Ecosystem Service Assessment of Wetland Water Purification for the Shepard Slough Study Area

A Report Prepared for Alberta Environment and Sustainable Resource Development for the Ecosystem Services Pilot Project

Report Prepared by: Irena F. Creed Consulting

September 6, 2011

FINAL REPORT

Alberta Government

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PREFACE

Parable of the Catskills watershed that provides drinking water to New York City:

"Over time, this watershed ecosystem became overwhelmed by sewage, industrial and agricultural runoff to the point that the water quality in the city fell below EPA drinking water standards. An economic analysis provided costs of two alternatives for restoring water quality. The cost of purchasing and restoring the watershed so that it could continue to provide the service of purification and filtration was calculated to be $1 billion. The cost of building and maintaining a water purification and filtration plant was $6–8 billion in capital costs, plus annual operating expenses of $300 million. The City has opted to buy and restore the watershed, i.e., to let nature work for people."

National Science Board, Task Force on the Environment, Environmental Science and Engineering for the 21st Century: The Role of the National Science Foundation <http://www.nsf.gov/cgi-bin/getpub?nsb0022> and <http://www.nsf.gov/nsb/tfe/nsb99133/box1.htm

ACKNOWLEDGEMENTS

I would like to acknowledge Ms. Gillian Kerr, Project Manager of the Ecosystem Services Pilot Project for her leadership in bringing the discussion of Ecosystem Services as a mechanism for wetland conservation to the forefront in the Province of Alberta.

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I thank Geneva Claessen who oversaw the activities of the consultants hired to conduct the ecosystem assessments, and members of the Biophysical Working Group and the Socio-economic Working Group, who provided advice to the consultants during the initial workshop and who asked many questions about the work which improved the final report. It has been wonderful to work with such an engaged ground of scientists and managers.

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Finally, I acknowledge David Aldred and Adam Spargo, for their contributions to the work activities, and to Nicholas Lantz, Samson Girma Mengistu, Christopher Quick, Gabor Sass and Chuiqing Zeng who provided an extra pair of hands to ensure that we met the ambitious deadline for this contract.

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EXECUTIVE SUMMARY

There is a critical need for regional scale assessments of wetlands for ecosystem services. This study reports on a regional scale assessment using Geographical Information Systems (GIS) and remote sensing (RS) technologies for water purification services provided by wetlands in Shepard Slough, the study area for the Ecosystem Services Pilot Project (ESPP). Prototypes were developed for both a basic (readily available GIS and RS data, most of it freely downloadable from the Internet) and advanced (higher quality datasets with higher spatial resolution) approach. Due to the severe time constraints of the contract (during which we were unable to gain access to the required data for the advanced approach), only the "Regional-Basic" approach was implemented. Based on this Regional-Basic approach, we found monetary benefits to increase from 1990 to 2010 for water purification, with the monetary increase due mainly to an increase in wetland area defined by inundated water. We expect the "Regional-Advanced" approach to provide a more precise analysis, as the basic approach is based largely on the area of wetlands for water purification and ignores many of the other wetland features important for water purification.

The following recommendations are made:

1. Ecosystem services selected for the ESPP are based on different wetland inventories, wetland areas, and functional attributes, as a result of work completed by three different consulting groups in a timeframe too short to allow for effective coordination of activities. Each ecosystem service assessment should be based on common ground rules including common wetland assessment units and common time periods for assessment of trends to enable realistic comparison among the ecosystem services and to enable fair trade-offs to be made between various services. **For future ecosystem service assessments, it is recommended that a consensus be reached as to the (scientific and technical) definition of wetland assessment units and the period of time over which the change in condition of wetland assessment units will be considered; and/or that one individual/group be tasked to provide these foundational data layers for the purpose of ecosystem service assessments.**

2. Ecosystem service assessments should be designed that (a) capture the dominant ecological and hydrological processes, and (b) reflect the availability of data to develop and test the ecosystem service assessments. **For future ecosystem service assessments related to water quantity and/or quality, it is recommended that the selected areas be based on a hydrological system, e.g., sub-watershed or watershed, with consideration of Government of Alberta water quantity/quality monitoring sites for ecosystem service assessment validation.**

3. The recommended methodology (the "Regional-Advanced approach) was not completed, not because it was too labour intensive, but rather because of delays in receiving specific data. There is a need for more effective and efficient data management to support ecosystem service assessments. **For future ecosystem service assessments, it is recommended that all data providers be brought together to compile, coordinate and evaluate what data are available for the assessment.**

4. Until site and regional assessments are directly compared, it will be difficult to precisely assess the overall utility in estimating ecosystem services at various scales of planning. **For future ecosystem service assessments, it is recommended that site approaches (WESPUS) are benchmarked to regional approaches, including the Regional-Basic (*sensu* Cobbaert) and Regional-Advanced (*sensu* Creed) approaches. Recent initiatives both by the ESPP project activities (led by Kerr) and AWRI-Wetland Health project activities (led by Bayley) provide site based assessments of about 100 wetlands throughout southern Alberta that can now be used to benchmark regional wetland assessment approaches.**

5. Current inventories do not factor in the temporal dynamics of wetlands including inundated and saturated areas. **For future ecosystem service assessments, it is recommended that a combination of LiDAR, Landsat/SPOT, and SAR imagery are used to map wetlands (both inundated (open water) and saturated areas), and determine their spatial and temporal dynamics over changing climatic conditions and response to human activities. It is also possible to determine wetland type (i.e., bog, fen, marsh, swamp) which may result in different influences on water purification potential.**

6. Regional climate is defined by two steady states (wet and dry). These different states strongly influence the presence of inundated (open) water on the landscape. Identifying and understanding the presence of climate regimes and drivers is important to allow quantification of human driven impacts on wetlands. Understanding the link between climate and surface water dynamics allows the incorporation of this natural driver into human drivers of wetland function. **For future ecosystem service assessments, it is recommended that the range of natural variation in wetland function (area) due to natural drivers (climate) should be defined using a combination of historic meteorological and remote sensing data.**

7. Natural drivers cause substantial variation in wetland structure and function, and it is important to understand this natural variation so that accurate estimates of ecosystem services can be achieved. One could monitor this natural variation on an annual basis. Alternatively, one could use the maximum extent of wetlands based on climate normal (past 30 years) or some other reasonable climate period to estimate the maximum potential for ecosystem services related to water purification. **For future ecosystem service assessments, it is recommended that regional wetland assessments be designed to consider both spatial and temporal dynamics of wetland function.**

8. For the ESPP, regional assessments for the ecosystem services provided by wetlands were done independently, considering one service at a time. **For future ecosystem service assessments, consideration of the potential for interaction effects of ecosystem services is needed so that trade-offs among ecosystem services may be considered.**

1.0 INTRODUCTION

The Ecosystem Services Pilot Project (ESPP) is intended to demonstrate a rigorous quantitative approach to ecosystem service assessments that will empower decision makers in the Province of Alberta. Decision makers have identified gaps in current policy tools, including insufficient evidence to support avoidance, mitigation and compensation decisions on wetlands; insufficient consideration of cumulative effects and long-term consequences of decision making; and limited ability to communicate the values of wetlands to developers and decision makers. To fill these gaps, the ESPP hired consultants to conduct a biophysical assessment of wetland ecosystem services that would advise the social and economic assessments that are occurring concurrently.

Specifically, the consultants were asked to:

- Develop documented tools and techniques for ecosystem service assessments of wetlands that are user friendly and based on existing data;
- Apply these tools to the ESPP to provide ecosystem service assessments of the past, present and future condition and trends (e.g., past 20 years, future 10 years); and
- Apply these tools to the ESPP to determine the magnitude and distribution of ecosystem services that wetlands provide or contribute to at regional and site-specific scales.

The ESPP Steering Committee selected the following ecosystem services as initial focal points: (1) flood control/water supply/storage; (2) water purification/quality; and (3) carbon storage.

Three consultants were selected to pursue the three selected ecosystem services, including O2 Planning + Design Inc. (led by George Roman) for water supply/storage and flood control, Irena F. Creed Consulting (led by Irena Creed) for water purification/quality, and Ducks Unlimited Canada (Pascal Badiou) for carbon storage. Each consultant was asked to produce a report that describes: the metrics, functions, values, services being measured and/or mapped; the approach taken, including potential metrics and units of measurement; the data assumptions and limitations (e.g. spatial and temporal availability and resolution); description of how the information produced is relevant to answering the wetland approval gaps identified previously; list of elements of the ecosystem services that are important and need to be highlighted for decision makers; and identification of elements of the ecosystem services which are approaching a threshold that places human well-being at risk.

The contract started June 27, 2011, with a draft report submitted August 6, 2011, and a final report submitted September 6, 2011. During the month between submitting the draft and final reports, questions were received from members of both the Biophysical and Socioeconomic working groups, and these questions were not only answered (See Appendix 6) but were the basis for the revisions made to the final report. It is important to note that our wetland assessment approach for water quality was not selected based on data available for the Shepard Slough, but rather on data for which data sharing agreements were established and data were received by July 25, 2011.

RECOMMENDATION #1:
Ecosystem services selected for the ESPP are based on different wetland inventories, wetland areas, and functional attributes, as a result of work completed by three different consulting groups in a timeframe too short to allow for effective coordination of activities. Each ecosystem service assessment should be based on common ground rules including common wetland assessment units and common time periods for assessment of trends to enable realistic comparison among the ecosystem services and to enable fair trade-offs to be made between various services. **For future ecosystem service assessments, it is recommended that a consensus be reached as to the (scientific and technical) definition of wetland assessment units and the period of time over which the change in condition of wetland assessment units will be considered; and/or that one individual/group be tasked to provide these foundational data layers for the purpose of ecosystem service assessments.**

2.0 THE SHEPARD SLOUGH CASE STUDY AREA

The Shepard Slough straddles the eastern boundary of the City of Calgary, and reaches into Rocky View County and the Town of Chestermere (Figure 1). This endorheic flatland at the eastern flanks of the foothills to the Rocky Mountains was chosen by the ESPP Steering Committee because it was hydrologically isolated from major water courses (G. Kerr, personal communication, June 21, 2011); a fact that has since been debated. As such, these lands are seen as an ideal location for ecologically “green” infrastructure that will satisfy multiple functions and services such as revitalized wetland habitat for biodiversity, water storage, water purification, flood control and carbon sequestration.

The Shepard Slough study area comprises 267 km^2 of rolling prairie landscape, which contains thousands of depressions. Given that the depressions are underlain by low permeability surficial geological materials, meltwater, as well as groundwater, discharging from deeper flowpaths, collects in these features and transforms many of them into marshy or reedy pools termed sloughs. The relatively low annual precipitation and high evaporative demand during the summer makes most of these wetlands ephemeral in nature, although larger ones can be described as permanent water bodies. The sloughs range in size from small pools to large shallow lakes that have provided wetland habitat for waterfowl and waterbirds for millennia. In a recent survey, several bird and amphibian species, as well as two grassland communities and species, were found that are listed either as provincially rare or species of concern (AECOM 2011).

Urban and agricultural development has led to the disappearance of many of the wetlands over recent years, a result of draining for either land conversion or the construction of irrigation ditches and canals (City of Calgary 2004). Despite this, due to legacy effects of increasingly wet years, an increase in inundated water on the landscape has been observed in Landsat imagery. The two main built water conveyances are the Western Headworks canal and the Shepard Ditch. Western Headworks transports water from the Bow River and stormwater from subdivisions lying to the north and feeds the artificial Chestermere Lake. Shepard Ditch was built early in the 20th century in order to alleviate flooding problems surrounding the Canadian Pacific railway line.

All of these changes to the drainage of this area have raised concern regarding water quality impacts to the Bow River, which now receives water through the Shepard Ditch. In addition, increased stormwater flows into Chestermere Lake have decreased the water quality of the lake, raising concerns of local residents. Apart from a water quality measurement station at Chestermere Lake, there are no other monitoring stations that can provide useful water quality indicators regarding the impact of development within the study area. The closest upstream and downstream water quality stations on the Bow River are so far removed from the study site (Figure 1 - inset) that it is impossible to determine the impact of development within the study area on the Bow River. As expected, downstream measurements indicate that the City of Calgary and abutting lands have a significant negative impact on the water quality of the Bow River, leading to seven fold increases in total phosphorus and total nitrogen and doubling of chlorophyll –*a* and turbidity levels (Figure 2). Government of Alberta personnel (Karen Raven, pers. Comm.) indicated that the pollutant of primary concern in the Calgary region, is phosphorus, although nitrogen should be a concern as well, with the greatest risk for phosphorus and nitrogen pollution from untreated sewage effluent and agricultural run-off carrying fertilizers. It is not known if the Shepard Slough lands are improving or deteriorating water quality within the Bow River.

Recently, the City of Calgary, along with the Government of Alberta, have recognized the potential value of this area in terms of habitat for wildlife, as well as the provision of services for humans in terms of water purification and flood control. In 2003, under the Shepard Stormwater Diversion Project, stormwater from parts of the City of Calgary has been diverted from Chestermere Lake into a constructed wetland complex (Shepard Constructed Wetland), 240 ha in size which eventually drains into a widened Shepard Ditch. It is planned that these constructed wetlands will ultimately treat more than 50 per cent of the stormwater from Calgary's east industrial parks and subdivisions to the north. Studies are required to determine the effects on water quality in the large receiving bodies of water such as the Bow River and Chestermere Lake, as well as the smaller wetlands dotting this area.

RECOMMENDATION #2:
Ecosystem service assessments should be designed that (a) capture the dominant ecological and hydrological processes and (b) reflect the availability of data to develop and test the ecosystem service assessments. **For future ecosystem service assessments related to water quantity and/or quality, it is recommended that the selected areas be based on a hydrological system, e.g., sub-watershed or watershed, with consideration of Government of Alberta water quantity/quality monitoring sites for ecosystem service assessment validation.**

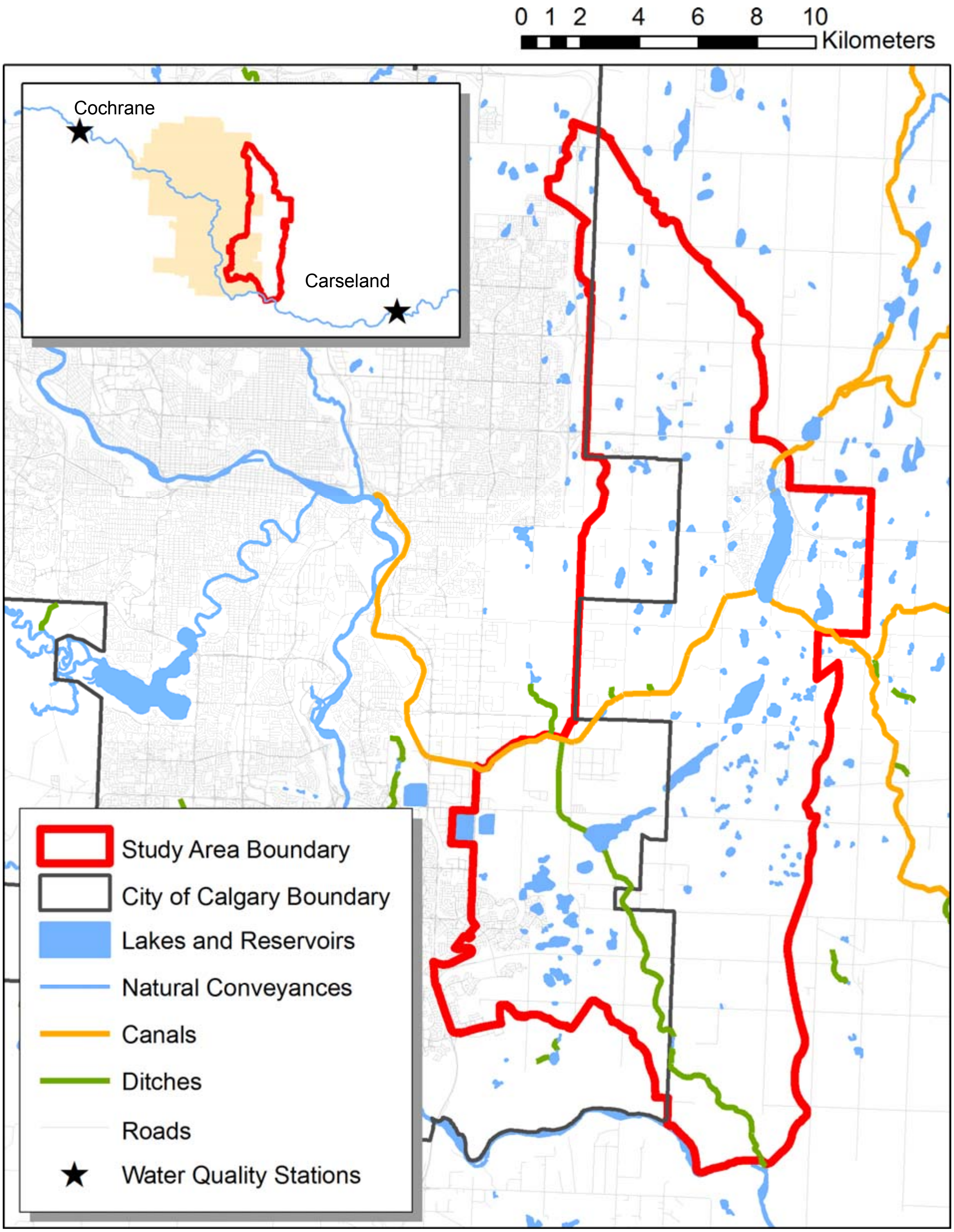


FIGURE 1: The Ecosystem Services Pilot Project's study area – Shepard Slough.

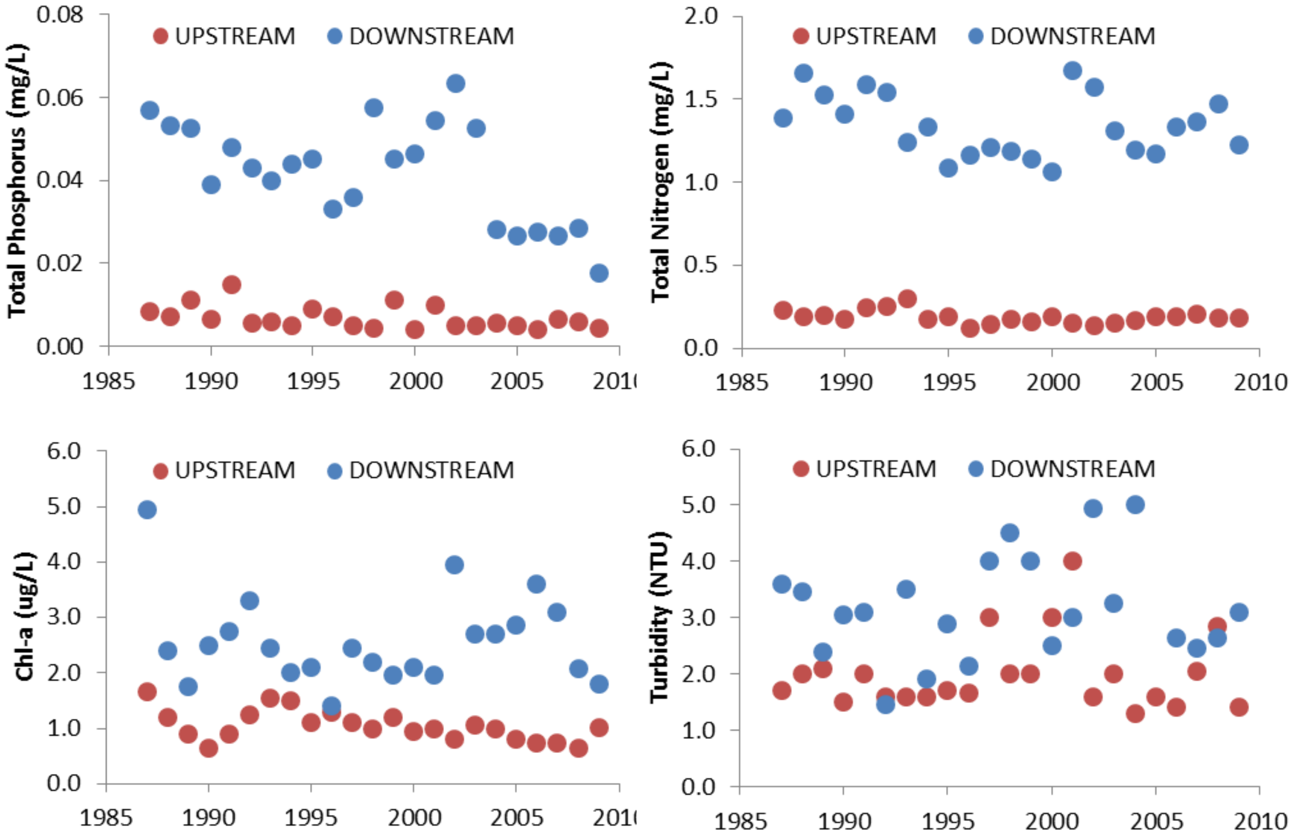


FIGURE 2: Time series of water quality at government water quality monitoring stations at an upstream (Bow River at Cochrane - AB05BH0010) and downstream (Bow River below Carseland Dam - AB05BM0010) location to the study area. Data points reflect annual median of approximately 12 water quality measurements taken at monthly intervals. Downstream TP and TN median values are approximately 7× the upstream value, whereas downstream Chlorophyll-*a* and turbidity median values are approximately 2× the upstream value.

3.0 WATER PURIFICATION: AN ESSENTIAL ECOSYSTEM SERVICE

Water quality refers to the physical, chemical and biological properties of a water supply. Water purification is the improvement of water quality by the removal of contaminants from a water supply. In this report, we focus on sediments and nutrients (nitrogen and phosphorus) as contaminants.

Wetlands provide natural water purification through biophysical processes whereby natural assets such as plants, fungi, bacteria, and animals remove harmful contaminants, pathogens (bacteria/viruses), metals, persistent organic pollutants, excess nutrients, and sediments as water moves through the wetlands and their associated contributing areas. Water purification depends on water infiltrating soils and removal of pollutants by adsorption to soil particles and/or absorption by living organisms in the soil or water. These "natural" purification processes provide clean drinking water and water suitable for human (recreation, industrial, agricultural) and non-human (biodiversity) uses.

Natural water purification is a function of the rate of water movement through the system and the integrity of purification processes related to the affinity of substrates to adsorb or absorb (metabolize) contaminants in the water.

Human activities can degrade the purification potential of wetlands by: (1) altering water flow pathways such that water by-passes (flows above or below) the natural purification system of the riparian buffers; (2) increasing sediment and nutrient loads beyond the purification potential; and/or (3) damaging the riparian buffers and thus its purification functions. The consequences of these degradations to the purification potential of wetlands are that sediments and nutrients may enter the water supply un-attenuated.

For example, human activities can decrease purification capacity of wetlands due to different alterations to the hydrological system. Perhaps most importantly, soil compaction significantly reduces the infiltration capacity of soils resulting in decreased infiltration where by polluted water is then delivered directly to surface waters. In the extreme case of impervious surfaces (e.g., roads, parking lots, highways, and buildings) all of the water is conveyed quickly into receiving waters or city drains. Altering water flow (rate and direction) within a hydrological system can also result in large changes to purification processes. Changing water flow processes and/or pathways can result in changes to the oxygen content of soils that may have differential effects on the fate of nutrients (e.g., N removal depends on transformation to N_2O/N_2 that requires oxygen poor soils whilst P removal depends on adsorption to soil particles that requires oxygen rich soils).

Furthermore, human activities can increase pollutant loading to water through urbanization and industrialization in the form of point source (e.g., factories) or non-point sources (e.g., fertilizer applications to agricultural fields).

Finally, human activities can change the composition of organisms within or adjacent to wetlands by introducing species with different nutrient fixation, transformation, and/or uptake potentials that may fundamentally alter the nutrient cycling potential of a wetland. The three zones that provide an important function in water purification are: emergent zone, wet meadow zone, and riparian upland zone. The species composition within these zones plays an important role in the sediment and nutrient retention potential of the wetland.

For example, an emergent zone dominated by *Typha spp*. would result in the accumulation of nitrogen in the biomass (Zedler 2000), as could Alder trees with symbiotic N2 fixing bacteria (Hurd et al 2001). Picard et al (2005) found that monocrop microcosms of three plant species (*Scirpus validus, Phalarisarundinacea* and *Typha latifolid*) removed nutrients under experimental conditions. An additional treatment combining these three species with another (*Carex lacustris*) also removed nutrients, suggesting that biodiversity can be maintained when planning for nutrient removal.

The most important part of a wetland's contributing area is the riparian area located directly adjacent to it. In many landscapes a riparian area of adequate width can be very effective at reducing sediment and nutrient loads before they reach the wetland proper. As a result removal or alteration of riparian areas (e.g. wet meadow zone, riparian shrub, and forest zones) reduces the ability of wetlands, streams and rivers to cleanse themselves.

Provincial guidelines have been developed that define riparian buffers for streams (30m), rivers (60m) and lakes (100m) (Alberta Environmental Protection 1994). Municipal guidelines are more liberal, requiring a 6m riparian buffer from water sources for development approvals (Municipal Government Act 2010). However, adaptive rather than standard, riparian buffer widths are advised, as the conditions required for effective purification function may vary greatly among wetlands. For example, in the boreal plains, Creed et al. (2008) found that hydrological flow pathways influence the formation of surface or near surface saturated areas (i.e., wet areas), and that riparian buffers should be defined by the extent of these wet areas to reduce sediment and nutrient (e.g., N) loads as they are transported to surface waters.

In general, the economic valuation of ecosystem services is very difficult. However, with respect to water purification it is perhaps easier to quantify. The classic example of putting a price tag on water purification comes from New York City, where the state opted to spend $1 billion to restore the Catskills watershed that provided New York City's drinking water rather than to spend $8 billion on building a new treatment facility and paying annual operating expenses of $300 million.

Using this example, the US National Research Council (NRC) developed four recommendations in terms of a watershed management strategy for a potable water supply in New York City (NRC 2000 Watershed Management for Potable Water Supply: Assessing the New York City Strategy).

NRC (2000) Watershed Management for Potable Water Supply: Assessing the New York City Strategy

- The watershed management program should be prioritized to place importance first on microbial pathogens, second on organic precursors of disinfection by-products, third on phosphorus, and fourth on sediment and turbidity.
- The concept of balancing watershed rules and regulations with targeted support of watershed community development is a reasonable strategy for NYC and possibly other water supplies.
- Water supplies should be receptive to the possibility of additional treatment options.
- Efforts to quantify the contribution of watershed management to overall reduction of risk from waterborne pollutants.

In this report, we focus on the last point of the NRC document: "Efforts to quantify the contribution of watershed management to overall reduction of risk from waterborne pollutants".

The framework we adopted is shown in Table 1, with terms defined in Table 2. We identify four steps, three of which are completed, in this wetland assessment for water purification services: (1) establish wetland assets; (2) estimate water purification service, which is related to both function and value; and (3) convert ecosystem service scores to dollars. This framework was defined for the ESPP by the Biophysical Team working group during the Calgary meeting (June 24, 2011).

