adequate flood control and water quality maintenance.
Wetland size	Averaged wetland size for the respective water catchment	Area, e.g. ha	*Wetland size* has a high influence on the capability of wetlands to maintain their functions: e.g. larger wetlands provide better support for wildlife habitat (Schweiger et al., 2002) and more effectively influence the improvement of water quality (Moreno-Mateos et al., 2010); decrease in wetland size reduces the spectrum of hydrological functions that wetland areas can maintain (Cohen & Brown, 2007).
Ratio between wetland and built-up area	Ratio of identified or predicted wetland area to built-up area for the respective water catchment.	Ratio, e.g. %	It is possible to evaluate the level of wetland-urbanization change by using the *ratio between wetland and built-up area* (see Wang et al., 2008). A decrease in the ratio indicates potential negative impact on wetlands and a negative tendency in regional wetland sustainability.

2.4.3 Data selection and classification

When selecting data for use in SEA baseline assessment for urban wetlands, several factors must be considered, including: the temporal extent of the data, acquisition time (e.g., seasonality), and resolution (e.g., spatial and, in case of RS imagery, spectral), and minimum output map unit. Additionally, for assessing urban land cover / land use, consideration needs to be given to data classification methods, definitions of land use and classes (i.e. "wetland", "built-up", and "non built-up" areas), and the desired accuracy assessment when using GIS and RS tools to support decision making about land uses and wetland conservation.

With regard to the temporal coverage of baseline data, Partidário (2007) suggests the need to adopt a generational scale in SEA as a prerequisite for sustainable development, or 20-35 years (Fenner, 2005). The choice of temporal scale of analysis in SEA baseline assessment, however, also depends on the type of methods to be used for predicting future impacts, i.e. methods for simulation of potential future conditions. For example, a quantitative trend extrapolation method requires historical data to be at least twice as long as the predicted period (Duinker & Greig, 2007). For wetland-based SEA applications, seasonality adds an additional data selection factor. Dahl and Watmough (2007) report that large wetlands, with a permanent presence of water, are much easier to identify than small, temporary, or seasonal wetlands that have very different hydrological conditions. Small urban wetland areas thus require the use of an optimally timed capture image for RS data, and a comparable resolution. In the prairie region of Canada, for example, the median size of wetlands is about 0.15 ha, and about 70% of wetlands are temporary to seasonal wetlands, suggesting that RS data obtained during the spring season is best for maximizing the full extent of wetland area detection (Dahl & Watmough, 2007). The Canadian Wetland Inventory adopts a one hectare minimum mapping unit based on the availability of satellite imagery, compatibility with already existing mapped wetland inventories,

and other studies indicating that such a resolution is appropriate for both regional and local assessments of wetlands (Fournier et al., 2007).

GIS and RS techniques are data-driven and their application in SEA requires consideration of the resolution of the input data in terms of the spatial scale of the ecological components to be considered in the assessment (Gontier, 2007; González et al., 2011), and the specific objectives of the SEA application itself. When identifying and delineating wetland areas, preference should be given to high-resolution data, including satellite and air photo imagery, if available. Parameters of RS data, such as image resolution, directly affect wetland detection output, and there is a need for at least four pixels within an object for its successful identification (Jensen & Cowen, 1999; Jensen, 2007). As such, output granularity can be described as:

$$\mathbf{OMU_{gr} = 4 \times RS_{res}^2} \qquad \text{Equation 2.1}$$

where OMU_{gr} is output mapping unit granularity and RS_{res} is input RS data spatial resolution. In terms of the spectral resolution of RS data, multispectral datasets are recommended for identification of wetlands in urban areas as they allow use of automated algorithms (e.g., supervised/unsupervised classification or spectral indices method) more successfully (Dahl & Watmough, 2007; Dechka et al., 2002; Fournier et al., 2007; Ozesmi & Bauer, 2002)

Information classes for wetland and urban areas also need to be established according to the context of the application and the degree of resolution required to assess potential impacts to wetlands and support land use decisions. For example, information classes may be as detailed as specific surface and feature classification (e.g., impervious surface type and area, vegetation type and structure, wetland type or class), or, for the purpose of a rapid assessment using RS

classification, as simple as: (i) “wet area,” which consists of all open water and saturated areas without taking into account the soil’s morphological properties (see Gala and Melesse 2012); (ii) urban area, defined as “built-up areas with various structures (e.g., housing units, schools)” (see MacGregor-Fors, 2011); and (iii) “non built-up area,” or all other areas that cannot be defined as either wet area or built-up area.

Several classification techniques are applicable for wetlands and urban areas. Pixel-by-pixel based unsupervised and supervised classification techniques are among the most widely used for wetland and urban areas identification (Erener, 2013; Fournier et al., 2007; Ozesmi & Bauer, 2002; Weng, 2012). To ensure the reliability of RS derived land cover or land use classifications, however, an estimation of classification accuracy is required. The Error Matrix and Khat index (the kappa coefficient of agreement) are two commonly used standards for accuracy assessment (Congalton, 2001; Foody, 2002). The Error Matrix includes overall classification accuracy that represents the accuracy of the modelled classification map; producer accuracy describes efficiency of the classifier prediction; and the user's accuracy the proportion of correctly predicted classes in the classified map. The Khat index is a statistical parameter, which shows total accuracy based on the agreement between modelled and observed pixels that could exist by chance (0 indicating no agreement, to 1 indicating full agreement).

2.4.4 Change analysis

Following data selection, acquisition and classification, the fourth stage is focused on the quantification of land cover / land use change from multi-date RS imagery. Image differencing, principal component analysis, and post-classification comparison techniques are amongst the most commonly used change analysis methods (see Coppin et al., 2004; Lu et al., 2004). The selection of an appropriate change analysis method for a particular SEA should consider

available resources, e.g. time, budget, and trained personnel, and its scope, both temporal and spatial. The post-classification comparison change detection method is proposed for identification of differences of built-up, non built-up, and wet areas in urban environments. In this way, land cover / land use classification results can be compared on a pixel-by-pixel basis and summarized in a matrix of change – a "FromTo" change detection matrix. A FromTo change detection matrix provides decision makers with information about the direction of land cover / land use change; in other words, *from* which, *to* which, type of land cover / land use the change has occurred. Such information, derived from the baseline assessment, can then be used for land cover / land use future modelling in SEA, including the consideration of alternative land use development scenarios and subsequent risks to wetlands.

2.4.5 Landscape change analysis

The final stage of the framework involves transformation of land cover / land use change data (e.g., quantity of built-up, non built-up, and wet area per assessed water catchment) to derive a baseline measure of sustainability for wetlands, using landscape indicators. When dealing with a large number of landscape indicators it is often preferable, for policy, planning, and communication purposes, to aggregate individual indicators into a single index so as to allow a multi-dimensional description of the assessed region in a single, unified measure. Any unification causes smoothing of data; however, the objective at the strategic level of policy and plan assessment is to summarize and simplify data for further analysis and for ease of communication to those involved in policy and planning decisions (Canter & Atkinson, 2011; Ebert & Welsch, 2004). The normalized Landscape Composite Index (nLCI) can be used to integrate landscape indicator based analysis results:

$$\mathbf{nLCI} = \frac{\sum \mathbf{nLI_i} + \sum(\mathbf{1} - \mathbf{nLI_j})}{\mathbf{N_{nLI_i}} + \mathbf{N_{nLI_j}}} \qquad \text{Equation 2.2}$$

where nLI – normalized landscape indicator with *i* – positive and *j* – negative tendency to wetland sustainability (e.g. nLI_i – normalized wet areas indicator, nLI_j – normalized built-up area indicator), and *N* is the number of respective indicators. Equation 2.2 assumes equality of all landscape indicators. A weighting factor can be added for prioritizing of indicators based on SEA objectives or practitioner needs. The nLCI varies from 0 to 1, where the index values closer to '0' is indicative of greater threats to wetland sustainability within an assessed region.

2.5 Application: the Saskatoon built environment, Saskatchewan

The above SEA framework for scoping and baseline assessment was applied to the development region for the city of Saskatoon, Saskatchewan, Canada (Figure 2-2). Since the first permanent settlements, the province of Saskatchewan has lost about 40% of its wetlands, primarily due to agricultural land conversion (Huel, 2000). In recent years, expanding urban settlements are placing increasing pressures on the remaining wetlands. The city of Saskatoon is located 348 kilometres north of the United States – Canada border. The city is located in the Prairie Ecozone and Moist Mixed Grassland Ecoregion. Saskatoon is the largest city in the province, with an estimated population of 222,189 (as of 2011), and has experienced considerable population growth in recent decades (1951 – 2011) with an average annual growth rate of 2.6% (City of Saskatoon, 2010; Statistics Canada & Census of Canada, 2011). The study area for the application was the Saskatoon urban region, including its growth sectors, as identified by the City's Future Growth Study (City of Saskatoon, 2000) and Official Community Plan Bylaw No. 8769 (City of Saskatoon, 2009); where the Northeast Sector almost matches the most recently identified Saskatoon Future Growth Area (City of Saskatoon, 2015)

Figure 2-2 Study area, Growth Sectors, and Assessment Areas

A GIS automated routine was designed to support the framework application in terms of spatial and temporal data collection, management, and analysis. The GIS and RS techniques described in the sections above were incorporated as a set of tools in the Esri ArcGIS environment. The design was completed using Python scripting and visual programming. This approach provides users a repeatable and flexible modelling tool with an opportunity to modify input parameters and re-run analyses as new data becomes available or as baseline conditions or development pressures change.

2.5.1 Assessment area delineation

Each of the City's planned growth sectors were spatially adjusted to the next closest water catchment, delineated by watershed analysis using the ArcHydro extension of ArcGIS software (see Maidment, 2002), and identified as the "assessment areas." The Canadian Digital Elevation Data (CDED), in the form of DEM, was used as input relief data for watershed analysis. The CDED contains elevation information of ground or reflective surfaces (in meters), recorded at

repeated intervals. The CDED is based on hypsographic and hydrographic maps from the National Topographic Data Base, at 1:50000 scale; and positional data or remotely sensed imagery, received from the provinces and territories in various scales (Government of Canada et al., 2007). The horizontal resolution of CDED is 18.6 meters, with a vertical resolution of 1 m for the study area. The delineation of assessment areas returned 14 regions comprising 70,737 ha in total. The area of spatial overlap varied considerably: the smallest assessment area is 622 ha (#4), and the largest is 9580 ha (#5). Spatial disposition of calculated assessment areas and their overlap with the growth sectors and city limits is shown in Figure 2-2.

2.5.2 Identification of landscape indicators

The following landscape indicators were adopted for measuring change in wetland sustainability in the assessment areas: total built-up area, built-up area to total water catchment area ratio, total wet area, number of wet areas, wet areas density, wet area to total water catchment area ratio, average wet area size, and wet areas to built-up area ratio (see Table 2-1). The choice of indicators was made based on several criteria. First, the indicators make it possible to relate landscape pattern change to potential change in, or risks to, wetland function and sustainability. Second, the indicators are related to the City's planning questions and development policies, including its wetland conservation strategy, which suggests the preservation of some amount of wetlands per planned city neighborhood. Third, the indicators are understandable to the general public and are technically feasible and scientifically grounded. Finally, the indicators selected are applicable for trend analysis in land cover / land use change and can serve as an early warning measure of cumulative threat to wetlands – e.g. the ratio between wet areas and total area is suggested to be between 3 and 7% (Mitsch & Gosselink, 2000).

2.5.3 Data selection and classification

Three Landsat 5 TM Surface Reflectance Climate Data Records (CDR) datasets (USGS, 2014) were used as RS data. The datasets are geometrically and radiometrically corrected by the vendor and have 30-meter spatial resolution. The acquisition dates were: 11 May 1985, 28 April 2006, and 19 May 2011. The selection of RS datasets was based on data availability and the following considerations. First, the spatial resolution of the datasets available for these dates, (approximately 0.09 ha, or 30 X 30 m, resulting in OMUgr = 0.36 ha) is a reasonable trade-off between the median size of Canadian prairie wetlands (0.15 ha) and is better than the recommended Canadian Wetland Inventory granularity (1 ha). The Landsat 5 TM datasets contain multispectral information, recommended for successful identification of wetland and urban areas using the application of automatic algorithms (Fournier et al., 2007). Second, the selected datasets span approximately three decades, which allows using the results of the temporal analysis for a grounded futures-based assessment of the City's growth plans (City of Saskatoon, 2009, 2013). Third, the selected datasets are cloud free dates and cover 100% of the assessment areas. Finally, the datasets were acquired in early spring, following snow melt, thus allowing consistent capturing of temporary and seasonal wetlands in their wet condition (Dahl & Watmough, 2007).

The RS unsupervised classification method was used for data mining. Data from all three remotely sensed datasets were classified into one of three classes: wet areas, built-up, and non built-up (Table 2-2). The open water area of the South Saskatchewan River, which runs through the centre of the city, was removed from the classification results. All classification layers were assessed for their accuracy using an on-screen procedure, where visual interpretation incorporated information on shape, colour, texture and other ground data. The original CDR datasets (1985, 2006, and 2011) and aerial photos (2005, 2006, 2008, and 2011), with 1-2.5 m

spatial resolution, were used as reference layers. A stratified random sampling was performed with 50 random pixels for built-up and non built-up areas, and 75 pixels for wet areas.

The overall classification accuracy (Table 2-2) was 92.4% for 1985, 93.6% for 2006, and 92.0% for 2011, which is higher than the suggested 85% least acceptable threshold of RS classified land cover / land use data (Anderson et al., 1976). Khat coefficients of 0.884 (1985), 0.903 (2006), and 0.878 (2011) indicate a strong agreement, as the values are greater than 0.8 (Landis & Koch, 1977).

2.5.4 Change analysis

The classification results indicate noticeable change in land use / land cover over the study period. Including all assessment areas, wetland area decreased from 5.4% of total area in 1985 to 3.6% in 2006, but increased to 5.4% in 2011; the built-up area increased from 10.7% in 1985, to 12.6% in 2011, and reached 14.5% of the total study area in 2011 (Table 2-2, Figure 2-3).

The growth of built-up area occurred mostly at the expense of non built-up area, and to a lesser degree by occupying identified wet area. However, by examining the wet area change pattern between 1985 and 2011, built-up area growth was responsible for about 10% of total identified wet area alteration. The noticeable increase of wet area from 2006 to 2011 was at the expense of non built-up area; most likely explained by an extremely wet period across the Canadian prairie region, particularly in 2010 (Chun & Wheater (2012), Kwok Pan Chun – Global Institute for Water Security, University of Saskatchewan, personal communication, November 30, 2013).

Table 2-2 RS derived land cover / land use classification and accuracy assessment

Land Cover / Land Use	1985				2006				2011			
	ha	% of total area	Producer's accuracy	User's accuracy	ha	% of total area	Producer's accuracy	User's accuracy	ha	% of total area	Producer's accuracy	User's accuracy
Built-up	7478	10.7%	94.4%	90.7%	8811	12.6%	95.8%	92.0%	10141	14.5%	93.2%	92.0%
Non built-up	58641	83.9%	91.5%	86.7%	58575	83.8%	93.0%	88.0%	55904	80.1%	90.0%	84.0%
Wet-areas	3767	5.4%	91.6%	98.0%	2499	3.6%	92.5%	99.0%	3772	5.4%	92.5%	98.0%
Overall accuracy			**92.4%**				**93.6%**				**92.0%**	
Khat			**0.884**				**0.903**				**0.878**	

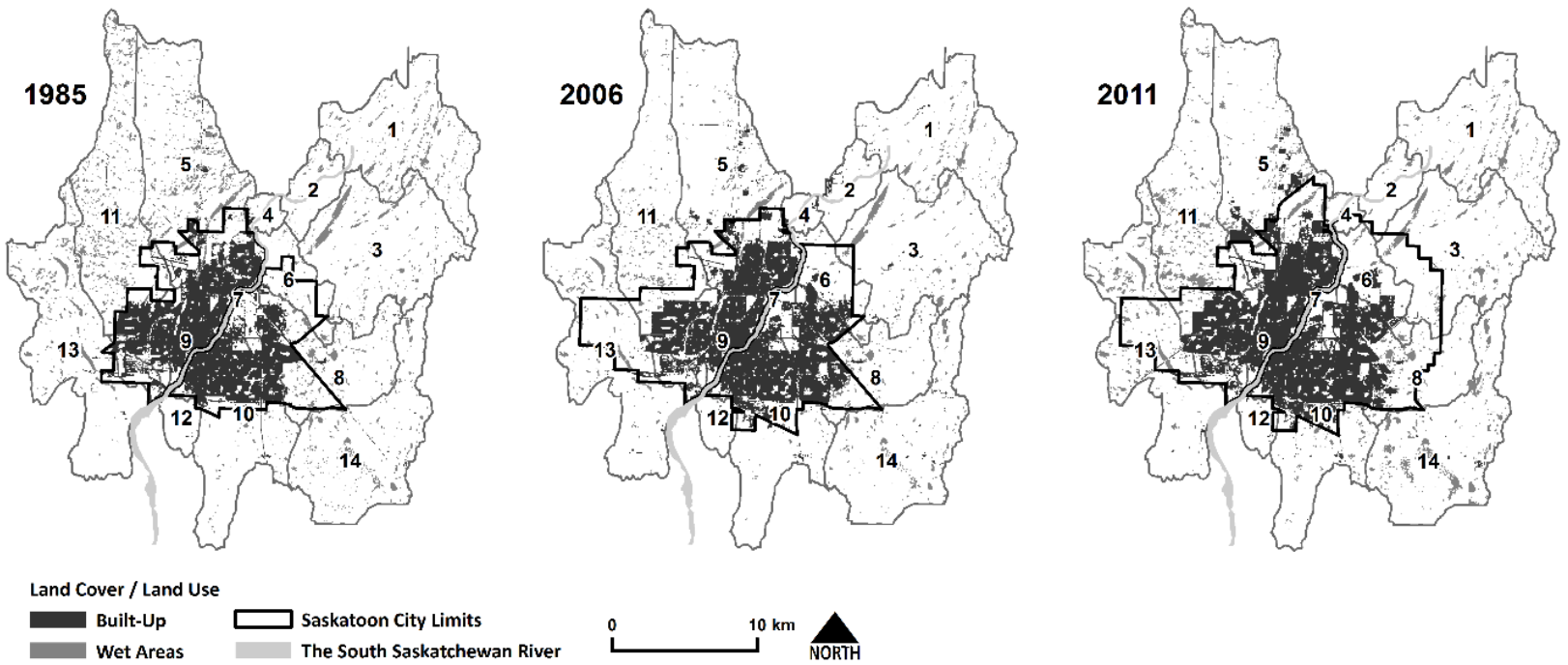

Figure 2-3 Land cover / land use classification maps for the study area

2.5.5 Landscape change analysis

To describe the change in wetland sustainability in the assessment area, landscape change analysis was performed using the following landscape indicators: total wet area, number of wet areas, wet area to total water catchment area ratio, wet areas density, average wet area size, total built-up area, built-up area to total water catchment area ratio, and wet areas to built-up ratio (Table 2-3).

