Ecosystem Service Approach Pilot on Wetlands

Assessment of Water Storage and Flood Control Ecosystem Services

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

Report Prepared by: O2 Planning + Design Inc.

August 22, 2011

FINAL REPORT

ISBN Number 978-1-4601-0284-8 (Printed Version)
ISBN Number 978-1-4601-0285-5 (Online Version)
Web Site: http/www.environment.alberta.ca

Any comments, questions or suggestions regarding the content of this document may be directed to:

Policy and Legislation Integration Branch
10th Floor, Oxbridge Place
9820 – 106 Street
Edmonton, Alberta T5K 2J6
Fax: (780) 422-4192

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment and Sustainable Resource Development
4th Floor, Twin Atria Building
4999 – 98 Avenue
Edmonton, Alberta T6B 2X3
Telephone: (780) 427-2700
Fax: (780) 422-4086
E-mail: env.infocent@gov.ab.ca

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Geographic Information Systems (GIS) technologies were used to model water storage and flood control functions as well as related beneficiaries and ecosystem services of wetlands in the Shepard Slough study area east of Calgary. The water storage model used a raster-based computer script using LiDAR inputs combined with a rating curve to estimate water storage capacity volumes for each wetland in the study area. The flood control model used eight separate predictor variables of wetland flood control functions. Notable results and conclusions of the study included:

- Study area wetlands provides a total water storage capacity of over 36 million m^3-greater than the combined total volume of the Glenmore Reservoir and Lake Chestermere;
- Wetland water storage provides many supporting and regulating ecosystem services upon which all other ecosystem services depend;
- Much water storage is located in the large central Shepard Slough Wetlands; however, the large number of small wetlands add up to a considerable storage volume on a cumulative basis;
- In the study area, Class IV wetlands tend to store the most water volume, both on a per wetland basis and on a cumulative basis, although variability within the class was very high;
- Class V wetlands also store large volumes, but there are fewer of them and they are less important on a cumulative basis than Class III wetlands overall;
- Class I and II wetlands have very small average wetland volumes, but they can add up to a considerable volume when taken together as a whole;
- A large number of wetlands have been drained in the study area, particularly within urban areas but also in agricultural areas, and the trend calculated over 1965-2005 is a 20% drop in wetland water storage volume;
- Users/beneficiaries of wetland water storage provisioning services are low in the study area;
- Cattle are the largest ecosystem service beneficiary of water storage and supply in the study area, with up to 144,000 m^3/year used by cattle;
- The flood control index indicates that many medium and small wetlands at high landscape positions provide considerable flood control benefits, particularly on a cumulative effects basis;
- “Hotspots” of high flood control services included a large cluster of wetlands near the north boundary of the study area, several wetlands east of Chestermere and in the north half of the Belvedere Area Structure Plan area in The City of Calgary;
- Smaller areas of wetlands with high flood control indicator values are dispersed throughout the study area;
- *All* wetlands have the potential to provide some measure of flood control ecosystem services, although this occurs to differing degrees and at different scales;

- According to a rough calculation, if all study area wetlands were drained effectively, peak flows in the Bow River immediately downstream would increase by up to 37%, indicating the level of importance of these wetlands at mitigating peak flows in the region; and
- Comparisons of the WESPUS site-scale results to the GIS model results showed:
  - WESPUS hydrologic function scores weakly positively correlated with water storage volume
  - WESPUS hydrologic scores moderately positively correlated with the flood control indicator
  - very high variability and in particular several outliers highlighted model mismatches
  - caution is required when interpreting indicator values from WESPUS or GIS models.

1. INTRODUCTION

This draft report summarizes the results of the water storage assessment and flood control assessment conducted by O2 for Alberta Environment and Sustainable Resource Development (ESRD) for the Ecosystem Services Approach Pilot on Wetlands in the Shepard Slough area east of Calgary. The broader pilot project includes a number of other components, stakeholders, and working group teams. Another component of the project being conducted by O2 is site-scale sampling of wetlands using the Wetland Ecosystem Services Protocol for the United States (WESPUS) as well as associated reporting, which is summarized separately from this report.

Assessing water storage and flood control ecosystem services provided by wetlands across the pilot study area has been highlighted by ESRD as a major priority in the context of the pilot study. Currently, few tools are available to assess ecosystem services and related benefits of a wetland in a quantifiable, comparable way. Nor are there clear methods to assess cumulative impacts attributable to multiple wetland disturbances. What matters gets measured. Therefore, methods to measure, map, and visualize wetland hydrological services across a broad scale has been undertaken, in order to provide input to address gaps identified in the current regulatory context for wetlands in Alberta. The scope of this component of the pilot project was to assess hydrological ecosystem services, including water quantity regulation (i.e., storage and supply) and flood control, by applying Geographic Information Systems (GIS) modelling approach. Existing condition and trends, where available, have been identified primarily using a series of maps.

Section 2 provides a general description of the study area. Section 3 summarizes the background review conducted prior to determining an appropriate assessment methodology. Section 4 describes some data pre-processing steps that were applied prior to conducting the assessment. Section 5 summarizes the water storage assessment, including methods, results, and a discussion of ecosystem service beneficiaries. Section 6 summarizes the flood control assessment, including methods applied, results, and a discussion of beneficiaries for flood control ecosystem services. Section 7 provides some preliminary conclusions.

2. STUDY AREA DESCRIPTION

The 267 km^2 study area includes portions of The City of Calgary, Rocky View County, and The Town of Chestermere. Gently rolling prairie topography and numerous pothole wetlands within small depressions characterize the area. The underlying glacial till dominating the area has very low hydraulic conductivity at depth (van der Kamp and Hayashi 2009). Land uses in the study area are dominated by agriculture, with considerable amounts of urban and industrial development and transportation infrastructure. In its natural condition, most of the area is a “non-contributing area”- or an endorheic basin with no surface outlet to the Bow River. GIS data have identified a total of >6,500 wetlands within the study area. Although most of these are very small ephemeral or temporary wetlands, 409 wetlands over 1 ha in size occur, and 44 wetlands >10 ha are present.