In this report, we illustrate how Steps 1-3 could be approached, including a basic economic valuation that was developed in consultation with Paul Adamus, an advisor to the ESPP. In no way is this basic economic valuation intended to replace the socioeconomic teams assessment; rather, it is to showcase one way of doing an economic valuation from which the socioeconomic team may benefit. We were advised not to complete a scenario analysis (Step 4), as this would be the focus of future ESPP activities.

TABLE 1: A wetland assessment framework for water purification services (adapted from personal communications from Ciara Raudsepp-Hearne, June 24, 2011 and Paul Adamus, June 27, 2011).

STEPS	DESCRIPTION	POTENTIAL METRICS
ESTABLISH wetland assets	ASSETS of wetlands on the landscape	Wetland area (ha)
ESTIMATE water purification service, which reflects both functions and values	FUNCTIONS relating to water infiltration; nutrient cycling; water purification by soils and vegetation; regulation of runoff; removal of sediment, nitrogen and phosphorus from runoff; removal of sediment, nitrogen and phosphorus from surface and/or ground water VALUES related to context of wetland processes with respect to upstream supply of pollutants and downstream demand for purified water	Change in indicators related to functional effectiveness of a specific wetland, the opportunity to remove pollutants of that wetland, the potential significance of the wetland to upstream and downstream water users, and the cumulative effect of the wetland on regional water supplies (see Section 4: Table4)
CONVERT ecosystem service scores to dollars *(To be done by the Socioeconomic Working Group)*	BENEFITS from water purification by wetlands on the landscape, including improved quality of water for drinking, recreation, aesthetic appreciation, and reduced risk of health complications	Change (% or $) in water treatment costs (related to increase in magnitude of pollutants due to removal of wetlands and/or reduction of wetland capacity to remove pollutants due to development pressures) Change in health care costs (% or $)
CONDUCT a scenario analysis for decision makers *(To be done in future phase of ESPP)*	SCENARIOS generated using regional-scale models (e.g., MARXAN) to establish wetland management targets that best minimize adverse impacts to water quality from wetland loss	Change (% or $) in water treatment costs Change in health care costs (% or $)
IDENTIFY policy indicators for decision makers	POLICIES developed to meet wetland management targets	Avoided cost of water treatment

TABLE 2: Definition of ecosystem system terms used in this report (adapted from Glossary generated by the ESPP on Wetlands Core Team, provided by Yihong Wang, June 27, 2011).

TERM	DESCRIPTION
Natural Asset	The quantity or store of a natural resource from which ecosystem services are provided
Ecological Integrity	The ability of an ecosystem to maintain its principal characteristics, within historical ranges of variability, over a long time period
Ecological Condition	The relative ability of a wetland to support and maintain its complexity with respect to ecological processes as compared to wetlands of a similar class without human alterations
Ecological Process	A characteristic physical, chemical and/or biological activity that influences the flow, storage and/or transformation of materials and energy within and through ecosystems
Ecological Function	A process that is necessary for the self-maintenance of an ecosystem and its integrity
Ecological Metric	An easily measured quantity that serves as a proxy or surrogate for more difficult to measure characteristics of ecosystem condition
Ecological Indicator	A composite of metrics used to represent a particular characteristic of a system
Ecological Value	A value that is provided by the function, that is defined both by its *upstream* demand for the ecosystem service (e.g., upstream areas contain pollutant sources that need purification) and its *downstream* supply of the ecosystem service (e.g., downstream water users rely on a pure water supply provided by the wetland)
Ecosystem Service	A combination of the process and its value
Driver	Any natural or human-induced factor that directly or indirectly causes a change in an ecosystem
Cumulative Effects	The combined effects of all past, present, and reasonably foreseeable future human activities on an ecosystem
Cumulative Benefits	The combined benefit that all wetlands are providing to ecosystem services.
Cumulative Effects	The combined effects of all past, present, and reasonably foreseeable future human activities on an ecosystem
Threshold	A change in driver that results in a problem condition in an ecological, economic, or other system
Scenario	A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships. Scenarios are neither predictions nor projections and sometimes may be based on a ‘‘narrative storyline’’
Policy Indicator	A quantitative measure that provides a means to communicate effectively with policy-makers regarding conditions and trends in ecosystem services
Water Purification	The removal of contaminants from a water supply for human use. In this report, contaminants refer to sediment and nutrients (nitrogen and phosphorous).
Water Quality	The physical, chemical and biological properties of a water supply. In this report, water quality focuses on sediment and nutrient (nitrogen and phosphorous) concentrations in the water supply.

4.0 WATER PURIFICATION ASSESSMENT APPROACHES

There is a critical need for the development of a tool for remote and rapid assessments of wetland ecosystem services, which would use only remote sensing (RS) data and existing GIS layers. Such a tool would be extremely useful for wetland avoidance, assessing cumulative effects to wetlands from development across large regions, and assessing the cumulative benefits of wetlands. For these reasons, it would form an important planning tool (P. Adamus, Pers. Comm., July 25, 2011).

In order for a wetland purification assessment approach to be scientifically rigorous it needs to be rooted in principles that are statements of fundamental truth about the biophysical form and function of a hydrological system. The principles that guide our assessment approach are listed in Table 3. These hydrological principles espouse a system's approach which considers the proper spatial and temporal context of a hydrological system under consideration, either for study or management. Other key considerations within these principles are hydrological connectivity, redundancy and diversity. They all need to be properly accounted for in order to manage ecosystems on a sustainable basis.

In developing this remote and rapid assessment tool, we recognized the need for data that were accessible and/or affordable and for which there was complete coverage for the Province of Alberta. Currently, most Government of Alberta (GOA) data are "static" – one map based on one snapshot. Wetland assessments for ecosystem services require not just a synoptic (one-time) assessment of wetland conditions, but rather a trend in wetland condition ideally over a generation (30 years). Some Government of Alberta datasets are "dynamic"(e.g. Landsat and SPOT coverage) but often have a trade-off. The trade-off is spatial resolution: the datasets with the highest temporal frequency of observation have decreased spatial resolutions. The data selected for this report reflect these tradeoffs, with the Government of Alberta of having the best spatial and temporal coverage for each of the data layers used to define the water purification functions and values.

In selecting the remote and rapid assessment toolkit, we hold the benchmark for comparison as the Wetland Ecosystem Service Protocol (WESP) that was developed for the United States (WESPUS) by Dr. Paul Adamus and presented at an ESPP workshop attended by the consultants(June 24-26, 2011). We need to emphasize that our understanding of WESPUS is that it focuses on water purification issues related to sediment, nitrogen and phosphorus removal and not other pollutants or contaminants (including metals, persistent organic pollutants, bacteria, and viruses).

1. **Site Assessment**
   (after WESP, Wetland Ecosystem Services Protocol, after Adamus 2011)
   - Assessments are based on a large number of metrics. While there are assumptions and associated errors with each metric, if averaged, the uncertainty associated with each metric appears to cancel out, leaving more intuitively correct results;
   - Assessments are conducted on individual wetlands;
   - It is field-based and uses expert and local knowledge, making it customized to each site; and
   - It is wetland-specific, with metrics that define functions and values specific to individual wetlands.

WESP conducts an in-depth, process-based analysis of a small area, providing a stronger ranking of wetlands, but it does not enable all wetlands to be ranked in the near future, prolonging avoidance decisions.

TABLE 3: Hydrological principles for sustainable ecosystem management (after Creed et al. 2011).

Delineate hydrological system boundaries *Consider the entirety of the hydrological system within which management actions take place*	Delineate hydrological system boundary based on knowledge of dominant hydrological flowpaths (many hydrological systems will coincide with topographic boundaries but in some places other factors control hydrological response units)
Identify critical hydrological features *Minimize disturbance to hydrological features with critical source, transfer and storage functions*	A) Minimize disturbance to soils, especially within or near source areas that focus the recharge of water into subsurface pathways B) Minimize disturbance in filter areas around streams, wetlands and lakes, and other sensitive sites (required buffer width will depend on dominant hydrological processes in given locale to maintain water quality of receiving water bodies) C) Minimize disturbance to storage areas (such as permanent and ephemeral wetlands)
Maintain hydrological connectivity *Minimize disruptions to water, sediment, nutrient flows within terrestrial system*	A) Consider the interconnectedness and interdependence of water pathways through watersheds when developing management plans (i.e. look beyond the wetland proper and consider where the wetland occurs with respect to the watershed and water flows) B) Locate roads, bridges, culverts, and areas of impact to ensure surface and subsurface hydrological connectivity is maintained and flow is neither impeded nor enhanced
Respect temporal variability *Acknowledge temporal (historic) factors that influence hydrological processes*	A) Recognize there is natural variability in hydrological processes at multiple scales from daily to multi-decadal B) Recognize there is human induced variability in hydrological processes of different severity (from past management practices to climate change) C) Recognize the timing, frequency, and magnitude of extreme events may be changing because of the interplay between natural and anthropogenic factors that are hard to separate
Respect spatial heterogeneity *Acknowledge spatial (geographic and scale) factors that influence hydrological processes*	A) Consider how scale influences dominance of hydrological processes (moving from headwaters to regional basins) B) Consider how geographic context influences dominance of hydrological processes, including climate, bedrock geology, surficial geology, soil type and depth, topography and its influence on the drainage network, and vegetation type and age
Maintain redundancy and diversity *Manage with the ethos that redundancy and diversity of hydrological form and function contributes to an ecosystem that can absorb outside disturbances*	A) Consider watershed functions that might be most impacted by future extreme events and plan to protect features that perform those functions B) Consider multiple ecosystem services when assessing “trade-offs” in making development choices (optimization for one ecosystem service may occur at the cost of another) C) Consider the interactive nature of the hydrological system with climatic, geomorphic, ecologic, and socio-economic systems

In our pursuit of regional assessments, it must be emphasized that regional assessments do not replace site assessments altogether. Perhaps at the regional planning stage they do, however, even for regional approaches there will always be a need for ground calibrations of the remotely derived products especially when working in new areas.

For individual permit decisions, regional assessments should not be a substitute for a field-based tool, like WESPUS, except in instances where wetlands are physically inaccessible (as in large areas of Alberta) or property access cannot be obtained. That is because there are important metrics of some wetland ecosystem services that are assessed much more accurately during a site visit (and the converse is true also). A fruitful way forward will be the clear articulation of the complementary nature of site and regional approaches at different parts of the planning process.

2. **Regional-Basic Assessment**
   (after US Rapid Assessment Methodology (RAM), customized for Alberta by Cobbaert et al. 2010)
   - Assessments are based on a small number of metrics, providing transparency, though this does not necessarily lead to intuitive results;
   - Assessments are conducted on many wetlands concurrently;
   - It is GIS based (static maps), once calibrated with field data; and
   - It is wetland-general, with metrics that define functions and values to many wetlands within the region. This would allow all wetlands to be ranked easily, helping to inform avoidance decisions sooner. However, the product is a potentially weak ranking of wetlands.

3. **Regional-Advanced Assessment**
   (after WESP, customized and regionalized for Alberta by Creed, this project)
   - Assessments are based on many metrics;
   - Assessments are conducted on many wetlands concurrently, enabling both region- and site-based assessments (reflecting a systems-based approach);
   - It is a GIS and RS based approach, using datasets that are generally available but not currently used by the GOA. This approach will enable consideration of both spatial and temporal dynamics (an improvement of even the site assessment); and
   - It has reduced reliance on local experts, enabling it to be usable at broad scales, but with a richer understanding/data inclusion than is currently possible with the REGIONAL-BASIC approach.

The merits of each approach were discussed and debated at meetings with the Biophysical Team held during the week of the Paul Adamus WESPUS workshop (June 24-26, 2011), with concerns related to the trade-offs of selecting one over the other identified.

We opted to proceed with the Regional-Advanced approach, as it was more consistent with the assessments currently being developed by the Alberta Water Research Institute (AWRI), Wetland Policy project (Bayley, Creed, Foote, and Krogman). We proceeded to develop the metrics, functions and values for this Regional-Advanced approach (Table 4). However, due to challenges in licensing and delivery of data within the brief (4 week) period of the contract, the wetland assessment approach for water quality was selected based on data received by July 25, 2011 (see Table 5); the required data were not received and therefore we used a modified Regional-Basic approach supported by data downloaded from the Internet.

We want to emphasize that our analysis does not tap into the full potential of what GOA data can provide for these types of analyses. A major step forward for the ESPP, as it transitions from pilot to implementation, will be the development of knowledge management systems that support the ecosystem service frameworks.

RECOMMENDATION #3:
The recommended methodology (the "Regional-Advanced approach) was not completed, not because it was too labour intensive, but rather because of delays in receiving specific data. There is a need for more effective and efficient data management to support ecosystem service assessments. **For future ecosystem service assessments, it is recommended that all data providers be brought together to compile, coordinate and evaluate what data are available for the assessment.**

RECOMMENDATION #4:
Until site and regional assessments are directly compared it will be difficult to precisely assess the overall utility in estimating ecosystem services at various scales of planning. **For future ecosystem service assessments, it is recommended that site approaches (WESPUS) are benchmarked to regional approaches, including the Regional-Basic (*sensu* Cobbaert) and Regional-Advanced (*sensu* Creed) approaches. Recent initiatives both by the ESPP project activities (led by Kerr) and AWRI-Wetland Health project activities (led by Bayley) provide site based assessments of about 100 wetlands throughout southern Alberta that can now be used to benchmark regional wetland assessment approaches.**

TABLE 4: A comparison of two regional wetland assessment approaches (advanced *vs.* basic) developed in this study to the WESPUS site wetland assessment approach (Adamus 2011) (continued on following two pages)

SITE – WESP		REGIONAL – ADVANCED		REGIONAL – BASIC	
Metric Description	**Metric Code**	**Metric Description**	**Metric Code**	**Metric Description**	**Metric Code**
Total number of metrics= 42		**Total number of metrics = 39**		**Total number of metrics = 8**	
FUNCTIONS					
Number of metrics = 17		**Number of metrics = 11**		**Number of metrics = 2**	
Historical change in wetland size	**D24**	Historical change in wetland size	RA1	Wetland size	RB1/WP1
Ratio of wetland area to wetland’s contributing area	**D36**	Ratio of wetland area to wetland’s contributing area	RA2	Ratio of wetland to contributing area	RB2/WP3
Interrupted hydroperiod (wetland generally covered with surface water but goes mostly dry at least once a year, *versus* wetland generally not covered with surface water but goes wet at least once a year)	**F5**	Interrupted hydroperiod (wetland generally covered with surface water but goes mostly dry at least once a year, *versus* wetland generally not covered with surface water but goes wet at least once a year)	RA3		
Saturated-only wetland (no part of the wetland is inundated for more than 14 consecutive days of the year)	**F6**	Saturated-only wetland (no part of the wetland is inundated for more than 14 consecutive days of the year)	RA4		
Inundated wetland (a significant percentage of the wetland is inundated more than 14days but less than 9 months)	**F7**	Inundated wetland (a significant percentage of the wetland is inundated more than 14days but less than 9 months)	RA5		
Inundated wetland (a significant percentage of wetland is inundated even during the driest period of the year)	**F8**	Inundated wetland (a significant percentage of wetland is inundated even during the driest period of the year)	RA6		
Annual fluctuation in water depth	**F11**				
Average annual or predominant depth of water	**F12**				
Presence of groundwater discharge within the wetland	**F17**	Presence of groundwater discharge within the wetland	RA7		
Relative width of the wet meadow zone (vegetated zone)	**F22**	Relative width of the wet meadow zone (vegetated zone)	RA8		
Absolute width of the wet meadow zone (vegetated zone)	**F23**	Absolute width of the wet meadow zone (vegetated zone)	RA9		
Presence of undercut banks visible above the water	**F24**				
Complexity of the upland open water edge (tortuosity)	**F56**	Complexity of the upland open water edge (tortuosity)	RA10		
Upland inclusions occur within the wetland	**F57**				
Soil composition within the wet meadow zone	**F58**	Soil composition within the wet meadow zone	RA11		
Ground irregularity defined by presence of burrows, fallen trees, boulders, mounds, etc.	**F60**				
Devegetation of the wet meadow zone through grazing or mowing	**F73**				

VALUES: Pollution sources					
Number of metrics = 6		**Number of metrics = 6**		**Number of metrics = 1**	
Upslope soil erodibility risk defined by soil maps	**D20**	Upslope soil erodibility risk defined by soil maps	RA12		
Unvegetated (disturbed - roads, rail, buildings, impervious surfaces) surface in the contributing area	**D37**	Unvegetated (disturbed - roads, rail, buildings, impervious surfaces) surface in the contributing area	RA13	Presence of disturbed land within the contributing area	RB3/WP2
Presence of water quality limited rivers and streams upslope and hydrologically connected wetland	**D40**	Presence of water quality limited rivers and streams upslope and hydrologically connected wetland	RA14		
Open water interspersion with emergent vegetation	**F15**	Open water interspersion with emergent vegetation	RA15		
Bare ground and accumulated plant litter in the wet meadow zone	**F55**				
Natural land cover in 100 ft upslope buffer	**F77**	Natural land cover in 100 ft upslope buffer	RA16		
		Presence of saline soils within the contributing area	RA17		
VALUES: Transport potential of pollutants					
Number of metrics = 5		**Number of metrics = 5**		**Number of metrics = 3**	
Ratio of upslope inundated wetlands to the wetland	**D38**	Ratio of upslope inundated wetlands to the wetland	RA18	% upslope wetlands to total wetlands within the stream catchment	RB4/WP3
Transport from upslope (defined by presence of disturbed land, ditches, channels, soils with high runoff coefficients in the contributing area)	**D39**	Transport from upslope (defined by presence of disturbed land, ditches, channels, soils with high runoff coefficients in the contributing area)	RA19		
Throughflow complexity (defined by direct or indirect flow of surface water through the contributing area and presence of woody vegetation in flow path)	**F21**	Throughflow complexity (defined by direct or indirect flow of surface water through the contributing area and presence of woody vegetation in flow path)	RA20	Percent non forested/shrubland class within the CA	RB5/WP3
Slope of the contributing area	**F61**	Slope of the contributing area	RA21	Slope of the contributing area	RB6/WP4
Connection with drainage ditches, culverts and pipes	**F9**	Connection with drainage ditches, culverts and pipes	RA22		
VALUES: Loading potential of pollutants					
Number of metrics = 4		**Number of metrics = 4**		**Number of metrics = 1**	
Drier water regime resulting from disturbances within the wetland (i.e., drainage ditches, deep ripping, widening of outflows)	**S3**	Drier water regime resulting from disturbances within the wetland (i.e., drainage ditches, deep ripping, widening of outflows)	RA23		
Do accelerated inputs of nutrients, contaminants, and/or salts from external sources occur within the contributing area (i.e., irrigation, fertiliser treatment)	**S6**	Do accelerated inputs of nutrients, contaminants, and/or salts from external sources occur within the contributing area (i.e., irrigation, fertiliser treatment)	RA24		
Is there excessive sediment loading from disturbances within the contributing area (i.e., construction, gravel roads)	**S7**	Is there excessive sediment loading from disturbances within the contributing area (i.e., construction, gravel roads)	RA25		
Has soil or sediment alteration occurred within the wetland (i.e., compaction, excavation, etc.)	**S8**	Has soil or sediment alteration occurred within the wetland (i.e., compaction, excavation, etc.)	RA26		

				Riparian wetland, defined by distance of wetland to nearest stream or river	RB7/WP5
VALUES: Potential significance					
Number of metrics = 5		**Number of metrics = 6**		**Number of metrics = 1**	
Relative elevation of wetland in watershed	**D35**	Relative elevation of wetland in watershed	RA27	Relative elevation of wetland in watershed	RB8/WP6
Presence of downstream drinking water sources	**D43**	Presence of downstream drinking water sources	RA28		
Annual duration of wetland outflow connection with surface water	**F18**	Annual duration of wetland outflow connection with surface water	RA29		
Outflow from wetland is confined by water control infrastructure (e.g., pipes, culverts, etc.)	**F19**	Outflow from wetland is confined by water control infrastructure (e.g., pipes, culverts, etc.)	RA30		
Presence of downstream domestic drinking water supply wells	**F71**	Presence of downstream domestic drinking water supply wells	RA31		
		Aquatic diversity rating of each wetland defined by the Aquatic Environmentally Significant Areas database	RA32		
CUMULATIVE EFFECTS					
Number of metrics = 5		**Number of metrics = 7**		**Number of metrics = 0**	
Presence of known water quality issues below the wetland	**D41**	Presence of known water quality issues below the wetland	RA33		
Presence of connection to known water quality issues below the wetland	**D42**	Presence of connection to known water quality issues below the wetland	RA34		
Wetland lies within a designated groundwater at risk aquifer	**D44**	Wetland lies within a designated groundwater at risk aquifer	RA35		
Wet season connection of wetland open water to offsite surface water	**F10**	Wet season connection of wetland open water to offsite surface water	RA36		
Is wetland's inundated water maintained by an existing dyke or berm or if removed will current hydrology be sustained	**F81**	Is wetland's inundated water maintained by an existing dyke or berm or if removed will current hydrology be sustained	RA37		
		Change in turbidity of major water sources in the area of interest	RA38		
		Connectivity of wetlands to the watershed outflow	RA39		

TABLE 5: Preliminary list of data resources available to support a Regional-Advanced wetland assessment approach [with metric codes from Table 4, data quality (Low, Medium, High) reflecting range of data options that are currently available, and data description providing examples of data that can be used for derivation of metrics] (continued on following page).

METRIC CODE	METRIC DESCRIPTION	DATA QUALITY			DESCRIPTION OF DATA TO DERIVE METRIC
		Low	Medium	High	
RA1	Historical change in wetland size		✓	✓	LiDAR DEM to provide potential wetland area, and combination of optical (aerial photography, LANDSAT TM, or SPOT) and microwave (ERS/RADARSAT) satellite imagery to provide inundated and saturated area dynamics
RA2	Ratio of wetland to contributing area			✓	LiDAR DEM required to map contributing area of wetlands in this relatively flat landscape
RA3	Interrupted hydroperiod		✓	✓	Optical (aerial photography, LANDSAT or SPOT) to map within year time series of inundated soils
RA4	Saturated-only wetland		✓	✓	Optical (aerial photography, LANDSAT or SPOT) and/or microwave (ERS/RADARSAT) to map within year time series of inundated (or saturated) soils
RA5	Inundated wetland		✓	✓	Optical (aerial photography, LANDSAT or SPOT) to map within year time series of inundated soils
RA6	Inundated wetland		✓	✓	Optical (aerial photography, LANDSAT or SPOT) to map within year time series of inundated soils
RA7	Presence of groundwater discharge within the wetland		✓		Thermal (LANDSAT) to map discharge areas within watershed
RA8	Relative width of the wet meadow zone		✓	✓	Optical (aerial photography) for wet meadow vegetation or microwave (ERS/RADARSAT) for saturated soils
RA9	Absolute width of the wet meadow zone		✓	✓	Optical (aerial photography) for wet meadow vegetation or microwave (ERS/RADARSAT) for saturated soils
RA10	Complexity of the upland open water edge			✓	LiDAR DEM with optical (aerial photography, LANDSAT or SPOT) to map within year time series of inundated soils
RA11	Soil composition within the wet meadow zone	✓	✓	✓	AGRASID soil map for soil types and optical data (aerial photography) for wet meadow vegetation or microwave data (ERS/RADARSAT) for saturated soils
RA12	Upslope soil erodibility risk defined by soil maps	✓			AGRASID soil map for soil erodibility risk
RA13	Unvegetated (disturbed - roads, rail, buildings, impervious surfaces) surface in the contributing area	✓	✓	✓	LiDAR DEM combined with LULC derived from optical data (LANDSAT or SPOT)
RA14	Presence of water quality limited rivers and streams upslope and hydrologically connected wetland	✓		✓	GOA water quality monitoring data and LiDAR DEM combined with microwave (ERS/RADARSAT) imagery to map probability of connections to water quality limited rivers
RA15	Open water interspersion with emergent vegetation			✓	Optical (aerial photography) to define emergent vegetation within open water
RA16	Natural land cover in 100 ft upslope buffer	✓	✓	✓	LiDAR DEM combined with LULC derived from optical data (LANDSAT or SPOT)
RA17	Presence of saline soils within the contributing area	✓			AGRASID soil map for soil salinity
RA18	Ratio of upslope inundated wetlands to the wetland		✓	✓	LiDAR DEM combined with high resolution optical (aerial photography or SPOT)
RA19	Transport from upslope (defined by presence of disturbed land, ditches, channels, soils with high runoff coefficients in the contributing area)			✓	LiDAR DEM combined with LULC plans for municipalities and/or optical data (LANDSAT, SPOT, and/or aerial photography)
RA20	Throughflow complexity (defined by direct or indirect flow of surface water through the contributing area and presence of woody vegetation in flow path)	✓	✓	✓	Time series of LULC change focused on human modification of drainage network from SPOT or LANDSAT imagery
RA21	Slope of the contributing area			✓	LiDAR DEM

RA22	Connection with drainage ditches, culverts and pipes		✓	✓	LiDAR DEM combined with high resolution optical data (aerial photography or SPOT)
RA23	Drier water regime resulting from disturbances within the wetland (i.e., drainage ditches, deep ripping, widening of outflows)	✓		✓	Municipality infrastructure and disturbance history, or optical data (aerial photography)
RA24	Do accelerated inputs of nutrients, contaminants, and/or salts from external sources occur within the contributing area (i.e., irrigation, fertiliser treatment)		✓		Optical data (LANDSAT) time series to define chl-*a* of open water
RA25	Is there excessive sediment loading from disturbances within the contributing area (i.e., construction, gravel roads)		✓		Optical data (LANDSAT) time series to define turbidity of open water
RA26	Has soil or sediment alteration occurred within the wetland (i.e., compaction, excavation, etc.)		✓		Optical data (LANDSAT) time series to define turbidity of open water
RA27	Relative elevation of wetland in watershed			✓	LIDAR DEM
RA28	Presence of downstream drinking water sources	✓			GOA water quality monitoring stations
RA29	Annual duration of wetland outflow connection with surface water			✓	LiDAR DEM combined with microwave (ERS/RADARSAT) imagery to map probability of connections both within and among years
RA30	Outflow from wetland is confined by water control infrastructure (e.g., pipes, culverts, etc.)	✓		✓	Municipality infrastructure data or optical data aerial photography)
RA31	Presence of downstream domestic drinking water supply wells	✓			Municipalities or GOA groundwater well location data
RA32	Aquatic diversity rating of each wetland defined by the Aquatic Environmentally Significant Areas database			✓	GOA AESA map and/or site based assessments for aquatic diversity (e.g., NAWAMP, DUC)
RA33	Presence of known water quality issues below the wetland	✓			GOA water quality monitoring stations
RA34	Presence of connection to known water quality issues below the wetland			✓	LiDAR DEM, natural and human modifications to drainage networks, GOA water quality monitoring stations
RA35	Wetland lies within a designated groundwater at risk aquifer		✓		GOA groundwater vulnerability maps
RA36	Wet season connection of wetland open water to offsite surface water			✓	LiDAR DEM combined with microwave (ERS/RADARSAT) imagery to map probability of connections both within and among years
RA37	Is wetland's inundated water maintained by an existing dyke or berm or if removed will current hydrology be sustained	✓		✓	Municipalities or GOA infrastructure data or optical data (aerial photography)
RA38	Change in turbidity of major water sources in the area of interest			✓	Optical data (LANDSAT) time series to define turbidity of open water
RA39	Connectivity of wetlands to the watershed outflow			✓	LiDAR DEM combined with microwave (ERS/RADARSAT) imagery to map probability of connections both within and among years

Many of the metrics listed in Table 5 are derived from LiDAR data. LiDAR is becoming the standard data for generation of digital elevation models. While LiDAR acquisition continues to be a priority for many government agencies, it will take time to obtain complete coverage for many provinces and states. For example, the Government of Alberta's license for LiDAR currently excludes much of the white (inhabited) zone and some portions of the green (forested) zone. This should not be viewed as a deterrent for site-specific wetland ecosystem service assessments.