The analysis of landscape indicators for 1985-2006 and 2006-2011 revealed the following for the assessment areas: wet area, number, density, the ratio between wet area and water catchment areas, and the ratio between wet area and built-up area declined between 1985 and 2006, and increased between 2006 and 2011. Average wet area size, built-up area, and the ratio between built-up and water catchment areas increased between 1985 and 2006 and between 2006 and 2011. The overall result for the study period was an increase in average wet area size, built-up area, and the ratio between built-up and water catchment areas, and a decrease in all other indicators.

The identified increase in wet area size was most likely due to the change in climate condition, described above, and could be a subject of climate variation. The increase of built-up area indicates an increase of disturbance factors or surface disturbances to wetland ecosystems in the urban area, posing a potential threat to wetland sustainability. The decrease in wetland density and wetland numbers indicate a decline in the relative ability of wetlands to benefit hydrological conditions in the region, including flood protection, and to provide efficient wildlife habitat.

Table 2-3 Changes in landscape indicators in the assessment areas

Assessment area		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total wet area	1985	413.2	58.7	482.8	10.0	762.9	66.8	2.7	360.5	2.4	76.1	696.6	8.6	474.8	348.2
	∨	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘
	2006	276.3	13.9	433.7	0.5	383.3	48.0	1.1	232.4	1.4	61.0	352.1	5.4	401.0	287.6
	∨	↗	↗	↗	↗	↗	↗	↘	↘	↗	↗	↗	↗	↗	↗
	2011	383.9	47.0	492.7	9.9	412.6	53.6	0.4	260.9	2.0	135.4	671.0	14.4	692.3	592.8
Number of wet areas	1985	242	41	196	13	378	49	4	175	1	76	417	11	180	218
	∨	↘	↘	↘	↘	↘	↘	↘	↘	↗	↘	↘	↘	↘	↘
	2006	146	11	130	1	172	27	2	107	2	44	229	8	155	137
	∨	↗	↗	↗	↗	↗	↘	↘	↘	↗	↗	↗	↗	↗	↗
	2011	172	12	137	4	185	16	1	101	3	77	244	13	195	189
Wet area to total water catchment area	1985	0.0598	0.0353	0.0620	0.0161	0.0796	0.0285	0.0013	0.0676	0.0010	0.0126	0.0803	0.0051	0.0578	0.0469
	∨	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘
	2006	0.0400	0.0084	0.0557	0.0007	0.0400	0.0205	0.0005	0.0436	0.0006	0.0101	0.0406	0.0032	0.0488	0.0388
	∨	↗	↗	↗	↗	↗	↗	↘	↗	↗	↗	↗	↗	↗	↗
	2011	0.0556	0.0282	0.0633	0.0159	0.0431	0.0229	0.0002	0.0489	0.0008	0.0223	0.0773	0.0085	0.0843	0.0799
Wet areas density	1985	0.0350	0.0246	0.0252	0.0209	0.0395	0.0209	0.0019	0.0328	0.0004	0.0125	0.0481	0.0065	0.0219	0.0294
	∨	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘
	2006	0.0211	0.0066	0.0167	0.0016	0.0180	0.0115	0.0010	0.0201	0.0008	0.0073	0.0264	0.0047	0.0189	0.0185
	∨	↗	↗	↗	↗	↗	↘	↘	↘	↗	↗	↗	↗	↗	↗
	2011	0.0249	0.0072	0.0176	0.0064	0.0193	0.0068	0.0005	0.0189	0.0013	0.0127	0.0281	0.0077	0.0238	0.0255
Average wet areas size	1985	1.7	1.4	2.5	0.8	2.0	1.4	0.7	2.1	2.4	1.0	1.7	0.8	2.6	1.6
	∨	↗	↘	↗	↘	↗	↗	↘	↗	↘	↗	↘	↘	→	↗
	2006	1.9	1.3	3.3	0.5	2.2	1.8	0.5	2.2	0.7	1.4	1.5	0.7	2.6	2.1
	∨	↗	↗	↗	↗	→	↗	↘	↗	→	↗	↗	↗	↗	↗
	2011	2.2	3.9	3.6	2.5	2.2	3.4	0.4	2.6	0.7	1.8	2.7	1.1	3.6	3.1
Total built-up area	1985	6.9	1.5	30.4	26.2	883.7	145.8	1135.5	632.9	1786.2	1558.4	872.8	289.0	76.8	32.9
	∨	↗	↗	↗	↘	↗	↗	↗	↗	↘	↗	↗	↗	↗	↗
	2006	17.5	51.2	33.9	20.0	1146.9	336.8	1170.5	1241.4	1709.2	1717.9	879.2	340.1	106.5	41.3
	∨	↘	↘	↘	↘	↗	↗	↗	↗	↗	↗	↗	↗	↗	↘
	2011	10.0	1.4	25.0	8.5	1630.8	519.6	1236.5	1378.8	1770.1	1940.7	1047.0	380.3	158.7	34.4
Built-up area to total water catchment area	1985	0.0010	0.0009	0.0039	0.0421	0.0922	0.0622	0.5527	0.1187	0.7499	0.2569	0.1006	0.1713	0.0093	0.0044
	∨	↗	↗	↗	↗	↗	↗	↗	↗	↘	↗	↗	↗	↗	↗
	2006	0.0025	0.0307	0.0044	0.0321	0.1197	0.1437	0.5698	0.2328	0.7175	0.2832	0.1014	0.2016	0.0130	0.0056
	∨	↘	↘	↘	↘	↗	↗	↗	↗	↗	↗	↗	↗	↗	↘
	2011	0.0014	0.0008	0.0032	0.0137	0.1702	0.2218	0.6019	0.2586	0.7431	0.3199	0.1207	0.2254	0.0193	0.0046
Wet area to built-up area	1985	59.7711	39.3952	15.8595	0.3835	0.8633	0.4580	0.0024	0.5695	0.0014	0.0489	0.7981	0.0298	6.1857	10.5737
	∨	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘
	2006	15.7532	0.2716	12.7779	0.0225	0.3342	0.1424	0.0009	0.1872	0.0008	0.0355	0.4005	0.0158	3.7664	6.9645
	∨	↗	↗	↗	↗	↘	↘	↘	↗	↗	↗	↗	↗	↗	↗
	2011	38.5707	34.7946	19.7456	1.1569	0.2530	0.1032	0.0003	0.1892	0.0011	0.0698	0.6409	0.0379	4.3624	17.2142

Indicator change trend in a respective time interval: ↗ increase, ↘ decrease, → neutral

The nLCI (Equation 2.2) was calculated for each water catchment as a composite measure of landscape change (Figure 2-4). The change in nLCI reflects a change in the sustainability of wetland habitat (using wet area as a proxy) within the assessed region: a decrease in nLCI was observed in the central, north, and north-east regions of the study area closer to the city boundary (assessment areas # 5, 6, 7, and 8), which corresponds to the direction of city growth. The assessment areas with less urban disturbed regions (# 1, 2, 3, 13, and 14) are characterized by an increase in nLCI. Including all assessment areas, the change in nLCI (mean | median) was a decline from 1985 to 2006 from 0.46 | 0.45 to 0.35 | 0.28, followed by an increase between 2006 and 2011 to 0.43 | 0.38.

Changes in the wet area proxy land cover class can be related to both natural (e.g. climate) and human related factors, while nLCI describes overall wetland sustainability in a modified landscape. Though, changes in climate conditions of the assessed region are intermediately reflected by nLCI through the change of included indicators, which most likely, resulted in an increase in nLCI in 2006-2011. However, for the assessment period (1985-2011), overall results indicate a decline in nLCI, showing an overall decrease of the sustainability of wetlands in the study area.

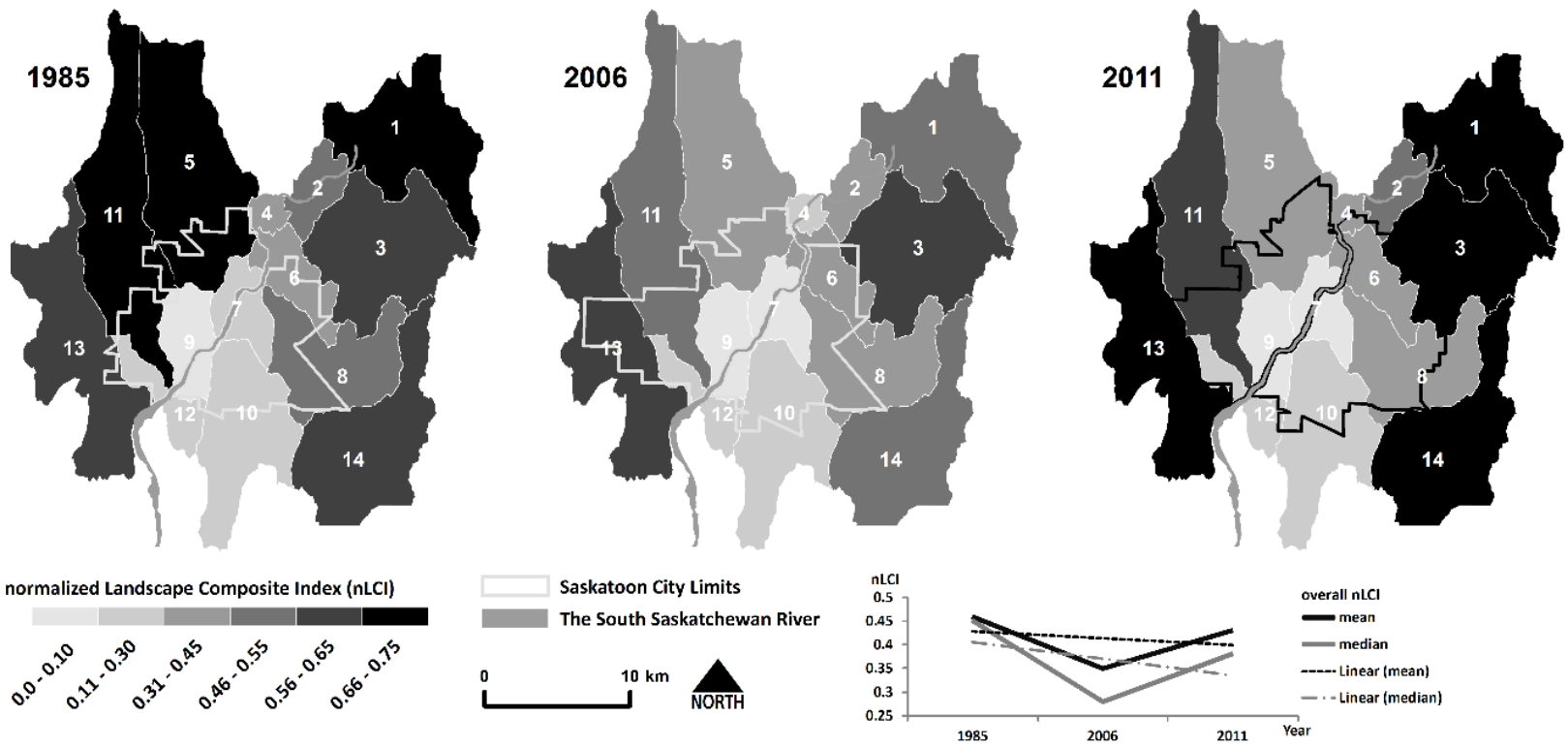

Figure 2-4 Temporal change of the normalized Landscape Composite Index

2.6 Discussion and implications for advancing SEA methodology

Effective planning and management of the current and future impacts of urban growth to wetlands, as well as the preparation of urban wetland conservation and restoration programs, require an improved understanding of the relationship between wetland loss and development pressure, especially the spatial and temporal trends and patterns of wetland change (Bartzen et al., 2010; Li et al., 2012; Office of the Deputy Prime Minister, 2005). SEA is well equipped to provide a methodological basis for the assessment and management of wetlands in urban environments (see Gunn & Noble, 2009; Geneletti, 2012; Li et al., 2012). However, Noble et al. (2012) reported the need for improved methodological support and operational guidance at the practitioner level for SEA design, with particular attention to the regional scale and context of SEA application. González (2012) noted that there are enough methods available for use in strategic assessment practice, but there is a lack of "spatially-specific environmental assessment methodology" for scientifically grounded and reliable results. In response to these needs and limitations to current assessment frameworks and practice, this research developed and advanced a spatial framework for SEA within the context of wetlands and urban land use change. The focus was specifically on scoping and environmental baseline assessment in SEA, arguably the most important and information-intense phases of the SEA process (Fischer, 2007; Hilding-Rydevik & Bjarnadóttir, 2007; Thérivel et al., 2004; Wright, 2007).

The approach adopted for assessment area delineation demonstrated how to integrate wetland regional ecological context in SEA scoping practices. Water catchment was used as the minimum hydrological unit in terms of capturing the ability of a wetland's system to maintain its functions and stability over the long-term (Committee on Mitigating Wetland Losses et al., 2001; Ehrenfeld, 2000). Rarely do urban land use and development plans consider ecological scales and processes as a basis for planning units. As such, to focus the SEA at an ecologically

meaningful scale, the framework demonstrated an approach to spatially adjust, or rescale, existing urban development and land use plans to the nearest water catchment areas – versus rescaling ecologically meaningful boundaries to accommodate development and land use plans, as is often the case (see Kristensen et al., 2013).

The use of landscape indicators, data selection principles, and a classification system provided a scientifically grounded and quantitative approach for the analysis of potential changes, or threats, to wetland sustainability at the landscape scale. Good SEA design for urban environments must consider the possible impacts from past, current, and proposed land uses and development, including potential direct and indirect effects. At the strategic level of urban policy and planning, the total or cumulative stress of urban development to the sustainability of wetland habitats may be described using indicators of landscape change and land use transition (see Noble et al., 2011). This approach conceptually relates linkages between spatial patterns and ecological processes (Canter & Atkinson, 2011). Although landscape based analysis in the context of wetland sustainability can be particularly demanding in terms of input data and classification processes, the framework demonstrated how selecting a few indicators (e.g. changes between wetland, built up and non-built up environments) can be effective at providing an overall, even if coarse, assessment of threats to wetland sustainability to support policy and planning practices. When multiple indicators are rolled-up into a normalized, landscape composite index, planners and decision makers have access to a multi-dimensional, and easy to understand and communicate, description of the assessed region in a single measure to examine, support, and understand the implications of potential land use and policy decisions (Canter & Atkinson, 2011; Ebert & Welsch, 2004).

The introduced framework does have its limitations. Like any such framework it can be constrained by data availability and by the processing and analytical methods used. The parameters of input elevation data (or DEM) for water catchment delineation (e.g., vertical and horizontal resolution), can directly influence the watershed analysis and, in turn, the calculation of the output boundaries. The resolution of input relief data should be carefully considered in terms of the desired spatial scale of the framework application. In our application in the City of Saskatoon, area delineation was performed for possible surface water drainage only and excluded groundwater – an important source of wetland recharge in some prairie wetlands. Wetland mapping was biased towards identification of larger wetlands ($\geq$ 0.36 ha) due to spatial resolution of used RS data. However, identification of small wetlands can be included in the framework in case of availability of high resolution spatial data, including air photo imagery and LiDAR data.

There are also opportunities for further testing and refinement of the framework, and the relationships between wetland sustainability of development pressure. First, our case application to the Saskatoon urban environment was limited to three simple classes: using wet areas as a proxy for wetlands, using built-up and non built-up areas for urban development. We acknowledge that cities can be very heterogeneous landscapes. For future applications, and for applications in different urban settings, a greater diversity of land cover classifications may be needed to meet the SEA goals or practitioner's needs, including classifications based on wetland type (e.g. natural, semi-engineered, storm water drainage ponds), development type (e.g. residential, industrial), and surface cover (e.g. vegetation type, impervious surfaces). Second, assessing natural or climate-induced wetland change, or possible change in wetland type, were not the focus of the framework application. However, there is an opportunity to expand on the

framework and introduce new techniques to test the influence of climate variability and extremes. Our objective in this paper was to introduce and demonstrate the applicability of the SEA framework and the range of analytical approaches available to the practitioner. For future practice, the analytical approaches can be adjusted based on data availability, land use planning goals, desired information resolution, and the particular practitioner's needs, but retain a consistent methodological design.

2.7 Conclusion

This paper introduced and demonstrated a spatial framework for SEA application, specifically for scoping and baseline analysis, within the context of urban wetland environments. The framework presents a methodological approach and suite of spatial tools and analytical procedures for proactive urban planning in the context of temporal analysis of wetland change at the landscape scale. The framework is, in part, a response to recent calls for advanced application of appropriate procedural and methodological frameworks, criteria, and indicators in SEA for spatial planning (Belcáková & Nelson, 2006), and to the need for more intelligent planning and design, including the development of more practical frameworks to assess and protect wetland habitat and services more efficiently (McInnes, 2010). Our focus was on the *scoping* and environmental *baseline assessment* phases of SEA – foundations to the SEA process.

The methodology could serve towards the consideration of historical and spatial particularities for environmental assessment, and provide the opportunity to offer recommendations for strategic decisions for wetland conservation through urban land use and planning processes. Further application and testing of the framework and supporting methods are required for futures-based assessments in a variety of data rich and data sparse conditions, so as to further develop practical tools and approaches for prospective analysis of the implications of

future land use decisions on wetland sustainability. The framework does, however, demonstrate that a strategic approach can be useful at providing an overall, even if coarse, assessment of threats to wetland sustainability to facilitate wetland policy decisions and urban planning practices. We agree with Croal et al. (2010) in that any SEA support tool or framework will need to be adjusted and elaborated in various ways to be sufficiently flexible to accommodate the complexities of actual SEA. Further, we suggest that advances in SEA methodology and supporting tools will only be successful in practice if accompanied by the development of an institutional environment that is supporting of adopting SEA as a meaningful component of planning and decision processes (Noble et al., 2012; Tetlow & Hanusch, 2012; Thérivel & Ross, 2007).