Over the past century, the natural hydrology of the area has been affected in many locations by drainage, development, and irrigation canals. The Western Headworks (WH) Canal bisects the area, conveying water from the Bow River to the artificial Lake Chestermere reservoir. The WH Canal also receives stormwater drainage from several developed areas to the north. Several additional constructed stormwater systems also now contribute runoff to the Bow River through outfalls.

The Shepard Ditch drainage canal provides one of the largest changes to the natural hydrology of the area. Initially constructed in the early part of the 20th century, this canal aimed to address flooding concerns related in part to the CPR railway. The Shepard Ditch drained wetlands south to the Bow River, especially during floods. Dredging and expansion of the Shepard drainage ditch, as well as drainage of surrounding wetlands through drainage tiles connected to the ditch has also occurred.

More recently, during the first decade of the 21st century, The City of Calgary designed and built the Shepard Stormwater Diversion Project. The main purpose of the project was to divert stormwater and related pollutant loads from Calgary out of the Western Headworks Canal to address the concerns of ESRD, the Western Irrigation District, and the Town of Chestermere. The completed project includes an underdrain to allow stormwater from developments north of the WH canal within the catchment to flow under the WH canal. It also includes a diversion structure to allow peak flows and high pollutant loads in the WH canal to be diverted out of the canal to the south. These two sources of flow are diverted through a channel into the Shepard Constructed wetland treatment cells, which occupy 227 ha at full supply level. Water is then discharged south from the Shepard Constructed wetlands through an expanded Shepard Ditch to an outfall on the Bow River.

In conclusion, the study area is no longer largely a “non-contributing” area, since it is now affected by various drainage and stormwater management systems. However, a large number of wetlands within depressions continue to persist throughout the area.

3. SUMMARY OF BACKGROUND REVIEW CONDUCTED

Background research conducted by O2 included a review of the following:

- O2 project proposal and O2 project charter;
- Recent published literature on wetland functions, hydrology, and wetland ecosystem services;
- The *Wetland Ecosystem Services Protocol for the United States (WESPUS),* including participation in a 3-day training workshop with Dr. Paul Adamus;
- Information available on the pilot project's sharepoint website, including but not limited to the Industrial Heartland (IH) wetland model;
- Discussions with ESRD, Deloitte, and other stakeholders;
- Review of various spatially based frameworks available for modelling ecosystem services;
- Review of the Shepard Regional Drainage Study (AECOM 2011) for a regional context; and
- Review and familiarization with data layers distributed by ESRD to date.

Table 3.1 summarizes the findings from various modelling options considered, including benefits and constraints associated with each option. Considerations such as project timing, data needs, suitability of existing data, computer processing time and hardware requirements, technical quality and reliability of the outputs, and potential utility in conducting subsequent economic valuation were all considered.

In addition, once a draft methodology had been completed and circulated, the proposed methodology was reviewed and revised in an iterative process, including feedback and discussions with:

- Ciara Raudsepp-Hearne (July 14th, 2011)
- Danielle Cobbaert (July 14th, 2011)
- Geneva Claesson (July 18th-19th, 2011)
- Irena Creed (July 19th-20th, 2011)
- Lyle Boychuk (Ducks Unlimited) (July 20th, 2011)
- Internal O2 staff reviews (July 14th-25th, 2011)
- Norma Posada-Flaherty (City of Calgary Water Resources) (July 19th-20th)
- Ernst Kerkhoven (ESRD) (July 25th, 2011)

Table 3.1. Summary of Benefits and Constraints of Model Options Considered

Model	Reference	Comparable Area of Application	Benefits	Constraints	Recommendations
WESPUS	Adamus (2011)	Intended for all of temperate North America Most widely applied in Oregon	Models many ecosystem services, including: -water storage and delay -sediment retention -phosphorus retention -nitrate removal Possible to adapt some criteria for GIS assessment but not directly	Requires field visits to each site Not intended for regional or landscape analyses 140 criteria Several criteria are unsuitable for Alberta Uses US imperial measures Indicators are not physically-based (cannot show m^3/s flood peak reduction, total m^3 storage)	Not applicable for the landscape-based scope (>6000 wetlands) Conduct additional site-based testing for pilot May be useful to measure ES changes associated with future development and allow regulators to adjust required compensation ratios as appropriate
Prairie Pothole Wetland FCI	O2 (2010), based on Gilbert et al. (2006)	Prairie Pothole region of North America, including North Dakota, Montana, Alberta, Saskatchewan	O2 has created an adaptation of this model to facilitate broad-scale analysis Converting indicator values to physical parameters can be undertaken Project team has experience working with this model	Original version required field-based site assessments Indicators are relative (not physically based) Based on functions, not necessarily services Awkward to interpret due to “relative” values, “reference” wetlands, and linear scaling factors applied	Application not recommended at this time However, some approaches and ideas from this model could be used to improve upon the modelling approach taken
Industrial Heartland GIS Model	Cobbaert et al. (2011)	Industrial Heartland (IH) NE of Edmonton	Purely GIS based assessment for broad-scale analysis Clear, easy, step by step methods Easy to conduct under project time constraints Previously accepted by AB Environment	Based on functions, not necessarily services Subcatchment delineation with ArcHydro Tools (often erroneous) Indicators are relative and not physically-based Impervious surface overestimate (residential=100% impervious?)	Adapt a similar method to the study area to provide a regional indication of wetland water storage and flood control potential. It is recommended that catchment delineation use a different process than ArcHydro
SWAT (Soil and Water Assess-ment Tool)	Yang et al. (2008) TAMU (2011)	Broughton Creek watershed, Manitoba	Outputs include physical quantities Well developed hydrological model	Time-consuming to calibrate and requires stream gauge (not available for the study area) Project team presently has low experience with this model Known issues in applying SWAT in cold climates as well as areas with no streams or rivers	Application not recommended
CRHM (Cold Regions Hydrologic Model)	Pomeroy (2010) Pomeroy (2011)	Saskatchewan including a prairie pothole landscape	Outputs include physical quantities Addresses: -internal drainage -blowing snow -frozen ground -“fill and spill” -ungauged basins	May be difficult and time-consuming to accurately model the study area Project team presently has low experience with this model	CRHM for the entire study area is not recommended Time permitting, CRHM model a smaller subset of the study area to measure flood control ecosystem services