In Table 5, we were strategic in identifying low, medium and high quality data options for defining the water purification metrics. A few of the metrics require high quality data (i.e., LiDAR) data, as they are currently defined (e.g., the metric for ratio of wetland to contributing area requires LiDAR to capture the subtle changes in topography that define these contributing areas). There are at least two options for dealing with such metrics when no LiDAR data are available: (1) remove that metric from the calculation of the wetland function score; and (2) develop proxies for the metric (e.g., in the absence of high quality data needed for definition of contributing areas, one could use lower quality data to define a fixed buffer width (such as 100m from water's edge instead of the contributing area)). It is clear that wetland ecosystem service assessments are an evolutionary and adaptive process – as finer datasets come on line then better metrics can be defined – and that we must start the process with whatever data are readily available with the promise that we will review and refine the process as better data become available.

5.0 WATER PURIFICATION: A DEMONSTRATION OF THE REGIONAL-BASIC ASSESSMENT APPROACH

5.1 WETLAND ASSETS

Wetlands can be defined as areas where the water table is at, near, or above the ground surface long enough to enable the accumulation of organic matter (Tarnocai 1980). Water storage is particularly important in terms of hydrological response (rapid water delivery to a stream or lake) as well as biogeochemical behaviour (e.g., storage, transformation or export of nutrients). In order to define and map wetland assets there are a number of ground and remote sensing (RS) based approaches available (cf. Creed and Sass 2011). RS approaches include airborne and satellite based platforms with both optical and microwave sensors (Appendix 1).

Wetland Inventory - Basic

A number of wetland inventory options exist that provide full coverage of wetlands within the Shepard Slough study area (see Appendix 1, Table A1.1). In particular, three inventory options were explored. The Ducks Unlimited (DU) wetland inventory provides coverage of Shepard Slough in 1965 and 2005. This inventory was developed using digitization of wetlands from aerial photography. The second inventory option uses digital terrain analysis techniques (Creed and Sass 2011) to define the potential of wetlands to occur on the landscape. The inventory is developed from a LiDAR DEM. The third inventory utilises RS optical and microwave image analysis techniques to identify open water that is then assumed to be the location of wetlands. Each technique generates a different wetland inventory for the area. Figure 3 compares the size distribution of wetlands derived from aerial photography (DU 1965 wetland inventory [static]), digital terrain analysis (LiDAR approach [static]) and satellite RS (LANDSAT TM imagery [dynamic]). Figure 4 compares the size distribution of the DU 2005 and Landsat 2005 mapping static maps.

The following criteria were used to guide the selection of the appropriate wetland inventory option:

(1) *Spatial consistency:* To provide consistency the option selected must provide full coverage over the entire Shepard Slough study area. Mosaicking wetland inventories with partial coverage will lead to biases in the ecosystem service assessments (i.e. better quality inventories for certain areas of Shepard Slough will result in the incorrect conclusion that those wetlands have a higher water purification function and value when it may simply be the result of improved delineation of the wetlands).

(2) *Temporal dynamics:* To allow assessment of changing human development pressures on ecosystem services provided by wetlands the option selected must provide wetland coverage throughout Shepard Slough for multiple time periods, particularly over the past 10 years when urban development has increased significantly in Shepard Slough.

Based on these criteria satellite based optical mapping of open water was chosen to develop the wetland inventory. Landsat images from 1984 to present were ordered from the United States Geological Survey (USGS) (http://glovis.usgs.gov). Wetland areas were derived by applying a threshold to each 30m resolution atmospherically corrected Landsat Band 5 image (Sass and Creed 2011).

The DU inventory is developed from manual digitization of wetland boundaries from fine resolution aerial photography and includes both the inundated (open water) and saturated zones. In contrast, the Landsat inventory is development from coarser resolution satellite imagery and includes the inundated zone only. We did not attempt to explicitly estimate inundated areas. Depending on the Stewart and Kantrud (1979) classification of wetlands, inundated areas may constitute a minor (Class 1, 2) to major (Class 3, 4, 5) portion of wetland surface. For this reason, we were not comfortable using a variable ratio between inundated and saturated areas to approximate saturated areas. Second, the inundated *versus* saturated areas serve distinct functions in terms of removal of contaminants. For example, inundated areas are important for P removal, but saturated areas are important for N removal. This complementary role of inundated and saturated areas in water purification processes is precisely why we advocate the Regional-Advanced wetland assessment approach, as the Regional-Basic wetland assessment approach does not represent these processes that are so important for water purification. For this reason, we believe this report showcases the theory of considering ecosystem services, but better data are needed before the theory is put into practice.

Our use of the Landsat inventory for wetlands results in a highly conservative estimate of the water purification potential of wetlands, because the saturated areas, which are important in the water purification function of wetlands, are not included. It must be emphasized that we are not endorsing the use of inundated areas alone as a basis for wetland water purification assessments. We fully recognize the importance of saturated areas, and in particular, Class 1, 2 and 3 wetlands, for water purification and other ecosystem services and these wetlands must not be excluded from policy decisions.

Wetland Inventory - Advanced

The wetland definition includes both inundated (open water) and saturated soils as part of a wetland. Both areas of a wetland play a role in water purification. It is therefore important to capture the spatial and temporal dynamics of both open water and saturated soils.

Cost effective emerging technologies enable us to do this (Sass and Creed 2011). Existing wetland inventories can be improved by adopting GIS and RS methods using readily available imagery (LiDAR, Landsat, SPOT and SAR) that can efficiently create a time series of wetland occurrence, their probability of being wet (showing range of natural variability) and permanent loss of wetlands (due to drainage).

RECOMMENDATION #5:
Current inventories do not factor in the temporal dynamics of wetlands including inundated and saturated areas. **For future ecosystem service assessments, it is recommended that a combination of LiDAR, Landsat/SPOT, and SAR imagery be used to map wetlands (both inundated (open water) and saturated areas), and determine their spatial and temporal dynamics over changing climatic conditions and response to human activities. It is also possible to determine wetland type (i.e., bog, fen, marsh, swamp), which may result in different influences on water purification potential.**

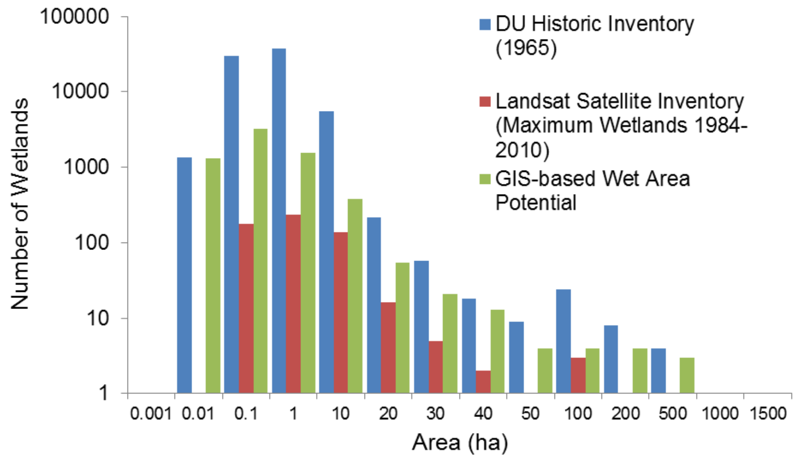


FIGURE 3: Size class frequency distribution of "historical" wetland area defined by three different techniques: (a) aerial photography based "static" approach (Ducks Unlimited 1965 wetland inventory); (b) GIS (LiDAR) based "static" approach; (c) satellite (LANDSAT TM imagery) based 'dynamic" approach.

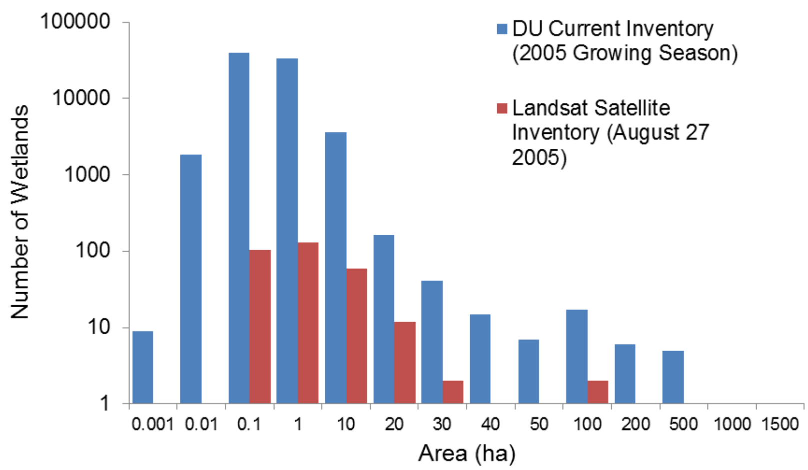


FIGURE 4: Size class frequency distribution of "current" wetland area defined by 2005 Ducks Unlimited Canada wetland inventory (based on "growing season" aerial photography) and 2005 LANDSAT TM imagery (based on August 27th satellite image, influenced by 30 mm storm event that occurred 3 days before image capture).

5.2 WETLAND ASSESSMENT – TREND

To tease out the effect of natural vs. human drivers, one has to establish a "reference condition" that is representative of the range of natural variability in climatic conditions in the region, and then compare the effects of human activity against this reference condition. A challenge occurs when the range of natural variability in climatic conditions translates into a broad range in wetland areas, causing the impacts of human activities to be "lost". In other words, the "signal" from human drivers cannot be distinguished from the "noise" from natural drivers. We attempted to establish a "reference condition" by exploring the relationship between climatic conditions and wetland areas.

5.2.1 NATURAL DRIVERS

The change in the amount of water stored on the land is influenced by climatic conditions (e.g., wetting versus drying trends). Within Shepard Slough, we examined these natural drivers of changing water storage by estimating the water budget. The water budget is defined as the water inputs [precipitation (P)] to the system *versus* the water outputs [evapotranspiration (ET) and discharge (Q)] from the system and is represented by the formula P = ET + Q. This formula assumes that the change in water stored in the wetland is negligible. This water budget was used to estimate the water surplus of the system.

We calculated a simple measure of effective precipitation, or how much water is available to enter the surface water or groundwater flow systems after accounting for evapotranspiration (the process by which water is transferred from the land to the atmosphere by evaporation from land surfaces and by transpiration from plants). The effective precipitation is computed using precipitation (P) minus potential evapotranspiration (PET, a measure of how much water would be lost to the atmosphere if an unlimited source of water were available). If the annual P-PET is positive, a water surplus exists and it is considered a wet year (i.e., energy limited). In contrast, if the annual P-PET is negative, a water deficit exists and it is considered a dry year (i.e., water limited).

The transient nature of evapotranspiration renders it a difficult parameter to measure, but an attentive assessment can be implemented using PET. In this report, PET was estimated using the technique by Hamon (1963), because it is simple and requires readily available data (temperature data only)
(Equation 1):

$$PET_{HAMON} = \frac{2.1 \times H_t^{\,2} e_s}{(T_a + 273.2)} \quad \text{Equation 1}$$

where PET_{HAMON} is in mm·month^{-1}, H_t is number of monthly average daylight hours per day, T_a (°C) is the mean monthly temperature, and e_s is the saturated water vapor density term (Equation 2):

$$e_s = 0.6108 \exp\left(\frac{17.27 T_a}{237.3 + T_a}\right) \quad \text{Equation 2}$$

In this report, the annual time series data for P-PET was derived based on water year defined as June 1 to May 31 of the following year. The 50-year annual P-PET average for Calgary International Airport was -37 mm (reflecting a moderately dry region), based on measurements from 1960 to 2010.

A time series of P-PET over the past 50 years is presented in Figure 5. It shows that P-PET at Calgary airport (about 10 km from the Shepard Slough centre) demonstrates strong cyclical variations over time, from a high of 185 mm in 1966, to a low of negative 252 mm in 1968. To assess the influence of global climatic oscillations on the Calgary regional climate, annual P-PET values were regressed on annual average indices of five major climatic oscillations (Table 6). Multivariate El Niño/Southern Oscillation Index (MEI), Northern Atlantic Oscillation (NAO) and Atlantic Multidecadal Oscillation (AMO) were found to influence the region's P-PET. While MEI was found to explain over 30% of the regional temporal variability in P-PET, NAO and AMO explained 28% and 26% of the P-PET fluctuation in the region respectively. The relationships between P-PET and the five climatic oscillations considered in this assessment were summarized as indicated below (Table 6). Table 6 provides the explanation of variance in P-PET caused by individual oscillations only; other work shows that when considering the interacting influences of multiple oscillations, more than 50% of the variance can be explained (S. Girma, Pers. Comm.). It is important to discriminate the relative importance of these natural drivers in future ecosystem service assessments because they have a predictable periodicity that can help in estimating near future hydro-climatic conditions.

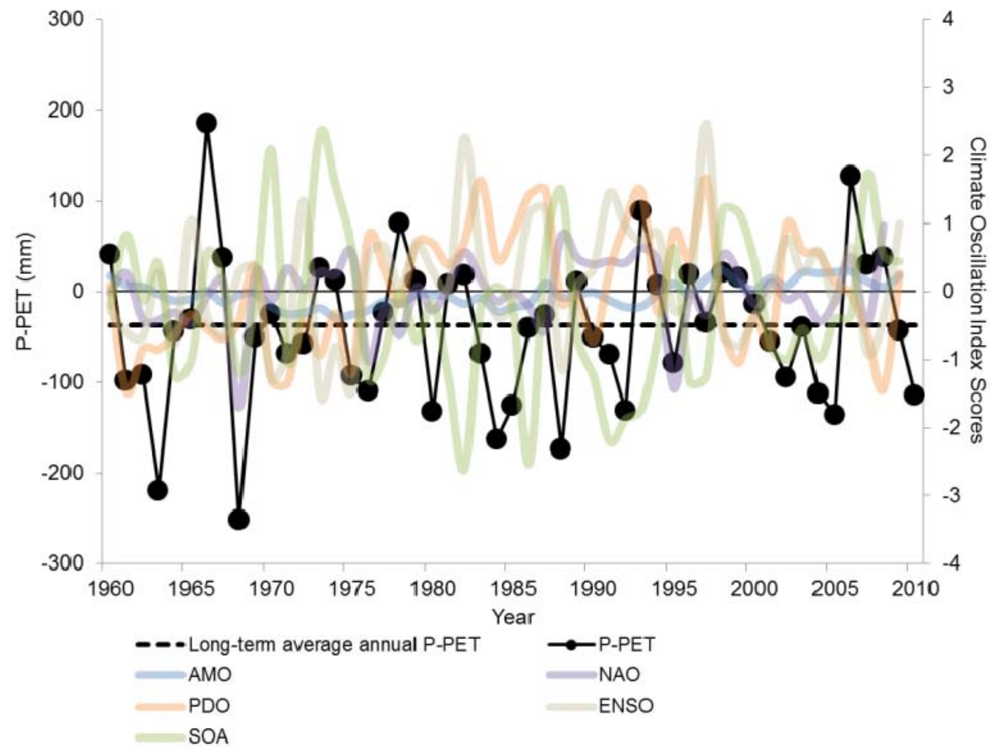


FIGURE 5: Fifty-year time series (1960-2010, water years from June to May) of natural (climatic) drivers of potential change in a wetland's water purification service: (a) precipitation *minus* potential evapotranspiration (P-PET); and (b) global climatic oscillations that influence P-PET, including the El Niño/Southern Oscillation (ENSO), the Northern Atlantic Oscillation (NAO), Atlantic Multidecadal Oscillation (AMO), Pacific Decadal Oscillation (PDO), and the Southern Oscillation Anomaly (SOA).

TABLE 6: Relationship of P-PET (mm/yr) as a function of global climate oscillations (yearly average. based on water year, June to May).

Climatic Driver	Code		R	R^2	P value
Multivariate El Niño/Southern Oscillation Index	MEI	$P-PET = -40.72 + 75.72.\sin(\frac{2\pi.MEI}{0.042} + 4.93)$	0.55	0.30	0.0012
Northern Atlantic Oscillation	NAO	$P-PET = -25.61 + 58.71.\sin(\frac{2\pi.NAO}{0.14} - 1.79)$	0.53	0.28	0.0019
Atlantic Multi-decadal Oscillation	AMO	$P-PET = -41.99 + 60.56.\sin(\frac{2\pi.AMO}{0.021} + 5.78)$	0.51	0.26	0.0034
Pacific Decadal Oscillation	PDO	$P-PET = -26.68 + 58.48.\sin(\frac{2\pi.PDO}{0.025} - 3.83)$	0.47	0.22	0.012
Southern Oscillation Index Anomaly	SOI	$P-PET = -28.78 + 62.06.\sin(\frac{2\pi.SOI}{0.128} - 2.57)$	0.48	0.23	0.0079

5.2.2 HUMAN DRIVERS

In addition to climatic drivers, changes in land use/land cover (LULC) have resulted in changes in size and magnitude of wetlands on the landscape, as well as water flows to sustain wetlands, and pollutant loadings that are to be purified by the wetlands. To examine the extent of LULC change over the selected 20 year trend period, a LULC based on LANDSAT TM imagery was developed (Figure 6).

Several options are available to provide complete LULC coverage of the Shepard Slough AOI (see Appendix 2, Table A2.1). The following criteria guided selection of the LULC option:

(1) *Spatial consistency:* To assess spatial patterns, it is important that each class (i.e., Forest, agriculture, urban) of the LULC map be derived from a single data source for the entire Shepard Slough. Where difference resolutions of LULC options exist, inherent biases can occur when combining these difference sources for the same class. For example, if a portion of Shepard Slough is based on a LULC map with greater assessment of forested areas, lower water purification scores will be estimated for this area over other potions using lower quality LULC.

(2) *Temporal dynamics:* To assess temporal patterns, it is important to have a time series of LULC to examine expanding development pressures on ecosystem services.

Given that there was a quality assured LULC map from AGCAN for 2009, we used it to define our 2010 LULC image. For 1990 and 2000 Landsat images were ordered from the United States Geological Survey (USGS) and atmospherically corrected. A supervised classification was developed for these two images using training polygons defined using the AGCAN LULC map and LANDSAT TM images. The three main classes chosen for the classification were agriculture (grassland, pastures and croplands), urban (commercial, and industrial land use along with road and rail infrastructure), and open water.

Due to the resolution of the Landsat imagery (30m), the Landsat LULC was unable to define the features of forests or shrubland (which occur only in small clusters throughout Shepard Slough but which could be important from a water quality perspective if they occur as riparian rings around wetlands). .A time series based in finer resolution data, such as SPOT (5m resolution), should enabled us to capture these natural land covers. Unfortunately, the SPOT data available contained panchromatic but not optical data, which precluded the ability to do this analysis.

This issue also highlights the need to consider what the study sites LULC baseline is. The major LULC in Shepard Slough over the timer series (1990 – 2010) is agriculture; so to assess the change in land use from natural to agricultural land use and its effect on water purification scores an historic LULC as a baseline would need to be established, which was beyond the scope of the study. Given the LULC reality of the Shepard Slough since the1990 baseline has been agricultural, with urbanization being the contemporary development pressure, agriculture was removed from the disturbed land use (used to determine WP2 metric scores, see section 5.3.1.2) to improve the signal from urbanization, which is expected to increase remarkably over the next few decades.

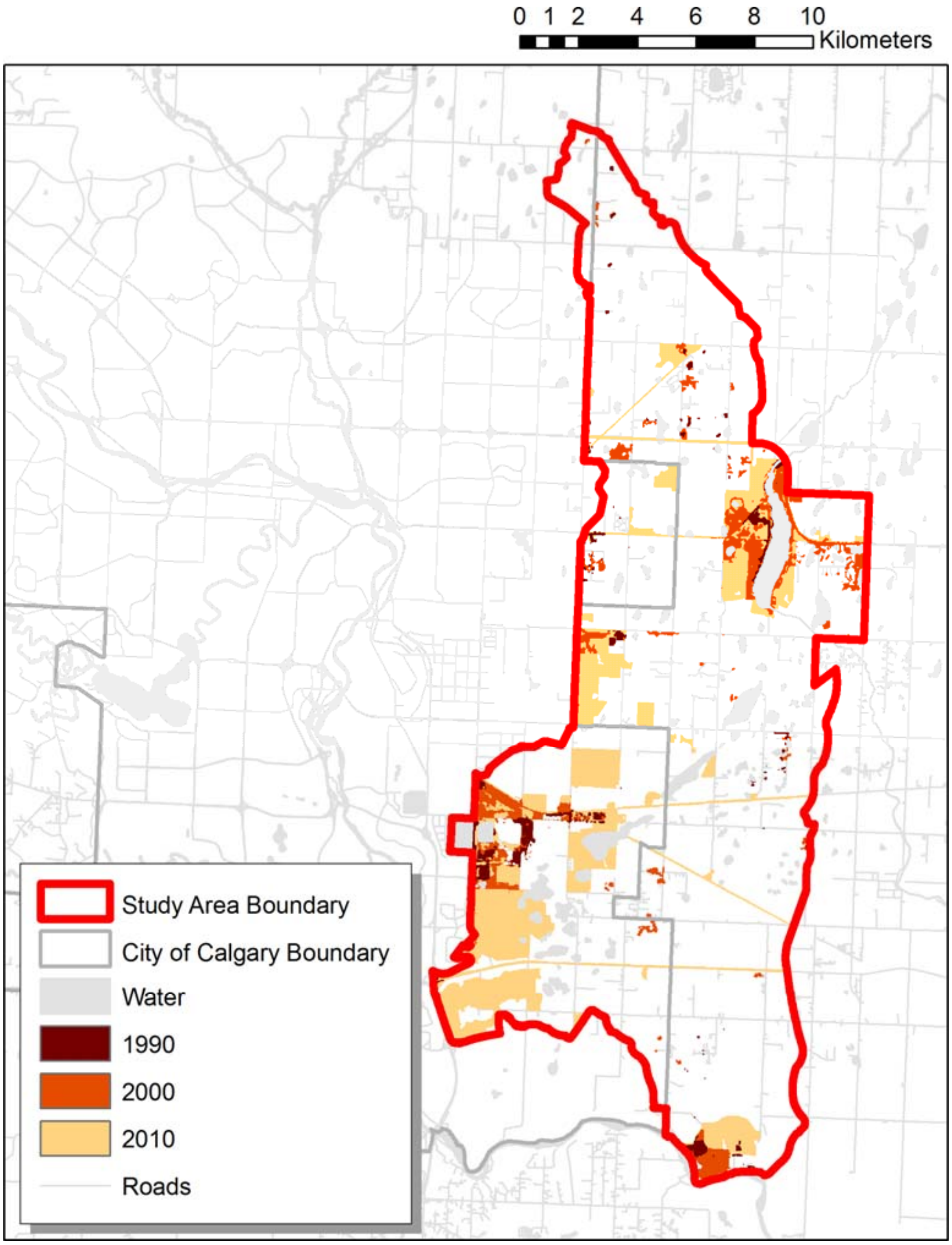


FIGURE 6: Change in urban land use from 1990, to 2000 and to 2010.

5.2.3 SELECTION OF TREND PERIOD

To examine trends in wetland water purification service, a 20 year time period from 1990 to 2010 was selected. The Millennium Ecosystem Assessment (2005) recommends a period of one generation (generally considered to be 30 years, during which children grow up and have children of their own) (Ciara Raudsepp-Hearne pers. comm., June 24, 2011). A 30 year time period was not achievable for two reasons: First, the satellite that provided the core data was launched in 1984, providing a maximum possible period of 26 years; and second, the climatic oscillations shown in Figure 5 play an immense roll in temporal variation of wetlands, that trend analyses becomes extremely difficult by creating relative dry and wet conditions during the 26 years.

To reduce the signal caused by natural drivers related to climatic conditions and to increase the signal caused by human drivers related to development, three “snap shots” of time, 1990, 2000, and 2009 (hereafter referred to as 2010) were selected (Figure 7). The rationale for selecting these years includes the following. A complex relationship was observed between climatic conditions and wetland area, where wetland areas appeared to fall within one of two steady states – a relatively dry state (small wetland area) and a relatively wet state (large wetland area). The selected years all fell on one of the two steady states (i.e., the relatively dry state). The relatively dry state was selected because the median of this dry state was closest to the long term average annual P-PET (-37 mm), and therefore were deemed “representative” of the region based on analyses for each year. However, even these years appeared to be influenced by the legacy effects of previous years (i.e., a relatively wet year could have long lasting effects on wetland area, Figure 7), and showed substantial variability among the years (e.g., total inundated areas of wetlands ranges from about 200 to 500 ha, Figure 8). Clearly, more scientific research is needed in this area to resolve the processes leading to these two steady states, and to develop a reference condition where the system can naturally oscillate between wet and dry conditions.

However, from the perspective of developing wetland ecosystem service assessment approaches that can be implemented in the current atmosphere of streamlining the development approval process, a more practical approach can be taken. We have shown that wetland areas defined by open water show high variation due to climatic variability, and that the associated wetland function can be significantly reduced in drier years, which would lead to significant underestimates of the economic benefits of these wetlands during these years. Rather than monitor this natural variation on an annual basis, one could use the maximum extent of wetlands to estimate the maximum potential for ecosystem services related to water purification. However, this maximum must be based on historical data available for the region.