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3 CHAPTER 3: FUTURES ANALYSIS OF URBAN LAND USE AND WETLAND CHANGE IN SASKATOON, CANADA: AN APPLICATION IN STRATEGIC ENVIRONMENTAL ASSESSMENT

3.1 Preface

Chapter 3 represents the second part of the research. This part presents an approach for spatiotemporal analysis and future simulation of environmental baseline as a data support for evaluation of potential impacts of PPP alternatives and actions on wetland change. This work was led by Anton Sizo under the supervision of Bram Noble and Scott Bell. The data were collected and analyzed by Anton Sizo, and reviewed by Bram Noble and Scott Bell. All authors were equally involved in the writing of the manuscript for publishing. Anton Sizo generated all maps and figures. The Chapter manuscript has been published in the Multidisciplinary Digital Publishing Institute (MDPI), under the open access license, in the journal Sustainability, 2015, 7(1): 811-830, co-authored by Dr. Bram Noble (second author) and Dr. Scott Bell (third author). All authors read and approved the final manuscript. The full manuscript citation is provided below. The MDPI open access allows free re-use of the published material if correct citation of the original publication is given. The Chapter manuscript has not been changed since its publication.

Sizo, A., Noble, B., & Bell, S. (2015). Futures Analysis of Urban Land Use and Wetland Change in Saskatoon, Canada: An Application in Strategic Environmental Assessment. *Sustainability*, *7*(1), 811–830. http://doi.org/10.3390/su7010811

3.2 Introduction

The majority of wetland alteration is driven by, or associated with, changes to land use and land cover (LUC) resulting from human-induced surface disturbance (Bartzen et al., 2010). In recent years, urban growth and regional development have become significant drivers of LUC change, due to the direct and indirect effects of surface disturbances to wetland hydrology, geomorphology, and ecology (Ehrenfeld, 2000; Nielsen et al., 2012). Spatial planning, including urban planning and development zoning, is a key policy instrument designed to direct future land use and development actions (Geneletti, 2011), but such planning and policy instruments do not always provide for adequate consideration of the potential impacts of urban LUC change to wetlands. Strategic Environmental Assessment (SEA), the assessment and integration of environmental and sustainability considerations in policy, plan, or program (PPP) development and decision making (Chaker et al., 2006; Thérivel, 2010), has gained considerable momentum in recent years as a proactive and spatially appropriate framework for assessing and shaping land use policies, plans, and development actions (Bidstrup & Hansen, 2014; Gunn & Noble, 2009), including urban and regional land use plans (Castellani & Sala, 2013; He et al., 2011), and managing their impacts on wetlands (Westbrook & Noble, 2013).

The basic premise of SEA is that it helps ensure that PPPs are developed and operationalized in an environmentally sensitive way, and that land uses and development actions are implemented within a sustainability framework. SEA is about understanding the context of a PPP or strategy being developed and assessed, identifying and understanding key trends, and assessing future environmental and sustainable outcomes to help achieve strategic objectives (Partidário, 2012). Its application typically focuses on the identification and assessment of trends in environmental baselines, and the analysis of future outcomes or scenarios under different land use or disturbance conditions (Canadian Council of Ministers of the Environment, 2009; Noble,

2008), thus identifying desired outcomes and what is required to achieve those outcomes (White & Noble, 2013).

The development and assessment of current and future land uses via scenario analysis and LUC modeling are foundational to SEA in the context of spatial planning and development (Geneletti, 2012; Gontier, 2007). Such scenario-based approaches, which produce visions of future conditions with and without currently planned development actions or initiatives (European Parliament and Council, 2003; Gontier, 2007; Schmidt et al., 2005), are widely promoted as good-practice in the impact assessment literature and recognized as a means to help overcome the challenges associated with predicting future outcomes under uncertain planning conditions (Duinker & Greig, 2007; Geneletti, 2012; Noble, 2008; Peterson et al., 2003; Zhu et al., 2011). However, despite the variety of LUC models applicable to land use analysis that currently exist (Sohl et al., 2010; Verburg et al., 2004), as well as a number of available scenario-based approaches (Duinker & Greig, 2007; Peterson et al., 2003; Zhu et al., 2011), their combined application in SEA is limited (Bragagnolo & Geneletti, 2013), particularly within the context of land use planning and assessment for managing impacts to urban wetlands (Ma et al., 2012; Mozumder & Tripathi, 2014). Noble et al. (2012) report that the majority of assessment methods and techniques applied in SEA are limited to a number of common, qualitative-based approaches and argue the need for more analytical-based, quantitative assessment methods to support SEA application in regional land use contexts.

This paper presents a scenario-based approach to SEA for wetland area change trend analysis and LUC modeling in an urban environment using a Markov Chain technique. The application is focused on the Saskatoon urban environment, a rapidly growing urban municipality in Canada's prairie pothole region. Specifically, this paper: (i) demonstrates a

scenario-based methodology for assessing the impact of a business as usual scenario through simulation of future LUC, based on trend analysis of historical wetland and urban conditions; (ii) assesses the impact of the City's proposed urban growth and development plan; and (iii) undertakes a comparison of futures with respect to the implications for urban wetland conservation. In doing so, the objective is to advance SEA design and quantitative approaches for wetland conservation planning in urban environments.

The following section provides a brief review of the wetland assessment and LUC modeling for futures and trend analysis in SEA application for urban planning and development. This is followed by a description of the study area, data, and methods used for wetland baseline and futures assessment; finally, the study results are presented. The paper concludes with a discussion of the results, challenges, and further research to advance strategic assessment methods for land use planning assessment in an urban wetland context.

3.3 SEA context: wetlands assessment and LUC modeling

The environmental significance of wetlands is well recognized: wetlands provide habitat for a large number of species, serve as flood control areas, and support ecosystems in terms of water quality maintenance, nutrient cycling, and carbon sequestration (Bartzen et al., 2010). Despite this, wetlands are decreasing more rapidly than any other type of ecosystem (Davidson & Finlayson, 2007; Mitsch & Gosselink, 2007). Currently, only about 5-8 percent of Earth's land surface is covered by wetlands – about 14 percent of Canada is wetlands (National Wetlands Working Group, 1997; Noble et al., 2011). In the context of the Canadian prairie region, a reported 71 percent of wetlands have been lost, due primarily to agricultural land conversion but also due to road development and urban growth (Mitsch & Gosselink, 2007; Nielsen et al., 2012; Westbrook & Noble, 2013).

According to Rubec and Hanson (2009), the Canadian Federal Policy on Wetland Conservation (FPWC) is intended to ensure an appropriate level of wetland conservation, the mitigation of environmental impacts to wetlands, and to sustain wetland functions. The FPWC applies to federal land, all activities on it, and all programs, expenditures, and decisions under federal jurisdictions. However, the majority of wetlands in Canada are on privately owned agricultural land (Neuman & Belcher, 2011), or in and surrounding urban municipalities, which makes both federal and provincial wetland protection policy largely ineffective.

Further, despite numerous policy and regulatory initiatives in Canada that relate to wetlands, there is a lack of standardized or formal methods for the assessment and mitigation of the environmental impacts of development and land use decisions on wetlands (Nielsen et al., 2012; Rubec & Hanson, 2009). The tool most often applied to wetland impact assessment and mitigation planning in Canada is project based Environmental Assessment (EA). However, Noble et al. (2011), Seitz et al. (2011), and Nielsen et al. (2012) report that a considerable number of proposed activities, which potentially affect wetlands directly and/or indirectly, including urban growth and expansion, are either not classified as significant enough to trigger EA or are not subject to formal EA regulation. When EA is conducted, assessments are often of the "screening-type", designed for formulaic projects with seemingly predictable impacts, and EA is often conducted perfunctorily, which is both spatially and temporally restrictive (Noble et al., 2011; Westbrook & Noble, 2013).

The development and application of tools for the assessment of LUC change and potential impacts on wetlands can methodologically improve EA for the sustainable management of wetlands in urban environments. LUC change is broadly defined as a spatiotemporal iteration between biophysical and human related drivers (Veldkamp & Verburg, 2004). A variety of LUC

change models are available for representation of LUC dynamics, its causes, and possible consequences. Schrojenstein Lantman et al. (2011) propose four core principles of LUC change modeling, where any given LUC change model is based on at least one principle:

(i) Historical trends. This principle is based on extrapolation of past LUC change, assuming permanency of the factors that underline the trend.
(ii) Suitability. The suitability principle describes LUC change based on the specific characteristics of a parcel of land (e.g., spatial, biophysical, or socio-economical preference) in terms of quantitative or qualitative based minimization of costs or maximization of profit.
(iii) Neighborhood interaction. The basis of this principle is that the possibility of land change depends on surrounding land uses and use characteristics. LUC change drivers in this case can be biophysical or socio-economic.
(iv) Actor interaction. In this principle, LUC change depends on the decision-making process, which is the result of actors' interaction. The drivers are socio-economic values and development policy.

Regardless of the principles behind a LUC change model, there are several considerations for any LUC model application (Sohl et al., 2010; Verburg et al., 2004), namely: land use history, temporal dynamics of land use, and the trajectory of land use changes; representative driving factors for a particular LUC change model; land use patterns, their spatial interaction and neighborhood effects; level of analysis and its complexity; scale, including spatial and temporal scale, model granularity, and analytical dimensions. The weight of consideration given to any set of considerations can vary depending on the particular LUC change model, the goals of the application, and practical constraints.

There are several underlying analytical approaches that are used most often in LUC change model applications, including: cellular automata, statistical analysis, Markov Chain, artificial neural networks, economic-based models, and agent-based model (Schrojenstein Lantman et al., 2011). Any one of these analytical approaches can be based on one or more of

principles described above and a number of them can be combined in any given LUC model. In the context of wetlands assessment, a Markov Chain approach, which is based on a historical trend principle, is a convenient and accurate model for LUC simulation and has been adopted in several simulation-based studies (see for example Zhang et al. (2011), Arsanjani et al. (2013), and Ma et al. (2012)). However, the benefits of such an approach to assessing scenarios of wetland change in urban development have not been explored within the context of SEA application.

3.4 Study area

The city of Saskatoon is located in the province of Saskatchewan, Canada, on the banks of the South Saskatchewan River. The province of Saskatchewan is part of the prairie pothole region, which covers approximately 480,000 km^2 (Bartzen et al., 2010) and contains approximately 11 percent of Canada's wetlands (Huel, 2000). Saskatoon is the largest city in the province of Saskatchewan with an estimated population of 254,000 as of June 30, 2014 (City of Saskatoon, 2014b). From the first permanent settlements in 1883, the city of Saskatoon has grown steadily (City of Saskatoon, 2011c); 1951–2011 was historically the period of fastest growth, with an average annual rate of population increase of 2.6% (City of Saskatoon, 2000; Statistics Canada & Census of Canada, 2011), and with a projected population of 387,742 (with annual growth rate of 2.5%) to 2032 (City of Saskatoon, 2013a).

The study area consists of five development sectors situated in the Suburban Development Areas of the city of Saskatoon. The development sectors are identified in the City of Saskatoon's Official Community Plan Bylaw No. 8769 (City of Saskatoon, 2009) and with planning documentation (Sector Plans) publicly available (City of Saskatoon, 2014c). However, publicly available Sector Plans do not fully reflect the most current planning strategy for the city.

As such, the Sector Plan boundaries for each development area were updated based on discussions with the City of Saskatoon Planning and Development Department, taking into consideration the City's most current development strategy. Next, following Sizo et al. (2014), the Sector Plans were then adjusted to the next closest (in terms of spatial extent) water catchments (land area that drains to a common waterbody, e.g. river or wetland) – referred hereinafter as assessment areas (Figure 3-1). These are considered the smallest geographically and ecologically meaningful regions for a regional level environmental assessment (Duinker & Greig, 2006). A water catchment was chosen for this assessment as it represents the minimum hydrological unit in terms of the ability of a wetland's system to maintain its functions and stability over the long-term (Committee on Mitigating Wetland Losses et al., 2001; Ehrenfeld, 2000).

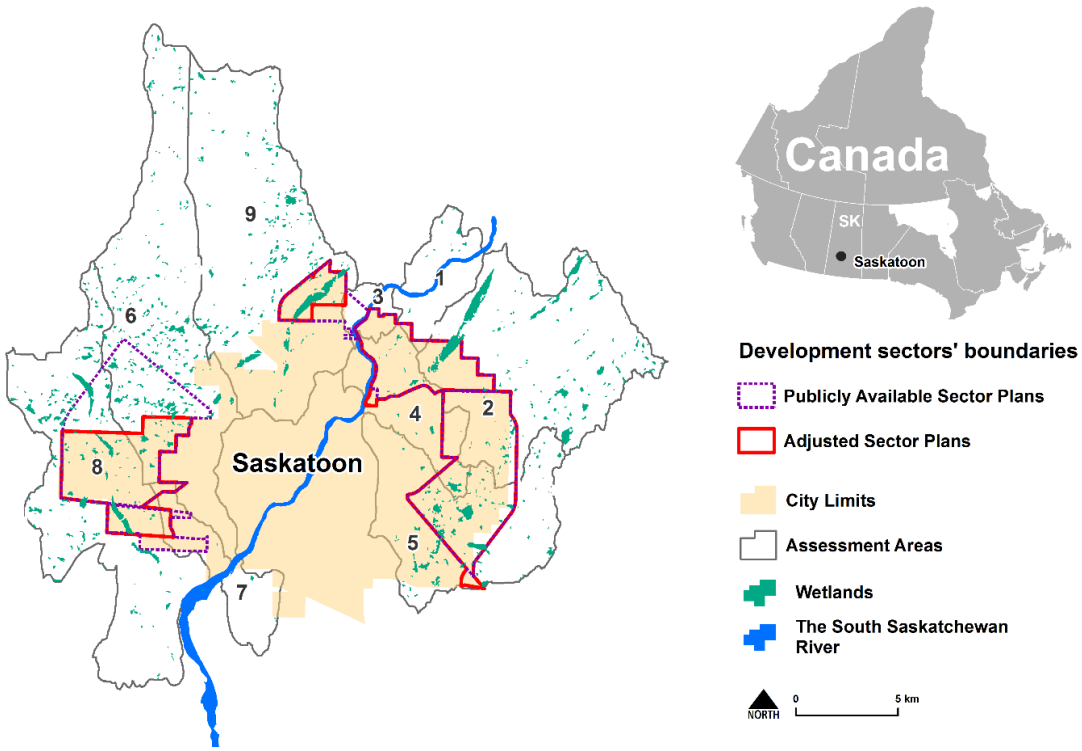


Figure 3-1 Saskatoon urban environment study area and adjusted sector plan areas (assessment areas)

The assessment areas contain approximately 1870 ha of wetlands, including about 506 ha of wetlands within the updated Sector Plans' area (Sizo et al., 2014). The future growth of the city will have both direct and indirect impacts on urban lands, including wetland areas. Similar to other urban municipalities across Canada, the impacts of urban development on wetlands under planned urban development activity is not subject to SEA under current federal or provincial laws or regulations (Noble et al., 2011).

3.5 Assessment approach

Baseline assessment is a key step in any SEA application that serves to establish the regional context for an assessed policy, plan, or program, and consists of an analysis of baseline conditions and changes across space and/or over time. Baseline assessment is arguably the most data and ancillary information intense stage of the SEA process, and is fundamental to the overall analytical quality of SEA and the reliability of SEA results (Fischer, 2007; Government of Canada et al., 2010; Gunn & Noble, 2009; Ramsar Convention Secretariat, 2010; Thérivel et al., 2004; Thérivel, 2010; Wright, 2007). Using the information from a baseline assessment, the scenario assessment and evaluation stage of SEA identifies and evaluates the potential impacts of strategic alternatives, or development scenarios, on current baseline conditions. A *zero alternative* or *business as usual* scenario describes a future without planned action and serves as a future baseline condition for comparison with *potential impacts from planned activities*, and is a required component of good SEA practice (Bonder & Cherp, 2000; European Parliament and Council, 2003; Government of Canada et al., 2010; Gunn & Noble, 2009; Ramsar Convention Secretariat, 2010a; Schmidt et al., 2005; Thérivel, 2010). Two alternative scenarios were developed and assessed for the study area: (i) a *zero alternative*, based on a trend analysis of historical wetland and urban change data; and (ii) a *current development plan* (CDP) scenario,

which was based on considering the current development plans and growth strategy for the City of Saskatoon. A discrete-time Markov Chain technique was applied for simulation of future LUC within the study area under each scenario.

3.5.1 Data

The assessment incorporated historic LUC change data and data from a landscape based temporal analysis of wetland change in the Saskatoon urban development region (Sizo et al., 2014). The assessment of LUC change was limited to three classes: (i) wet area; (ii) built-up area; and (iii) non built-up area. *Wet area* was used as a proxy for wetlands and consisted of open water or saturated areas without taking into account morphological properties of the soil (Gala & Melesse, 2012). *Built-up area* captured urban development features and associated structures (e.g., housing units, schools) (MacGregor-Fors, 2011). All other areas, which were not identified as wet area or built-up area, were classified as *non built-up areas*.

Historic LUC change data covered 1985–2011, and three Landsat 5 TM Climate Data Record Surface Reflectance datasets (USGS, 2014) were used as remote sensing (RS) data sources. The selection of RS data was based on image quality, availability, and seasonality. Spring images were preferred, as suggested by Dahl and Watmough (2007) for wetland identification in Canada prairie region. The acquisition dates for RS images were: May 11, 1985, April 28, 2006, and May 19, 2011. The post classification comparison method was used for LUC change data extraction in the form of a change detection table (Table 3-1). RS unsupervised classification method was used for the image classification with a resulting 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 (Sizo et al., 2014). Change detection data was used as a LUC area transition matrix for subsequent Markov Chain models.