*Note: Several other modelling approaches were also reviewed, including all those in Anderson et al. (2011) such as InVEST, MARXAN, ATEAM, ARIES, MIMES, and SAVANNAH. All of these were considered to have low potential for success in the context of either hydrologic services of prairie pothole wetlands and/or the project timeline.

4. DATA PRE-PROCESSING STEPS

Several fairly detailed data pre-processing steps were undertaken for the study and are summarized below. Section 4.1 describes the creation of a contiguous high-resolution land cover data set for the study area. Section 4.2 describes how a hierarchical system of catchment delineation was completed using several different information sources.

4.1 Land Cover Data Set Creation

A variety of data sets were used to build the land cover layer used in this study, as shown in the map "*Data Source Used to Generate Land Cover"*. Ducks Unlimited provided high resolution wetland shape files. The Calgary-Rocky View County Intermunicipal Development Plan (IDP) land cover dataset (O2 2010a) provides high resolution land cover data, but it does not extend to the western and eastern edges of the study area. The provincial Grasslands Vegetation Inventory (GVI) provides recent land cover, but its 'wetland' class does not provide sufficient resolution, and coverage does not extend to the northern edge of the study area. Several small remaining minor gaps in land cover were filled in using the federal Geobase land cover classification, which is of much lower resolution and spatial accuracy and was derived by the National Land and Water Information Service (NLWIS) of Agriculture and Agri-Food Canada (AAFC) using Landsat 5 and Landsat 7 imagery. Although specific dates of acquisition for these layers differ, data sets were generally created based on imagery from the period 2005-2008, which is sufficient for the purposes of this study[1].

Classes in the Final Landcover dataset (see Map "*Land Cover Classification"*) included:

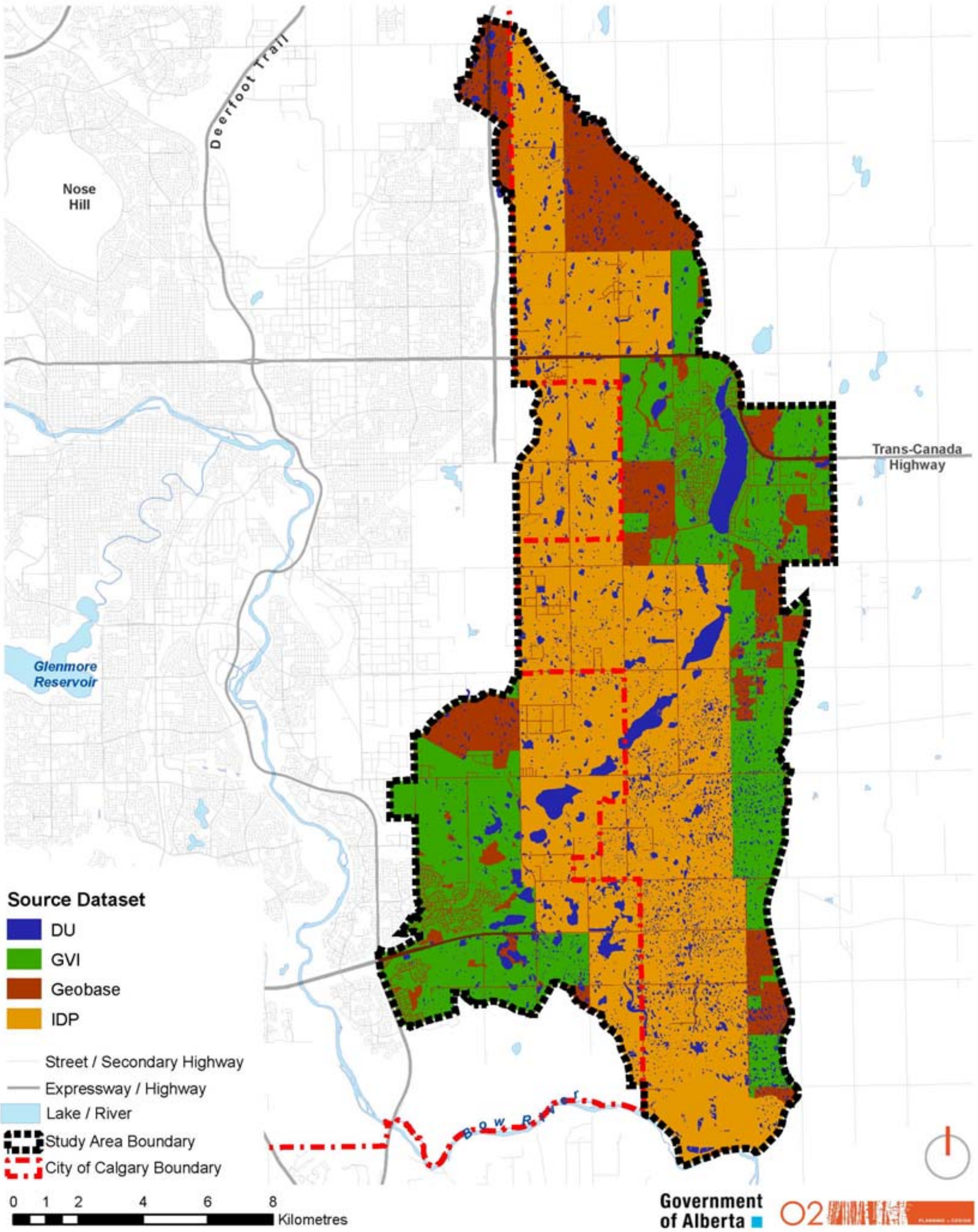
1. **Wetlands:** Assembled from the Ducks Unlimited Current Wetland Inventory, supplemented by wetlands identified in the IDP study (including contiguous 'open water', 'wetland' and 'wet cropland' land cover classes), as well as the Geobase classes 'water' and 'wetland' where necessary. A single polygon (landscapePolygonID 2329064) from the GVI was also used for one large wetland not covered by any of the other data sets.
2. **Anthropogenic:** Assembled from the IDP 'anthropogenic' class, supplemented by the GVI classes of 'Pits', 'Developed', 'Urban', and 'Rural', and the Geobase 'Developed' class. Subclasses include industrial lands, urban residential lands, country residential lands, roads, and pits.
3. **Cropland:** Assembled from the IDP 'Cropland' class, supplemented by the GVI classes of 'Crop – Irrigated', 'Crop – Non-Irrigated', and the Geobase 'Annual Cropland' class.
4. **Tame Pasture and Non-Native Grass:** Assembled from the IDP 'Grassland-1' and 'Grassland-2' classes, supplemented by the GVI classes of 'Tame Pasture or Hay Irrigated', 'Tame Pasture or Hay Non-Irrigated', and the Geobase 'Perennial Cropland and Pasture' class.