RECOMMENDATION #6:
Regional climate is defined by two steady states (wet and dry). These difference states strongly influence the presence of inundated (open) water on the landscape. Identifying and understanding the presence of climate regimes and drivers is important to allow quantification of human driven impacts on wetlands. Understanding the link between climate and surface water dynamics allows the incorporation of this natural driver into human drivers of wetland function. **For future ecosystem service assessments, it is recommended that the range of natural variation in wetland function (area) due to natural drivers (climate) should be defined using a combination of historic meteorological and remote sensing data.**

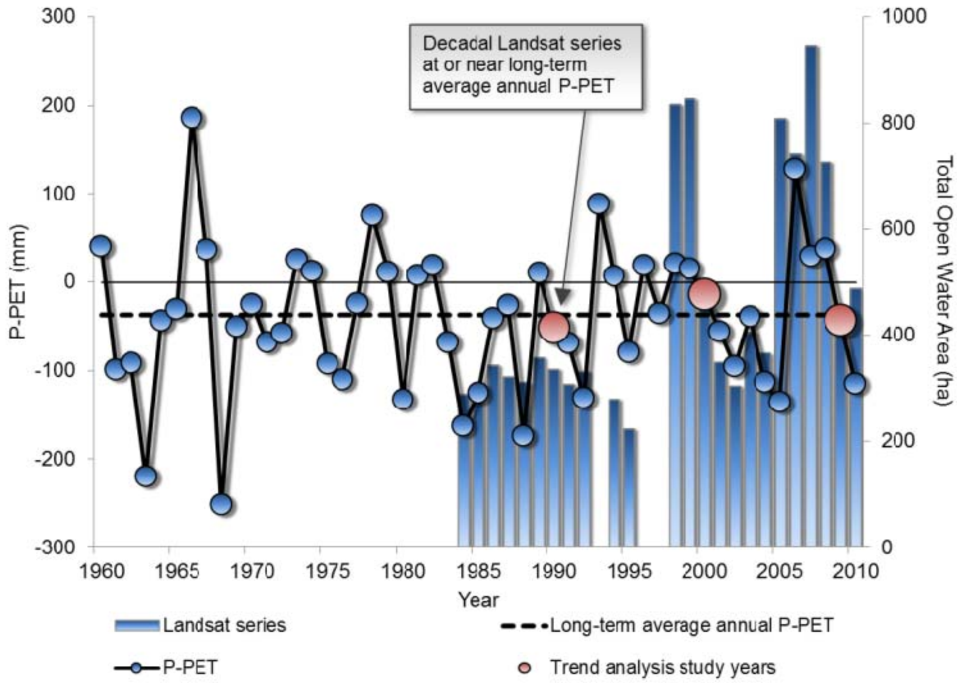


FIGURE 7: Fifty-year time series (1960-2010, water years from June to May) of natural (climatic) drivers of potential change in a wetland's water purification service: (a) precipitation *minus* potential evapotranspiration (P-PET); and (b) change in wetland area (ha) derived by LANDSAT TM imagery, with water years selected for trend analysis highlighted.

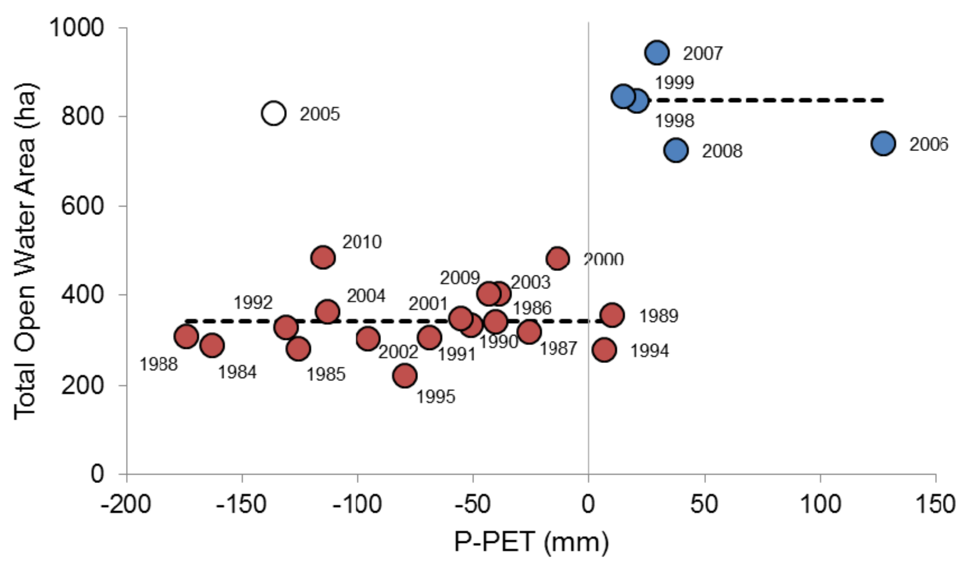


FIGURE 8: Relationship of P-PET (mm/wyr) *versus* wetland area (ha), revealing alternative steady states, with wetlands showing a dry state when P<PET and a wet state when P>PET.

5.3 WETLAND ASSESSMENT – CONDITION

5.3.1 WETLAND FUNCTIONS

Wetland water purification function and value was determined using the six metrics described in Table 7. Each metric was determined using GIS and/or RS techniques. For each metric, the wetland complex was used as the wetland assessment unit (defined in Table 7).

TABLE 7: Description of GIS and remote sensing data products and the method of derivation that were used to estimate water purification metrics (after Strahler 1957).

Name	Description
Wetland **WP1**	Land 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 that area adapted to a wet environment. Ephemeral wetlands are only periodically covered by standing or slow moving water. Manual, probabilistic and object-based methods using air photos or LiDAR DEMs map wetlands by this definition. Methods using satellite-based radar images define wetlands as inundated areas and surrounding areas of soil saturation. Data used for trend analysis in this report was limited to satellite-based optical images – this limitation constrained the methods used here to a definition of wetland as the presence of open water determined as areas of low reflectance in 30-meter Landsat Band 5 (1.55 - 1.75μm).
Wetland complex **WP1**	Two or more separated wetlands related by biological or hydrological functions. Wetland complexes are generally determined through distance and surface area thresholds. Wetland complexes are determined in this report by joining wetlands within a 50-meter (< 2 Landsat 30m pixels) buffer. Methods using satellite-based radar images would permit wetland complexes to be determined by hydrological connections between wetlands defined by soil saturation probability.
Land use/land cover for 1990, 2000, 2010 **WP2, WP3**	1990 and 2000 LULC developed using a supervised classification of LANDSAT TM optical bands. The classification is not ground-truthed and training areas were selected based on the respective LANDSAT images and the 2010 LULC developed from the crop type mapping in the Prairies 2009 and the Grassland Vegetation Inventory LULC.
Wetland's contributing area **WP2, WP3, WP4**	Area in which water drains into a water body. Contributing areas are determined from LiDAR DEMs resampled to 5-meter grid resolution using wetland complexes as the target water bodies.
Sub-watershed **WP5**	Area in which water drains into a stream outlet. Sub-watersheds are determined from LiDAR DEMs resampled to 5-meter grid resolution using 1st, 2nd and 3rd order stream intersections as the target points.
Watershed **WP3, WP6**	Area in which water drains into a river outlet. Watersheds are determined from Canadian Digital Elevation Data DEMs using outlets of streams or ditches flowing out of study area at Bow River and Red Deer River.
Stream drainage network **WP5**	Total streams contributing to a watershed outlet. Stream drainage networks are determined by applying a threshold to flow accumulation layers derived from LiDAR DEMs resampled to 5-meter grid resolution so that accumulation grid values greater than the threshold are considered as stream grid cells. Thresholds are determined to include main, secondary and tertiary branches to the watershed outlet.
Stream order **WP5**	Number assigned to a stream as a measure of its branching complexity where headwater streams near contributing area divides are designated as 1st order and stream order increases downstream as links of equal order join (Strahler, 1957).
Human modified stream drainage network **WP5**	Stream drainage networks modified by artificial water structures including canals, drainage ditches and stormwater infrastructure. Stream drainage network delineation using LiDAR DEMs captures open (uncovered) human modifications. Locations of bridges and culverts that connect water features but are covered from airborne LiDAR sensors are required to "burn" stream flows into LiDAR elevation values to avoid disconnection of automatically derived streams and drainage areas.

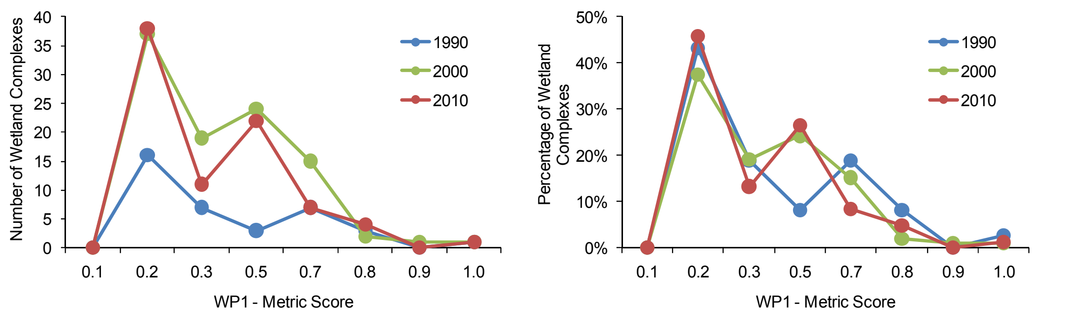
5.3.1.1 WETLAND PURIFICATION METRIC 1 (WP1), WETLAND AREA

What is the metric? Wetland size was defined as the total area of open water within a wetland complex. Although the definition of a wetland includes saturated soils surrounding the open water, the data constraints of the project prevented the identification of this zone (see Section 5.1).

How is it being measured? Wet area was determined for each period from LANDSAT Band 5 using a threshold value of 20. Wetland size was defined as the total area of wet areas within a wetland complex.

What is the condition? In 2010 the highest frequency of wetlands falls within the 0.05 to 0.5ha range. Also, the majority of wetlands in 2010 are smaller than 4ha (Figure 9). Based on the metric score most of the wetlands within Shepard Slough have medium to low value (metric score < 0.5) in terms of wetland size.

What is the trend? Wetland size generally increased throughout the time period with the maximum total wetland area occurring in 2000 (Figure 9). As discussed in Section 5.2.1 wet area is strongly influenced by climatic variation in the region. Across all three time periods the highest frequency of wetlands falls within the 0.05 to 0.5 ha range with a large increase in the number of wetlands in the 1 to 4 ha range occurring in 2000 and 2010. The increase in the number and area of wetlands is largely due to the legacy effect of previous wet years resulting in larger amounts of water on the landscape. Wetlands smaller than 0.05ha were not identified as the resolution of Landsat (30m) is too coarse to identify these features.



Metric Score	0.1	0.2	0.3	0.5	0.7	0.8	0.9	1.0
Area (ha)	<0.05	0.05 to < 0.5	0.5 to < 1	1 to < 4	4 to < 10	10 to <20	20 to <50	≥ 50
1990	0	16	7	3	7	3	0	1
2000	0	37	19	24	15	2	1	1
2010	0	38	11	22	7	4	0	1

FIGURE 9: Trends in frequency distribution of water purification scores for wetland assessment unit: WP1, wetland area.

In the Regional-Basic wetland assessment approach used in the report, wetland area is the single wetland-specific feature that determines the natural purification potential of wetlands. The assumption is that wetland area is directly correlated with other wetland features that contribute to the purification potential of wetlands (e.g., wet meadow and emergent vegetation areas). No assessment has been undertaken to determine the validity of this assumption. In the Cobbaert et al. (2010) report, there is supporting literature to suggest that wetland area is a simple proxy for many purification functions. However, in the Regional-Advanced wetland assessment approach based on the Adamus (2010) method, many features of the wetland contribute to the purification potential of wetlands. Data and time constraints prevented adoption of further metrics of purification potential of wetlands from being assessed.

5.3.1.2 WETLAND PURIFICATION METRIC 2 (WP2), POLLUTANT SOURCES

What is the metric? The potential for a wetland to treat contaminated surface water is dependent on the presence of disturbed land use within the wetlands contributing area. Urban runoff water is a source of nutrients (nitrogen and phosphorus) and sediment loads to surface waters. Wetlands intercepting this runoff water have a higher value to downstream water users in terms of water purification than wetlands intercepting runoff from undisturbed or natural land cover such as forest and shrub land.

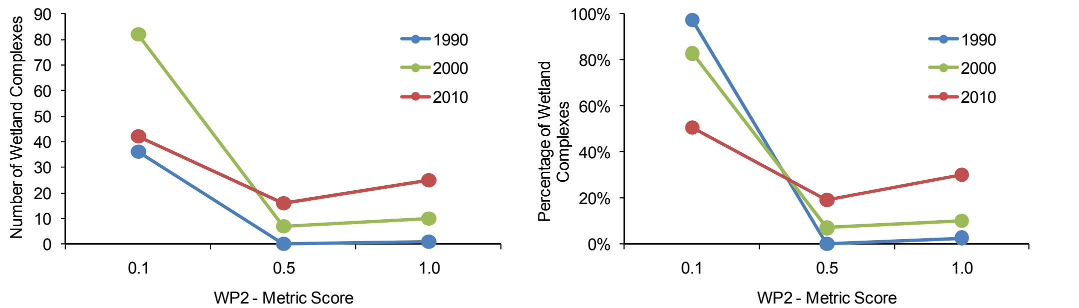
The WP2 metric addresses the potential pollutant sources to a wetland. The WP2 metric is the percentage area of the wetlands contributing area that is considered urban land use, where urban land use is defined as residential, commercial and industrial areas along with roads and rail infrastructure. This is a deviation from how the WP2 metric was calculated in the original Cobbaert et al. (2010) report.

The reason for this deviation is twofold. First, WP2 scores were not influenced by natural land cover, as less than 1per cent of the Shepard Slough land cover is classified as natural or undisturbed. Second, WP2 scores were strongly influenced by agricultural land cover. WP2 scores for all wetlands were 1.0 throughout the time series when agriculture was included in the calculation. To try and capture temporal variation in WP2, agriculture was removed when determining the metric scores. The assumption made was that runoff from urban areas has higher sediment and nutrient loads than runoff from agricultural areas. This is not a hard and fast rule and is dependent on a range of variables including urban land use (industrial compared to residential), fertiliser application rates and tilling practices. Removing agriculture from the WP2 metric results in a lower overall WPS for wetlands in Shepard Slough. If the technique is to be used across Alberta, we advise that agriculture in WP2 be included to maintain consistency across the province.

How is it being measured? Using zonal statistics in ArcGIS the total area of each land use within the wetland complex contributing area was determined from the LULC maps described in Section 5.2.2. Percentage urban land use was then determined by summing the areas of urban, roads and rail together and dividing by the total area of the contributing area.

What is the condition? In 2010, 30 per cent of wetland complexes have greater than 50 per cent of their contributing area occupied by urban land use (Figure 10). The distribution of wetland complexes amongst metric scores is fairly even although there is a higher concentration of wetlands in 2010 with low urban influences (greater agricultural influences).

What is the trend? As expected for all years land use within wetland contributing areas is dominated by agriculture. This has resulted in the largest distribution of wetland complexes in the <20 per cent urban land use category. There has however been a significant expansion of urban areas within Shepard Slough over the 20 year time period. Figure 10 shows an increase in wetland complexes dominated by urban land use (1.0 metric score) over the trend period. This has resulted in an increase in the water purification value of wetlands as they are forced to treat poorer quality water.



Metric Score	0.1	0.5	1.0
Percent urban land use within wetland's contributing area	≤ 20%	20% to 50%	≥ 50%
1990 (Number, Percent)	36, 97%	0, 0%	1, 3%
2000 (Number, Percent)	82, 83%	7, 7%	10, 10%
2010 (Number, Percent)	42, 51%	16, 19%	25, 30%

FIGURE 10: Trends in frequency distribution of water purification scores for wetland assessment unit: WP2, pollutants within the wetland's contributing area.

5.3.1.3 WETLAND PURIFICATION METRIC 3 (WP3), POLLUTANT REMOVAL OPPORTUNITY

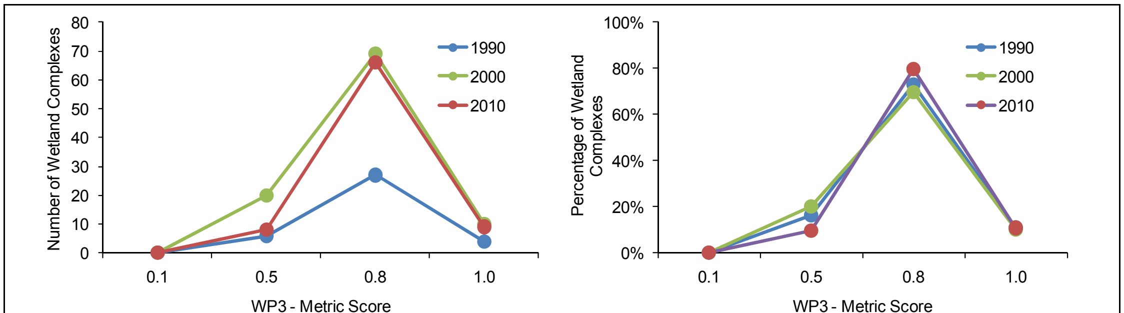
What is the metric? WP3 metric attempts to identify three key factors that affect the potential of a wetland to improve water quality. These are: (A) The majority (80%) of the wetland's contributing area is not forested or shrubland. The rationale is that contributing areas that are not dominated by dense forest or shrubland are likely to have increased sediment loads in runoff water. (B) Wetland is less than five per cent of its contributing area. It is understood that increased sediment and nutrient loads to wetlands increase with a decrease in the ratio of wetland area to wetland contributing area. (C) Wetlands upslope of the wetland comprise less than five per cent of the stream catchment. Where wetlands occur upslope of the wetland, runoff reaching the wetland will likely have already been treated by those wetlands upslope.

How is it being measured? The three elements of the metric were measured as follows: (A) the percent disturbed (urban and agriculture) land use within each wetland complex contributing area was determined from the LULC maps described in Section 5.2.2. All wetland complexes with a total percent disturbed area within the contributing area greater than 80 per cent were assigned a value of 1. All other wetland complexes were assigned a value of 0. (B) The wetland complex size defined for the WP1 metric was divided by the area of the wetland complex contributing area. All wetland complexes with a wetland area to contributing area ratio of less than 0.05 were assigned a value of 1. All other wetland complexes were assigned a value of 0. (C) The two major watersheds within Shepard Slough were defined by creating a specific contributing area from the Canadian Digital Elevation DEM. Two drainage outlets were identified (one in the north and one in the south), from the DEM and using Terrain Analysis Software (TAS), and the contributing areas for those drainage outlets were defined. Wetland complexes were then assigned to each major watershed based on their location. The elevation of each wetland complex was determined from the LiDAR DEM. For each wetland complex all wetlands with a higher elevation were determined and the area of those wetlands summed. This total area of wetlands upslope of each wetland complex was divided by the total area of wetlands within each wetland complexes respective major watershed.

All wetland complexes with less than five per cent of the total area of wetland supslope were given a value of 1. All other wetland complexes were assigned a value of 0. The metric score for each wetland complex was determined by summing the scores for (A), (B) and (C).

What is the condition? The majority (80 per cent) of wetland complexes in Shepard Slough in 2010 satisfy two of the elements of this metric (Figure 11). For WP3, the condition for the majority of wetland complexes is defined by the lack of natural cover and upslope wetlands within the contributing areas of the wetlands.

What is the trend? The long-term trend shows an increase in wetlands satisfying two of the elements of this metric. The percentage of wetlands for each year within each metric score does not change significantly throughout the period (Figure 11). This indicates that although wetlands defined by open water have increased, the distribution of those wetlands among the WP3 metric scores has not changed significantly. The trend shows no change in the pollutant removal opportunity of each wetland, although the number of wetlands performing that function increases.



Metric Score	**0.1**	**0.5**	**0.8**	**1.0**
Number of criteria that are true: **a) ≤ 20% of wetland's contributing area is forested or shrubland** **b) ≤ 5% of wetland's contributing area is wetland** **c) ≤ 5% of wetland's upslope stream watershed is wetland**	**None**	**One**	**Two**	**Three**
1990 (number, percent)	0, 0%	6, 16%	27, 73%	4, 11%
2000 (number, percent)	0, 0%	20, 20%	69, 70%	10, 10%
2010 (number, percent)	0, 0%	8, 10%	66, 80%	9, 10%

FIGURE 11: Trends in frequency distribution of water purification scores for wetland assessment unit: WP3, purification potential of wetland.

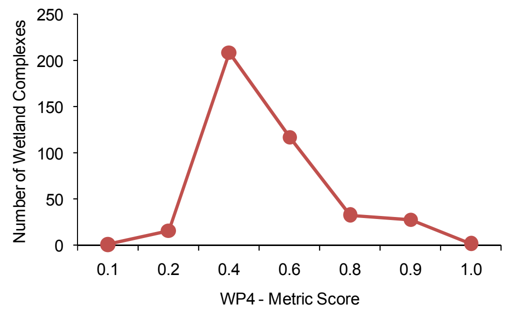
5.3.1.4 WETLAND PURIFICATION METRIC 4 (WP4), POLLUTANT TRANSPORT POTENTIAL

What is the metric? The metric is the mean slope of a wetland's contributing area. Steep slopes can lead to increased export of nutrients and sediment in runoff water. Wetland complexes with a higher mean slope within their contributing area will have a higher potential for receiving contaminated water and thus their value is higher.

How is it being measured? A slope layer is created in ArcGIS from the LiDAR DEM. Mean slope is calculated using zonal statistics based on the contributing areas of each wetland complex.

What is the condition? The majority (80 per cent) of wetland complexes have a low to moderate mean slope (2° to 4°) within the contributing area (Figure 12). Very few contributing areas are flat (<1°) or have steep (>10°) slopes within Shepard Slough.

What is the trend? As slope is a static metric there is no trend analysis.



Metric Score	0.1	0.2	0.4	0.6	0.8	0.9	1.0
Average or median slope (%) of the wetland's contributing area is:	≤ 1	1 to ≤ 2	2 to ≤ 3	3 to ≤ 4	4 to ≤ 5	5 to ≤ 10	≥ 10
All wetland complexes	1	16	209	117	33	28	2

FIGURE 12: Trends in frequency distribution of water purification scores for wetland assessment unit: WP4,purification demands on wetland.

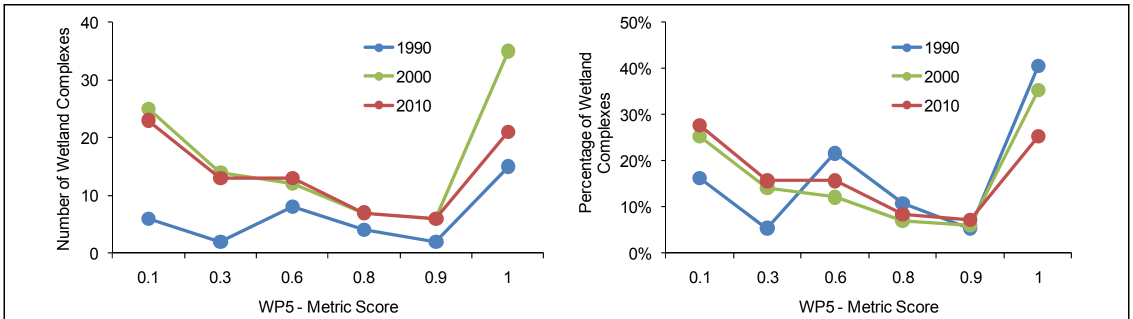
5.3.1.5 WETLAND PURIFICATION METRIC 5 (WP5), POTENTIAL SIGNIFICANCE

What is the metric? Riparian wetlands are defined by their distance from the nearest river or stream. Riparian wetlands have the opportunity to directly treat water before it flows into a river or stream that will convey water to downstream users. As a result riparian wetlands have a greater value to water purification than wetlands a long distance from streams and rivers.

How is it being measured? Distance is measured as the Euclidean distance from the boundary of a wetland complex to the nearest river or stream. Distance to the stream network based on flow distance as opposed to Euclidean distance would provide a better determination of the distance from the connection to a river or stream; however, time constraints prevented this further analysis.

What is the condition? This metric shows that there is a wide variation in the presence of riparian wetlands (Figure 13). In 2010, 28 per cent of wetland complexes are situated greater than 600m from the stream network whilst 25 per cent are within 50m. This suggests that Shepard Slough still maintains a high portion of riparian wetlands on the landscape.

What is the trend? Since 1990 there has been an increase in both the number and percentage of non-riparian wetlands (>600m from a stream or river) (Figure 13). This suggests that during wetter years (2000 and 2010) wetlands are becoming inundated in the upper reaches of the catchment further from the stream network whilst those closer to the stream network maintain open water and ultimately improved function during dryer periods.



Metric Score	0.1	0.3	0.6	0.8	0.9	1.0
Proximity (m) of wetlands to nearest stream	≥ 600	300 to ≤ 600	150 to ≤ 300	100 to ≤ 150	50 to ≤ 100	0 to ≤ 50
1990 (number, percent)	6, 16%	2, 5%	8, 22%	4, 11%	2, 5%	15, 41%
2000 (number, percent)	25, 25%	14, 14%	12, 12%	7, 7%	6, 6%	35, 35%
2010 (number, percent)	23, 28%	13, 16%	13, 16%	7, 8%	6, 7%	21, 25%

FIGURE 13: Trends in frequency distribution of water purification scores for wetland assessment unit: WP5, proximity of wetland to stream or river.

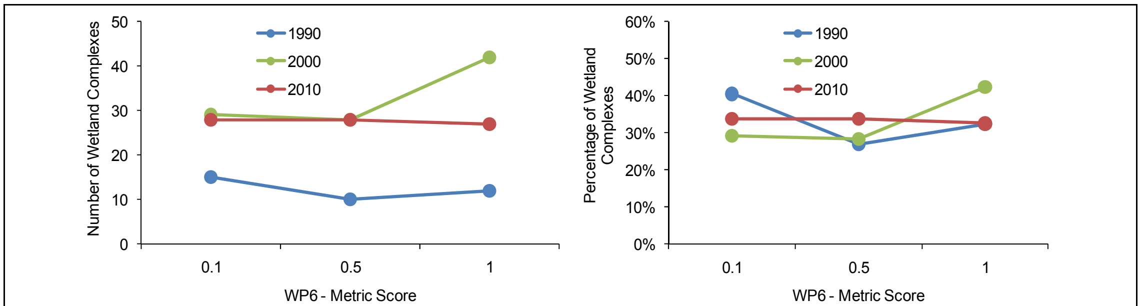
5.3.1.6 WETLAND PURIFICATION METRIC 6 (WP6), RECHARGE POTENTIAL

What is the metric*?* The position of a wetland based on elevation in the watershed. Wetlands situated in the upper third of the catchment (headwater wetlands) treat precipitation and runoff dominated water supply to first order streams. These wetlands can desynchronise flow and prevent the accumulation of nutrient and sediment inputs in overland flow. Higher elevation wetlands also have the potential to provide recharge water to the local groundwater system.

How is it being measured? Shepard Slough was divided into two major watersheds (north and south). The LiDAR DEM was clipped using the watershed boundaries. The watersheds were then divided into three regions (lower, middle and upper) based on area weighted elevation. Each clipped DEM was then reclassified into three groups using a 3 group quantile function in ArcGIS. This function creates three equal area (pixel) groups with increasing elevation ranges. Wetland complexes were classified into the three regions based on their maximum elevation.

What is the condition? In terms of area weighted elevation, wetland complexes are currently evenly distributed throughout Shepard Slough (Figure 14).

What is the trend? In 1990 during the driest year of the three years studied there is a greater percentage of wetlands in the lower regions of Shepard Slough. In comparison during 2000, the wettest year of the three, there are a greater percentage of wetlands in the upper regions of Shepard Slough (Figure 14). This indicates that natural (climatic) drivers have a strong influence on the elevation position of wetlands in Shepard Slough. Under drier climate scenarios resulting from climate change, the higher value (metric score = 1) headwater wetlands will be preferentially lost. Understanding the effects of climate variation on wetland position will be important for informing future decisions on wetland conservation.