Table 3-1 Land use and land cover (LUC) change data (area transition matrix)

AA	LUC class	1985-2006			1985-2011		
		Built-up	Non built-up	Wet areas	Built-up	Non built-up	Wet areas
1	Built-up	0.0	1.4	0.0	0.0	1.4	0.0
	Non built-up	50.9	1422.8	0.1	1.4	1442.3	17.6
	Wet areas	0.1	45.1	14.0	0.0	29.3	29.9
2	Built-up	4.3	25.6	0.4	3.8	26.0	0.5
	Non built-up	27.5	7172.4	72.1	20.3	7101.4	150.3
	Wet areas	2.3	119.4	360.8	0.9	140.5	341.2
3	Built-up	10.1	15.9	0.0	7.4	18.5	0.0
	Non built-up	10.1	508.1	0.0	0.9	502.9	5.5
	Wet areas	0.0	9.5	0.5	0.0	5.6	4.4
4	Built-up	116.7	27.1	0.0	113.6	30.2	0.0
	Non built-up	208.0	1826.2	8.8	385.1	1631.3	21.5
	Wet areas	5.9	20.5	39.3	14.2	19.6	32.0
5	Built-up	568.9	68.9	0.0	581.6	56.1	0.1
	Non built-up	615.1	3680.1	36.1	734.5	3533.5	63.3
	Wet areas	61.7	101.9	196.5	66.3	96.6	197.1
6	Built-up	752.4	118.1	0.0	769.9	95.0	5.4
	Non built-up	124.6	6924.4	50.7	272.2	6531.0	296.1
	Wet areas	0.8	395.4	301.6	3.9	323.6	370.4
7	Built-up	230.0	59.6	0.0	233.3	55.4	0.0
	Non built-up	110.2	1222.5	3.6	146.4	1176.1	11.2
	Wet areas	1.4	5.5	1.7	1.9	3.4	3.2
8	Built-up	41.4	34.5	0.0	47.3	28.5	0.0
	Non built-up	63.5	7500.2	49.1	109.5	7213.4	279.9
	Wet areas	0.0	122.6	351.7	0.0	62.9	411.4
9	Built-up	710.8	169.5	1.4	762.7	117.8	1.3
	Non built-up	407.9	7420.6	79.7	804.4	6986.6	117.2
	Wet areas	26.5	433.6	302.0	61.7	407.0	293.5

Area unit is ha **Source: Sizo et al. (2014)**

3.5.2 Simulation of future LUC: Markov Chain technique

The Markov Chain technique is a stochastic model and can be defined as a set of states, $St = \{St_0, St_1, St_2, \dots, St_n\}$, where the modeled process moves from one state to another in a series of steps with a denoted transition probability p_{ij}. When a transition matrix $P = [p_{ij}]$ is defined, each element of the matrix, p_{ij}, shows the probability of land use area change from type *i* in time period *n-1* to type *j* in time period *n*, with *R* total number of land use types:

$$\mathbf{P} = \begin{bmatrix} \mathbf{p_{11}} & \mathbf{p_{12}} & \cdots & \mathbf{p_{1R}} \\ \mathbf{p_{21}} & \mathbf{p_{22}} & \cdots & \mathbf{p_{2R}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{p_{R1}} & \mathbf{p_{R2}} & \cdots & \mathbf{p_{RR}} \end{bmatrix} \qquad \text{Equation 3.1}$$

Using the probability matrix in the initial state, it is possible to calculate the state transition probabilities from the initial state to the n^{th} state:

$$\mathbf{P_{ij}^{(n)} = \sum_{k=0}^{R-1} P_{ik} P_{kj}^{(n-1)}} \quad \text{Equation 3.2}$$

The probability matrix was calculated based on the LUC area transition matrix (Table 3-1), using the following formula:

$$\mathbf{P_{ij} = \frac{A_{ij}}{\sum_j A_{ij}}} \quad \text{Equation 3.3}$$

where A_{ij} is the area of land use type that has been in state *i* in period *t-1* and is in state *j* in period *t*.

The initial state matrix, defined as *St(0)*, identifies the starting situation – the current state of the baseline environment. The future land use distribution was predicted based on the initial state matrix and transition probability, using a Markov Chain simulation model *St(n)*:

$$\mathbf{St(n) = St_{(n-1)} \times P^{(1)} = St(0) \times P^{(n)}} \quad \text{Equation 3.4}$$

In Equation 3.4, n is the relation between desired time period and observation length:

$$\mathbf{n = \frac{L_d}{L_o}} \quad \text{Equation 3.5}$$

where L_d is the desired time period (for a land use prediction) and L_o is observation length.

For computation of the probability matrix $P^{(n)}$ the spectral decomposition approach was applied, where matrix *P* was represented by its eigenvalues (*EigVal*) and eigenvectors (*EigVect*):

$$\mathbf{P = EigVect \times EigVal \times EigVect^{-1}} \quad \text{Equation 3.6}$$

and respectively:

$$\mathbf{P^{(n)} = EigVect \times EigVal^{n} \times EigVect^{-1}} \qquad \text{Equation 3.7}$$

where

$$\mathbf{EigVal^{n}} = \begin{bmatrix} \boldsymbol{\lambda_1^n} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \boldsymbol{\lambda_2^n} & \cdots & \vdots \\ \vdots & \vdots & \ddots & \mathbf{0} \\ \mathbf{0} & \cdots & \mathbf{0} & \boldsymbol{\lambda_m^n} \end{bmatrix} \qquad \text{Equation 3.8}$$

and λ_m is the m^{th} eigenvalue and associated with m column of *EigVect*. The negative eigenvalues when appeared were replaced by zero (Rebonato & Jackel, 2000). The initial state matrix *St(0)*, based on LUC data for the assessment areas, was defined as:

$$\mathbf{St(0)} = \begin{bmatrix} \mathbf{A_b} \\ \mathbf{A_{nb}} \\ \mathbf{A_w} \end{bmatrix} = \begin{bmatrix} \mathbf{Built-up} \\ \mathbf{Non\ built-up\ (other)} \\ \mathbf{Wet\ areas} \end{bmatrix} \qquad \text{Equation 3.9}$$

were *A* is the area for a respective LUC class.

3.5.3 Markov Chain models and LUC alternatives

Two Markov Chain LUC simulation models were developed using 1985 LUC data based St(0): (i) MC1985–2006, using a 1985–2006 probability matrix, and (ii) MC1985–2011, using a 1985–2011 probability matrix. The MC1985–2011 model was used for a quality assessment of the Markov Chain technique, while the MC1985–2006 model was used for scenario development. Two alternative scenarios were developed for the future analysis:

(i) The *zero alternative*, which simulates business as usual, where future LUC is based on historical trends in wetland/urban change using the MC1985–2006 model for the entire study area and describing future conditions without the introduction of planned urban development actions.

(ii) The *current development plans* (*CDP) alternative*, which describes future conditions assuming the City's development plans and strategy are implemented, using the MC1985–2006 model for the area which lies outside the spatial extent of the proposed Sector Plans of urban development.

3.5.4 Quality assessment of Markov Chain simulation

The assessment was performed for the built-up class, as wetness condition (and respectively wet area change tendency) changed significantly between 1985 and 2011 (Chun & Wheater, 2012). The simulated MC1985–2011 model LUC area for 2006 was compared with results of 2006 RS images classification. The Relative Error (RE) was calculated for each assessment area as follows:

$$\mathbf{RE} = \frac{|\mathbf{X_o} - \mathbf{X_p}|}{\mathbf{X_o}} \qquad \text{Equation 3.10}$$

where X_o are the original values (the result of the 2006 RS classification) and X_p are modeled values (the results of the MC1985–2011 simulation for 2006). The accuracy assessment for the model yielded good overall average and median accuracy of 66.3% and 69.1%, respectively (Figure 3-12), with one outlier in assessment area #1 (more than two standard deviations).

3.5.5 City planning and neighborhood urban development evaluation

The City of Saskatoon's Official Community Plan Bylaw No. 8769 identifies the temporal scope of CDP application not by year but with a population threshold of 500,000 (City of Saskatoon, 2009). As such, to calculate an end date for the CDP for modeling purposes, the City of Saskatoon Population Projection data (City of Saskatoon, 2013a) was used.

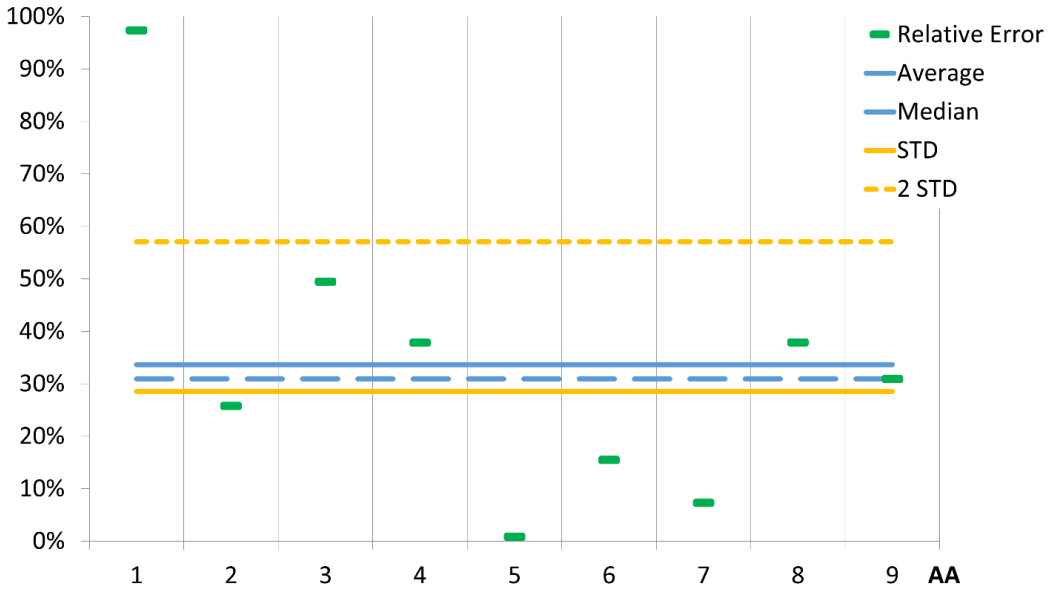


Figure 3-2 Quality assessment of Markov Chain simulation (built-up class)

The projection report covered 2012–2032; the report's population estimations for the years 2012, 2017, 2022, 2027, and 2032 (assuming annual growth rate 2.5%) were extrapolated using a 2nd order polynomial regression to the population level of 500,000, which resulted in the year 2043. The expected scope of planned development over the next 30 years was confirmed by discussions with a senior planner at the Planning and Development Branch, the City of Saskatoon.

To assess future LUC for the CDP alternative, the following steps were performed (Figure 3-3): first, the updated Sector Plan area (the area of proposed urban development) was removed from the assessment areas and reclassified; second, the MC1985–2006 model was applied to the rest of the assessment area to simulate future LUC to the end date of the expected scope of planned development; and, finally, reclassification results of the Sector Plans and the MC1985–2006 simulation for the remaining assessment areas were combined as the CDP alternative. Please see details below.

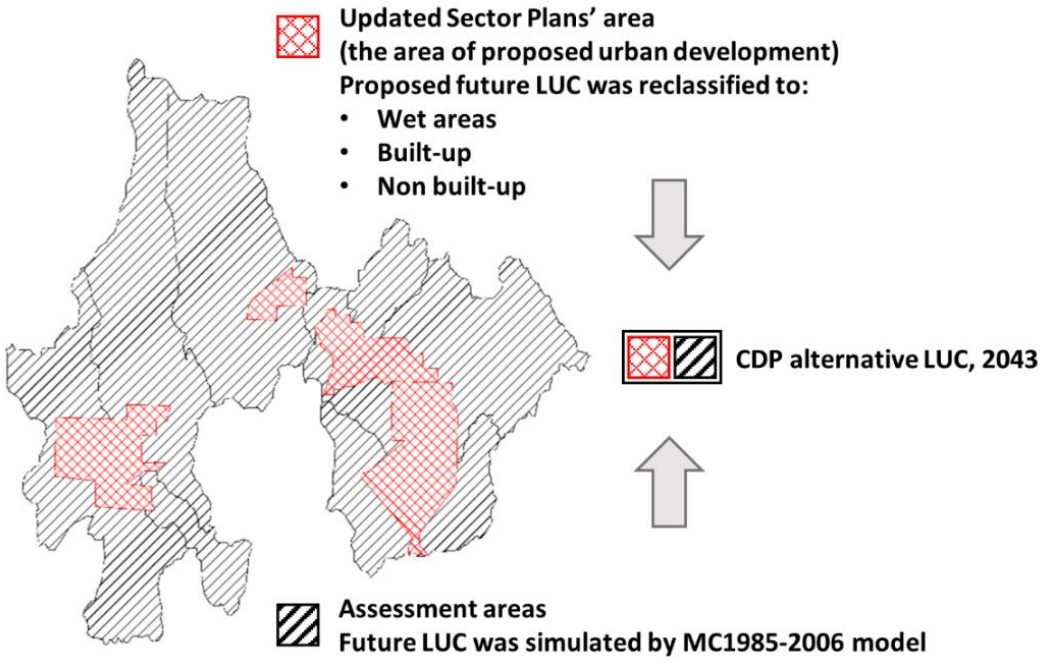
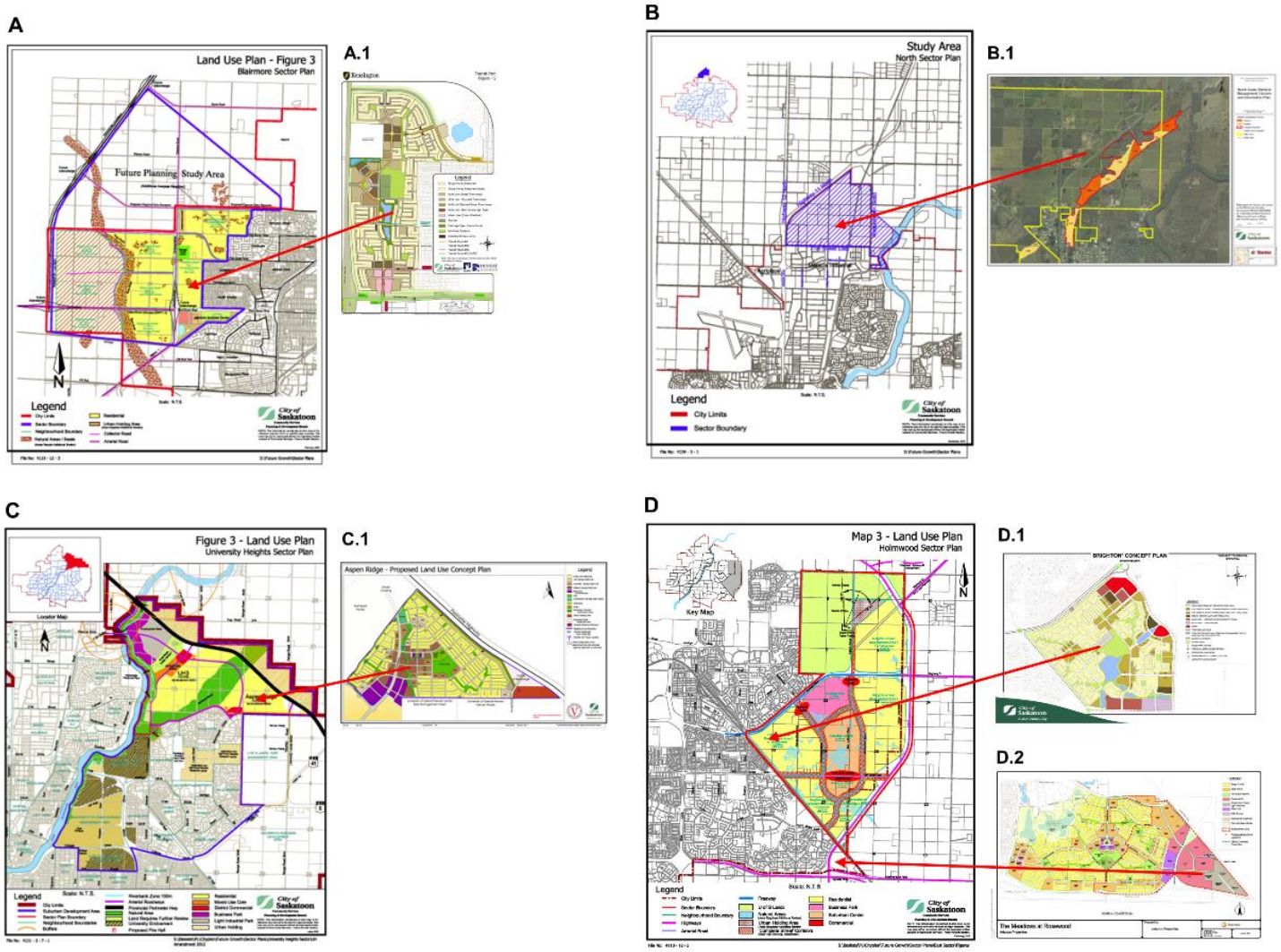


Figure 3-3 Current development plan (CDP) alternative LUC simulation

The planning and development documentation for the City (bylaws and Sector Plans) were prepared in different years and with different levels of detail contained in each plan. Some planning areas (e.g., Blairmore, University Heights, and Holmwood) contained only neighborhood outlines; four neighborhoods (Kingston, Aspen Ridge, Brighton, and Rosewood) had very detailed Sector Plans, containing street details and neighborhood housing/land use block boundaries; the North Sector plan for the city contained the lowest level of planning detail, where only the boundary of planned development with the area was identified (Figure 3-4).



Sector Plans: A – Blairmore, A.1 – Kensington; B – North Sector, B.1 – Zonal screening; C – University Heights, C.1 – Aspen Ridge; D – Holmwood, D.1 – Brighton, D.2 - Rosewood.

Figure 3-4 Sector Plans' LUC, publicly available for the study area (overview, please see City of Saskatoon (2014b) for original maps)

To compensate for the difference in the level of planning details provided across the Sector Plans, and to include the most current planning strategy in the LUC simulation, LUC within the Sector Plans was reclassified into three classes: wet areas, built-up, and non built-up. The residential, business, and industrial areas were classified as built-up. Water and storm water ponds and constructed wetlands (where specified) were classified as wet areas. Wet areas also included: RS identified wet areas within development sectors where no land alteration had been planned for the next 30 years; and wet areas located in west, north, and north-east swales that had been directly identified for conservation. All other areas were classified as non built-up.

The reclassification scheme was reviewed and discussed with the City of Saskatoon Planning Department for confirmation of the most current planning strategy and data available. As a result, a number of suggestions were added to the reclassification results (Figure 3-5):

(i) In the neighborhoods with detailed plans, open space areas (e.g., parks) were identified as non built-up; constructed wetlands, conserved wetlands with original boundaries, and water/storm ponds were identified as wet areas; all other areas were identified as built-up.

(ii) Neighborhood areas without detailed plans were classified as built-up with a variable rate of non built-up: (1) 0% and 5% for non residential and (2) 10% for residential use. The neighborhoods without wet areas that were directly prescribed for conservation (e.g., west and north swale) were identified for conservation of 30% of existing wet areas per neighborhood.