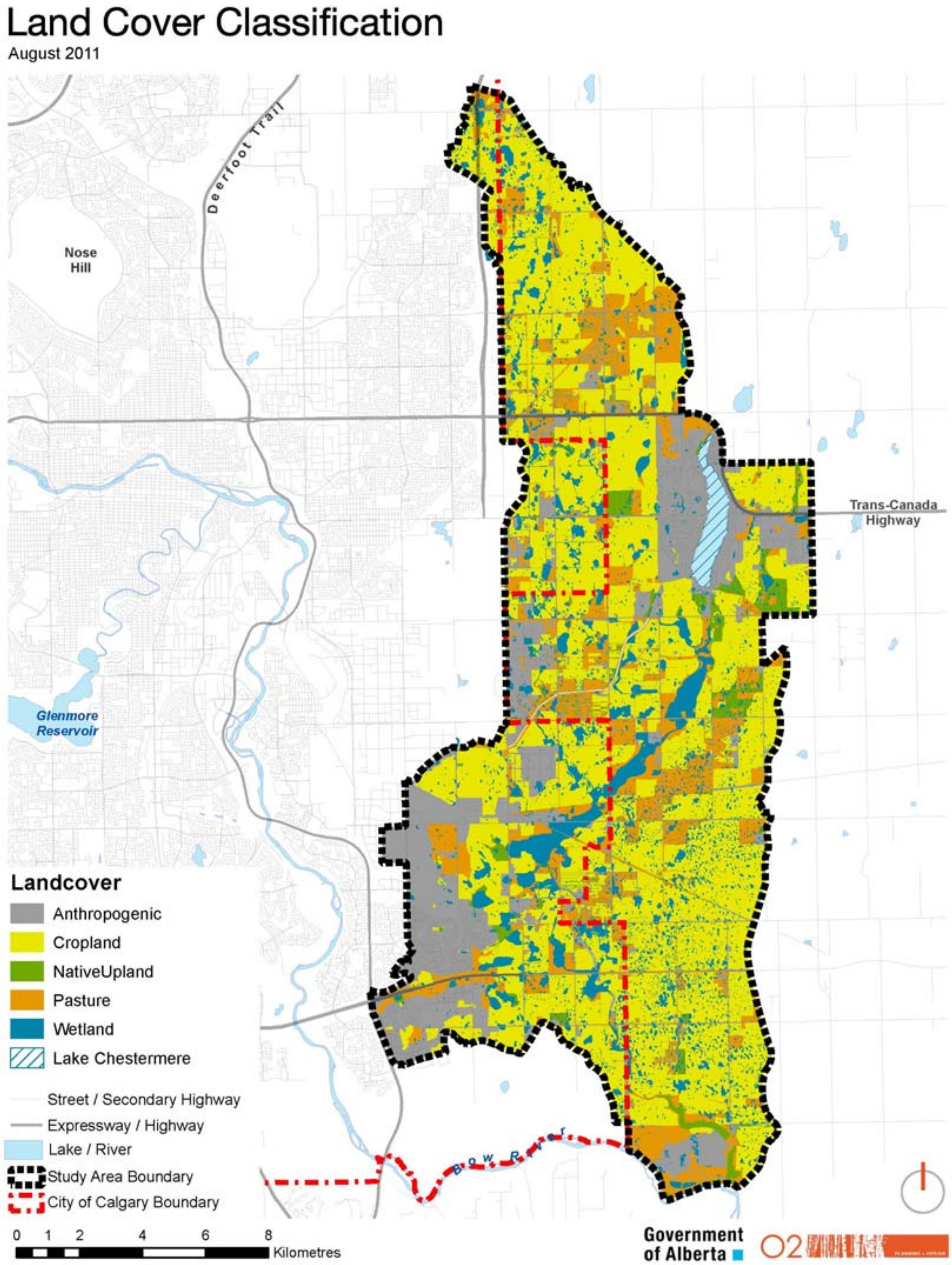
[1] However, metadata for the federal Geobase layer indicates that the layer is valid for circa year 2000 which will introduce some additional small errors for areas where Geobase has been applied

5. **Native Upland:** Assembled from the IDP 'Grassland - 3', 'Shrubland', 'Trees', and 'Coulee Complex' classes, supplemented by the GVI classes ‘Sub-irrigated’, ‘Overflow’, ‘Loamy’, ‘Limy, Sand’, ‘Blowouts / Solonetzic Order’, ‘Thin Breaks’, ‘Saline Lowland’, ‘Badlands/ Bedrock Bd’L classes, and the Geobase 'Shrubland', 'Shrub Tall', 'Herb', 'Grassland', and 'Barren/non-vegetated' classes.