Metric Score	0.1	0.5	1.0
Position (elevation) of wetland within the watershed	Bottom	Middle	Upper
1990 (number, percent)	15, 41%	10, 27%	12, 32%
2000 (number, percent)	29, 29%	28, 28%	42, 42%
2010 (number, percent)	28, 34%	28, 34%	27, 33%

FIGURE 14: Trends in frequency distribution of water purification scores for wetland assessment unit: WP6, position within wetland's stream watershed.

5.3.1.7 WETLAND PURIFICATION FUNCTION SCORE

The wetland Water Purification Score (WPS) was determined using the following formula:

$$WPS = \frac{(WP1 + WP2 + WP3 + WP4 + WP5 + WP6)}{6}$$

The wetland purification score ranges from 0 to 1.0 (it is the average of the wetland purification metrics WP 1 to 6). Equal weight was given to each water quality metric as no field-based assessment was available to develop and validate a model-based approach to integrate individual metric scores.

Figure 15 presents the percentage of wetland complexes within each WPS score. The majority (87 per cent) of wetland complexes within Shepard Slough have a medium wetland purification score (0.4 to 0.7) (Figure 15). No wetland falls in the lowest category (WPS = 0.1, 0.2) or the highest category (WPS = 1.0).

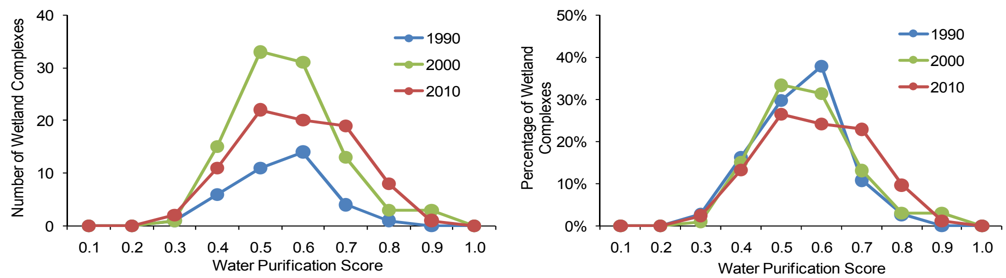
Figure 16 shows the absolute change in water purification scores for wetland complexes throughout the trend period. Where there are negative changes, i.e., where the wetland water purification has declined from 1990 to 2010, there has been a loss of wetland function related to water purification. This could be due to loss of wetland area. Where there are positive changes, i.e., where the wetland water purification has inclined from 1990 to 2010, there has been a gain of wetland function related to water purification. This could be either due to (1) gain of wetland area and/or (2) increase in the water purification function *or* increase in its importance.

Figure 16 shows a general increase in WPS from 1990 to 2010. This is primarily the result of incorporating wetlands that were not included in the 1990 wetland inventory. Those wetlands that show a reduction in WPS are the result of removal of the wetland following urbanization.

As wetlands are lost or degraded on the landscape, the remaining ones will have higher value with respect to purification potential. This should not be interpreted as an incentive to disturb wetlands, but rather a disincentive. With the loss of each wetland, it becomes more critical to protect the remaining ones. Of course, some wetlands will have higher value than others, and it is important to identify these before further development occurs to ensure they are protected.

In the future, the wetland purification scores could be improved in at least two ways. First, we could improve our understanding of the relationship between Stewart and Kantrud's (1979) wetland classes and water purification function. Given that we used a Landsat wetland inventory, we were not able to explore the relationship between wetland classes 1 to 5 and their relative water purification function. This is, however, an important question, that could be pursued using a combination of the City of Calgary's class 1 to 5 wetland inventory, and the application of either the Remote-Basic or Remote-Advanced wetland assessment approaches for water purification, with verification using the WESPUS site based wetland assessments completed on behalf of the Ecosystem Services Pilot Project.

Second, we could calibrate the relative wetland purification scores to actual wetland purification quantities, as sediment and nutrient removal data become available.



WPS	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
1990 (number, percent)	0, 0%	0, 0%	1, 3%	6, 16%	11, 30%	14, 38%	4, 11%	1, 3%	0, 0%	0, 0%
2000 (number, percent)	0, 0%	0, 0%	1, 1%	15, 16%	33, 33%	31, 31%	13, 13%	3, 3%	3, 3%	0, 0%
2010 (number, percent)	0, 0%	0, 0%	2, 2%	11, 13%	22, 27%	20, 24%	19, 23%	8, 10%	1, 1%	0, 0%

FIGURE 15: Trends in frequency distribution of aggregated water purification scores.

RECOMMENDATION #7:
Natural drivers cause substantial variation in wetland structure and function, and it is important to understand this natural variation so that accurate estimates of ecosystem services can be achieved. One could monitor this natural variation on an annual basis. Alternatively, one could use the maximum extent of wetlands based on climate normal (past 30 years) or some other reasonable climate period to estimate the maximum potential for ecosystem services related to water purification. **For future ecosystem service assessments, it is recommended that regional wetland assessments be designed to consider both *spatial* and *temporal* dynamics of wetland function.**

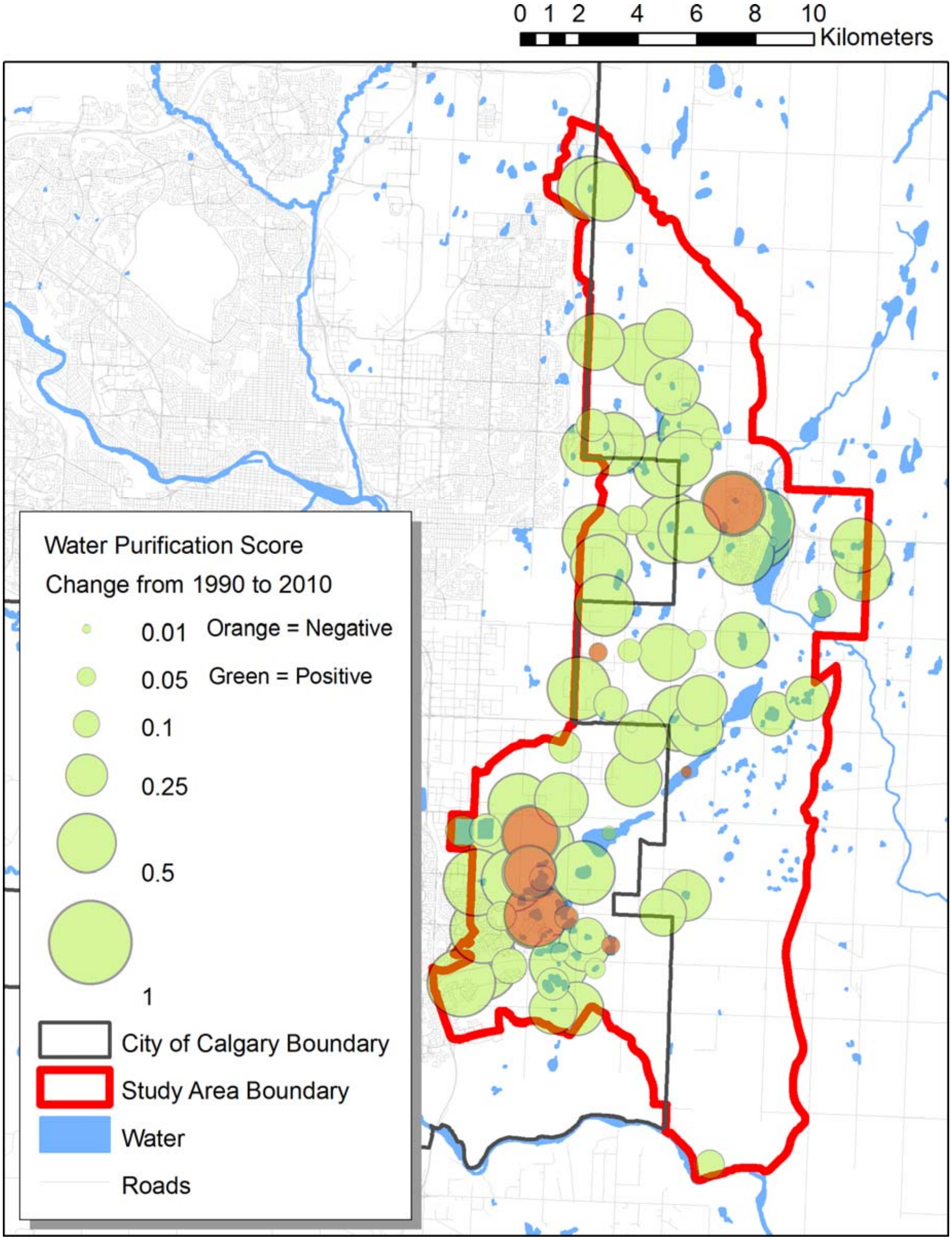


FIGURE 16: Change in wetland purification potential from historic condition (1990) to current condition (2010).

5.4 WETLAND WATER PURIFICATION BENEFITS

To determine the monetary worth of wetland water purification benefits a literature search of wetland ecosystem service assessments was undertaken. Kazmierczak (2001) provides a synthesis of wetland water purification valuations throughout the United States that were reported in published studies. The methods for determining wetland valuations varied, but were predominately based on cost savings from traditional water treatment options. Wetland type also varied and ranged from coastal marshes to forested swamps.

Figure 17 presents the distribution of 22 wetland water purification benefit figures that are synthesized by Kazmierczak (2001). To understand the full range of monetary wetland benefits three values were selected: \$50/ha, \$500/ha, and \$5,000/ha. The total benefit of wetlands for 1990, 2000 and 2010 is presented in Table 8. It is important to note that the figures used to determine the monetary worth of wetland benefit in this section are not intended to be a comprehensive assessment of the dollar value of wetlands within Shepard Slough. Rather, it is intended to complete the story of wetland water purification. Also, it is critical to understand the individual case studies that provide the benefit monetary worth in Figure 17. The upper limit is likely the most representative figure for wetland benefit evaluation as case studies in the literature are unlikely to be conducted on the best case wetland (WPS = 1.0). An appropriate benefit monetary worth would be one determined from actual water purification determined from field monitoring of nutrient and sediment retention in wetlands based on each individual WPS class (0.1 to 1.0).

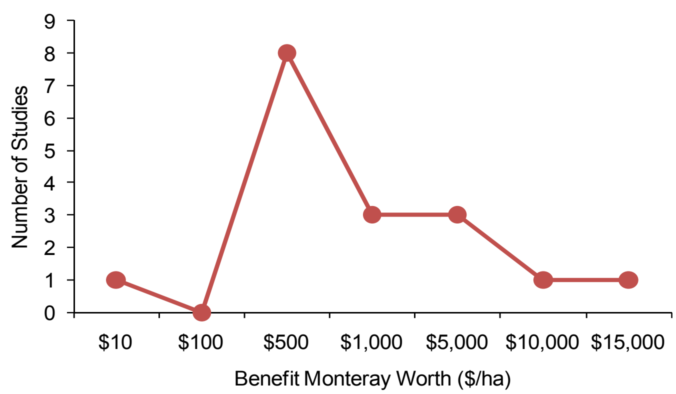


FIGURE 17: Year 2000 \$USD frequency distribution of published studies estimating economic benefit of wetlands for purification of water supplies (Kazmierczak 2001).

Current Benefits (2010) of Wetlands to water purification within Shepard Slough:
Depending on the unit benefit worth of wetland water purification the current total benefit of the 404 ha of wetlands in the Shepard Slough towards water purification ranges from \$13,396 (\$50/ha) to \$1,339,560 (\$5,000/ha), with an estimate based on the median worth (\$500/ha) of \$133,936.

Change in Benefits (difference between 1990, 2000, and 2010) of Wetlands within Shepard Slough:
There has been an overall increase of 21 per cent in wetland benefit to water purification of all wetlands within Shepard Slough from 1990 to 2010. There are two main drivers for this increase. The first and largest driver is the natural climate driver. This has resulted in an increase in wetland area from 1990 to 2010. The second driver is the human influence driver defined as an increase in urban areas within Shepard Slough from 1990 to 2010.

The increase in urban areas results in higher metric scores, which define the opportunity of a wetland to treat contaminated water (WP2, WP3).

The metric scores indicate that the benefit of wetlands for water purification is increasing in Shepard Slough. This is the result of both natural (wet years leading to increased open water area) and human (increase in urban areas leads to more pollutants) drivers. However, there is a cautionary note when the increase in inundated areas is the dominant driver in the increase of wetland benefits within Shepard Slough. As the wetland inventory is based on inundated areas only (and does not include saturated areas), there appears to be a climatically- driven increase in wetlands on the landscape which results in an inflation of wetland monetary benefits. In reality, this climatically-driven increase in wetlands would become much less (if not disappear altogether) if the saturated areas were included, and we would be able to focus on changes in wetland area caused by human activities. There is a need to develop a comprehensive time series of wetlands that reflect the true wetland boundary by including both inundated (current study) and saturated soils.

Recommendation #8:
For the Ecosystem Services Pilot Project, regional assessments for the ecosystem services provided by wetlands were done independently, considering one service at a time, and by different consultants. **For future ecosystem service assessments, consideration of the potential for interaction effects of ecosystem services is needed so that trade-offs among ecosystem services may be considered.**

TABLE 8: Wetland derived water purification benefits. To achieve the range of $/ha for the range of WPS values, the WPS value is multiplied by $50/ha, $500/ha, or $5,000/ha (from literature). This results in a lower $/ha cost for lower WPS values. For example, for a wetland with a WPS of 0.1 the $/ha cost is determined by multiplying the $500/ha by the WPS, 0.1 x $500 = $50/ha. This is then multiplied by the area of the wetland (ha) to determine the overall $ benefit of that wetland.

WPS	AREA (ha)			TOTAL WETLAND WORTH ($/year, with rates of $50, $500 or $5,000/ha)								
	1990	2000	2010	1990			2000			2010		
				$50/ha	$500/ha	$5000/ha	$50 ha	$500/ha	$5000/ha	$50/ha	$500/ha	$5000/ha
0.1	0	0	0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0.2	0	0	0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0.3	1	1	1	$14	$135	$1,350	$10	$108	$1,080	$13	$135	$1,350
0.4	1	25	17	$16	$162	$1,620	$493	$4,932	$49,320	$342.00	$3,420	$34,200
0.5	32	53	27	$792	$7,920	$79,200	$1,320	$13,207	$132,075	$684	$6,840	$68,400
0.6	53	129	60	$1,598	$15,984	$159,840	$3,855	$38,556	$385,560	$1,800	$18,009	$180,090
0.7	248	259	282	$8,681	$86,814	$868,140	$9,065	$90,657	$906,570	$9,878	$98,784	$987,840
0.8	0	2	15	$0	$0	$0	$75	$756	$7,560	$612	$6,120	$61,200
0.9	0	2	1	$0	$0	$0	$72	$729	$7,290	$64	$648	$6,480
1.0	0	0	0	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL	**335**	**469**	**404**	**$11,102**	**$111,015**	**$1,110,150**	**$14,895**	**$148,946**	**$1,489,455**	**$13,396**	**$133,956**	**$1,339,560**

6.0 CONCLUSIONS

Based on our implementation of the Regional-Basic wetland assessment approach at Shepard Slough in southern Alberta, for which metrics could be easily derived from GIS and remote sensing (RS) that were accessible at no cost, we make the following conclusions:

1. **Wetlands provide monetary benefits (via avoided water treatment costs).** An increase in monetary benefits of 21 per cent from 1990 to 2010 of 21% was observed. Specifically, depending on the published rate of natural purification benefit used, the dollar value increase ranged from $2,294 (based on $50/ha) to $229,410 ($5,000/ha). Lack of data on purification rates from water treatment facilities in the Shepard Slough precluded deriving estimates specific for the region; as these data become available, the monetary benefits could be easily calibrated to the region.

2. **Surprisingly, a major factor in the rise in wetland monetary benefits was natural drivers, with climatic conditions over the 20 year period that formed the basis of evaluation leading to an increase in wetlands on the Shepard Slough landscape (although it is possible that human modifications to the drainage system may have also led to an increase in wetlands).** Specifically, the average water purification score increased from 0.51 to 0.54, suggesting minor change in purification function of wetlands. However, the total wetland area changed from 335 ha to 404 ha, suggesting major change in the size of wetlands performing that purification function. Natural drivers of the number and area of wetlands on the landscape underscore the need to use a "proper" wetland inventory, that
3. (1) considers inundated and saturated conditions (as the inundated areas used in this study fluctuate widely in response to climatic conditions); and (2) establishes a reference condition that reflects the natural range of variation in wetlands on the landscape. Once these natural drivers are better considered in wetland assessments, more reasonable estimates of monetary benefits will be achieved.

4. **Plans reveal that future development within Shepard Slough reveal substantial changes in land use/land cover that will lead to more substantial changes in water purification scores.** If plans result in no net loss of wetlands, than wetland purification scores will increase, and their ability to naturally purify water increases (increased pollutant loads = increased opportunity to purify water, assuming the wetland purification capacity has not been exceeded). Alternatively, if plans result in a net loss of wetlands, depending on where the wetland is lost (e.g., upslope wetlands vs. downslope wetlands), an individual wetland's purification score may increase or decrease, but the regional wetland purification score will decrease.

The Regional-Basic wetland assessment approach served the needs of a demonstration of how to estimate water purification services provided by wetlands required over the time constraints of the ESPP project. However, the decision to use it as a demonstration is in no way an endorsement of this approach – scientific concerns include the fact that it does not represent some of the ecological processes that determine wetland purification functions (e.g., the sole metric for determining wetland-specific function is wetland area), it does not adequately represent water flow paths or processes, and it does not consider both spatial and temporal dynamics. Practical concerns include that it does not embrace emerging technologies that could result in more comprehensive assessments.

The Regional-Advanced wetland assessment approach is recommended for future considerations. Its conceptual underpinnings is based on the site-based wetland assessment for ecosystem services approach called WESPUS (Adamus 2011), thus benefitting from decades of science and practice in wetland assessments in the United States led by Dr. Paul Adamus. It benefits from a strong foundation of scientifically peer-reviewed studies specific to the prairie pothole regions typical of southern Alberta (i.e., it captures processes that dominate in the White Zone). However, it needs further investigation (and possible modification or adaptation of metrics) prior to its application to northern Alberta (i.e., it may not capture processes that dominate in the Green Zone). To adopt this approach the following (real or perceived) barriers need to be overcome:

1. **Implement effective knowledge management strategies.** There is a need to compile and coordinate the disparate data needed for ecosystem service assessments province-wide. A starting point is to expand the provincial GIS web portal (AltaLIS) to bring together all of the relevant datasets (WSC and research gauging stations, MSC meteorological data, field-based measurements, GIS and RS data) into a single, publicly accessible venue. Such a centralized database would encourage value-added cross-site comparisons and meta-experiments, greatly expanding knowledge generation, and increasing the incorporation of these resources into land management planning and operations. This centralized web portal should also be linked to federal datasets for ease of upscaling or downscaling of relevant data.

2. **Embrace emerging technologies.** There are terabytes of data being processed every day by many sensors; however, much of them are being discarded because there is no mandate or resources to archive all imagery. The Province of Alberta needs to support federal and international RS programs that are creating multi-decadal image datasets which will be vital for ecosystem service assessments now and in the future and needs to encourage government agencies to embrace these technologies and incorporate them into government activities.

3. **Continue and expand monitoring programs.** Even in this digital age of satellite sensors and distributed sensor networks, field based measurements are still crucial. For example, Alberta like all other areas of Canada has lost many meteorological and water survey stations since the golden age of hydrometric data collection in the 1970s. This trend of closures, however, needs to be stopped and reversed. Existing water monitoring stations need to be maintained because many of the critical questions, especially those related to climate change, that can only be addressed by analyzing long-term datasets. Furthermore, monitoring network needs to be expanded to stations targeting meso-scale watersheds (like that of Shepard Slough), whose size is more compatible with management activities. The Province of Alberta should take the lead in developing a provincially coordinated ecohydrology monitoring network, and build partnerships with universities, industries, municipal governments, and other stakeholders including the public, to increase monitoring the environment.

4. **Transfer of technologies and techniques to end users.** Even if the best of data, tools and models are available, they will languish if there are not qualified people to use them. In an era of increasing water insecurity, it is essential to promote and enhance interdisciplinary training in the water resource sciences and applications. We need enhanced knowledge transfer from product developers in digital terrain

analysis, remote sensing, and distributed simulation modeling, to ecosystem scientists and managers. It is important that managers and scientists work together to better understand the complexity of the management questions as well as the potential solutions. The best way for this learning to occur is through the use of Web 2.0 technologies where information flows both ways and “end-users” become “engaged-users” of GIS and RS techniques.

This was a valuable exercise, even if the sole benefit was to get people to start thinking of wetlands as valuable natural assets for the ecosystem services that they provide.

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9.0 APPENDICES

A1. COMPARISON OF METHODS FOR WETLAND INVENTORIES

TABLE A1.1: Comparison of different methods for wetland inventories available for ecosystem service assessments of the Shepard Slough.

	STATIC METHODS				DYNAMIC METHODS	
	Airborne Remote Sensing Source				Satellite Remote Sensing Source	
Name/ Method	Calgary-Rocky View County Intermunicipal Development Plan (IDP)	DU Wetland Inventory	Probabilistic shape analysis (Creed Probability Method)	GIS-based wet area object recognition	GIS-based open water mapping	GIS-based surface water and saturation classification
Relative cost	$$$$$	$$$$$	$	$$$	$	$$$
Manual or automated	Manual	Manual	Automated	Automated	Automated	Automated
Wetland description	Saturated + inundated area map (class 1 to 5 wetlands)	Saturated + inundated area map (dugout, headland, marsh, open water)	Saturated + inundated area potential map	Saturated + inundated area map	Inundated area map	Saturated + inundated area probability map
Wetland area threshold	> 0.001 ha	> 0.001 ha	> 0.01 ha	> 0.001 ha	> 0.1 ha (Landsat) > 0.01 ha (SPOT)	> 0.1 ha
Data Source	Air photos	Air photos	LiDAR bare earth DEM	Air photos	Landsat/SPOT	Landsat/SPOT + ERS/Radarsat-1/ASAR SAR
Data Provider	City of Calgary	GOA	GOA	GOA (historic) City of Calgary (current)	USGS (Landsat) ATIC (SPOT)	USGS (Landsat) ATIC (SPOT) ASF (ERS SAR) MDA (Radarsat-1 SAR) ESA (ASAR SAR)
Spatial resolution	30 cm grid	1:30000	5 meter grid	1:30000 – 1:70000 (historic) 30 cm grid (current)	30 meter grid (Landsat) 2.5 – 20 meter grid (SPOT)	25 meter grid
Temporal resolution	2008	1965 2005 growing season	Long-term potential	1947 – present	1984 – present (Landsat) 1992 – present (SPOT)	1992 – present
Coverage	Partial	Complete	Complete	Complete	Complete	Complete

Acronym Definitions:

ATIC: Alberta Terrestrial Imaging Centre (Lethbridge)
USGS: United States Geological Survey
GOA: Government of Alberta
ASF: Alaska Satellite Facility
MDA: MacDonald, Dettwiler and Associates Ltd.
ESA: European Space Agency

A2. COMPARISON OF METHODS FOR LAND USE/ LAND COVER MAPS

TABLE A2.1: Comparison of Land Use/ Land Cover (LU/LC) maps available for ecosystem service assessments of the Shepard Slough.

	PUBLICLY AVAILABLE LULC				GIS & RS DERIVED LULC	
Name	Crop type mapping in the Prairies 2009	Grassland Vegetation Inventory (GVI)	Intermunicipal Development Plan (IDP)	GOA Vector Layers	LANDSAT TM	SPOT
Number of LULC classes	22	32	11	3	Dependant on classification	Dependant on classification
Date range	2000 and 2009	2009	2008	Lakes and Rivers = 2004, Roads = 2008, Rail = 2007	1985 to 2010	
Spatial resolution	56m	5m	30cm aerial photo	1m	30m	5m
Spatial coverage	Complete	Complete	Incomplete	Complete	Complete	Complete
Data provider	National Land and Water Information Service	Alberta Sustainable Resource Development	City of Calgary and Rocky View County	Alberta Sustainable Resource Development	United States Geological Survey	
Pros	Complete coverage of Shepard Slough	Complete coverage of the Shepard Slough. Accurate coverage of urban class for 2009	High resolution provides greatest definition of rare classes such as forest and shrub land	Provides clear delineation of narrow linear features	Time series available	Time series available
Cons	Urban class coverage is not consistent with the 2009 LANDSAT TM urban coverage. Poor delineation of roads, rail, lakes, and rivers	No forest or shrubland classification	Incomplete coverage of Shepard Slough. Higher resolution than other LULCs	No temporal variation captured	Non-ground-truthed classification	Data not available within project timeline

To provide a LULC that covers the entire Shepard Slough and identifies each of the key classes a composite of specific layers from LULC's described in Table A2 was completed. The Crop type mapping in the Prairies 2009 was chosen as the base layer for the LULC because it provided complete coverage of the Shepard Slough in terms of agriculture and natural (forest and shrubland) classes. Although the LULC was completed for 2009 the urban class is severely underestimated when compared with urban areas identified in the 2010 LANDSAT TM image. To overcome the underestimation of urban areas the urban class defined in the Grassland Vegetation Inventory was overlain on the base layer. The urban class closely matches the urban areas visible in the 2010 LANDSAT TM image. The base layer classifies the canal infrastructure as urban land use. To define the canal separately the canal features defined in the GVI were extracted and overlain on the base layer. Due to the spatial resolution of the base layer (56m) finer features such as roads, rail, lakes and streams are often not present in the LULC. To overcome this the vector layers for these classes available from the Government of Alberta were rasterised and expanded where necessary (roads expanded from 1m to 15m wide, Rail expanded from 1m to 10m wide). Expansion was based on comparison with the 2010 LANDSAT TM image. Once completed these layers were overlain on the base layer. Wetlands derived from the 2010

LANDSAT TM image using a threshold of 20 on Band 3 were also overlain on the base layer to provide consistency with the wetland inventory developed for the ESPP.