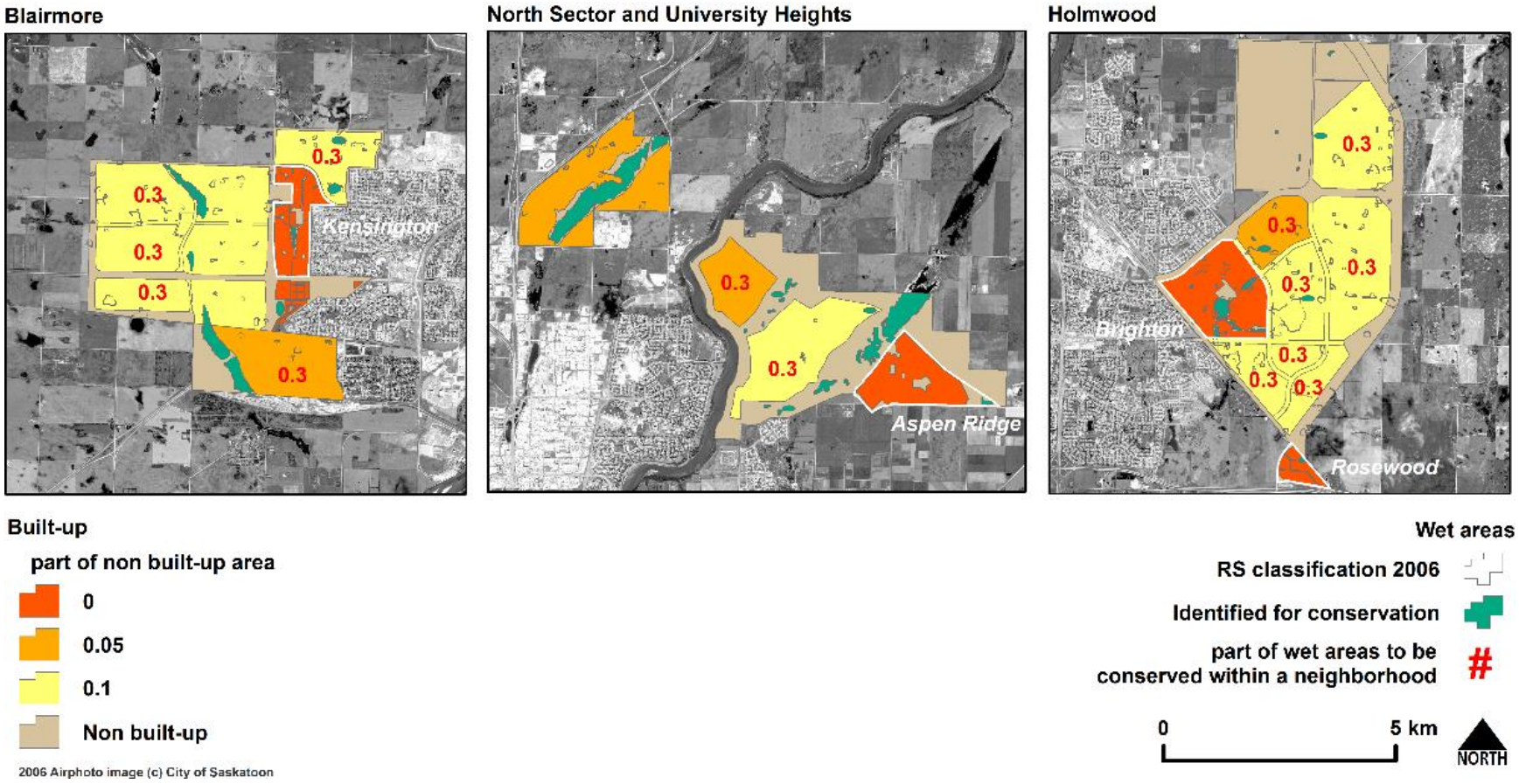


Figure 3-5 Reclassification of Sector Plans' LUC

3.6 Results

The comparison of simulated wet areas with historical data (Figure 3-6) shows a steady decrease in wet area for most of the study area, and simulated values are below the 5% average wetland area threshold for temperate-zone watersheds, suggested by Mitsch and Gosselink (2000). Wetland area is a major indicator for wetland habitat evaluation, as it is reasonable to assume that the loss or degradation of wetland area negatively affects the ability of wetlands in a watershed to maintain their functions within a water catchment, including adequate flood control, water quality maintenance, and support efficient wildlife habitat (Dahl & Watmough, 2007; Mitsch & Gosselink, 2000).

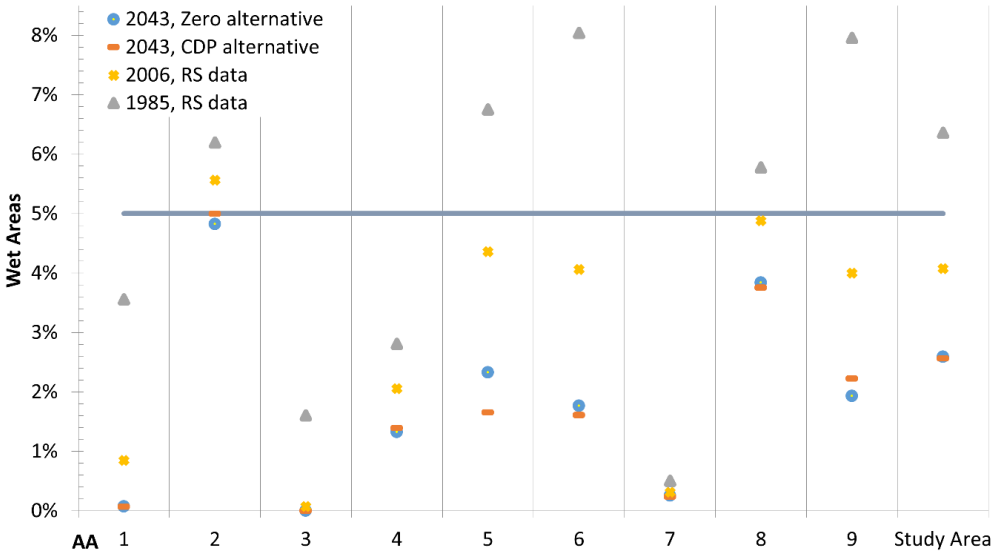


Figure 3-6 CDP and zero alternatives wet areas comparison

The CDP and zero alternatives identify and estimate future LUC change in the study area. The wet areas simulated for the zero alternative scenario considered the historical trend of wetland/urban change in the study area, while the simulation for the CDP alternative included

the most recent development Sector Plans and the City's current development strategy for the next 30 years. The comparison of wet area simulation between the two alternatives shows that five of the nine assessment areas (*i.e.*, adjusted Sector Plan areas) have a less than 0.1% difference in wet area (# 1, 3, 4, 7, and 8); three assessment areas show a difference between scenario conditions of 0.15% and 0.3% (# 2, 6, and 9); and assessment area # 5 resulted in the most difference between scenarios, with a 0.67% difference in wet area. For the entire study area, the 2043 wet area under the zero alternative is 2.59% and for the CDP alternative is 2.56%. Overall, the 2043 simulation results for wet areas are close, which may indicate that the wetland conservation strategy, identified in the CDP, will have little overall effect on wet area when compared to *business as usual* under the zero alternative. Part of the challenge is that the City's planning initiatives, including wetland conservation strategies, are bounded by administrative units, which is often the case for urban development (Kristensen et al., 2013), as opposed to capturing wetland functional scales (Gontier, 2007), which were considered in this analysis and may be considered minimal spatial units in terms of ensuring the ability of wetlands to maintain their long-term functions and resiliency in urban environments (Committee on Mitigating Wetland Losses et al., 2001; Ehrenfeld, 2000).

The Markov Chain technique itself is not an explicit spatial analysis method. However, it is possible to examine the spatial variability of wet area conservation trends among assessment areas. It can be done through an investigation of the spatial distribution of differences between the CDP and the zero alternative with regard to wet areas Markov Chain simulation, despite the close simulation result overall (for the study area). This allows identification of areas where the current development strategy either benefits (assessment areas with positive difference, *i.e.*, # 2, 3, 4, and 9) or does not benefit (with negative difference, *i.e.*, # 1, 5, 6, 7, and 8) from the city's

proposed wetland conservation strategy, compared to the historical trend (Figure 7). The variability in net benefits indicates that, in terms of ensuring wetland conservation improvements, a unified strategy as identified under the CDP may not be effective for all urban planning units within city boundaries. Rather, what may be required is a diversity of conservation plans within the study area, where the planning strategy respects overall wetland vulnerability by water catchment, e.g. considering existing wetland/urban patterns, overall wetland area, size, and distribution.

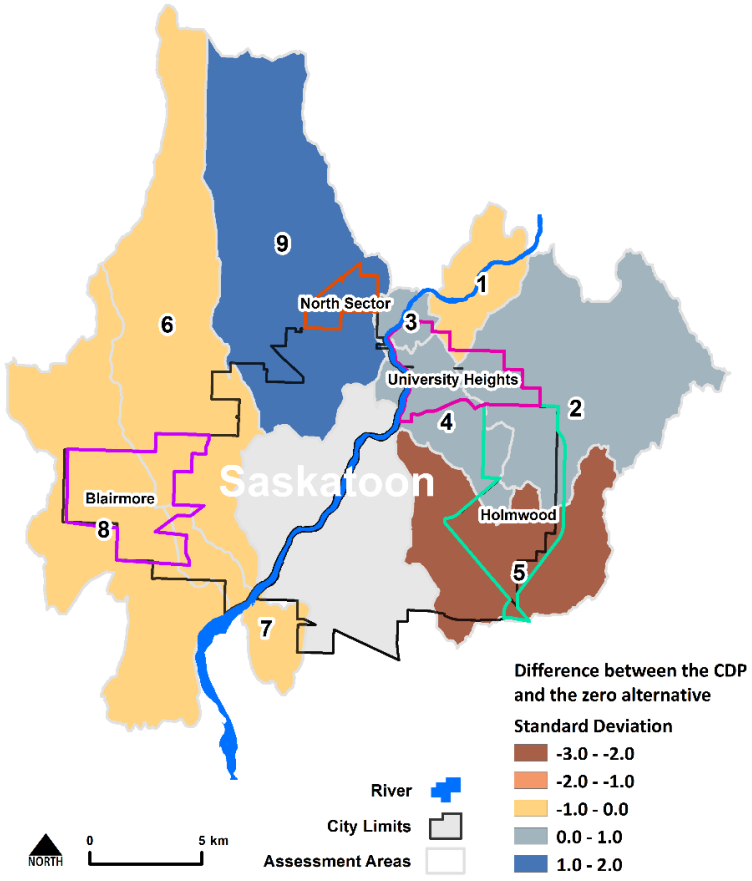


Figure 3-7 Difference of wet areas Markov Chain simulation between the CDP and the

3.7 Discussion

Appropriately managing the potential impacts of urban development on wetlands requires an understanding of trends in environmental baselines and some forethought and foresight about future urban growth and resulting LUC conditions. Scenario-based assessment is foundational to SEA (Duinker & Greig, 2007; Geneletti, 2012; Peterson et al., 2003; Zhu et al., 2011); however, its application, quantitatively, and supporting methods and tools have been relatively limited (Noble et al., 2012). Consideration of a zero alternative (business as usual scenario) can provide a vision of a future without currently planned development actions, and support the comparison of the impacts of future outcomes with those of planned activities (Bonder & Cherp, 2000; European Parliament and Council, 2003; Schmidt et al., 2005).

It could be argued that there is a need for consistent and complete baseline data to support sophisticated future trends analysis in SEA applications. Schrojenstein Lantman et al. (2011) noted that consistent data is a precondition for good LUC modeling. Unfortunately, as was found during this research, consistent and comprehensive datasets are rarely available in actual urban planning contexts. Publicly available planning data is often not up-to-date, particularly in fast-growing municipalities such as the one in this study and as such may not actually reflect the most current planning and development strategy. González et al. (2011) reported that impact assessment with the use of GIS techniques is widely constrained by the level of detail of available datasets. However, Thérivel (2010) argued that "not all the baseline data must be available for an SEA to proceed;" João (2007) agreed, in that SEA can be completed with missing baseline data and argues that there is a need to reach a balance between data collected and data needed. The current study used development plans proposed to establish a development strategy for the city of Saskatoon for the next 30 years. Each of the neighborhood or land use Sector Plans, however, contained varying levels of planning detail. As such, to facilitate trends

analysis and scenario development, it was necessary to supplement and standardize the granularity of data and land use classification based on more qualitative data, based on discussion and recommendations from the representatives of the City's Development and Planning Department.

A Markov Chain, a stochastic method, was then used for LUC simulation. A stochastic approach is recommended against others to account for the uncertainty and variability associated with future conditions (see for example MacDonald (2000)). However, as with all futuring methods, the Markov Chain has its limitations (Winston, 1997). The probability distribution of the next period's state depends on the current state and does not depend on the states the chain had previously passed through. That means the variation of the probability of change between two states is not a part of the Markov Chain model and is not reflected in the simulation of future. Also, as the transition probability determination plays an important role in Markov Chain modeling, the accuracy of the input data needs careful consideration. In terms of the current study, the probability matrix was calculated from the area transition matrix, based on RS change analysis of the study region, with an overall accuracy of 92.4% for 1985, 93.6% for 2006, and 92.0% for 2011, and Khat coefficients 0.884, 0.903, and 0.878, respectively (Sizo et al., 2014). If feasible, the quality assessment of the Markov Chain model should be performed for the area of application. For the study area, the MC1985–2011 model was evaluated with a good overall average and median accuracy of 66.3% and 69.1%, respectively. Another assumption of the Markov Chain technique is that the probability law relating the next period's state to the current state does not change. That means the change remains stationary over time after the evaluated states. In the current study, this feature of the Markov Chain was used for the zero alternative of

LUC change, *i.e.*, for the historic trend description; while the planned change of the LUC condition, *i.e.*, planned urban development, was used for the CDP alternative.

The assessment of LUC change in this research was limited to the three basic classes: a wet areas class was adopted as a proxy for wetlands and built-up and non built-up classes were used for urban development. The LUC simulation was based on the change of RS identified wet areas, though some dried wetlands could have been classified as non built-up class due to the difference in environmental conditions over time. However, the intention was to show the applicability of the Markov Chain approach for scenario development and analysis in SEA practice. For practitioner's needs, the classification scheme can be adjusted depending on desired information resolution and can include, for example, dried wetlands and agriculture field classes separately.

The zero alternative simulated the tendency of urban development before prescribed urban planning and development actions have taken place, while the CDP alternative simulated future LUC in order to account for prescribed development plans and wetland conservation initiatives. Overall, results for the year 2043 under the CDP and zero LUC simulations were similar. In the context of wetlands management, this suggests that the application of the current wetland conservation strategy, only within administrative based planning units, will not be sufficient to compensate for the historic trend of wetland area decrease in the city. However, the variability analysis of difference between the current development strategy and the historical trend wet areas simulations (the CDP and the zero alternatives) identified areas of positive and negative difference. The areas with positive differences are located at the north-east of the city and might experience improvements in wetland coverage due to conservation initiatives; the rest of the Study Area does not have a wetland benefit in terms of wetland conservation. The

variability is most likely a reflection of a difference in landscape wetland/urban spatial patterns that was not fully considered in development planning. Overall, for wetland conservation policy improvement, it is suggested that: (i) any wetland conservation strategy should consider wetland functional scale and ecologically meaningful units, e.g., water catchments, as opposed to solely administrative based planning units; and (ii) a variable conservation rate based on consideration of the particular qualities and variability of the LUC (e.g., existing wetland area and wetland/urban spatial patterns) is preferred to a standard conservation prescription across the urban area.

The scenario-based approach presented in this work provides a basis for wetland trends and future LUC analysis, which, in future practice, may be extended by using a range of alternatives; for example, based on modeled planning documentation with respective desired outcomes that may involve different urban development plans, different patterns of urban growth and density, and alternatives wetland conservation policies or targets. Despite the frequent lack of consistency in input data for undertaking such quantitative-based analysis in urban wetland contexts, the approach presented here utilizes a reliable and replicable method for futures analysis that can be contextualized for wetland conservation. This research may be used to support urban planners and wetland policy makers in the development and comparison of completing planning, development, and land use zoning options to help ensure that urban wetland conservation goals are achieved.

3.8 Conclusion

This paper presented an approach for the assessment of urban planning futures in the context of urban wetland conservation. The research was designed as a scenario planning exercise, where two alternatives, a zero alternative and current development plan alternative, described potential

wetland futures based on past trends of urban development and wetland change. The study addresses the currently recognized need for contextualized methodology in SEA to support scenario development and LUC modeling (Bragagnolo & Geneletti, 2013; Ma et al., 2012; Mozumder & Tripathi, 2014), particularly within the context of wetland conservation. The scenario exercise did reveal some shortcomings and difficulties in on-the-ground application, specifically related to assessment contextualization, data quality, data availability, and data consistency. The approach presented in this paper may be useful for SEA practitioners, whose work is related to wetland and urban growth analysis, in environmental assessment and leverage data and information that can be helpful in development plan design, in the comparison and revising of wetland conservation strategies, as well as in providing a sound basis for decision and policy making in urban environmental management.

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4 CHAPTER 4: A STRATEGIC ENVIRONMENTAL ASSESSMENT APPROACH TO WETLAND CONSERVATION POLICY DEVELOPMENT AND IMPLEMENTATION IN AN URBAN CONTEXT

4.1 Preface

Chapter 4 represents the third part of the research. This part presents a scenario-based approach for evaluation of alternative wetland conservation policy options, based on strategic urban planning goals, and then translating broad strategic policy direction to site-specific wetland conservation planning priorities. This work was led by Anton Sizo under the supervision of Bram Noble and Scott Bell. The data were collected and analyzed by Anton Sizo, and reviewed by Bram Noble and Scott Bell. All authors were equally involved in the writing of the manuscript for publishing. Anton Sizo generated all maps and figures. The Chapter manuscript has been submitted for publication and is under review in the journal Impact Assessment and Project Appraisal, co-authored by Dr. Bram Noble (second author) and Dr. Scott Bell (third author). All authors read and approved the final manuscript. The manuscript citation is provided below. The Chapter manuscript has undergone minor changes (e.g. spelling and syntax correction) since its submission.

Sizo, A., Noble, B., & Bell, S. (2015). A strategic environmental assessment approach to wetland conservation policy development and implementation in an urban context. *Impact Assessment and Project Appraisal (Under Review).*

4.2 Introduction

Wetlands provide important ecological services, including carbon sequestration, wildlife habitat provision and flood control. Despite that, wetlands are amongst the most threatened habitat in the

world; close to 50 percent of original wetlands worldwide have been completely lost, including an estimated 71 percent of wetlands in the Prairie Region of Canada (Mitsch & Gosselink, 2007). The majority of wetland loss has historically been attributed to agricultural land conversion; however, urban growth is now a significant driver of wetland loss and degradation (Bartzen et al., 2010; Rubec & Hanson, 2009; Sizo et al., 2015). The primary instrument in Canada for assessing and managing land use and development impacts to wetlands is project-based Environmental Assessment (EA). However, project-based EA is a reactive process, based on project-by project assessment and impact mitigation, as opposed to ensuring actions or policies that serve to create or enhance the sustainability of environmental systems (Westbrook & Noble, 2013). Further, urban development, urban land use planning, and wetland conversion in urban environments typically do not trigger any form of EA process in Canada (Noble et al., 2011).