Data Source Used to Generate Land Cover

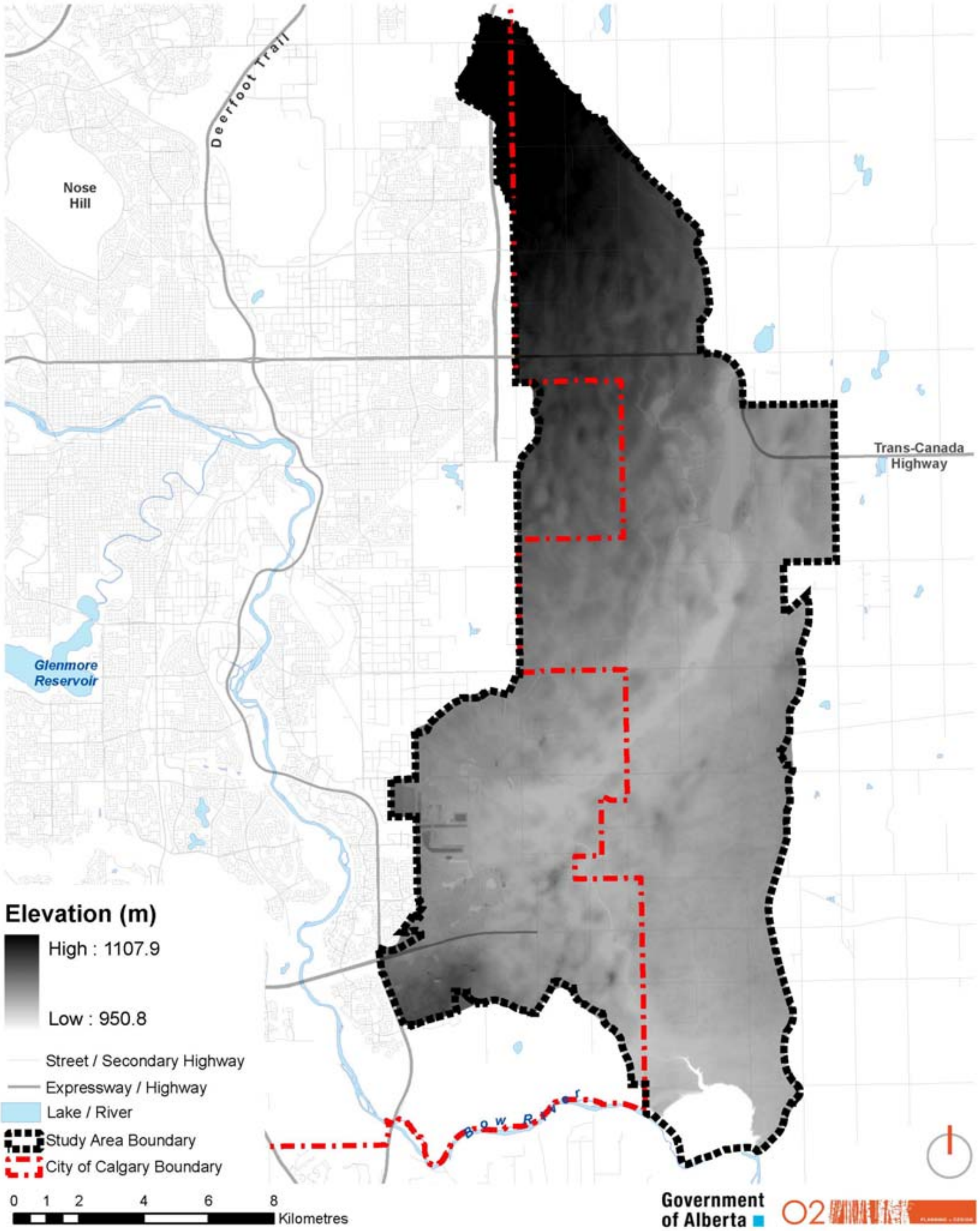
August 2011




Land Cover Classification
August 2011
Deerfoot Trail
Nose Hill
Glenmore Reservoir
Trans-Canada Highway
Bow River
Landcover
Anthropogenic
Cropland
NativeUpland
Pasture
Wetland
Lake Chestermere
Street / Secondary Highway
Expressway / Highway
Lake / River
Study Area Boundary
City of Calgary Boundary
0 1 2 4 6 8
Kilometres
Government of Alberta
O2

LIDAR Bare Earth Digital Elevation Model

August 2011



4.2 Delineating a Nested Hierarchy of Watersheds

Drainage basins or watersheds exist in a nested hierarchy of scales. When assessing wetland functions and services, it is useful to examine a range of scales. In particular, with flood control, highly localized flood control functions can also be linked to broader flood control services at other scales in the watershed hierarchy. For the purposes of this study, the nested hierarchy of watershed scales was provided a naming convention of “W1”, “W2”, “W3”, down to “W6”, with W1 being the broadest scale and W6 being the finest scale.

The broadest scales in the watershed hierarchy are too coarse for use in this study area, but provide the context within which the study area’s wetlands are situated. However, beneficiaries of wetland ecosystem services originating within the study area may be located in downstream portions of these broad-scale watersheds. From the national hydrographic network, the study area is situated within:

- **“W1”** Nelson-Saskatchewan system (drains to Hudson Bay)
- **“W2”:** Bow River watershed
- **“W3”:** Bow-Crowfoot

For the next scale lower in the watershed hierarchy **(“W4 Subwatershed”),** it was determined that The City of Calgary’s “storm subcatchments”, which are available for the entire study area, were appropriate units of analysis. These are defined based on both topography and major infrastructure such as the WH Canal and the Shepard Ditch. Note that in developed areas, several stormwater subcatchments were combined to provide comparable units of analysis. The result is a total of 14 W4 watersheds occurring within the study area.