A3: MAPS OF WATER PURIFICATION METRICS 1 TO 6 AND THE INTEGRATED WATER PURIFICATION SCORE

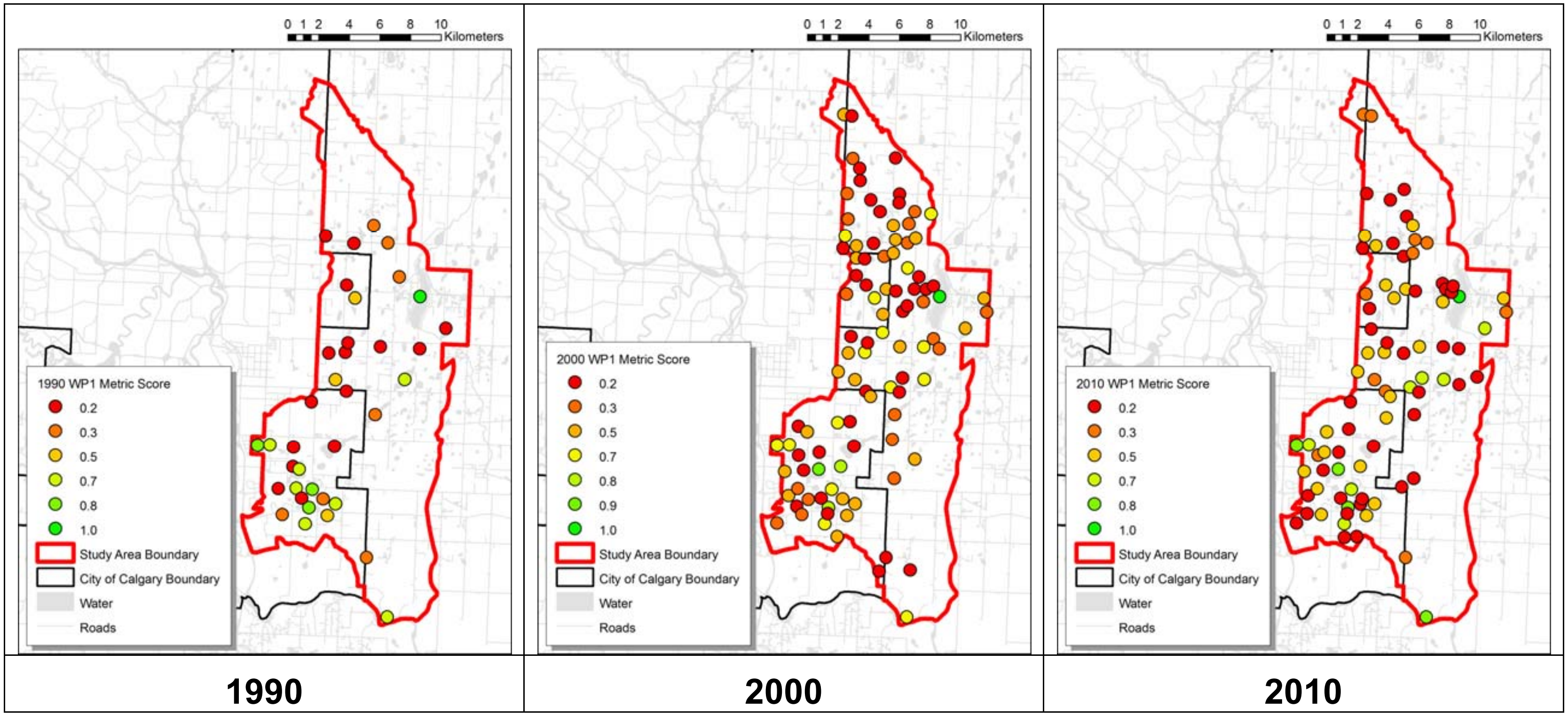


Figure A3.1: WP1 metric scores for wetlands in Shepard Slough

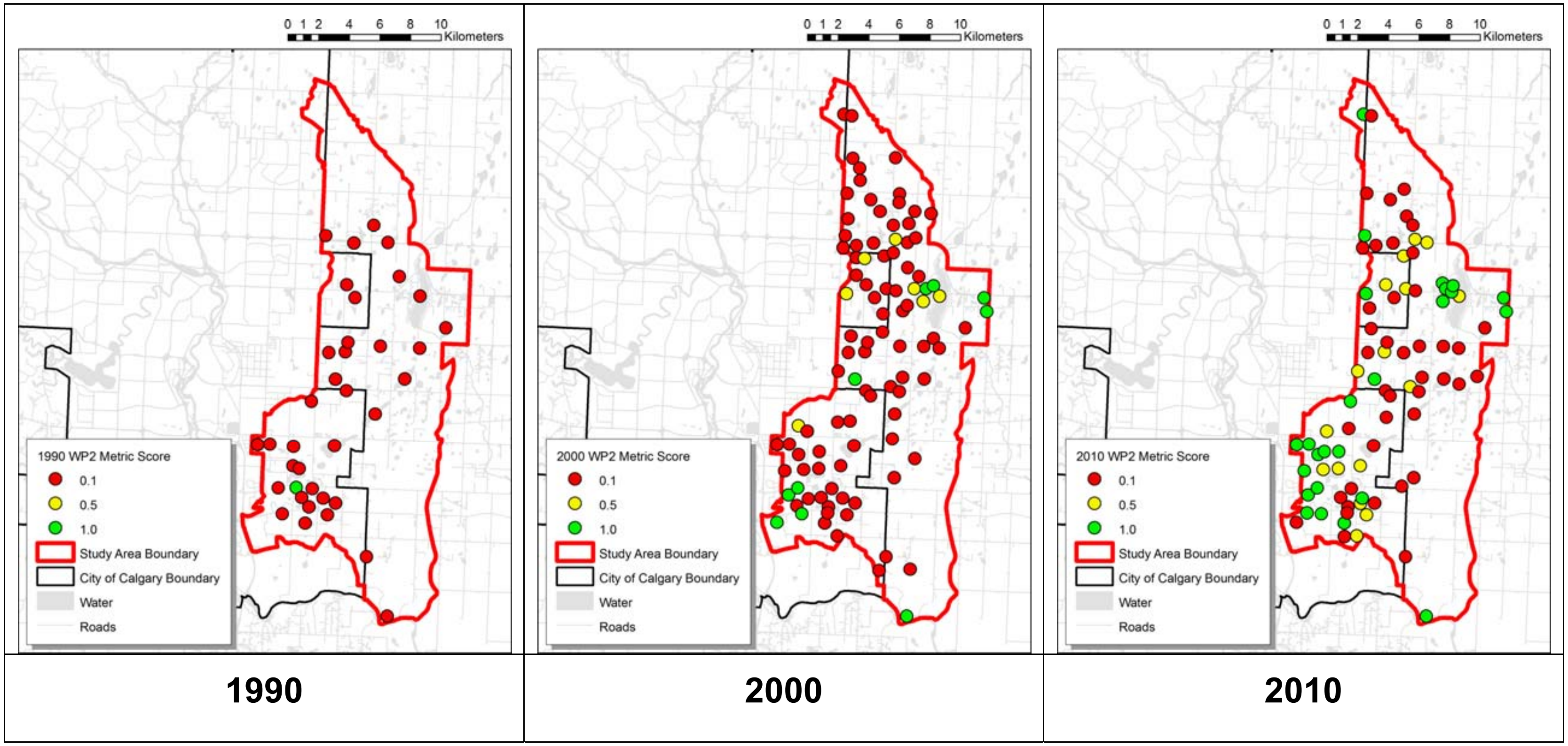


Figure A3.2: WP2 metric scores for wetlands in Shepard Slough

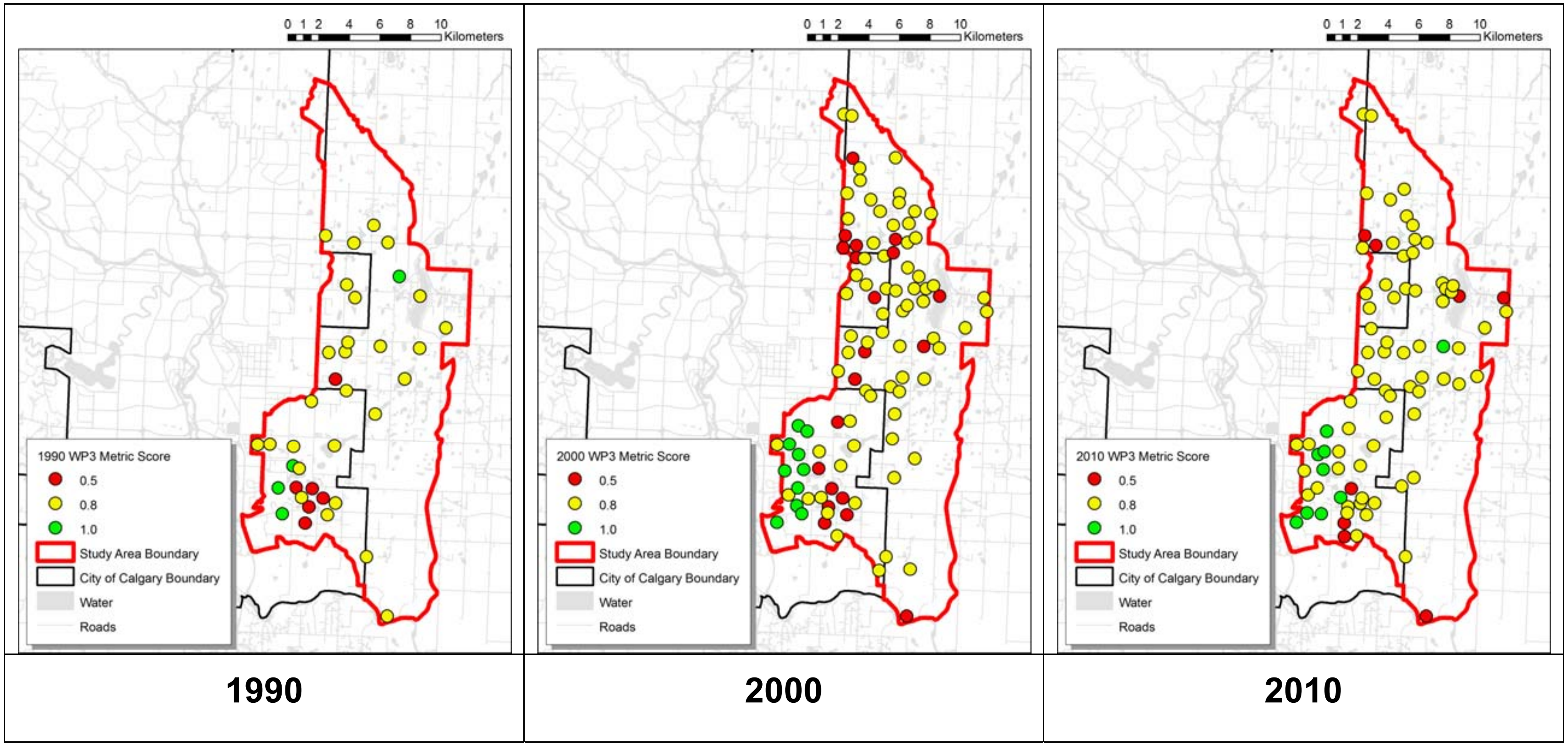
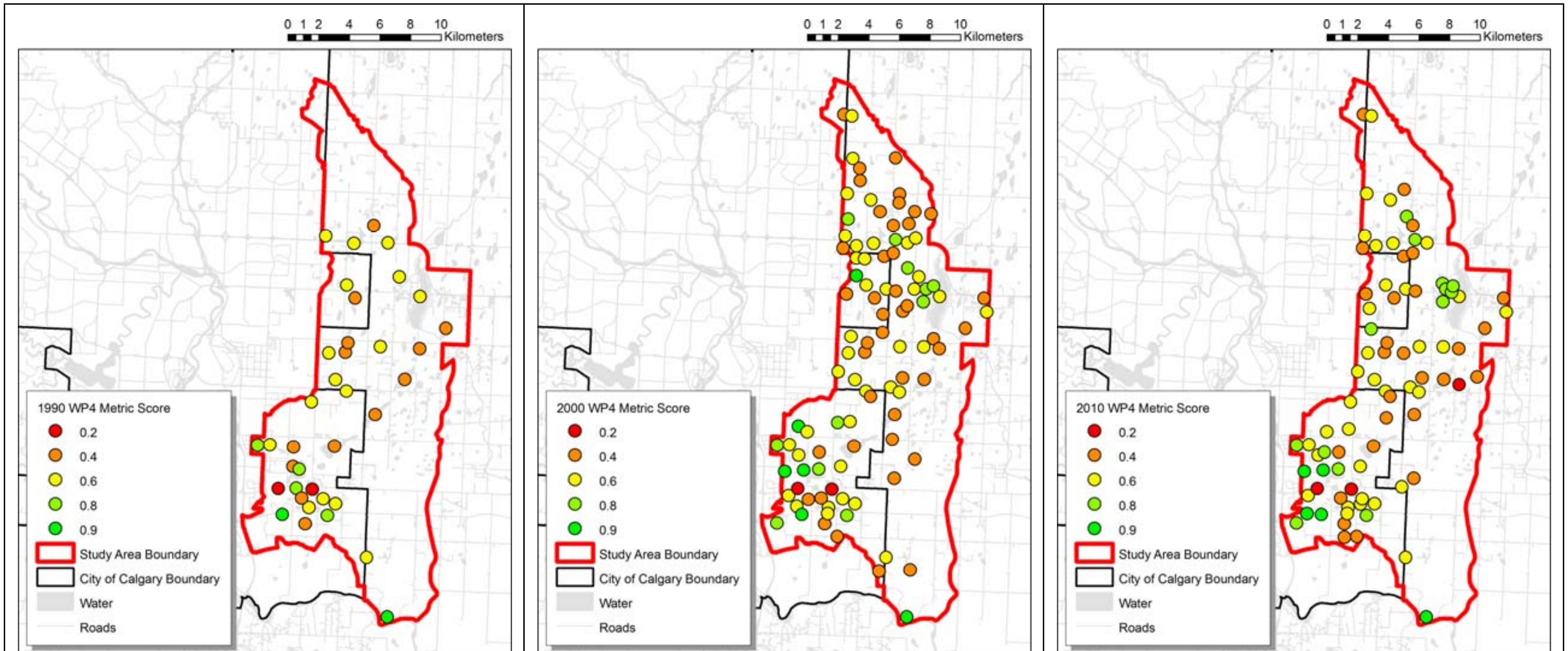


Figure A3.3: WP3 metric scores for wetlands in Shepard Slough



1990	2000	2010

Figure A3.4: WP4 metric scores for wetlands in Shepard Slough

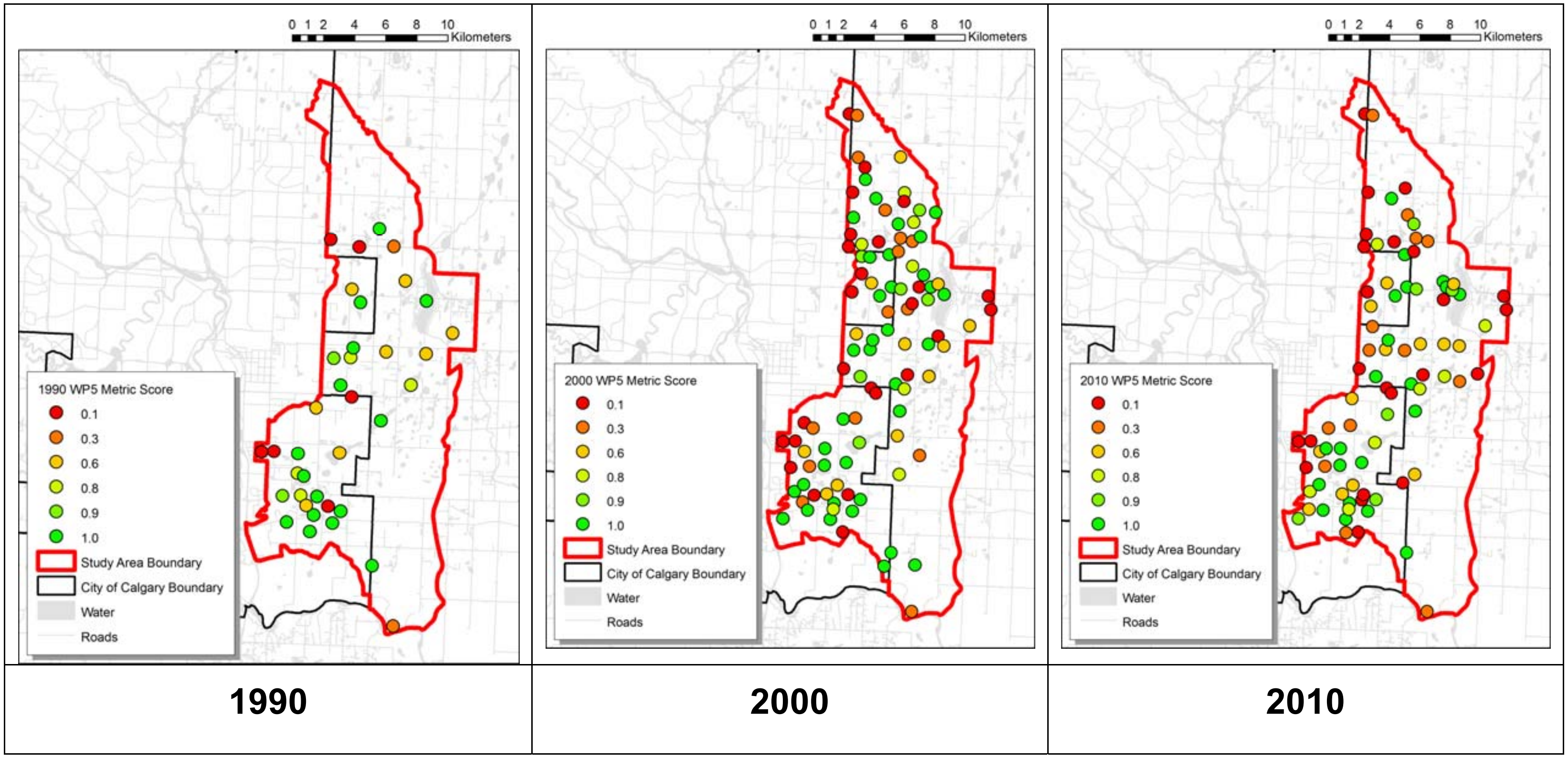


Figure A3.5: WP5 metric scores for wetlands in Shepard Slough

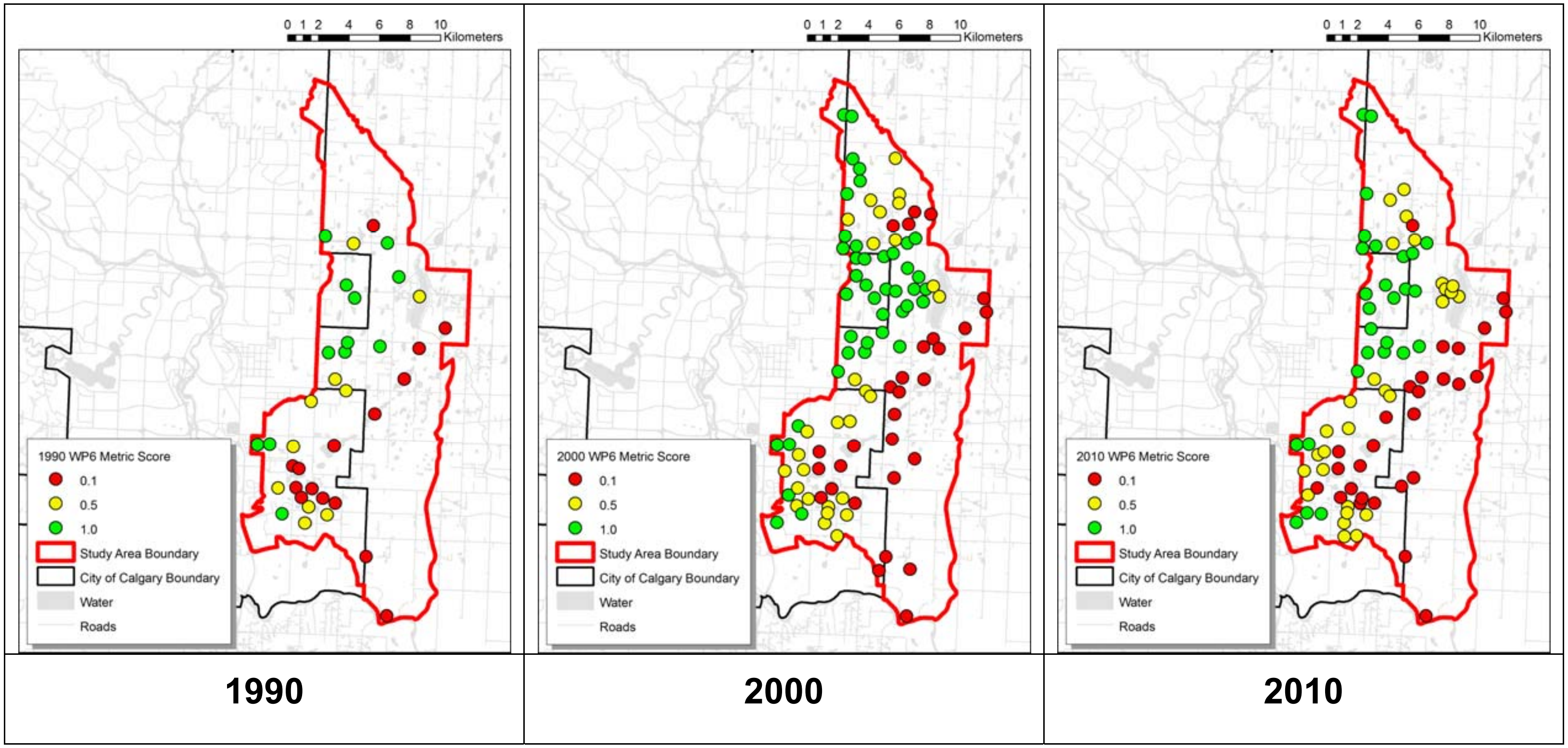


Figure A3.6: WP6 metric scores for wetlands in Shepard Slough

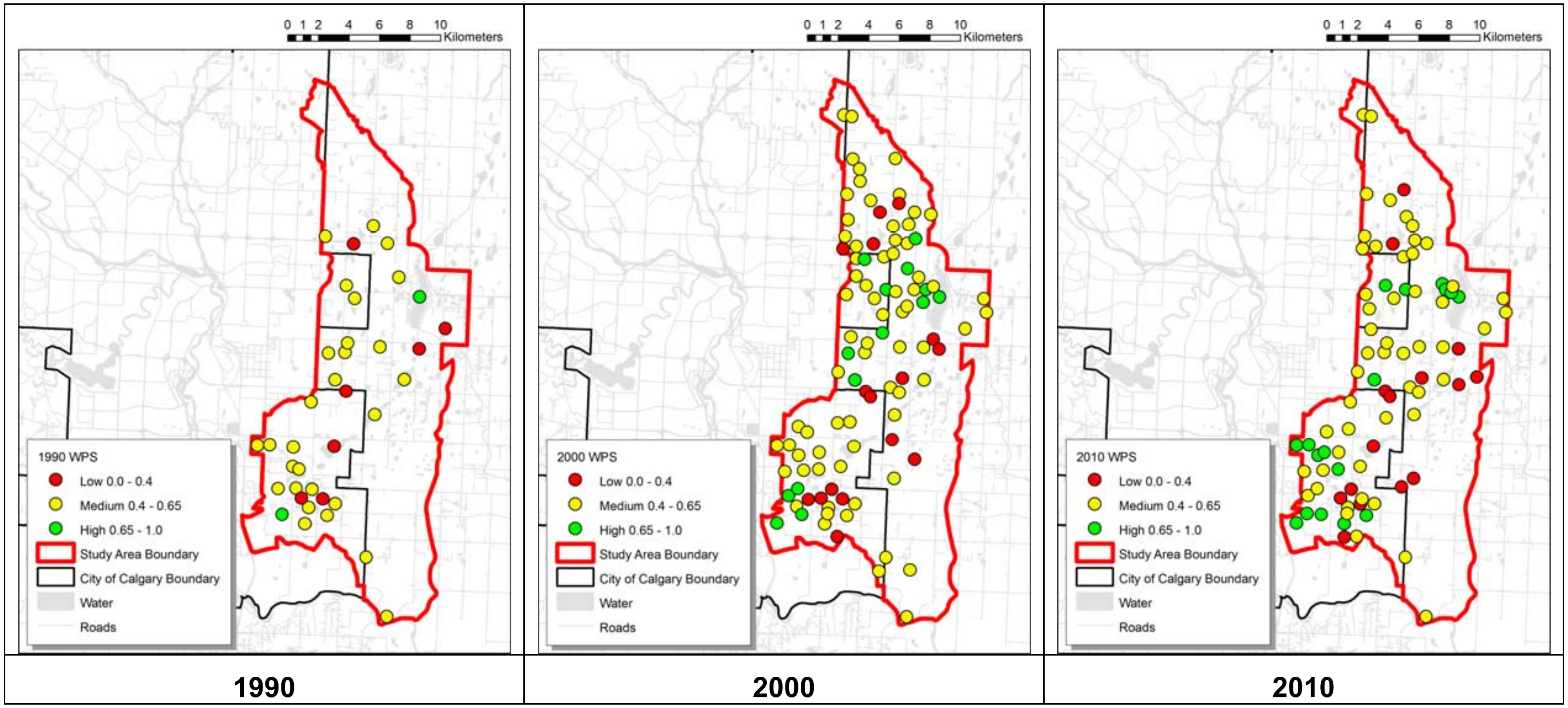


Figure A3.7: Water purification scores (WPS) wetlands in Shepard Slough

A4: DATA FOR WATER PURIFICATION METRICS 1 TO 6 AND THE INTEGRATED WATER PURIFICATION SCORE

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
1																									$5,000			
2	15.1	9.5	13.4	0.8	0.7	0.8	0.1	0.1	1	0.8	0.8	0.8	0.8	0.8	0.8	0.1	0.1	0.1	1	1	1	0.600	0.583	0.750	$5,000	$45,360	$27,563	$50,288
3		0.9	0.2		0.3	0.2		1	0.1		1	1		0.8	0.8		1	0.9		1	1		0.850	0.667	$5,000		$3,825	$600
4																												
5																												
6																												
7		1.3	1.4		0.5	0.5		0.1	1		1	0.8		0.9	0.9		0.1	0.1		0.5	0.5		0.517	0.633	$5,000		$3,255	$4,275
8																												
9																												
10		1.7	0.4		0.5	0.2		1	1		0.8	0.8		0.6	0.6		1	0.8		1	0.5		0.817	0.650	$5,000		$6,983	$1,170
11	6.8	4.6	5.8	0.7	0.7	0.7	0.1	0.1	1	0.8	1	0.8	0.6	0.6	0.6	0.1	0.1	0.1	1	1	1	0.550	0.583	0.700	$5,000	$18,810	$13,388	$20,160
12			0.3			0.2			1			1			0.9			0.6			1			0.783	$5,000			$1,058
13																												
14																												
15																												
16		0.1			0.2			0.5			1			0.9			0.1			1			0.617		$5,000		$ 278	
17	0.1	0.8	1.9	0.2	0.3	0.5	0.1	1	1	1	1	0.8	0.2	0.2	0.2	0.9	1	1	0.5	0.5	0.1	0.483	0.667	0.600	$5,000	$ 218	$2,700	$5,670
18		0.1			0.2			0.1			1			0.6			0.3			0.5			0.450		$5,000		$203	
19		0.2	0.6		0.2	0.3		0.1	1		1	1		0.6	0.6		0.6	0.6		0.5	0.5		0.500	0.667	$5,000		$450	$2,100
20																												
21																												
22																												
23		0.2	0.3		0.2	0.2		0.1	0.5		1	1		0.9	0.9		0.3	0.3		0.5	0.5		0.500	0.567	$5,000		$450	$765
24	0.5	0.7	1.4	0.3	0.3	0.5	0.1	1	1	1	1	1	0.9	0.9	0.9	1	1	1	1	1	1	0.717	0.867	0.900	$5,000	$1,935	$3,120	$6,480
25																												
26			1.6			0.5			1			1			0.8			1			0.5			0.800	$5,000			$6,480
27		1.4	3.5		0.5	0.5		0.1	0.5		1	1		0.6	0.6		0.3	0.3		0.5	0.5		0.500	0.567	$5,000		$3,600	$9,945
28																												
29																												
30																												
31		1.0			0.3			0.1			0.8			0.4			0.1			0.5			0.367		$5,000		$1,815	
32																												
33																												