Strategic Environmental Assessment (SEA) is one means to address, in part, the reactive and project-focused nature of current EA practices. The concept of SEA was introduced in the late 1980s, referring to EA appropriate to policies, plans and programs (PPPs) of a more strategic nature than those applicable to individual projects (Partidário, 2007). The strategic nature of SEA, and what differentiates SEA from other forms of EA, has little to do with the level of application (PPPs), and more to do with how PPPs are approached, developed, implemented and influence decision making (Bina, 2003; Cherp et al., 2007; Noble, 2000). Partidário (2012) argues that ‘strategic’ is an attribute that qualifies ways of thinking, attitudes and actions related to strategies, thus characterizing SEA as instrument with a ‘strategic nature,’ meaning that it, among other things, helps to create a development context towards sustainability and determine the necessary transformations to ensure successful PPPs.

In principle, SEA has the potential to provide a framework to support urban wetland sustainability-based policy and planning decisions (Nielsen et al., 2012; Ramsar Convention Secretariat, 2010; Sizo et al., 2015). Recent reviews of SEA, however, indicate that challenges remain in translating broad strategic principles and objectives in SEA into more specific, operational plans and practices (Noble, 2009; White & Noble, 2013). Important though strategy is to defining the nature of SEA, broad strategic level principles in SEA are not always translated into operational practices through decision making process (Fischer, 2003; White & Noble, 2013). It is important that strategies steer implementation (Emmelin & Nilsson, 2006), and that strategic directions emerging from SEA are accompanied by practical direction for 'on-the-ground' PPP implementation (Acharibasam & Noble, 2014).

Strengthening the relationship between the strategic and the tactical in SEA is important to the continued adoption of SEA, and more importantly to its influence on on-the-ground PPP practices. Strategic and tactical planning are interrelated and complementary processes, which must link to each other and inform and support one another for the effective development and implementation of PPPs. Compared to discussions of broad strategic principles, practical frameworks and methods supporting SEA, particularly quantitative approaches that support both strategic and tactical SEA design, have been much less prominent in the academic literature, even through practical methods and guidance remain amongst the main challenges encountered during SEA implementation (Liou et al., 2006; Noble et al., 2012). There is a need for further methods development in SEA, particularly quantitative-based methods that are sensitive to the often fuzzy nature of strategic issues, but at the same time capable of providing tactical guidance for those implementing PPPs.

This paper presents a SEA analytical approach demonstrating how to tier the strategic and operational levels of a PPP in an applied urban land use planning and decision making context. Specifically, this paper demonstrates an approach to SEA to support PPP development and implementation for urban wetland conservation. The SEA design focuses first on the evaluation of alternative wetland conservation policy options based on strategic urban planning goals and second on translating broad strategic policy direction to site-specific wetland conservation planning priorities. In the sections that follow, the study area for this research is introduced, followed by the SEA design and methods used for the strategic and tactical assessment. Results of the SEA application to the city of Saskatoon, Saskatchewan – one of the fasted growing cities in Canada, situated in the middle of the prairie pothole (wetland) region, are then presented. The paper concludes with a discussion of the results, including the SEA approach and directions for SEA research and sustainable planning in the context of urban wetland conservation.

4.3 Study area

The study area for the development and application of the SEA approach was the city of Saskatoon urban development region, Saskatchewan, Canada. The city of Saskatoon is located on the banks of the South Saskatchewan River, in the Prairie Ecozone and Moist Mixed Grassland Ecoregion. Despite the ecological and societal importance of wetlands to the prairie region (Rubec & Hanson, 2009), approximately 40 percent of wetlands in the province of Saskatchewan have been lost, with half of the remaining wetlands considered threatened (Huel, 2000).

The city of Saskatoon is the largest city in the province with an estimated population of 222,189 (as of 2011). The city is experiencing significant growth, with an average annual

population growth rate of 2.6% (City of Saskatoon, 2010; Statistics Canada & Census of Canada, 2011) and a projected population of 387,742 by 2032 (City of Saskatoon, 2013a). The majority of land development, including residential, to meet population growth has been in the form of outward expansion and suburban neighborhood development. Over 80% of the local native prairie landscape in Saskatoon and its surrounding area has been transformed by urban development and resource industries (City of Saskatoon, 2014a). The future development of the city will result in both direct and indirect impacts to nearby lands, including wetlands. However, the possible impacts of urban development activity on wetlands in Canada is not a subject to SEA under current federal or provincial laws or regulations (Noble et al., 2011).

The assessment focused on the city's four urban planning units: Blairmore, Holmwood, North Sector, and University Heights (Figure 4-1), defined based on the City's development sector planning process (City of Saskatoon, 2014c). These four planning units were selected because they represent the city's future growth area and the spatial extent of development over the next 30 years (Sizo et al., 2015). The spatial extent of each of the four urban planning units were then adjusted to the next closest water catchment (referred hereinafter as *assessment areas*, see Figure 4-1), arguably the smallest geographically and ecologically meaningful scale for a regional level assessment (Dubé et al., 2013). Water catchments represent the minimum hydrological unit in terms of the ability of a wetland's system to maintain its functions and stability over the long-term (Committee on Mitigating Wetland Losses et al., 2001; Ehrenfeld, 2000). The assessment areas contain approximately 1,870 ha of wetlands, with approximately 506 ha of wetlands located within the urban planning sectors (Sizo et al., 2014).

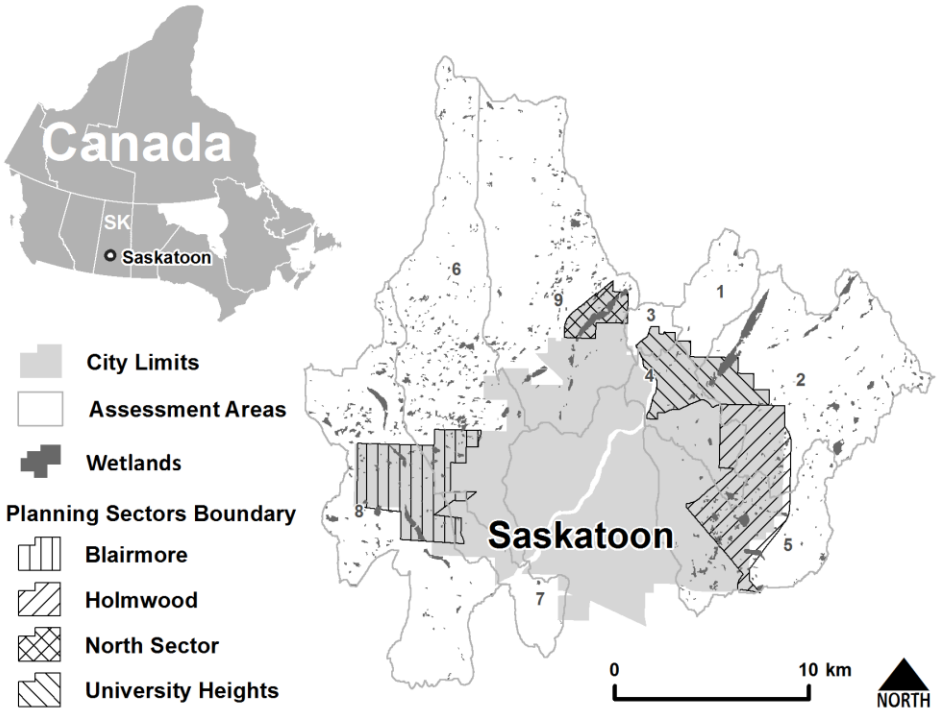

Figure 4-1 Saskatoon urban and wetland environment assessment areas and planning sectors

4.4 Methods

The SEA design consisted of two phases (Figure 4-2): a *strategic phase*, focused at the policy level and on the identification of a strategic direction (wetland conservation target), considering also competing sustainable urban development goals; and *a tactical* phase, focused at the operational level of implementing the policy 'on-the-ground,' considering the application of a wetland conservation target within the urban planning process. In the strategic phase, a scenario analysis exercise was developed to assess alternative, city-wide, wetland conservation policy targets on the basis of existing urban development planning goals for the City, using an expert-based multi-criteria evaluation process. In the tactical phase, results of the expert-based assessment, and the preferred wetland conservation policy targets, were applied to the City's planning units' design, identifying individual wetland conservation priorities within each of the planning units.

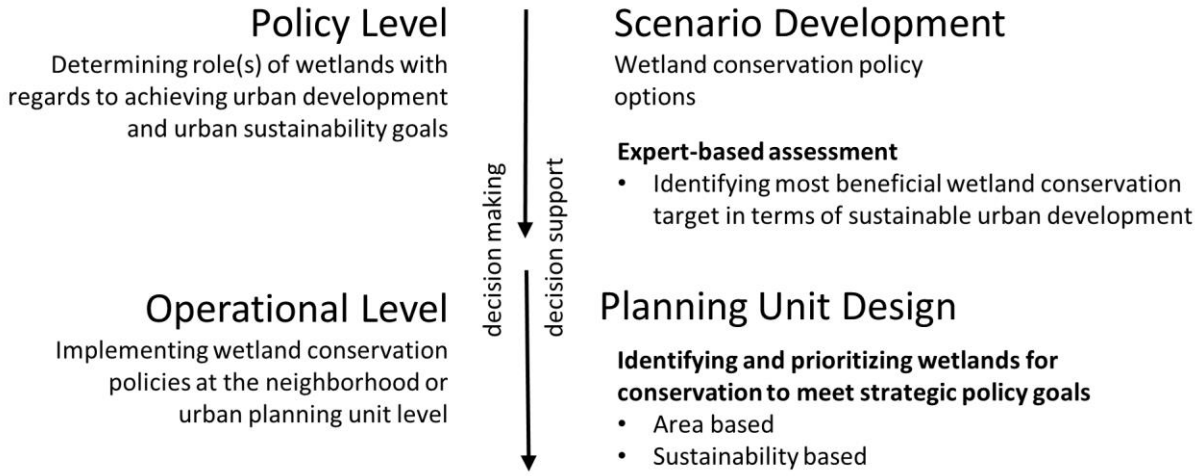

Figure 4-2 SEA design approach

As a means to assist planners in determining how best to apply a city-wide policy or conservation target on the ground, and in different urban planning units, two conservation priority algorithms were examined: (i) wetland conservation based on wetland area only, whereby the largest wetlands are given higher conservation priority; and (ii) wetland conservation based on broader wetland sustainability criteria, which complements the area based approach with landscape-based metrics of wetland value, utilizing a normalized Landscape Composite Index (nLCI)(Sizo et al., 2014). Each of these phases is described below.

4.4.1 Strategic assessment: Urban wetland policy options

Four policy options for wetland conservation in the city of Saskatoon were identified for the analysis. The options were developed to cover two possible extremes of wetland conservation: 0% and 100% conservation of existing wetland areas across the urban region, with intermediate trade-offs established at 33% and 66% conservation targets. This stepped approach allowed investigation of the City's current wetland conservation strategy, which assumes integration of preserved or constructed wetlands into new neighborhood design with a conservation target of

approximately 30% of existing wetland area in any development sector (Personal communication, City of Saskatoon, Planning Division, 25 November 2014).

Each policy option was assessed in terms of its potential implications for meeting the urban planning and development goals of the City of Saskatoon. City planning and development goals were identified based on: (i) goals and objectives specified in city planning documents, (ii) discussions with city planners; and (iii) drawing also on urban sustainability policy and planning literature. These goals were developed as criteria Table (4-1) and used as the basis for an expert-based assessment of alternative wetland policy conservation targets.

Table 4-1 Evaluation criteria for wetland policy conservation targets

	Environmental sustainability (En)	**Economic well-being (Ec)**	**Quality of life (QL)**
Evaluation criteria	En_1: Advance the city's "compact city" strategy (e.g. minimize urban sprawl)	Ec_1:Increase the affordability of housing	QL_1: Advance the "complete communities" strategy (in the context of access to open space, recreational areas, aesthetic landscapes)
	En_2: Advance the city's responsible environmental management and conservation strategy	Ec_2: Increase the marketability of future neighborhoods	QL_2: Advance sustainable transportation and connectivity (in the context of pedestrian and bicycle friendly design of neighborhoods)
	En_3: Decrease greenhouse gas emissions	Ec_3: Minimize cost of urban flood control infrastructure	QL_3: Increase water security in the region

The *environmental sustainability* (En) criteria attempt to capture issues that relate to the footprint of urban growth and development. Criterion En_1, for example, concerns the potential impact of a proposed policy or initiative, in this case a wetland conservation policy, on the urban development footprint, or the compact city design – a concept espoused by the City as a way to reduce waste, decrease transportation network expansions, and increase neighborhood accessibility (City of Saskatoon, 2000, 2009, 2013b). Criteria En_2 and En_3 are based on meeting the sustainable city growth concepts and environmental management policies of the City (City of

Saskatoon, 2000, 2009, 2011a, 2011c, 2013b) and are directly related to the services provided by wetlands, including habitat provision and carbon sequestration (McInnes, 2010; Mitsch & Gosselink, 2000).

The *economic well-being* (Ec) criteria are based on how the implementation of a policy or plan may impact the overall economic wellbeing of Saskatoon. In the case of wetland policy, criterion Ec_1 addresses the relationship between the conservation of wetland area and the availability of land for residential development, including housing affordability (City of Saskatoon, 2009, 2011b, 2013b). Criterion Ec_2, marketability, captures the relationship between the services provided by urban wetlands (e.g. recreational, aesthetic, cultural) and the living attractiveness of a neighborhood (Bolitzer & Netusil, 2000; Bolund & Hunhammar, 1999). Criterion Ec_3 addresses the implications of a policy or plan for flood control, and thus captures the possible economic cost of the replacement of natural flood control services provided by urban wetlands (Mitsch & Gosselink, 2000).

The final group of criteria, *quality of life* (QL), takes into consideration the social and health benefits or costs of a policy or plan. Criterion QL_1 is based on the complete community concept (City of Saskatoon, 2011a, 2013b), focused on accessibility to natural open spaces, recreational activity support, and aesthetics. Criterion QL_2 considers accessibility implications, and particularly the availability of green transportation (e.g. pedestrian trails, bike trails) (City of Saskatoon, 2009, 2013b). Criterion QL_3 addresses issues related to water security, namely quality and quantity, but also considering how a policy or plan may alter urban hydrology.

4.4.1.1 Expert-based assessment

An expert-based assessment of wetland policy options was structured using the analytic hierarchy process (AHP) (Saaty, 2008), a form of multi-criteria analysis that allows for the ranking of options based on a set of competing evaluation criteria. The AHP has proved successful in a variety of evaluation and assessment contexts (Herva & Roca, 2012; Mendoza & Martins, 2006; Noble & Christmas, 2008; Noble, 2002). The AHP was structured based on an overarching goal, defined by the three groups of criteria, which was used to assess the four wetland conservation policy targets (Figure 4-3).

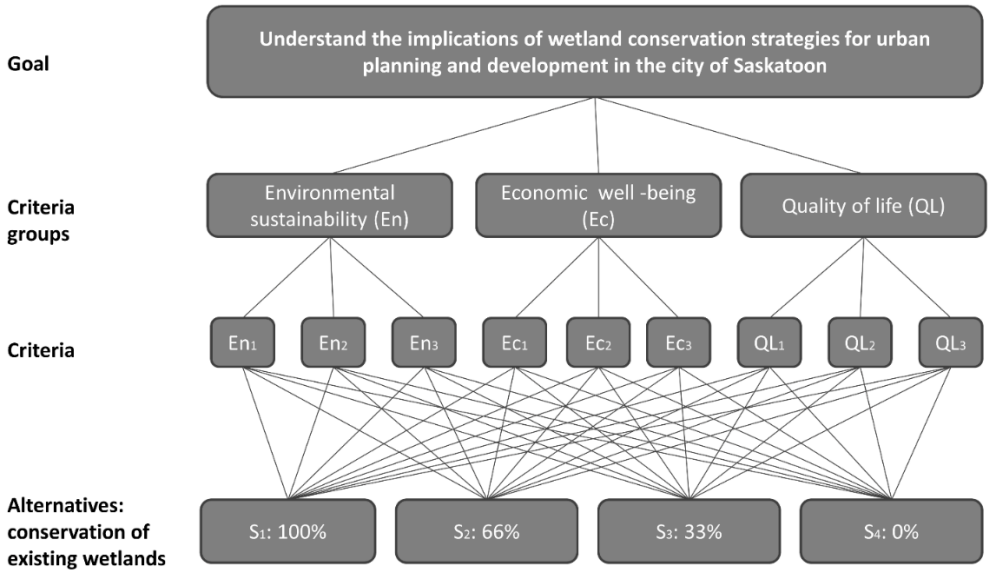

Figure 4-3 AHP evaluation structure for wetland conservation policy scenarios

An expert panel was compiled based on invitations sent to City of Saskatoon organizations involved, or who have an expressed interest in land use, city planning and development, or wetland conservation. A total of 16 individuals from 12 organizations agreed to participate, including municipal planners (e.g., urban planners, environmental planners, wetland and urban policy analysts), the private sector (e.g., land developers, environmental consultants),

and researchers (e.g., wetland ecologists, planners). Participants reported a median of 17 years experience in their respective field of expertise.

The assessment process consisted of two parts. In the first part, participants were asked to evaluate the relative importance of each evaluation criterion within the broader context of future planning and urban sustainability goals for the city of Saskatoon, using a pairwise comparison approach. The pairwise approach was based on comparing groups of criteria, and then criteria within each group, using the Saaty's (2008) assessment scale (Table 4-2). In the second part of the survey, participants used the same pairwise approach to assess each wetland conservation policy option (S1-4) against each other policy option in terms of its perceived impact on, or contribution to, the City's planning and development goals (see Table 4-1).