The next scale lower in the watershed hierarchy (**“W5 Subwatershed”**) was based on the “Shepard Drainage Study Catchments” generated for the Shepard Drainage Plan area as defined by AECOM (2011). These were delineated based on LiDAR data inputs, and matched up fairly well with the W4 watershed boundaries as well as with major infrastructure such as the Shepard Ditch. The other advantage to using this data source was that it has been accepted by all three municipalities within the study area as an accurate representation for stormwater servicing and development planning purposes. A total of 242 W5 subwatersheds occur within the study area.

Finally, the finest scale in the watershed hierarchy **(“W6 Wetland Catchment”)** was based on LiDAR data inputs to generate *local* catchments for *each* wetland defined with relatively high accuracy. The use of WHITEBOX freeware was recommended for the finest scale local catchment delineation. As Dr. Irena Creed and her research group were very familiar with this software tool, her team conducted the local wetland catchment delineations using centroids for wetlands in both the current and drained Ducks Unlimited wetland shape file layers as the inputs. Due to data processing constraints, her method only delineated local catchments for wetlands larger than 0.1 ha. Full credit goes to Dr. Irena Creed for providing outputs for this level of catchment delineation. A total of 5,371 W6 watersheds occur within the study area.

5. WATER STORAGE ASSESSMENT

This section describes the methods applied, results, and ecosystem service beneficiaries for the water storage assessment. Section 5.1 summarizes the methods applied. Section 5.2 outlines the results. Section 5.3 provides the trend analysis assessment. Section 5.4 discusses potential beneficiaries of ecosystem services and potential next steps for the socioeconomics subtask team.

5.1 Methods Summary

All wetlands in the study area were assessed for water storage functions. The method applied to determine condition was to apply the 1m grid LiDAR data in combination with a rating curve. The time of LiDAR data acquisition for most of the study area was during very dry periods in late fall (October, 2007 and September, 2009); therefore, many wetlands were dry at the time of LiDAR acquisition, while many others had very low water levels. In these cases, there is an excellent opportunity to determine total above-ground water storage capacity within wetland boundaries using high resolution LiDAR data. Where a water surface *does* occur within wetlands during data acquisition, estimating total storage capacity of wetlands is more of a challenge as there is no accurate bathymetric data below the water surface, and collected LiDAR data on elevation depends on individual water levels at the time of acquisition. Therefore, to determine total water storage capacity of each wetland, two steps were taken:

1. *Existing water volume in wetland.* To evaluate the volume of water within an existing wetland, a calculation based on the estimated area of the water surface was used, after the method used for the Upper Assiniboine River Basin study ($V = 2850 * A^{1.22}$, where V is predicted water volume in cubic meters and A is area of the wetland in hectares) (Manitoba Conservation et al. 2000).

2. *Additional wetland capacity.* To assess the volume of the total capacity of the wetland when full, the maximum water level is calculated as the mean elevation of the boundary of the wetland. The volume calculation uses the difference between the maximum water level and the measured elevation at all points within the wetland, multiplied by the area of each individual pixel in the elevation raster.

Output data has been summarized according to grouped areas of interest, as well as size classes and Stewart-Kantrud wetland class where available[2].

Trends in wetland water storage were also estimated by running the water volume computer script described above based on those wetland boundaries present in 1965[3]. These boundaries were largely based on the Ducks Unlimited drained wetlands inventory, but also supplemented by information from the IDP and Geobase layers for those areas where major errors in the Ducks Unlimited 2005 inventory were detected. The difference between wetland water storage in 2005 vs. wetland water storage in

[2] Wetland water storage capacities in this report must be understood as the surface water storage *capacity* of a wetland. During dry periods, actual water stored in a wetland will be lower than the storage capacity.

1965 was then calculated. One limitation of this method is that detailed digital elevation data in 1965 is unavailable, and use of current LiDAR imagery introduces errors that would be more pronounced in areas of urban or industrial development.

5.2 Results

The total estimated wetland water storage capacity in the study area is 36.3 million m^3. To put this number into context, this is larger than the total storage capacity of the Glenmore Reservoir in south west Calgary (See Figure 5.1). Water storage capacities of individual wetlands are shown in the attached entitled "*H1: Wetland Storage Volume (cubic metres)*". Water storage capacities aggregated by The City of Calgary defined stormwater subcatchment areas are shown in the attached map "*Total Wetland Storage by W4 Subwatershed*".

Much of the total water storage capacity of wetlands is only full during spring, and drops considerably during summer, fall, and dry years. During the time of LiDAR data acquisition in the study area, the actual total wetland volume was only 14.3 million m^3.

Water storage capacities according to wetland sizes were also analyzed. Table 5.1 indicates water storage according to several wetland size class intervals. It is clear that, in the study area, most water storage occurs in just a few very large (>10 ha) wetlands. Although the vast majority of wetlands in the study area are very small (<0.1 ha), total storage capacity of these is only 3.2 per cent of the total amount. Wetlands between 0.1 and 1.0 ha account for over eight per cent of the total, which, although small, is higher than the combined total of all wetlands between 2 to 5 hectares, and is almost as high as the total of those wetlands between 5 to 10 hectares (Table 5.1). Therefore, from a cumulative effects perspective, small wetlands do perform significant functions when taken together as a whole.