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
34																												
35																												
36	0.1			0.2			0.1			1			0.4			0.8			0.1			0.433			$5,000	$195		
37	9.6	34.4	16.9	0.7	0.9	0.8	0.1	0.1	0.5	0.8	0.5	0.8	0.8	0.8	0.8	1	1	1	0.1	0.1	0.1	0.583	0.567	0.667	$5,000	$28,088	$97,410	$56,400
38	0.1			0.2			0.1			0.8			0.4			1			0.5			0.500			$5,000	$225		
39	4.3			0.7			1			0.5			0.8			0.8			0.1			0.650			$5,000	$14,040		
40																												
41																												
42	13.3	15.7	12.3	0.8	0.8	0.8	0.1	0.1	0.1	0.5	0.5	0.8	0.6	0.6	0.6	1	1	1	0.5	0.5	0.5	0.583	0.583	0.633	$5,000	$38,850	$45,675	$39,045
43																												
44																												
45	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.8	0.8	1	0.4	0.4	0.4	0.6	0.6	0.6	0.1	0.1	0.1	0.367	0.367	0.400	$5,000	$165	$165	$180
46																												
47		0.2	0.2		0.2	0.2		0.1	1		0.8	0.8		0.4	0.4		1	1		0.1	0.1		0.433	0.583	$5,000		$390	$525
48																												
49	4.1	6.4	6.3	0.7	0.7	0.7	0.1	0.1	1	0.5	0.5	0.5	0.4	0.4	0.4	1	1	1	0.5	0.5	0.5	0.533	0.533	0.683	$5,000	$10,800	$17,040	$21,525
50																												
51																												
52																												
53			0.3			0.2			0.1			0.5			0.4			0.3			0.5			0.333	$5,000			$450
54																												
55	12.3	7.6	5.5	0.8	0.7	0.7	0.1	0.1	0.1	0.5	0.5	0.5	0.2	0.2	0.2	1	0.6	0.6	0.1	0.1	0.1	0.450	0.367	0.367	$5,000	$27,743	$13,860	$10,065
56		0.1	0.1		0.2	0.2		0.1	0.1		0.8	0.8		0.6	0.6		0.8	0.8		0.5	0.5		0.500	0.500	$5,000		$225	$225
57			0.2			0.2			0.1			0.8			0.6			0.3			0.5			0.417	$5,000			$375
58	0.2		0.1	0.2		0.2	0.1		1	0.8		0.8	0.6		0.6	0.6		0.6	0.5		0.5	0.467		0.617	$5,000	$420		$278
59																												
60																												
61																												
62																												
63	0.2	0.3	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.8	0.8	0.8	0.4	0.4	0.4	0.6	0.9	0.8	0.1	0.1	0.1	0.367	0.417	0.400	$5,000	$330	$563	$180
64																												
65																												
66																												
67																												

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
68		4.2			0.7			0.1			0.5			0.8			1			0.5			0.600		$5,000		$12,690	
69		12.1	3.5		0.8	0.5		0.1	0.5		0.8	0.8		0.6	0.6		1	1		0.1	0.1		0.567	0.583	$5,000		$34,170	$10,238
70		1.1	0.1		0.5	0.2		0.1	0.5		0.8	0.8		0.4	0.4		0.1	0.1		0.5	0.5		0.400	0.417	$5,000		$2,160	$188
71		1.6	1.2		0.5	0.5		0.1	0.5		0.8	0.8		0.6	0.6		0.1	0.1		1	1		0.517	0.583	$5,000		$4,185	$3,413
72																												
73																												
74																												
75																												
76																												
77			0.1			0.2			0.5			0.8			0.6			0.1			0.1			0.383	$5,000			$173
78																												
79	0.9	1.5	0.2	0.3	0.5	0.2	0.1	0.1	1	0.5	0.5	0.8	0.6	0.6	0.6	0.1	0.1	0.1	0.1	0.5	0.1	0.283	0.383	0.467	$5,000	$1,275	$2,933	$420
80																												
81		0.5	0.1		0.2	0.2		0.1	0.1		0.5	0.8		0.4	0.4		0.1	0.1		1	1		0.383	0.433	$5,000		$863	$195
82																												
83		1.3	0.8		0.5	0.3		0.1	1		0.8	0.8		0.4	0.4		0.1	0.1		1	1		0.483	0.600	$5,000		$3,045	$2,430
84																												
85	0.1	4.1	2.7	0.2	0.7	0.5	0.1	0.1	1	0.8	0.5	0.5	0.6	0.6	0.6	0.1	0.1	0.1	1	1	1	0.467	0.500	0.617	$5,000	$210	$10,350	$8,325
86																												
87																												
88																												
89		0.9	0.7		0.3	0.3		0.5	1		0.8	0.8		0.4	0.4		0.1	0.1		1	1		0.517	0.600	$5,000		$2,325	$2,160
90	1.1	2.9	1.9	0.5	0.5	0.5	0.1	0.1	0.5	0.8	0.5	0.8	0.8	0.8	0.8	1	1	1	0.5	0.5	0.5	0.617	0.567	0.683	$5,000	$3,330	$8,160	$6,458
91		0.5	0.5		0.3	0.2		0.1	0.1		0.8	0.8		0.6	0.6		0.1	0.1		1	1		0.483	0.467	$5,000		$1,305	$1,050
92	0.3	1.2	2.5	0.2	0.5	0.5	0.1	0.1	0.1	0.8	0.8	0.8	0.6	0.6	0.6	0.9	1	0.3	1	1	1	0.600	0.667	0.550	$5,000	$810	$3,900	$6,930
93																												
94																												
95																												
96		0.7			0.3			0.1			0.8			0.8			1			0.5			0.583		$5,000		$2,100	
97																												
98			0.1			0.2			0.1			0.8			0.6			0.6			1			0.550	$5,000			$248
99	1.3	2.3	0.9	0.5	0.5	0.3	0.1	1	1	0.5	0.5	0.8	0.6	0.6	0.6	1	0.9	1	0.5	0.5	0.5	0.533	0.667	0.700	$5,000	$3,360	$7,500	$3,150
100		0.4			0.2			0.1			0.8			0.6			0.3			0.5			0.417		$5,000		$750	
101		0.5			0.2			0.1			0.8			0.6			0.6			1			0.550		$5,000		$1,238	

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
102																												
103		0.8			0.3			0.1			0.5			0.6			0.3			1			0.467		$5,000		$1,890	
104		0.5	0.6		0.2	0.3		0.1	0.1		0.8	0.8		0.6	0.6		0.3	0.3		1	1		0.500	0.517	$5,000		$1,125	$1,628
105																												
106																												
107		2.2	2.1		0.5	0.5		0.1	0.1		0.5	0.5		0.6	0.6		0.8	0.8		1	1		0.583	0.583	$5,000		$6,300	$6,038
108																												
109			0.2			0.2			0.1			0.8			0.8			0.3			1			0.533	$5,000			$480
110																												
111																												
112																												
113																												
114	4.1	1.7	2.0	0.7	0.5	0.5	0.1	0.1	0.1	0.8	0.8	0.8	0.6	0.6	0.6	1	1	0.9	0.1	0.1	0.1	0.550	0.517	0.500	$5,000	$11,385	$4,418	$4,950
115																												
116																												
117																												
118																												
119																												
120																												
121		3.1			0.5			0.1			0.5			0.6			0.9			1			0.600		$5,000		$9,180	
122																												
123																												
124																												
125																												
126		0.4			0.2			0.1			0.8			0.9			0.1			1			0.517		$5,000		$930	
127																												
128																												
129																												
130																												
131																												
132																												
133																												
134																												
135																												

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
136		0.4			0.2			0.1			0.8			0.4			0.1			1			0.433		$5,000		$780	
137		0.4			0.2			0.1			0.8			0.4			1			1			0.583		$5,000		$1,050	
138																												
139																												
140																												
141																												
142																												
143	0.4	9.5	1.7	0.2	0.7	0.5	0.1	0.1	0.5	0.8	0.5	0.8	0.4	0.4	0.4	0.8	1	0.6	1	1	1	0.550	0.617	0.633	$5,000	$990	$29,138	$5,415
144																												
145																												
146	0.1	0.3	2.0	0.2	0.2	0.5	0.1	0.1	0.5	0.8	0.8	0.8	0.6	0.6	0.6	0.6	0.6	0.6	1	1	1	0.550	0.550	0.667	$5,000	$248	$743	$6,600
147																												
148																												
149		0.1			0.2			0.5			0.8			0.6			1			1			0.683		$5,000		$308	
150			2.5			0.5			0.1			0.8			0.4			0.9			0.1			0.467	$5,000			$5,880
151	0.1	0.4	0.7	0.2	0.2	0.3	0.1	0.1	0.1	0.8	0.8	0.8	0.6	0.6	0.6	0.1	0.1	0.1	0.5	0.5	0.5	0.383	0.383	0.400	$5,000	$173	$690	$1,440
152																												
153																												
154																												
155																												
156																												
157																												
158																												
159	0.2	0.3	0.5	0.2	0.2	0.2	0.1	0.1	0.1	0.8	0.8	0.8	0.4	0.4	0.4	1	1	1	1	1	1	0.583	0.583	0.583	$5,000	$525	$788	$1,313
160																												
161																												
162		2.3	1.8		0.5	0.5		0.1	0.1		0.8	0.8		0.4	0.4		0.1	0.1		0.5	0.5		0.400	0.400	$5,000		$4,680	$3,600
163																												
164																												
165																												
166																												
167		0.3	0.5		0.2	0.2		0.1	0.1		0.8	0.8		0.6	0.6		1	1		0.5	0.5		0.533	0.533	$5,000		$720	$1,200
168																												
169	1.3	7.3	2.4	0.5	0.7	0.5	0.1	0.1	0.1	0.8	0.5	0.8	0.4	0.4	0.4	1	1	1	1	1	1	0.633	0.617	0.633	$5,000	$3,990	$22,478	$7,695

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
170																												
171																												
172	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.8	0.8	0.8	0.6	0.6	0.6	0.1	0.1	0.1	0.5	0.5	0.5	0.383	0.383	0.383	$5,000	$173	$173	$173
173																												
174																												
175																												
176																												
177																												
178																												
179																												
180																												
181																												
182																												
183																												
184		0.5			0.2			0.1			0.8			0.4			1			0.1			0.433		$5,000		$975	
185																												
186																												
187		5.4			0.7			0.1			0.8			0.4			1			1			0.667		$5,000		$18,000	
188																												
189		0.1			0.2			0.1			0.8			0.4			0.3			0.5			0.383		$5,000		$173	
190																												
191	1.0	0.8	0.1	0.3	0.3	0.2	0.1	0.1	0.1	0.8	0.8	0.8	0.4	0.4	0.4	1	1	1	0.1	0.1	0.1	0.450	0.450	0.433	$5,000	$2,228	$1,823	$195
192																												
193																												
194																												
195			0.1			0.2			0.1			0.8			0.6			0.1			0.1			0.317	$5,000			$143
196																												
197			0.1			0.2			0.1			0.8			0.4			0.1			0.5			0.350	$5,000			$158
198																												
199		1.1			0.5			0.1			0.8			0.4			0.3			1			0.517		$5,000		$2,790	
200			0.5			0.2			0.1			0.8			0.4			0.3			1			0.467	$5,000			$1,050
201																												
202																												
203																												

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
204																												
205																												
206		0.8	0.5		0.3	0.2		0.1	0.5		0.8	0.8		0.4	0.4		1	1		1	1		0.600	0.650	$5,000		$2,430	$1,463
207																												
208																												
209																												
210		1.1	1.4		0.5	0.5		0.1	0.5		0.8	0.8		0.6	0.6		1	1		1	1		0.667	0.733	$5,000		$3,600	$4,950
211		9.1	6.3		0.7	0.7		0.1	0.5		0.8	0.8		0.6	0.6		1	1		0.1	0.1		0.550	0.617	$5,000		$24,998	$19,425
212	0.7	0.5	0.5	0.3	0.2	0.3	0.1	0.1	0.1	0.8	0.8	0.8	0.6	0.6	0.6	1	1	1	0.1	0.1	0.1	0.483	0.467	0.483	$5,000	$1,740	$1,050	$1,305
213																												
214			0.3			0.2			0.1			0.8			0.8			0.3			0.5			0.450	$5,000			$608
215																												
216																												
217																												
218																												
219	0.6	3.0	1.3	0.3	0.5	0.5	0.1	0.1	0.1	0.8	0.8	0.8	0.4	0.4	0.4	1	1	0.9	0.1	0.1	0.1	0.450	0.483	0.467	$5,000	$1,418	$7,178	$2,940
220																												
221		0.5			0.3			0.1			0.8			0.4			0.6			0.1			0.383		$5,000		$1,035	
222																												
223																												
224																												
225																												
226		2.9	0.5		0.5	0.3		0.1	0.1		0.5	0.8		0.4	0.4		0.3	0.1		1	1		0.467	0.450	$5,000		$6,720	$1,215
227																												
228		0.6	0.3		0.3	0.2		0.1	0.1		0.8	0.8		0.4	0.4		0.8	0.6		0.1	0.1		0.417	0.367	$5,000		$1,313	$495
229		0.4	0.2		0.2	0.2		0.1	0.1		0.8	0.8		0.4	0.4		0.9	0.9		1	1		0.567	0.567	$5,000		$1,020	$510
230		1.4	0.9		0.5	0.3		0.5	0.5		0.5	0.8		0.8	0.8		0.3	0.3		0.5	0.5		0.517	0.533	$5,000		$3,720	$2,400
231		0.2			0.2			0.1			0.8			0.4			0.6			0.5			0.433		$5,000		$390	
232																												
233																												
234		0.1	4.2		0.2	0.7		0.1	0.1		0.8	0.8		0.4	0.4		0.1	0.1		0.1	0.1		0.283	0.367	$5,000		$128	$7,755
235	4.3	8.6	11.2	0.7	0.7	0.8	0.1	1	1	0.8	0.5	0.5	0.9	0.9	0.9	0.3	0.3	0.3	0.1	0.1	0.1	0.483	0.583	0.600	$5,000	$10,440	$25,200	$33,480
236	0.4	2.2	2.4	0.2	0.5	0.5	0.1	0.1	0.1	0.8	0.8	0.8	0.6	0.6	0.6	0.6	0.6	0.6	1	1	1	0.550	0.600	0.600	$5,000	$990	$6,480	$7,290
237		0.2			0.2			0.1			0.8			0.4			0.8			0.5			0.467		$5,000		$420	

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
238																												
239		0.1			0.2			0.1			0.8			0.4			0.1			0.5			0.350		$5,000		$158	
240		0.1	0.1		0.2	0.2		0.1	0.1		0.8	0.8		0.6	0.6		0.8	0.8		0.1	0.1		0.433	0.433	$5,000		$195	$195
241																												
242																												
243																												
244																												
245																												
246																												
247		0.5			0.2			0.1			0.8			0.4			0.3			1			0.467		$5,000		$1,050	
248																												
249																												
250																												
251																												
252																												
253	0.7	0.5	0.7	0.3	0.3	0.3	0.1	0.1	0.5	0.8	0.8	0.8	0.6	0.6	0.6	0.3	0.3	0.3	1	1	1	0.517	0.517	0.583	$5,000	$1,860	$1,395	$2,100
254																												
255																												
256		7.5			0.7			0.1			0.8			0.8			0.8			1			0.700		$5,000		$26,145	
257																												
258																												
259																												
260		0.4			0.2			0.1			0.8			0.4			0.1			1			0.433		$5,000		$780	
261																												
262		0.1			0.2			0.1			0.8			0.4			1			0.1			0.433		$5,000		$195	
263		0.5			0.3			0.1			0.8			0.4			0.8			0.1			0.417		$5,000		$1,125	
264																												
265																												
266																												
267																												
268																												
269																												
270		1.2			0.5			0.1			0.8			0.4			0.3			0.1			0.367		$5,000		$2,145	
271																												

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
272																												
273																												
274																												
275		0.4			0.2			0.5			0.8			0.6			0.1			1			0.533		$5,000		$960	
276																												
277																												
278																												
279		0.9			0.3			0.1			0.8			0.4			0.9			0.1			0.433		$5,000		$1,950	
280		1.4			0.5			0.1			0.8			0.6			1			1			0.667		$5,000		$4,800	
281	6.2	5.4	9.3	0.7	0.7	0.7	0.1	0.1	0.1	0.8	0.8	0.8	0.4	0.4	0.4	0.8	0.6	0.8	0.1	0.1	0.1	0.483	0.450	0.483	$5,000	$15,008	$12,150	$22,403
282																												
283																												
284																												
285																												
286	0.6	0.1		0.3	0.2		0.1	0.1		1	0.8		0.6	0.6		0.6	1		1	1		0.600	0.617		$5,000	$1,890	$278	
287																												
288		1.0	1.4		0.3	0.5		0.5	1		0.8	0.8		0.8	0.8		0.9	0.1		1	0.5		0.717	0.617	$5,000		$3,548	$4,440
289																												
290																												
291																												
292																												
293																												
294																												
295																												
296																												
297																												
298																												
299																												
300																												
301																												
302																												
303																												
304		7.5	0.3		0.7	0.2		0.1	0.1		0.5	1		0.6	0.6		1	0.6		0.1	0.1		0.500	0.433	$5,000		$18,675	$585
305																												

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
306																												
307			0.2			0.2			1			0.8			0.8			1			0.5			0.717	$5,000			$645
308																												
309																												
310																												
311																												
312																												
313																												
314																												
315		0.2	0.5		0.2	0.2		1	1		0.8	0.8		0.8	0.8		1	1		1	0.5		0.800	0.717	$5,000		$720	$1,613
316																												
317																												
318																												
319																												
320																												
321																												
322																												
323																												
324																												
325																												
326																												
327		5.4			0.7			0.1			0.8			0.4			1			0.1			0.517		$5,000		$13,950	
328	243.2	238.2	244.5	1	1	1	0.1	0.5	0.5	0.8	0.5	0.5	0.6	0.6	0.6	1	1	1	0.5	0.5	0.5	0.667	0.683	0.683	$5,000	$810,600	$813,953	$835,478
329																												
330																												
331																												
332																												
333																												
334			0.2			0.2			1			0.8			0.8			0.9			0.5			0.700	$5,000			$630
335																												
336		0.6			0.3			0.1			0.8			0.4			0.1			0.1			0.300		$5,000		$945	
337																												
338		0.1	0.2		0.2	0.2		1	1		0.8	0.8		0.8	0.8		0.6	0.6		0.5	0.5		0.650	0.650	$5,000		$293	$585
339																												

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
340																												
341																												
342																												
343																												
344																												
345	0.1	0.5	0.4	0.2	0.3	0.2	0.1	0.1	0.1	0.8	0.8	0.8	0.4	0.4	0.4	0.6	0.6	0.6	0.1	0.1	0.1	0.367	0.383	0.367	$5,000	$165	$1,035	$660
346																												
347																												
348			0.4			0.2			0.1			0.8			0.2			0.3			0.1			0.283	$5,000			$510
349																												
350																												
351																												
352																												
353																												
354																												
355																												
356																												
357																												
358																												
359																												
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373																												

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
374																												
375																												
376																												
377																												
378																												
379																												
380																												
381																												
382																												
383																												
384																												
385																												
386																												
387																												
388																												
389																												
390			0.2			0.2			0.1			0.8			0.4			0.1			0.1			0.283	$5,000			$255
391																												
392																												
393																												
394																												
395																												
396																												
397																												
398	0.2	3.3	6.9	0.2	0.5	0.7	0.1	0.1	0.1	0.8	0.8	0.8	0.4	0.4	0.4	0.6	0.6	0.8	0.1	0.1	0.1	0.367	0.417	0.483	$5,000	$330	$6,938	$16,748
399																												
400																												
401																												
402																												
403																												
404		1.2	3.0		0.5	0.5		1	1		0.8	0.5		0.4	0.4		0.1	0.1		0.1	0.1		0.483	0.433	$5,000		$2,828	$6,435
405																												
406																												
407		0.5	0.7		0.3	0.3		1	1		0.8	0.8		0.6	0.6		0.1	0.1		0.1	0.1		0.483	0.483	$5,000		$1,305	$1,740

Table A4.1: Metric and water purification scores (WPS) for all wetland complexes present in 1990, 2000 and 2010. NOTE: where there is no data present for a wetland complex, no open water was present during the year but open water has been present at some stage during the period 1984 to 2010.

Wetland complex ID	Area (ha)	Area (ha)	Area (ha)	WP1			WP2			WP3			WP4			WP5			WP6			WPS			Dollar Value	Wetland Benefit ($)		
Year	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	1990	2000	2010	$/ha)	1990	2000	2010
Total	334.7	469.3	404.4																							$1,060,313	$1,452,968	$1,310,423

A5: RESPONSES TO QUESTIONS FROM THE BIOPHYSICAL AND SOCIOECONOMIC TEAM LEADERS ON THE REPORT PREPARED FOR THE ECOSYSTEMS SERVICES PILOT PROJECT ENTITLED ECOSYSTEM SERVICE ASSESSMENT OF WETLAND WATER PURIFICATION FOR THE SHEPARD SLOUGH STUDY AREA, dated SEPTEMBER 3, 2011

Responses to questions from the biophysical and socioeconomic team leaders on the report prepared for the Ecosystem Services Pilot Project entitled *Ecosystem Service Assessment of Wetland Water Purification for the Shepard Slough Study Area* by Irena F. Creed Consulting dated September 3, 2011

This document details responses to questions received from the ESPP biophysical and socioeconomic team leaders regarding the draft report *Ecosystem Service Assessment of Wetland Water Purification for the Shepard Slough Study Area* (submitted August 6, 2011). The responses provided will be integrated into a final report that will be submitted September 6, 2011.

Questions received August 29, 2011

Question 1

Please confirm. Definitions of key terms p.9 Table 2
The socio-economic team asked (in previous communications), "What is the definition you used in this report for water purification and water quality?" It is our understanding that (based on page 6), the definition used was: "wetlands provide natural water purification …"; "…natural purification processes provide clean drinking water …and non-human (biodiversity) uses."; and "Natural purification is a function of the rate of water movement…related to the affinity of substrate to adsorb or absorb (metabolize) contaminants in the water".
Response
***Water purification*: Water purification is the removal of contaminants from a water supply. In this report, contaminants refer to sediments and nutrients (nitrogen and phosphorus).**
***Water quality*: Water quality refers to the physical, chemical and biological properties of a water supply. In this report, water quality focuses on sediment and nutrient (nitrogen and phosphorus) concentrations in the water supply.**

Question 2

Page 6, section 3.0, third paragraph. Please clarify the first sentence: "unfiltered water than by-passes the purification system and enters directly the water supply", regarding human-induced degradation. Does this refer to the next paragraph that discusses point and NPS inputs?
Response
The following change will be made to the section referred to in Question 2:
"Human activities can degrade the purification potential of wetlands by (1) altering water flow pathways such that water bypasses (flows above or below) the natural purification system of the riparian buffers; (2) increasing sediment and nutrient loads beyond the purification potential; and/or (3) damaging the riparian buffers and thus its purification functions. The consequence of these degradations to the purification potential of wetlands is that non-point sources of sediments and nutrients may enter the water supply attenuated."

Question 3

Page 7, 1st paragraph. Please clarify “redox potential” as it relates to the service delivery, particularly for a lay audience.

Response

The following change will be made to the section referred to in Question 3:
“Changing water flow processes and/or pathways can result in changes to the oxygen content of soils that may have differential effects on the fate of nutrients (e.g., N removal depends on transformation to N_2O/N_2 that requires oxygen poor soils whilst P removal depends on adsorption to soil particles that requires oxygen rich soils).

Question 4

Page 7, 1st paragraph. It’s noted that introducing non-native species may alter the nutrient cycling potential of a wetland. We are not including the nutrient cycling services in the pilot project but understand there is a linkage. To what extent does the composition of species near/adjacent to wetlands influence the water filtration capacity? And, are there particular species in this area that are essential for the delivery of this service (and if the information is not available, are you aware of other studies that looked at wetland plant species important for this function?).

Response

The three zones that provide an important function in water purification are emergent zone, wet meadow zone and riparian upland zone. Changing the composition of organisms within or adjacent to wetlands by introducing species with different nutrient fixation, transformation, and/or uptake potentials may fundamentally alter the nutrient cycling potential of a wetland. For example, an emergent zone dominated by Typha spp. would result in the accumulation of nitrogen in the biomass (Zedler 2000), as could Alder trees with symbiotic N_2 fixing bacteria (Hurd et al 2001). Picard et al (2005) found that monocrop microcosms of three plant species (*Scirpus validus*, *Phalaris arundinacea* and *Typha latifolid*) removed nutrients under experimental conditions. An additional treatment combining these three species with another (*Carex lacustris*) also removed nutrients, suggesting that biodiversity can be maintained when planning for nutrient removal.

Question 5

Page 7, 2nd paragraph. The report notes the importance of riparian areas. Are there guidelines as to the size of ‘buffer’ required to maintain purification function (e.g., hectares, metres)?

Response

Provincial guidelines have been developed that define riparian buffers for streams (30m), rivers (60m) and lakes (100m) (Alberta Environmental Protection 1994). Municipal guidelines are more liberal, requiring a 6m riparian buffer from water sources for development approvals (Municipal Government Act 2010). However, adaptive, rather than standard, riparian buffer widths are advised, as the conditions required for effective purification function may vary greatly among wetlands. For example, in the boreal plains, Creed et al. (2008) found that hydrological flow pathways influence the formation of surface or near surface saturated areas (i.e., wet areas), and that riparian buffers should be defined by the extent of these wet areas to reduce sediment and nutrient (e.g., N) loads as they are transported to surface waters.

Question 6

Wetland inventory graphics (Pages 19 and 20): The variance between DU Historic and 2005 inventory, and the Landsat Satellite inventory is substantial. What is the reason for the variance? As the method selected chooses the latter, would you consider your results highly conservation estimates of function?

Response

The DU inventory is developed from manual digitization of wetland boundaries from fine resolution aerial photography and includes both the inundated (open water) and saturated zones. The Landsat inventory is developed from coarser resolution satellite imagery and includes the inundated zone only. The class 1 and 2 wetlands and smaller class 3 wetlands that are typically dry and do not have an open water zone will not be captured in the Landsat inventory and are not included in the report. As a result, the Landsat inventory is highly conservative because the saturated areas, which are important in the water purification function of wetlands, are not included. The implicit assumption is made that there is a constant ratio between inundated and saturated areas that allows us to infer the value of the saturated zone from the inundated zone. However, this ratio has not been defined or assessed as part of this report. It must be emphasized that the Class 1, 2 and 3 wetlands that are not captured are still important for water purification and other ecosystem services and should not be excluded from policy decisions.