Table 4-2 Paired comparison assessment scale

Intensity	Definition	Explanation
1	Equal	Two criteria/option are equally preferred/important
3	Moderate	One criterion/option is slightly preferred to/more important than the other
5	Strong	One criterion/option is strongly preferred to/more important than the other
7	Very strong	One criterion/option is very strongly preferred to/more important than the other
9	Extreme	One criterion/option is extremely preferred to/ important than the other

Intensity values 2, 4, 6, and 8 can be used as transition rates Source: Saaty (2008)

Expert Choice Comparion™ web-based survey software (Expert Choice, 2014) was used to administer the survey and to derive criteria priorities and scenario preference scores. The scenario preference scores were plotted against the wetland conservation scenario targets to identify any association between wetland conservation targets and expert's preferences: higher preference scores would depict a preference for wetland conservation scenario targets that are more beneficial to the achievement of the City's development goals. Then, one-at-a-time local

sensitivity analysis (Hamby, 1994) was performed to evaluate the sensitivity of the conservation scenario scoring. To do this, the groups of criteria priorities (i.e. En, Ec, and QL) were repeatedly adjusted, one priority at a time, with their minimum (0) and maximum (1) values and results reassessed to understand the possible range of scenario priority scoring. This allowed an assessment of the stability of the expert's scoring of conservation policies against the evaluation criteria.

4.4.2 Tactical assessment: Wetland conservation policy application on the ground

Results from the expert-based strategic level assessment provided an understanding of the overall conservation policy preference; however, it did not provide operational guidance on policy application at the urban planning unit level. Overall, the City's policy is based on achieving a balance between the conservation of wetland functions and other considerations that affect the form of urban development, including compact development, transportation, connectivity, financial feasibility, and quality of life (City of Saskatoon, 2009). This approach is consistent with the notion of wetland sustainability within the context of land use planning. It refers to the maintenance of a wetland environment over the long term, ensuring "the greatest continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations" (Ramsar Convention Secretariat, 2010b).

In the current wetland conservation strategy, the City assumes integration of preserved or constructed wetlands into new neighborhood designs. In general, the City assumes larger wetlands, and 'complexes' of a number of high-quality wetlands to be more likely preserved than small and/or isolated wetlands (Personal communication, City of Saskatoon, Planning Division, 25 November 2014). Wetland size and wetland complexes are important, but not the only parameters that can be used for prioritizing how to implement an urban wetland conservation

policy. Numerous indicators related to wetland functions can be used to assess wetland sustainability, or threats to sustainability, and thus prioritize wetlands within a water catchment (Brooks et al., 2006; Canter & Atkinson, 2011). These include landscape indicators that have been shown to provide insight to the sustainability of wetlands within a water catchment, namely: total built-up area, built-up area to total water catchment area ratio, total wetland area, number of wetland areas, wetland density, wetland area to total water catchment area ratio, average wetland area size, and wetland to built-up area ratio (Mitsch & Gosselink, 2000; Schweiger et al., 2002; Wang et al., 2008).

4.4.2.1 Policy application using an area-based conservation preference algorithm for prioritizing individual wetlands

An area-based wetland conservation preference algorithm assumes that larger wetlands are more preferable for conservation than smaller wetlands and thus for meeting any strategic policy or target for urban wetland conservation. This is based on the notion that wetland size has a high influence on the capability of wetlands to maintain their functions (Dahl & Watmough, 2007); that larger wetlands provide better support for wildlife habitat (Schweiger et al., 2002), more effectively influence water quality (Moreno-Mateos et al., 2010), and that a decrease in wetland size reduces the spectrum of hydrological functions that wetlands can maintain (Cohen & Brown, 2007). Prioritization of wetlands for conservation were calculated using the following formula:

$$\mathbf{ABI} = \frac{\mathbf{W_k}}{\mathbf{W}} \qquad \text{Equation 4.1}$$

where ABI is area based conservation preference or priority index of the wetland, W is total wetland area, and W_k is the individual wetland area. The ABI is calculated for an individual

wetland per urban planning unit, assuming a higher ABI indicates a higher preference for conservation when applying a city-wide wetland conservation target based on wetland area.

4.4.2.2 Policy application using a sustainability-based conservation preference algorithm for prioritizing individual wetlands

A sustainability-based wetland conservation preference algorithm complements the area-based approach with the use of landscape indicators as a proxy for the sustainability of wetland functions and was based on a normalized Landscape Composite Index (Sizo et al., 2014). The normalized Landscape Composite Index (nLCI) is a multi-dimensional description of wetland sustainability in an assessment area in a single measure, which encompasses a number of landscape indicators:

$$\mathbf{nLCI} = \frac{\sum \mathbf{nLI_i} + \sum (\mathbf{1} - \mathbf{nLI_j})}{\mathbf{N_{nLI_i}} + \mathbf{N_{nLI_j}}} \qquad \text{Equation 4.2}$$

where nLI is normalized landscape indicator, with *i* indicating a positive and *j* a negative threat to wetland sustainability, and *N* is the number of indicators considered. The nLCI varies from 0 to 1, assuming index values closer to '0' represent lower levels of wetland sustainability (i.e., higher risks to wetlands) in an assessment area. The following indicators were used for nLCI calculation for each assessment area: total built-up area, ratio between built-up area and water catchment area, wetland area, wetland number, wetland density, ratio between wetland area and total water catchment area, average wetland size, ratio between wetland and built-up area (see (Sizo et al., 2014). Individual wetland conservation priorities were calculated by the following nLCI adjustment ($nLCI_{adj}$):

$$\mathbf{nLCI_{adj}} = (\mathbf{1} - \mathbf{nLCI}) \times \mathbf{ABI} \qquad \text{Equation 4.3}$$

where nLCI is the normalized Landscape Composite Indicator for an assessment area, and ABI is the area based individual wetland priority. The $nLCI_{adj}$ was calculated for each wetland and describes the individual importance of a wetland in terms of its likely contributions to broader wetland sustainability within an assessment area.

4.5 Results

The sections that follow present the results of the SEA application. First, results of the expert-based strategic assessment of wetland conservation policies are presented. This is followed by an example of operational level wetland conservation policy implementation within the urban planning units, comparing the area and sustainability based conservation prioritization approaches.

4.5.1 Expert-based strategic assessment of wetland conservation policy options

Results of the experts' assessment of environmental, economic, and quality of life development goals, and respective criteria (Table 4-1), are summarized in Figure 4-4. Overall, the quality of life and the environmental sustainability criteria were almost equally prioritized (0.39 and 0.36 respectively) by respondents as more important for informing planning and development decisions than the economic well-being group of criteria (0.25). Increasing the marketability of future neighbourhoods, criterion (Ec2), received the lowest priority of all criteria, and advancing the City's responsible environmental management and conservation strategy, criterion (En2), received the highest score.

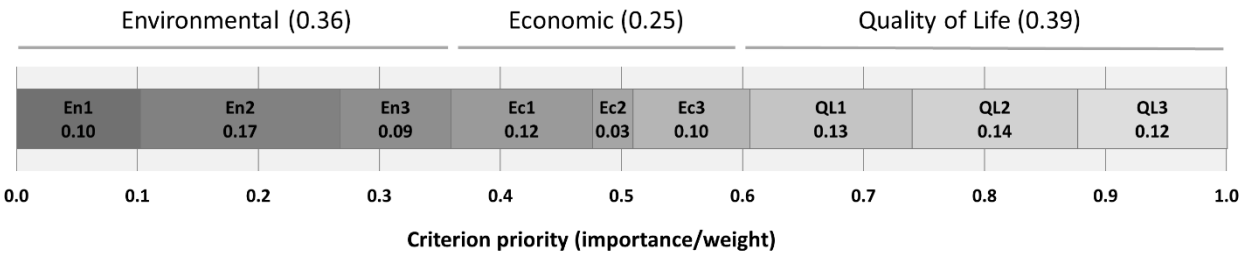

Figure 4-4 Relative priority assessments of environmental (En), economic (Ec) and quality of life (QL) development goals and respective criteria

In the second part of the survey, the implications of alternative wetland conservation policy targets were examined with regard to the City's overall planning and development goals. Conservation policy preference scores for environmental, economic, and quality of life criteria behaved similarly across the set of competing wetland conservation targets (Figure 4-5A). There is a considerable increase in preference scoring from the 0% (S_4) to 33% (S_3) and 66% (S_2) wetland conservation targets, but little change in assessment results between the 66% and 100% (S_1) policy option. For S_1, a 100% wetland conservation target, preference increases only marginally based on economic criteria and slightly decreases based on meeting environmental and quality of life criteria. Across the full set of urban planning goals, participants identified a 66% conservation target as the preferred basis for an urban wetland policy (S_2) (Figure 4-5B), after which an increase in the wetland conservation target to 100% was not seen as providing additional benefit based on the suite of urban planning and development goals. The sensitivity analysis indicated relative stability in the experts' scenario assessment results, based on the overall ranking of wetland conservation scenarios and the magnitude of difference between scenarios (Figure 4-5B).

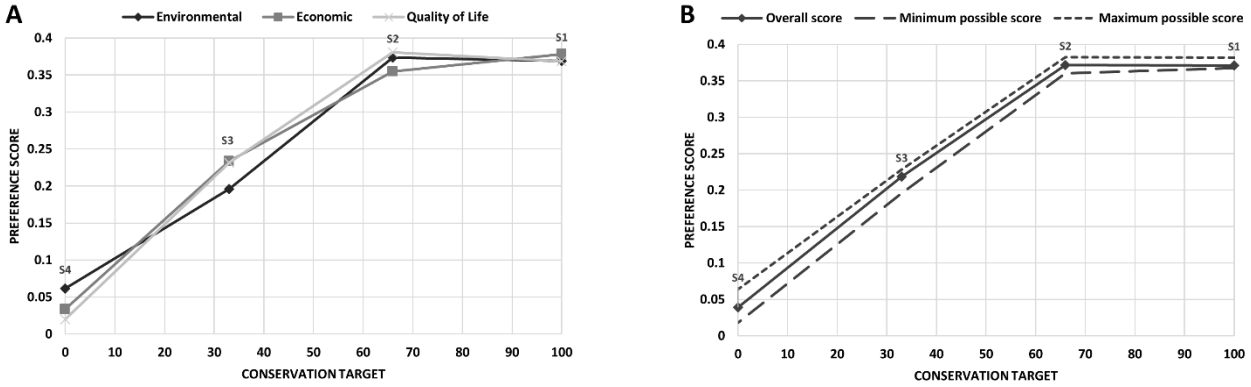

Figure 4-5 Wetland conservation scenario preference scores based on environmental, economic, and quality of life development goals (A), and overall score with sensitivity analysis (B)

4.5.2 Area and sustainability based approaches for wetland conservation policy application within urban planning units

Two wetland policy scenarios, S_2 and S_3, with conservation targets of 66% and 33%, respectively, were chosen to assess wetland conservation policy application at the scale of individual urban planning units. Both area- and sustainability-based preference algorithms were used for calculation of individual wetland conservation priorities (ranks). Scenario S_3 approximates the City's current wetland conservation strategy (30% of existing natural or constructed wetlands); S_2, a 66% conservation target, was identified in the expert assessment as the preferred policy option, after which an increase to the next conservation target was assessed as generating no further benefit to the City's development goals.

Figure 4-6 depicts wetlands that were identified for conservation using the area- and sustainability-based algorithms for scenario S_3 (Figure 4-6 A.1-A3) and scenario S_2 (Figure 4-6 B.1-B3), as options to meet the strategic policy targets. In most cases, both the area-based and sustainability-based algorithms identified the same wetlands to meet the specified policy targets. However, under both scenarios, there were wetlands identified by only one of the area-based or sustainability-based method. The arrows in Figure 6 denote these. For example, in Figure 4-6

A.3 a wetland in the north central region was selected using the sustainability algorithm to meet the conservation targets, in combination with a wetland in the central region of the planning unit. The sustainability algorithm considered numerous landscape factors, including total built-up area, ratio of built-up area to water catchment area, wetland density, and the ratio of wetland and built-up areas. However, using only the area-based approach, which is the City's current approach, a wetland in the southern part of the planning unit was selected to meet prescribed conservation targets, in combination with a wetland in the central part of the planning unit. The results indicate a combination of wetland options for planners or land developers to meet the City-wide conservation targets, but also indicate that how the policy is implemented, using area or broader sustainability parameters, will affect the distribution of wetlands selected to meet policy targets.

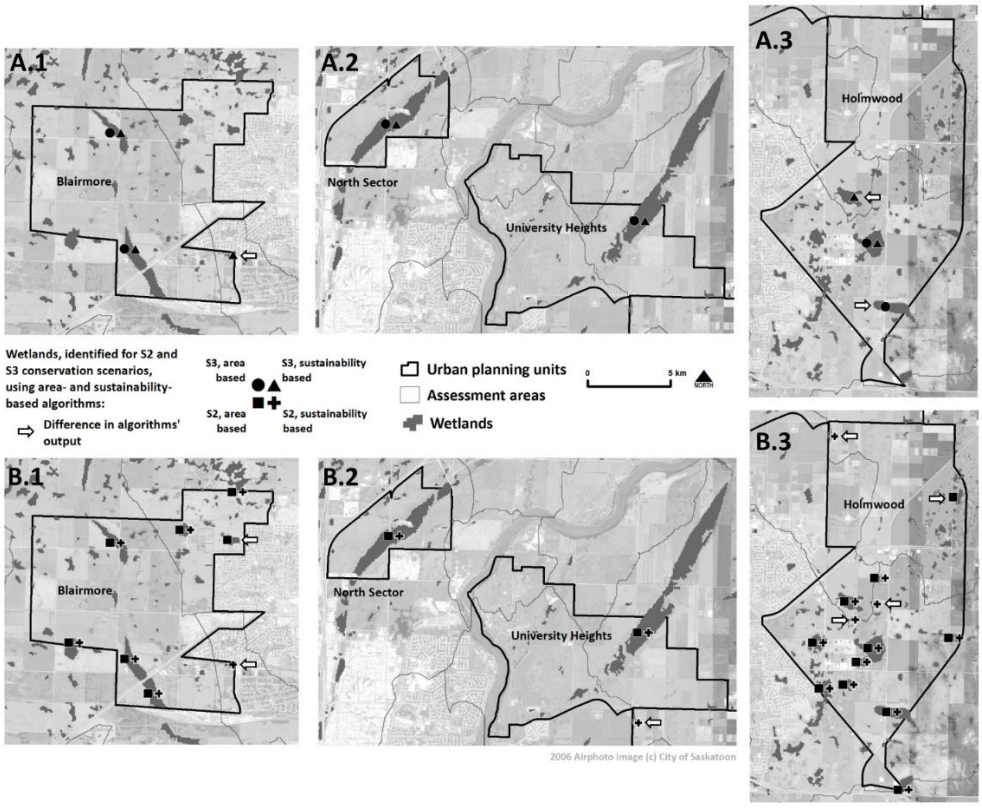

Figure 4-6 Urban planning units with wetlands, identified for S3 (A.1-A3) and S2 (B.1-B3) conservation scenarios using area- and sustainability-based algorithms

4.6 Discussion

This research demonstrated an SEA approach with both strategic and tactical elements, based on an evaluation of the potential implications of wetland conservation strategies on sustainable urban development goals. Four scenarios S_{1-4}, defined by alternative wetland conservation targets (0, 33, 66, and 100%), were assessed by a panel of experts against city-wide urban development goals to identify a preferred policy direction that most benefits social, quality of life, and environmental sustainability urban development priorities. A city-wide wetland conservation target of 66% (scenario S_2) was identified as the preferred policy direction, after which the next higher-level conservation target was assessed as not providing any additional benefit based on supporting the City's sustainable urban development goals. The preferred conservation target was double the City's current policy, which is an approximate 30% conservation target.

To link broad policy direction with on-the-ground implementation, and determine how best to meet the preferred conservation target in planning practice, wetlands within individual neighborhood planning units were prioritized using two algorithms: area- and sustainability-based. The area-based algorithm reflects the City's current wetland conservation practice, where decision about the conservation of a particular wetland or wetland complex is based on the neighborhood design and, in particular, total wetland area. Larger wetlands are given conservation priority. The sustainability-based approach considered a combination of landscape indicators at the water catchment scale (Sizo et al., 2014) to identify and select wetlands for conservation prioritization within individual urban planning units. Under both the 33% conservation policy target (approximating the city's current policy) and the 66% target (the expert-identified preferred policy option), different wetlands were identified for conservation based on the area- versus sustainability-based approach, providing operational guidance, and

design choices, for planners when implementing the City-wide wetland conservation policy within individual neighborhood planning units.

Overall, the results indicate that the City's current wetland conservation policy of approximately 30% is not sufficient, based on the expert-based assessment of conservation targets against sustainable urban development goals. Further, increasing wetland conservation to 100% provides no significant, additional benefit. Results also indicate that the current approach to policy implementation, selecting wetlands for conservation based primarily on wetland area, may meet city-wide policy targets but results in less-preferred wetland selection for conservation based than when based on broader landscape metrics that consider broader water catchment land uses and wetland threats

Beyond the regional context, and the specific application demonstrated in this paper, this research responds to two primary concerns in the literature regarding applied SEA. First, the need for structured and quantitative approaches in SEA to address the often-fuzzy nature of strategic-level PPPs (Noble et al., 2012), including the need for need for SEA research to better address analytical methods (Geneletti, 2015). Second, the difficulty often experienced in advancing SEA principles to practice, as there have been few concrete examples and little guidance as to how to operationalize strategic principles in an applied SEA context (Noble, 2009; White & Noble, 2013) – that is, how to better connect strategic thinking in SEA design with applied PPP practice. The SEA design presented here is applicable for the use in scenario analysis and can provide planners with answers to ad hoc requests regarding options for PPP implementation, in this case wetland conservation, at the operational level. The structured approach means that the SEA practitioner can under different tactical 'what if' scenarios and generate reliable results without having to collect new assessment data (White & Noble, 2012).

This provides flexibility for the practitioner in examining the robustness of the recommended PPP, to see what happen, should broader policy or development objectives, or specific on-the-ground planning conditions or constraints change – i.e. how strategic changes might affect operational decisions. Similarly, the practitioner can examine alternative operational designs for meeting strategic policy objectives, and test for consistency with strategic-level values.

There are limitations to the approach demonstrated here that could be addressed in future applications. First, the assessment was limited to a small group of experts and could be expanded to include much broader public participation. This might include, for example, local community members, aboriginal groups, and/or other interested parties. Using an on-line assessment tool, as demonstrated in this exercise, provides an opportunity to easily expand 'strategic' discussions beyond the expert panel to include members of the public from across the urban region. Second, the evaluation criteria were based on the Saskatoon city's development goals, so as to ensure application that was meaningful in the current urban planning environment. Future assessments might extend beyond prescribed goals and explore even broader evaluation criteria, identified by assessment participants. Finally, the individual wetland preference ranking exercise used the $nLCI_{adj}$ landscape based index as a proxy for a wetland's ecological value. Other, physically based measures of wetland functions could be integrated in the assessment, depending on a data and/or resource availability, for example using wetland data on biodiversity (wildlife habitat and/or vegetation), hydrology, nearby land use, or water quality.