Table 5.1. Water Storage in Study Area by Wetland Area Class Intervals

Variable	Wetland Area Class Intervals (ha)						
	<0.1 ha	**0.1-1 ha**	**1-2 ha**	**2-3 ha**	**3-5 ha**	**5-10 ha**	**>10 ha**
Total number in study area (n)	4647	1520	200	75	45	45	43
Mean volume (m^3)	248	1944	9010	17,776	31,490	68,476	571,849
Standard deviation of volume (m^3)	221	1393	5336	6726	11,266	31,024	1,223,217
Total volume in study area within size class (million m^3)	1151	2956	1802	1333	1417	3081	24,590
% of total study area volume	3.2%	8.1%	5.0%	3.7%	3.9%	8.5%	68%

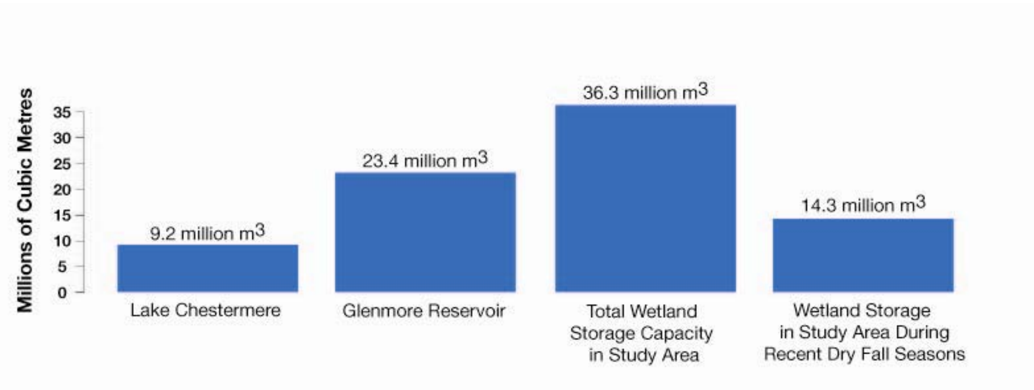
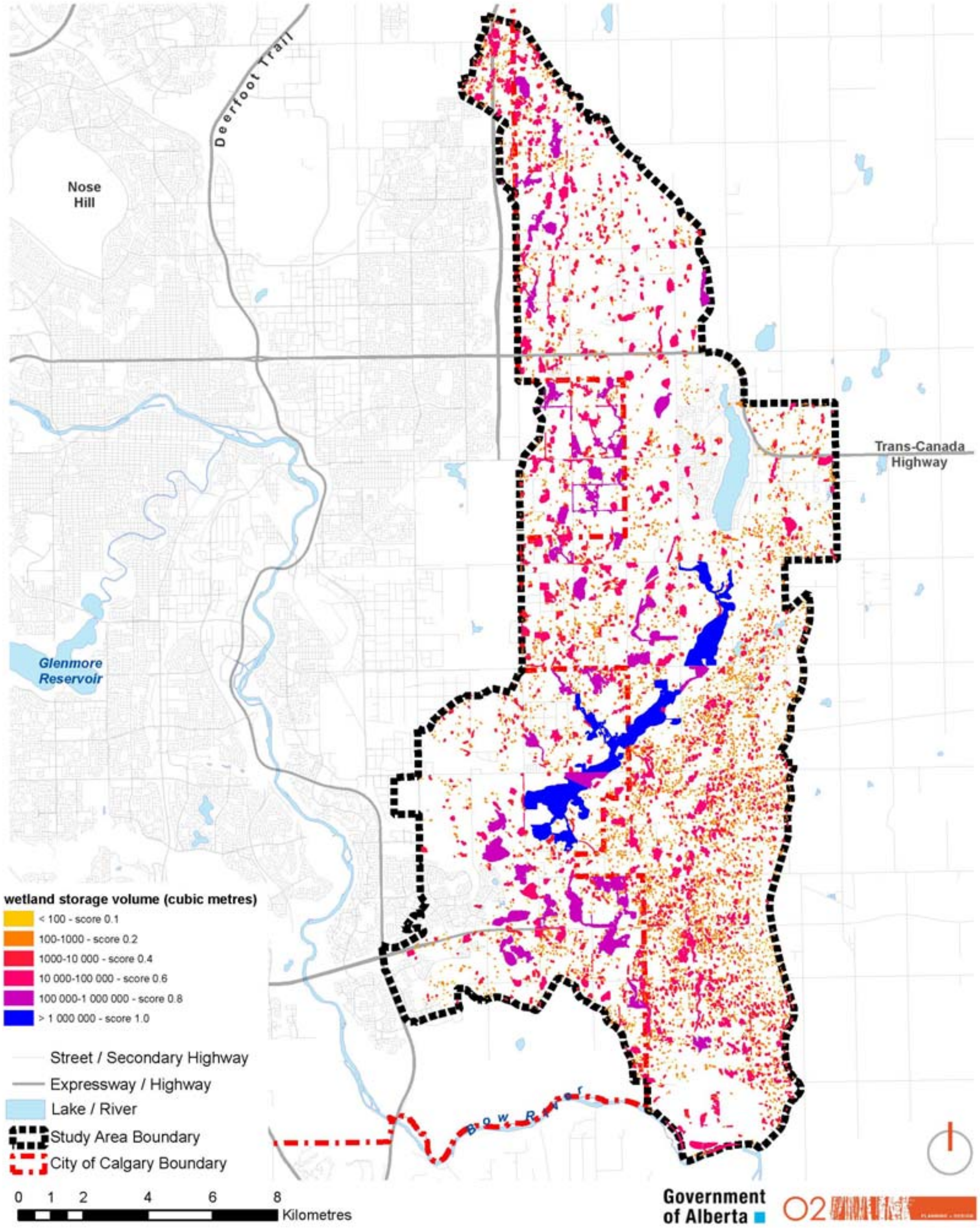


Figure 5.1. Study Area Wetland Water Storage + Comparison to Local Constructed Reservoirs

H1: Wetland Water Storage (cubic metres)