Question 7

Section 5.2.: What is the definition of "water budget" used in this report? (precipitation minus evapotranspiration?)

Response

The water budget is defined as the water inputs [precipitation (P)] to the system *versus* the water outputs [evapotranspiration (ET) and discharge (Q)] from the system and is represented by the formula P = ET + Q. It is assumed that the change in water stored in the wetland is negligible. This water budget is used to estimate the water surplus of the system (P-PET) where potential evapotranspiration (PET) can be estimated using a range of techniques available in the literature. In this report, PET was estimated using the technique by Hamon (1963), because it is simple and requires readily available data (temperature data only). If the annual P-PET is positive, a water surplus exists and it is considered a wet year (i.e., energy limited). In contrast, if the annual P-PET is negative, a water deficit exists and it is considered a dry year (i.e., water limited).

The Hamon (1963) equation is as follows:

$$PET_{HAMON} = \frac{2.1 \times H_t^2 e_s}{(T_a + 273.2)}$$

Where PET_{HAMON} is in mm month^{-1}, H_t is number of monthly average daylight hours per day, T_a (°C) is the mean monthly temperature, e_s is the saturated water vapor density term calculated as follows:

$$e_s = 0.6108 \exp\left(\frac{17.27 T_a}{237.3 + T_a}\right)$$

Question 8

Section 5.2.2: Do you have maps with the LULC available? (e.g., agriculture, urban and open water). Figure 6 provides on changes in urban land use.

Response

Land Use Land Cover (LULC) figures are now presented in Appendix 2 of the report.

Question 9

WP2 uses disturbed land use in the calculation (including residential, commercial and industrial, and roads and rail infrastructure). Do the LULC maps you have available show these three land use types? Section 5.2.2 only notes agriculture, urban and open water.

Response

The urban land use category used in the 1990, 2000, and 2010 Land Use Land Classifications incorporates residential, commercial, and industrial land use along with road and rail infrastructure. These are not broken down into individual classes.

Question 10

Please explain why agriculture was removed from the WP2 metric (rationale provided notes that "the metric allows us to account for spatial and temporal variation in wetland function resulting from land use". Would agriculture not be a key driver of wetland degradation and reduced function? Or, is the inclusion of agriculture in WP3 sufficient to include the effect of this driver?

Response

WP2 addresses the potential pollutant sources to a wetland (see table 4) and is defined by the presence of disturbed land within a wetlands contributing area. The metric scores for WP2 are calculated as 0.1 for <20 per cent disturbed land, 0.5 for 20 to 50 per cent disturbed land, and 1.0 for >50 per cent disturbed land within the contributing area. When both urban and agricultural land use are included as disturbed land, WP2 metric scores for all wetlands within Shepard Slough are 1.0 throughout the time series (1990 – 2010). To try and capture the change in land use over the time period, agriculture was removed when determining the WP2 metric scores. The assumption made was that runoff from urban areas has higher sediment and nutrient loads than runoff from agricultural areas. This is not a hard and fast rule and is dependent on a range of variables including urban land use (industrial compared to residential), fertiliser application rates and tilling practices. Removing agriculture from the WP2 metric results in a lower overall WPS for wetlands in Shepard Slough. If the technique is to be used across Alberta, we advise that agriculture in WP2 be included to maintain consistency across the province.

Question 11

Section 5.3.1.3. Is there an error in the "What is the metric" section? "WQ3 metric attempts…." Should this be WP3?

Response

This is an error and will be corrected in the report to read "WP3."

Question 12

Please explain the relationship between WPS and /ha value. A GOA reviewer commented, "If WPS represents the quality of the filtration potential that presumably ones with higher WPS will have higher /ha value."

Response

The WPS is a value between 0 and 1. To achieve the range of $/ha range for the range of WPS values, the WPS value is multiplied by $50/ha, $500/ha, or $5,000/ha (representing the median and range of values from the literature). This results in a lower $/ha cost for lower WPS values. For example, for a wetland with a WPS of 0.1 the $/ha cost is determined by multiplying the median value of $500/ha by the WPS, 0.1 x $500 = $50/ha. This is then multiplied by the area of the wetland (ha) to determine the overall $ benefit of that wetland.

Question 13

Cumulative effects vs. cumulative benefits, p.10. Please clarify the differences between these two terms used in the report.

Response

***Cumulative Effect* – is the combined impact that anthropogenic activity is having on all wetlands in the Shepard Slough area.**

***Cumulative Benefit* – is the combined benefit that all wetlands are providing to water purification in the Shepard Slough area**.

Question 14

Natural drivers vs. human drivers, p.22. How could you tease out/separate the impact of natural drivers and human drivers?

Response

To tease out the effect of natural vs. human drivers, one has to establish a "reference condition" that is representative of the range of natural variability in climatic conditions in the region, and then compare the effects of human activity against this reference condition. A challenge is when the range of natural variability in climatic conditions translates into a broad range in wetland areas, causing the impacts of human activities to be lost. In other words, the "signal" from human drivers cannot be distinguished from the "noise" from natural drivers. We attempted to establish a reference condition by exploring the relationship between climatic conditions (i.e., P-PET) and wetland areas. We observed a complex relationship, where wetland areas appeared to fall within one of two steady states – a relatively dry state (small wetland area) and a relatively wet state (large wetland area). We were careful in selecting the time series (1990, 2000, 2009) that was used to establish trends. We selected years that all fell on one of the two steady states (the relatively dry state). Clearly more work is needed in this area to resolve the processes leading to these two steady states and to develop a reference condition where the system can naturally oscillate between wet and dry conditions.

Question 15

Wetland assessment framework, p.8, Table 1

The approach taken in this study in doing economic valuation (convert ES scores to dollar values) is a different approach from the potential metrics identified in the last column. What is the purpose of listing the last column since it's not undertaken in the study?
Table 1 - wetland assessment framework mentions avoided cost of water treatment as policy indicator, is this what Table 8 is supposed to show?
Response
Table 8 provides an overview of the wetland assessment framework defined for the ESPP by the Biophysical Team during the Calgary meeting (June 24, 2011). The report attempts to demonstrate the different steps in the framework, including a basic economic valuation that was developed in consultation with Dr. Paul Adamus, an advisor to the ESPP. In no way is this basic economic valuation intended to replace the socioeconomic team's work; rather, it is to showcase one way of doing an economic valuation from which the socioeconomic team may benefit. This has been emphasized in the final report.

Question 16

Different definitions for wetland size, p.25
The wetland by definition here is the open water area, excluding saturated soil zone. Any significant impact on the results and on the physical water purification capacity?

Previous Response: This is a complex question, which we will try to answer in two parts. First, depending on the Stewart and Kantrud (1979) classification of wetlands, inundated areas may constitute a minor (Class 1, 2) to major (Class 3, 4, 5) portion of wetland surface. For this reason, we are not comfortable assigning a margin of error to the wetland area by *not* including saturated areas. Second, the inundated vs. saturated areas serve distinct functions in terms of removal of contaminants. For example, inundated areas are important for P removal, but saturated areas are important for N removal. This complementary role of inundated and saturated areas in water purification processes is precisely why we advocated the Regional- Advanced wetland assessment approach, as the Regional-Basic wetland assessment approach does not represent these processes that are so important for water purification. In summary, we believe the main benefit of this consulting project was to report on a mental exercise to showcase the importance of considering ecosystem services of wetlands (albeit one that required a great deal of number crunching!), but better data are needed before the theory is put into practice.
---this could be made more explicit in the final report.

Response
We will make this more explicit in the final report.

Question 17

Wetland purification function score, p.30
17a. In the function score calculation, wetland open water size is the only factor that represents the physical function/condition. Does that address enough for the physical condition of water purification function?
Response
No, wetland area alone doesn't capture the purification potential of wetlands. In the Regional-Basic wetland assessment approach used in the report, wetland area is the

single wetland-specific feature that determines the natural purification potential of wetlands. The assumption is that wetland area is directly correlated with other wetland features that contribute to the purification potential of wetlands (e.g., wet meadow and emergent vegetation areas). No assessment has been undertaken to determine the validity of this assumption. In the Cobbaert et al. (2010) report, there is supporting literature to suggest that wetland area is a simple proxy for many purification functions. However, in the Regional-Advanced wetland assessment approach based on the Adamus (2010) method, many features of the wetland contribute to the purification potential of wetlands. Data and time constraints prevented adoption of further metrics of purification potential of wetlands from being assessed.

17b. Water purification scores increase from 1990 to 2010, mainly due to an increase in the number of wetlands. Do we know the changes in scores for individual wetlands? If it's generally positive, what is the reason?

<u>Response</u>

The sentence, "This is mainly due to an increase in the number of wetlands present in 2010 over 1990" will be removed from the final report. Figure 15 presents the percentage of wetland complexes within each WPS score. There is no significant difference in the percentage distribution of wetland complexes among WPS values from 1990 and 2000, however it is noted that there is a shift towards higher WPS values in 2010, and this is predominantly due to the increase in urban land use observed in the 2010 Land Use Land Classification.

17c. In the function score equation, human settlement factors have more effects over the function factor. Would the scores thus be biased by human disturbances on the landscape? As increase in urban areas results in higher scores and thus higher values, e.g. the increasing opportunity of a wetland to treat contaminated water. This makes sense generally. But is that suggesting that more human disturbance results in more value, which may become a justification for the developers to disturb the land?

<u>Response</u>

Yes, as wetlands are lost or degraded on the landscape, the remaining ones will have higher value with respect to purification potential. This should *not* be interpreted as an incentive to disturb wetlands, but rather a disincentive. With the loss of each wetland, it becomes more critical to protect the remaining ones. Of course, some wetlands will have higher value than others, and it is important to identify these before further development occurs to ensure they are protected.

17d. The scores do not allow for calculation of physical quantity of nutrients being avoided. If physical quantity was available then we could calculate the cost of treatment.

<u>Response</u>

Yes, if data were available, the relative scores could be calibrated to actual quantities of nutrients removed.

Question 18

Figure 16. p.31
The title of Figure 16 may change from "from current condition to historic condition" to "from historic condition to current condition".

<u>Response</u>

The title has been changed in the report.

Question 19

Economic values, p.32
What's the context of the dollar values from the literature? What valuation techniques have been used to yield those estimates? It may be critical if we want to transfer those numbers. Speaking of value, there is no reference cited for where the economic values are coming from. Some context about these values would be needed. Also, I would recommend biophysical water quality report not go into values.
Response
Dollar values for water purification were derived from Kazmierczak (2001). Kazmierczak (2001) provides a synthesis of wetland water purification valuations throughout the US found in the literature. The methods for determining wetland valuations vary but are predominately based on cost savings from traditional water treatment alternatives. Wetland types assessed also vary in the study and range from coastal marshes to forested swamps. Kazmierczak (2001) identifies 22 wetlands studied in the US for water purification valuations. Figure 17 of the report presents the distribution of the wetland studies throughout the range of $/ha figures.

Question 20

If available, please provide a map to present the function scores for individual wetlands (also in the final report). This could show the hotspots for the wetlands with low and high function scores. Maybe three levels of functions scores within some range (low, medium, high).
Response
Maps of Water Purification Scores will be provided in Appendix 4 of the report.

Question 21

If available, please provide individual map for each of the 6 indicators. For example, a map of recharge potential indicator on p.29.
Response
Maps of each of the six Water Purification Metrics will be provided in Appendix 4 of the report.

Question 22

If available, please provide sources to allow an understanding of the relationship between wetland classes and water purification function? Also, the absorption rate of P and N related to different vegetation within wetlands.
Response
We assume by wetland classes you mean Stewart and Kantrud's (1979) class 1 to 5 classification. If so, given that we used a Landsat wetland inventory, we are not able to explore the relationship between wetland classes 1 to 5 and their relative water purification function. This is, however, an important question, that could be pursued using a combination of the City of Calgary's class 1 to 5 wetland inventory, and application of either the Remote-Basic or Remote-Advanced wetland assessment approaches for water purification, with verification using the WESPUS site-based wetland assessments completed by O2 Consulting.

We have already responded to the request for N and P removal rates related to different species of plants in the riparian buffers within wetlands – we have not completed a

comprehensive literature review on sediment and nutrient removal rates in mineral wetlands related to plant species that are present, but we offer some key reference citations based on a quick survey of the literature.

Question 23

Please provide the data/maps (mid- and end-products) used in the calculation in this study, including the spreadsheet used to calculate the values described.
Response
Maps for the following will be provided:

- **Individual wetland purification metric scores (WP1-6) and the integrated wetland purification scores (WPS) for each wetland for 1990, 2000 and 2010**
- **Land use/land cover maps for 1990, 2000, 2010**

Tables for the following will be provided

- **1990, 2000 and 2010 wetland area, WP1-6 metric scores, WPS**
- **Metric score calculator**

Questions received August 12, 2011
Questions 1 to 11 and 15 to 16 were included in the Questions received August 29, 2011. The remaining questions are presented below.

Question 12

I am not convinced that wetland inventories are not "proper" if they do not consider year to year variations. First of all, consideration of natural fluctuations in the area inundated requires intensive use of multiple data sources. I am not convinced that during an atmosphere of streaming approvals GOA staff (particularly within my department) are going to have time, resources and data available to make such a calculation on an individual wetland basis. I am also not convinced that there is a need to have an economic determination that considers such fluctuations. Rather, I would think that the economic valuable consider "potential" for services related to water purification and then could ignore the issues related to year to year variation.
Response
This is an important point in terms of developing wetland ecosystem service assessment approaches that can be implemented in an atmosphere of streamlining approvals. Natural drivers cause substantial variation in wetland structure and function, and it is important to forecast this natural variation so that accurate estimates of ecosystem services can be achieved. However, it was never intended that individuals would have to monitor this natural variation annually. Rather, it was intended that historical data be used to define realistic reference conditions or benchmarks for wetland structure and function, against which human drivers of change could be monitored. In the report, we show that wetland areas defined by open water show high variation due to climatic variability, and that the associated wetland function can be significantly reduced in drier years, which would lead to significant underestimates of the economic benefits of these wetlands during these years. A simpler approach would be to use the maximum extent of wetlands to estimate the maximum potential for ecosystem services related to water purification, as the reviewer suggested (i.e., maximum rather than median or some other reference condition). However, this maximum must be based on historical data available for the region.

Question 13

The GOA's license for LiDAR currently excludes much of the white zone and some portions of the green (forested) zone. Many of the metrics identified in Table 5 are not yet possible for vast areas of Alberta's landscapes.

Response

LiDAR acquisition continues to be a priority for many government agencies. It is becoming the standard for digital elevation models; but it will take time to obtain complete coverage for many provinces and states, and it will take time before complete coverage of LiDAR is available for the Province of Alberta. This should not be viewed as a deterrent for site-specific wetland ecosystem service assessments. In Table 5, we were strategic in identifying low, medium and high quality data options for defining the water purification metrics. A few of the metrics require high quality data (i.e., LiDAR) data, as they are currently defined (e.g., the metric for ratio of wetland to contributing area requires LiDAR to capture the subtle changes in topography that define these contributing areas). There are at least two options for dealing with such metrics when no LiDAR data are available: (1) remove that metric from the calculation of the wetland function score; and (2) develop proxies for the metric (e.g., in the absence of high quality data needed for definition of contributing areas, one could use lower quality data to define a fixed buffer width (such as 100 m from water's edge instead of the contributing area)). It is clear that wetland ecosystem service assessments are an evolutionary and adaptive process – as finer datasets come online, better metrics can be defined – and that we must start the process with whatever data are readily available with the promise that we will review and refine the process as better data become available.

Question 14

I do agree with Irena's overall comments on pages 35-36

Response

Comment only, does not require a response.

Questions received prior to August 10, 2011

August 4
Yihong Wang via Gillian Kerr

From my understanding of the work done on water quality (I may be wrong), they have modified WESPUS but using GIS and Remote Sensing techniques to produce a water purification score, which is a relative score of the function and value proxies. They also did an economic valuation by assigning a range of dollar values (from literature) to compute a range of benefits. This is similar to what we have discussed on integrating the WESPUS score into the economic valuation. Generally speaking, it is a relative ranking assessment, which is quite different from what we were expecting as a physical assessment of proper proxies/indicators of water purification functions from wetlands. I have attached the email with the notes captured by Geneva in our discussion with Dr. Creed about what they can deliver on July 22. It mentioned some response variables (turbidity and chlorophyll) would be provided in the report to serve as proxy for N and P as well as other info. I could be wrong but I didn't locate them in the report.

Response*

A lot of work was completed (including what was captured in Geneva's email dated Friday July 22, 2011), which was not included in the final report. The work related to

implementation of a “Regional-Advanced” wetland assessment approach modelled after WESPUS (Adamus 2011) and the Index of Hydrologic Integrity and Index of Nutrient Integrity developed as part of the AWRI funded Wetland Health project (Creed Unpubl. Data). This would have incorporated the wetland specific turbidity and chlorophyll-a measurements but was not included. Despite waiting until the latest possible date (midnight, Friday July 22, 2011), we never received the data requested to complete the Regional-Advanced wetland assessment approach, and that is why these analyses were not included. Due to the problems in gaining timely access to the data from the GOA, we had to start over and complete the Regional-Basic wetland assessment approach to meet the ESPP contract deadline of August 2, 2011. Given this short timeframe, we not only completed a wetland assessment for water purification, but we went beyond what was committed by including a piece on monetary benefits associated with the water purification. This is what was reported in the Final Report, with the draft submitted August 2 and final report submitted August 6.

August 4, 2011
From Ciara Raudsepp-Hearne

Question 1

Figure 16: Title: 'Water purification score change from 1990 to 2010' – it is unclear whether the number represents % change or absolute change in scores. There are a few negative changes of large magnitude (again what do numbers represent?). Can you tell us from your data why those negative changes occurred there? (Fewer wetlands in those areas?)

<u>Response</u>

The wetland purification score ranges from 0 to 1.0 (it is the average of the wetland purification metrics WP 1 to 6). The figure shows the absolute change in scores. Where there are negative changes (i.e., where the wetland water purification has declined from 1990 to 2010) there has been a loss of wetland function related to water purification. This could be either due to (1) loss of area from an individual wetland or (2) loss of wetlands. Figure 16 shows a general increase in wetland purification scores due largely to the apparent increase in wetland area (due to natural drivers, i.e., shift from dry to wet conditions). There are a few exceptions to this generalization, and these are due to loss of wetlands from increase in urbanization/industrialization.

If the recommended wetland assessment method could have been implemented, it is expected that there would still be an increase in wetland purification scores at individual wetlands as climate drivers would likely increase the wetlands function by increasing the emergent and wet meadow zones (unless disturbance at the wetland decreases these zones). However, the increase would not be as dramatic using our Basic-Advanced approach as we would have identified far more wetlands in the drier years due to the better wetland detection techniques we would have used.

Question 2

How certain are we about the change in number of wetlands over time? Can we contextualize this trend within the pattern of wetting/drying years? Does this represent an ongoing trend or simply a dry year and a wetter year? You talk about this towards the beginning of the report, but for your conclusions, it would help me if you interpreted the results using your understanding of longer-term trends in the system.

<u>Response</u>

Wetlands are defined by the combination of inundated and saturated areas. When considered in combination, the wetland boundaries may change, but not to the same degree as the inundated area of the wetlands. For this reason it is critical that wetland

assessments be conducted on inundated plus saturated areas. Given the time constraints of the project, we were unable to do such an assessment. We were forced to make a decision: abandon the request to do a "trend analysis" over recent time period (i.e., last 30 years) and focus on DU wetland inventories of 1965 (an average year) and 2005 (a relatively dry year, which would have inflated wetland loss) *versus* accept the limitations of a LANDSAT TM based wetland detection technique and do the trend analysis. We chose to do the latter.

We are confident about the measured change in inundated areas over time. However, we do not believe this can be a proxy for change in inundated plus saturated areas over time. Given additional time and resources, we are confident that (1) we could create a recent (past 20 years) time series of inundated plus saturated areas based on a combination of optical and microwave imagery (see Recommendation #5); and (2) we could create a baseline that reflects the natural range of variability in climatic conditions in the region from which wetland gains or losses could be measured (see Recommendation #6).

We would be happy to include this interpretation of climate drivers on wetland function and value in the conclusions.

Question 3

The next question is linked to this: 'Are we not losing any wetlands?' In the introduction it says we are, but the results suggest otherwise. Can you help me make sense of this for our report readers?

Response

Wetlands are being lost in the urbanized/industrialized areas.

Question 4

What margin of error do we get for not including saturated areas (and not just open water wetlands)? What are the implications for not including those types of wetlands for the service of water quality (are they more or less important for water filtration, or similar to open water wetlands)?

Response

This is a complex question, which we will try to answer in two parts. First, depending on the Stewart and Kantrud (1979) classification of wetlands, inundated areas may constitute a minor (Class 1, 2) to major (Class 3, 4, 5) portion of wetland surface. Visual assessment of Google Earth images suggests a large number of Class 3, 4, 5 wetlands in the study area, so we feel that the margin of error may be considerable. For this reason, we are not comfortable assigning a margin of error to the wetland area by *not* including saturated areas. Second, the inundated vs. saturated areas serve distinct functions in terms of removal of contaminants. For example, inundated areas are important for P removal, but saturated areas are important for N removal. This complementary role of inundated and saturated areas in water purification processes is precisely why we advocated the Regional-Advanced wetland assessment approach, as the Regional-Basic wetland assessment approach does not represent these processes that are so important for water purification. In summary, we believe the main benefit of this consulting project was to report on a mental exercise to showcase the importance of considering ecosystem services of wetlands (albeit one that required a great deal of number crunching!), but better data is needed before the theory is put into practice.

Question 5

At the top of page 26, there's a statement that 'removing ag from the metric allows us to account for spatial and temporal variation in wetland function resulting from land use'. I don't quite understand the context of this sentence, I'm assuming the original metric included ag land use, and removing it is more appropriate for this system, can you give me a little more explanation about this?

Response

This question is related to Section 5.3.1.2.

This is an important question that highlights the challenges we faced with the Land Use/Land Cover data. We used the LULC map from AgCan (2009), from which we based supervised classification techniques on LANDSAT TM imagery to create the required LULC time series from 1990, 2000, and 2009 (referred to as 2010). This time series of maps (with 30 m resolution) created some constraints in our assessments. Specifically, the resolution meant that natural land covers, including forest and shrub land, were not detected (as they are too small to be detected on the landscape), and therefore the natural purification functions of natural cover could not be considered. A time series based on finer resolution data, such as SPOT, would have enabled us to capture these natural land covers. Unfortunately, the SPOT data in the ESPP database contained panchromatic but not optical data, which precluded our ability to do this analysis. (See Recommendation #3, and Section 5.2.2, last paragraph, p. 23).

This question also highlights the need to consider what our LULC baseline is. The major LULC over the entire time series is agriculture; we would have to establish a historic LULC as a baseline if we want to determine the effect of land conversion from natural to agriculture on wetland purification scores, which was beyond the scope of the study. Given the LULC reality of the Shepard Slough since our 1990 baseline has been agricultural, with urbanization/industrialization being the contemporary development pressure, we decided to remove agriculture from the WP2 metric to improve the signal from urbanization/industrialization, which is expected to increase remarkably over the next few decades.

Question 6

Page 27, 'What is the condition': The statement is that 'the majority of wetland complexes in Shepard Slough in 2010 satisfy two of the elements of this metric. Due to the dominance of agriculture within Shepard Slough all wetlands satisfied the requirements of A. The above is a bit cryptic. What is the actual condition? The findings for the trends are also a bit cryptic, referring to the metrics as opposed to stating simply what the trends are. I want to make sure I understand the findings, could you provide a sentence that is a bit clearer?

Response

This question is related to Section 5.3.1.3.

We provide a statement of "condition" and "trend" for each of the wetland purification metrics that are used in calculated of the wetland purification scores. In so doing, we wanted to deconstruct the causes behind changes in wetland purification function over the time period investigated. For example, for WP3 (pollutant removal opportunity), there are three sub-metrics that define the metric: (1) the proportion of forested or shrub land within the contributing area of the wetland; (2) the proportion of upslope wetland within the contributing area; and (3) the proportion of the wetland itself. In our report, we explain that the WP3condition for the majority of wetland complexes (the wetland assessment unit) is defined by the lack of natural cover and upslope wetlands within the contributing areas of the wetlands; and the WP3 trend shows no change in the pollutant

removal opportunity of each wetland, although the number of wetlands performing that function increases.

Question 7
Finally, from what you understand of the major pollutants in the system, is it possible to identify where the greatest risks for pollution might be occurring? For the moment, I understand the major quality issues are measured in terms of loading from urban run-off. Is this the greatest concern? Are there others?
Response
Our informal consultations with Karen Raven from GOA (via Geneva Claessen) indicate that the "pollutant of primary concern" is phosphorus, although nitrogen should be a concern as well (See Figure 2, p. 6). The greatest risk for phosphorus and nitrogen pollution is from untreated sewage effluent and agricultural run-off carrying fertilizers. Within the Shepard Slough, the surface hydrological pathways were assumed to be the major pathways for phosphorus and nitrogen transport to surface waters. For the Regional-Advanced wetland assessment approach, we compiled loading coefficients of phosphorus and nitrogen from different LULC classes, so that we could identify where the greatest risks for pollution were occurring. Unfortunately, we were unable to complete this approach. For the Regional-Basic wetland assessment approach, we can only infer where the greatest risk for pollution might be occurring from the LULC maps.

August 3, 2011
From Geneva Claesson and Ciara Raudsepp-Hearne

Question 1
Based on the data you've seen, can we calculate vegetated buffer zones?

Question 2
What type of vegetation contributes most to purification? Is this measureable with the data available (e.g., GVI)?
Response
In terms of calculating a vegetative buffer around wetlands, we don't currently have the data needed to estimate it adequately (See Recommendation #3, and Section 5.2.2, last paragraph, p. 23).
For the Regional-Basic wetland assessment approach, indicator WP3 looks at the percentage of forest and shrub land within a wetland's contributing area making the assumption that contributing areas with a high proportion of forest and shrub will remove more sediment and nutrients from overland flow before it reaches the wetland. These wetlands will have less value (lower metric score) because the wetland is treating less polluted water.
For the Regional-Advanced wetland assessment approach, metric RA16 (Natural land cover in 100ft upslope buffer) determines the forest and shrub land vegetation within a 100 m buffer of the wetland. Higher percentage of native vegetation within this buffer would increase the metric score. For future analysis it would be possible to determine the vegetative buffer width. However the GVI will not be helpful in this case. The GVI only identifies 10 polygons within Shepard Slough that are considered natural land cover and these only contain < 30% forest and trees. Because of the low occurrence of forest and shrub land within Shepard Slough, a finer scale SPOT LULC classification with ground-truthing (by aerial photographs or ground inspections) would be needed to identify natural vegetation cover adjacent to a wetland. With additional time and resources, we could conduct this analysis.

For specific species that contribute to water purification, we encourage you to read the material presented by Dr. Paul Adamus, both the manual and his literature review for the prairie potholes. We have provided these references below, and can provide you with a copy, if requested.

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