4.7 Conclusion

Wetlands provide important functions in urban environments, including habitat provision, carbon sequestration, and flood control; however, more efficient and intelligent approaches are needed for the conservation of wetlands in urban environments, as well as methods that allow for the

consideration of social, economic, and environmental concerns in urban planning (He et al., 2011; McInnes, 2010). Strategic EA, in turn, is a framework that assesses future environmental outcomes to help achieve strategic development goals. The ability to integrate social, economic and environmental issues early in the design of strategic initiatives is one of its key characteristics (Desmond, 2007; Partidário, 2012). However, strategic initiatives emerging from SEA, including policies for wetland conservation or management (Amezaga & Santamaría, 2000), often prove difficult to implement at the operational level (White & Noble, 2013) and there remains a disconnect between strategic direction provided through SEA and the tactical direction required by those responsible for implementation. It is that often broad strategic level initiatives, based on stakeholder views or values, are not translated sufficiently into operational practices through planning and decision making processes (Fischer, 2003; Noble et al., 2012; White & Noble, 2013). As such, scholars have argued for the development of appropriate methods and guidance for SEA to assist the translation of sustainable strategic choices into operational practice (Noble et al., 2012; White & Noble, 2013), including more analytical-based SEA design (Geneletti, 2015).

This paper presented an approach to support decision making in SEA, based on an application to urban wetland conservation policy implementation, that links the *strategic context*, where conservation policy scenarios are evaluated against urban planning goals, with the *operational context*, were decisions are made regarding the conservation of individual wetlands to meet broader policy objectives. The approach is valuable for examining 'what if' strategic options, in a structured and quantitative analytical framework at the operational level, and for providing the 'on-the-ground' guidance on how to meet of high level strategic policy targets. More research is still needed on effectively linking strategic-level initiatives, including those

PPPs developed based on SEA processes, with the tactical planning and implementation measures that meet the broader strategic-level goals. Specifically, there is a need for examples for practice, reporting on the lessons learned, and guidance for assessing and then operationalizing strategic initiatives in different PPP land use contexts.

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CHAPTER 5: CONCLUSION

Urban growth and industrial development continues globally and have recently become a significant driver of wetland loss and degradation (Bartzen et al., 2010; Rubec & Hanson, 2009) due to the direct and indirect effects of surface disturbances to wetland hydrology, geomorphology, and ecology (Ehrenfeld, 2000; Nielsen et al., 2012). About 50 percent of original wetlands worldwide have been completely lost (Mitsch & Gosselink, 2007); in Canada, it is reported that 71 percent of wetlands have been lost in the Prairie Region and 40 percent in Saskatchewan, with half of the remaining wetlands in the province threatened (Huel, 2000; Mitsch & Gosselink, 2007). Spatial planning, including urban planning and development zoning, is a major policy instrument designed to direct future land use and development actions (Geneletti, 2011), but such planning and policy instruments do not always provide for adequate consideration of the potential impacts of urban growth on urban wetlands. The integration of environmental principles in urban planning is a key requirement for sustainable regional development and for urban wetland sustainability.

SEA has gained considerable momentum in recent years as a proactive and spatially appropriate framework for assessing and shaping land use policies, plans and development actions (Bidstrup & Hansen, 2014; Gunn & Noble, 2009), including urban and regional land use plans (Castellani & Sala, 2013; He et al., 2011) and managing their impacts on wetlands (Westbrook & Noble, 2013). Currently adopted in approximatelly 60 countries (Tetlow & Hanusch, 2012), SEA should be advanced enough for practical applications, with sufficient methods and techniques to support urban planning for wetland sustainability (Nielsen et al., 2012; Ramsar Convention Secretariat, 2010a; Thérivel, 2010). However, Noble et al. (2012) identified the lack of direction for selecting the best methodological design for specific SEA applications and described the methods used in SEA as restrictive and limited to a number of

common qualitative-based approaches. The methodological guidance available for SEA internationally is too generic for specific applications and there is a need for systematic methodology, including practical tools, models, and examples; furthermore, guidance is needed on method selection for contextualized SEA at different PPPs levels (Noble et al., 2012). Belcáková and Nelson (2006) emphasize the added value of SEA to spatial planning, but also noted the need to develop supporting procedural and methodological frameworks, criteria, and indicators. McInnes (2010) requested more sustainable approaches in urban development and the need for more advanced urban planning, including development and application of more efficient frameworks for the protection of wetland ecosystem services.

The purpose of this research was to advance current understanding and tools in SEA design and applied methodology for wetland conservation and wetland policy within the context of urban growth planning. The objectives of this research included the identification of methods for SEA evaluation in the context of urban growth planning and wetland habitat conservation; the development of an applied methodological approach to SEA to support decision making and sustainable planning in the context of wetland habitats in urban development; and the application of the SEA methodology to the Saskatoon region.

4.8 SEA framework for landscape-based, temporal analysis of wetland change in urban environments

The first part of this research introduced a spatial framework for SEA application within the context of urban wetlands, specifically focusing on the scoping and environmental baseline stages of SEA, arguably the most important and information-intense phases of the SEA process (Fischer, 2007; Hilding-Rydevik & Bjarnadóttir, 2007; Thérivel et al., 2004; Wright, 2007). This was in response to the needs for improved spatial methodological support and operational

guidance at the practitioner level for SEA design (Noble et al., 2012), particularly in the urban wetlands context, alongside calls for the development of advanced procedural and methodological frameworks for spatial planning (Belcáková & Nelson, 2006); the need for more advanced urban planning and design decision support systems; and the development of more practical frameworks to assess and protect wetland habitat and services more efficiently (McInnes, 2010).

The framework developed in this research presented a methodological approach and suite of spatial tools and analytical procedures for proactive urban planning in the context of temporal analysis of wetland change at the landscape scale. The framework presents an approach for assessment area delineation – a practical means to integrate the wetland regional ecological context in SEA scoping practices in urban environments. To focus SEA on an ecologically meaningful assessment scale – a water catchment (Committee on Mitigating Wetland Losses et al., 2001; Ehrenfeld, 2000), the framework adopted an approach to spatially adjust, or rescale, existing urban development and land use plans to the nearest water catchment areas – versus rescaling ecologically meaningful boundaries to accommodate development and land use plans, as is often the case (see Kristensen et al. (2013)). For the analysis of potential changes or threats to wetland sustainability at the landscape scale, the scientifically grounded and quantitative approach was presented, utilizing landscape indicators, data selection principles, and a land use classification system.

At the strategic level of urban policy and planning, the total or cumulative stress of urban development to the sustainability of wetland habitats may be described using such indicators of landscape change and land use transition (Noble et al., 2011). This approach conceptually relates linkages between spatial patterns and ecological processes (Canter & Atkinson, 2011). Although

landscape based analysis in the context of wetland sustainability can be particularly demanding in terms of input data and classification processes, the framework demonstrated how selecting a few key indicators (e.g. changes between wetland, built up and non-built up environments) can be effective at providing an overall, even if coarse, assessment of cumulative threats to wetland sustainability to support policy and planning practices. When multiple indicators are rolled-up into a normalized, landscape composite index, planners and decision makers have access to a multi-dimensional, and easy to understand and communicate, description of the assessed region in a single measure to examine, support, and understand the implications of potential land use and policy decisions (Canter & Atkinson, 2011; Ebert & Welsch, 2004). By adopting LUC metrics and indices, the framework and methodology developed in this research provides an applied tool for SEA practitioners and city planners working within the limited timeframes of urban planning processes. The methodology could serve towards the consideration of historical and spatial particularities for environmental assessment, and provide the opportunity to offer recommendations for strategic decisions for wetland conservation through urban land use and planning processes. The underlying concepts of the SEA design are also easily transferable to other land resource and land use planning contexts.

4.9 Futures analysis of urban land use and wetland change: an application in SEA

In the second part of this research, an approach was developed for the assessment of urban planning futures in the context of urban wetland conservation. The study addressed the currently recognized need for contextualized methodology in SEA to support scenario development and LUC modeling (Bragagnolo & Geneletti, 2013; Ma et al., & Li, 2012; Mozumder & Tripathi, 2014), particularly within the context of wetland conservation. The research was designed as a scenario planning exercise whereby two alternatives, a zero (or business as usual) alternative and

the current City of Saskatoon's development plan alternative, described potential wetland futures based on past trends of urban development and wetland change.

It could be argued that there is a need for consistent and complete baseline data to support sophisticated future trends analysis in SEA applications. Schrojenstein Lantman et al. (2011) noted that consistent data is a prerequisite for good LUC modeling. Unfortunately, as was found during this research, consistent and comprehensive datasets are rarely available in urban planning contexts. Publicly available planning data is often not up-to-date, particularly in fast-growing municipalities such as the one in this study, and as such may not actually reflect the most current planning and development reality. This research used development plans proposed to establish a 30 year strategy for the city of Saskatoon. Each of the neighborhood or land use sector plans, however, contained varying levels of planning detail. As such, to facilitate trends analysis and scenario development, it was necessary to supplement and standardize the granularity of data and land use classification based on more qualitative data, based on discussion with and recommendations from representatives of the City's Development and Planning Department.

A Markov Chain, a stochastic method, was used for LUC simulation. A stochastic approach is recommended against others, as it accounts for the uncertainty and variability associated with future conditions (MacDonald, 2000). The zero alternative simulated the tendency of urban development before prescribed urban planning and development actions have taken place, while the current development plan alternative simulated future LUC to account for prescribed development plans and wetland conservation initiatives. Overall, results for the year 2043 under the current development plan and zero LUC simulations were similar. In the context of wetlands management, this suggests that the application of the current wetland conservation

strategy, only within administrative based planning units, will not be sufficient to compensate for the historic trend of wetland area decrease in the city. However, the variability analysis of difference between the current development strategy and the historical trend wet areas simulations (the current development plan and the zero alternatives) identified areas of positive and negative difference, most likely a reflection of a difference in landscape wetland \ urban spatial patterns that was not fully considered in development planning.

The scenario-based approach presented in this work provides a basis for wetland trends and future LUC analysis, which, in future practice, may be extended by using a range of alternatives – for example, based on modeled planning documentation with respective desired outcomes that may involve different urban development plans, different patterns of urban growth and density, and alternative wetland conservation policies or targets. Despite the often lack of consistency in input data for undertaking quantitative-based analysis in urban wetland contexts, the approach presented here utilizes a reliable and replicable method for futures analysis that can be contextualized for wetland conservation. This research may be used to support urban planners and wetland policy makers in the development and comparison of planning, development, and land use zoning options to help ensure that urban wetland conservation goals are achieved. The approach also may be useful for SEA practitioners, whose work is related to wetland and urban growth analysis, in environmental assessment and leverage data and information that can be helpful in development plan design, in the comparison and revising of wetland conservation strategies, as well as in providing a sound basis for decision and policy making in urban environmental management.

4.10 A strategic environmental assessment approach to wetland conservation policy development and implementation in an urban context

Building on the previous stages, the final part of this research developed and demonstrated an analytical approach to SEA, focusing on bridging the strategic level assessment of policy objectives with operational planning and strategic decision implementation for urban wetland conservation. The SEA design focused first on a strategic phase (policy level) – identification of a strategic direction (wetland conservation target), considering also competing sustainable urban development goals; and second on a tactical phase (operational level) – implementation of the policy 'on-the-ground,' considering the application of a wetland conservation target within the urban planning process.

In the strategic phase, a scenario analysis exercise was developed to assess alternative wetland conservation policy targets on the basis of existing urban development planning goals (environmental, economic, and quality of life) for the City of Saskatoon. An expert-based assessment of wetland policy options was structured using the AHP approach, a form of multi-criteria analysis (Saaty, 2008). In the tactical phase, results of the expert-based assessment, and the preferred wetland conservation policy targets, were applied to the City's planning unit designs, identifying individual wetland conservation priorities within each of the planning units. Two conservation priority algorithms were then examined: (i) wetland conservation based on wetland area only, which assumes that larger wetlands are more preferable for conservation than smaller wetlands, and thus for meeting any strategic policy or target for urban wetland conservation; and (ii) a sustainability-based algorithm that complements the area-based approach with the use of landscape indicators as a proxy for the sustainability of wetland functions utilizing nLCI approach.

The results of the expert's assessment demonstrated that 'quality of life' and 'environmental sustainability' urban development criteria were almost equally prioritized, and more important for informing planning and development decisions than 'economic well-being.' The second part of the assessment examined the implications of alternative wetland conservation policy targets with regard to the City's overall planning and development goals. The results demonstrated that conservation policy preference scores for environmental, economic, and quality of life criteria behaved similarly across the set of competing wetland conservation targets (0%, 33%, 66%, and 100% conservation). A considerable increase in preference scoring from the 0% to 33% and 66% of wetland conservation targets was found, with little change in assessment results between the 66% and 100% policy option. Across the full set of urban planning goals, participants identified a 66% conservation target as the preferred basis for an urban wetland policy, after which an increase in the wetland conservation target to 100% was not seen as providing additional benefit based on the suite of urban planning and development goals.

Two wetland policy scenarios with conservation targets of 66% and 33% were chosen to assess wetland conservation policy application at the scale of individual urban planning units. The 33% conservation target scenario approximated the City's current wetland conservation strategy, i.e. 30% of existing natural or constructed wetlands; and the 66% conservation target scenario was identified in the expert assessment as the preferred basis for an urban wetland policy. Both area- and sustainability-based preference algorithms were used for calculation of individual wetland conservation priorities (ranks). In most cases, both the area-based and sustainability-based algorithms identified the same wetlands to meet the specified policy targets. However, under both scenarios, there were wetlands identified by only one of the area-based or sustainability-based methods. That indicated that despite the current approach to policy

implementation, i.e. selecting wetlands for conservation based primarily on wetland area, may meet city-wide policy targets, but may result in less-preferred wetland selection for conservation when based on broader landscape metrics that consider broader water catchment land uses and wetland sustainability threats.

The results of this research objective contribute to addressing recently identified concerns of how to better connect strategic thinking in SEA design with applied PPP practice. The proposed SEA design: (i) met the need for structured and quantitative approaches in SEA to address the often-fuzzy nature of strategic-level PPPs (Noble et al., 2012), including the need for SEA research to better address analytical methods (Geneletti, 2015), and (ii) responded to the difficulty often experienced in advancing SEA principles to practice, as there have been few concrete examples and little guidance as to how to operationalize strategic principles in an applied SEA context (Noble, 2009; White & Noble, 2013). The SEA design presented here is applicable for use in scenario analysis and can provide planners with answers to ad hoc requests regarding options for PPP implementation, in this case wetland conservation, at the operational level. The practitioner can examine alternative operational designs for meeting strategic policy objectives, and test for consistency with strategic-level values.

4.11 Research limitations and future work

The SEA design, methodology and suite of tools developed and demonstrated in this research do have their limitations. Like any SEA design, the research can be constrained by two main factors: (i) data, including data quality and availability; and (ii) supporting methods, including the processing and analytical methods. For example, González et al. (2011) reported that impact assessment with the use of GIS techniques is widely constrained by the level of detail of available datasets. The need for consistent and complete baseline data to support SEA, or any

assessment process, is often identified as a constraining factor to good-practice. As was found in this research, consistent and comprehensive environmental and planning data is rarely available, especially as required for temporal and spatial analyses. However, Thérivel (2010) argues that "not all the baseline data must be available for an SEA to proceed;" João (2007) agrees, in that SEA can be completed with missing baseline data and argues that there is a need to reach a balance between data collected and data needed.

This research was constrained by horizontal and vertical resolution of elevation data for water catchment delineation. The parameters of input elevation data can directly influence the watershed analysis and, in turn, the calculation of the output boundaries. The resolution of input relief data need to be carefully considered in terms of the desired spatial scale of the framework application. The spatial resolution of RS data was 30x30 m, resulting in mapping unit of 0.36 ha, which biased wetland mapping towards identification of larger wetlands. However, due to data availability and quality, it is a reasonable trade-off between the median size of Canadian prairie wetlands granularity (0.15 ha) and is better than the recommended Canadian Wetland Inventory mapping unit (1 ha). The planning and development documentation for the City (bylaws and Sector Plans) were prepared in different years and with different levels of detail contained in each plan. To compensate for the difference in the level of planning details available, LUC within planning area was reclassified into three LUC classes (wet areas, built-up, and non built-up), compatible with previous RS LUC classification.

The assessment area delineation, performed for the City of Saskatoon case study, considered possible surface water drainage only and excluded groundwater – an important source of wetland recharge in prairie wetlands. The assessment of LUC change was also limited to the three simple classes: using wet areas as a proxy for wetlands, using built-up and non built-up

areas for urban development, and focused on RS optical data for change detection. Natural or climate induced wetland loss or possible change in wetland type were not in the focus of this research; adjustment of the framework to climate variability is seen as possible future work. However, some recommendations may be offered for future operation: the selection of landscape indicators may include a variety of wetland parameters and wetland spatial characteristics, depending on descriptive data availability and resources: e.g. including wetland wet area / dry area, wetland type diversity etc.; depending on RS data availability: RS assessment classes may include wetland type classes, dried wetlands class etc.; the selection of RS datasets may be at first based on year climate characteristics.

As with all futuring methods, the Markov Chain technique has its limitations. The probability distribution of the next period's state depends on the current state and does not depend on the states the chain had previously passed through. This means that the variation of the probability of change between two states is not a part of the Markov Chain model and is not reflected in the simulation of future states. Also, as the transition probability plays an important role in Markov Chain modeling, the accuracy of the input data needs careful consideration. If feasible, a quality assessment of the Markov Chain model should be performed for the area of application. Another assumption of the Markov Chain technique is that the probability law relating the next period's state to the current state does not change. This means that the change remains stationary over time after the evaluated states.

The wetland conservation policy assessment exercise was also limited to a small group of experts and could be expanded in the future to include much broader public participation. This might include, for example, local community members, aboriginal groups, and/or other interested parties. This could be easily accommodated with the use of an on-line assessment tool,

such as Expert Choice, as was used in this study. The assessment evaluation criteria were based on the City of Saskatoon development goals, so as to ensure application that was meaningful in the current urban planning environment. Future assessments might extend beyond prescribed goals and explore even broader evaluation criteria, identified by assessment participants. The individual wetland preference ranking exercise used the $nLCI_{adj}$ landscape based index as a proxy for a wetland's ecological value; for future application other, physically-based measures of wetland functions could also be integrated in the assessment, depending on data and/or resource availability.

The intention of the City of Saskatoon case study was to demonstrate the applicability of SEA design and the range of analytical approaches available to practitioners. For future practice, the analytical approaches can be adjusted based on data availability and quality, urban planning and development goals, desired information granularity, and the particular practitioners' needs, but retain a consistent and structured methodological design.

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