August 2011



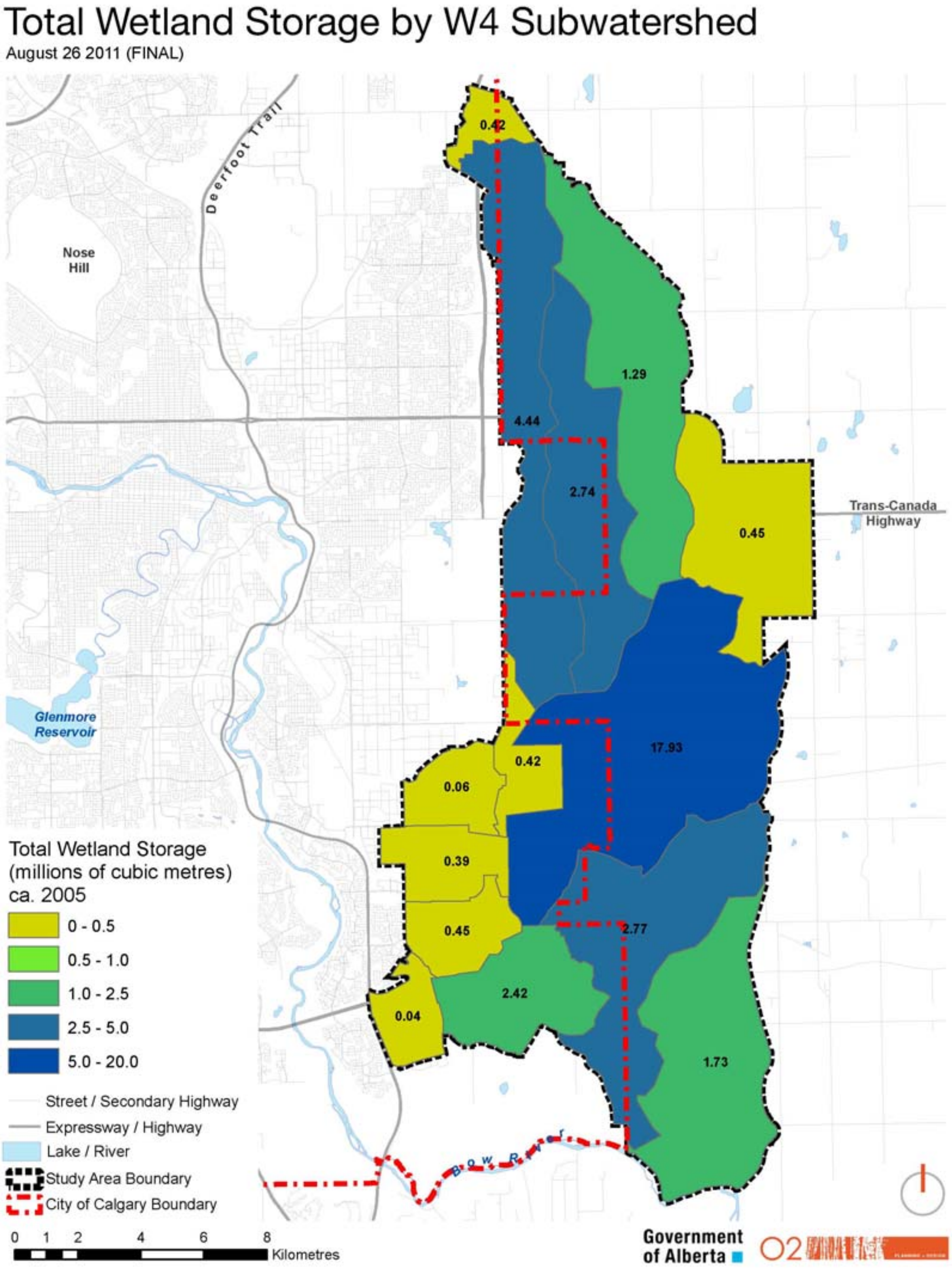

Total Wetland Storage by W4 Subwatershed
August 26 2011 (FINAL)
Deerfoot Trail
Nose Hill
Glenmore Reservoir
Trans-Canada Highway
Bow River
0.42
4.44
1.29
2.74
0.45
17.93
0.42
0.06
0.39
0.45
2.77
2.42
0.04
1.73
Total Wetland Storage (millions of cubic metres) ca. 2005
0 - 0.5
0.5 - 1.0
1.0 - 2.5
2.5 - 5.0
5.0 - 20.0
Street / Secondary Highway
Expressway / Highway
Lake / River
Study Area Boundary
City of Calgary Boundary
0 1 2 4 6 8 Kilometres
Government of Alberta
O2

Figure 5.2 below shows a scatterplot (log linear scale) of volume vs. area. Figure 5.3 shows box plots for water storage by wetland area class. Clearly, wetland area has a direct relationship with wetland storage capacity. In addition, the log linear relationship shown in Figure 5.2 indicates that large wetlands have a disproportionately larger capacity to store water, on a per area unit basis, compared to smaller wetlands. However, it should still be stressed from a cumulative effects perspective that many small wetlands will still add up to the same overall water storage function as one large wetland.

Statistics were also calculated for those wetlands in the study area where Stewart-Kantrud wetland classes were available from other studies. However, it must be understood that wetlands with no available S-K classification account for 40 per cent of total wetland storage in the study area (Table 5.2). Figure 5.4 also shows box plots for water storage by Stewart-Kantrud wetland class.

Table 5.2. Water Storage in Study Area by Stewart-Kantrud Wetland Class

	Stewart-Kantrud Wetland Classification (where available)					
Variable	**Class I**	**Class II**	**Class III**	**Class IV**	**Class V**	**Unknown/ Missing**
Sample size (n)	253	207	151	131	26	5799
Mean volume (m^3)	1192	1924	10,597	56,085	24,732	4485
Standard deviation of volume (m^3)	4145	4367	55,487	295,157	66,702	-
Estimated % of total volume in study area	1%	2%	6%	28%	3%	60%

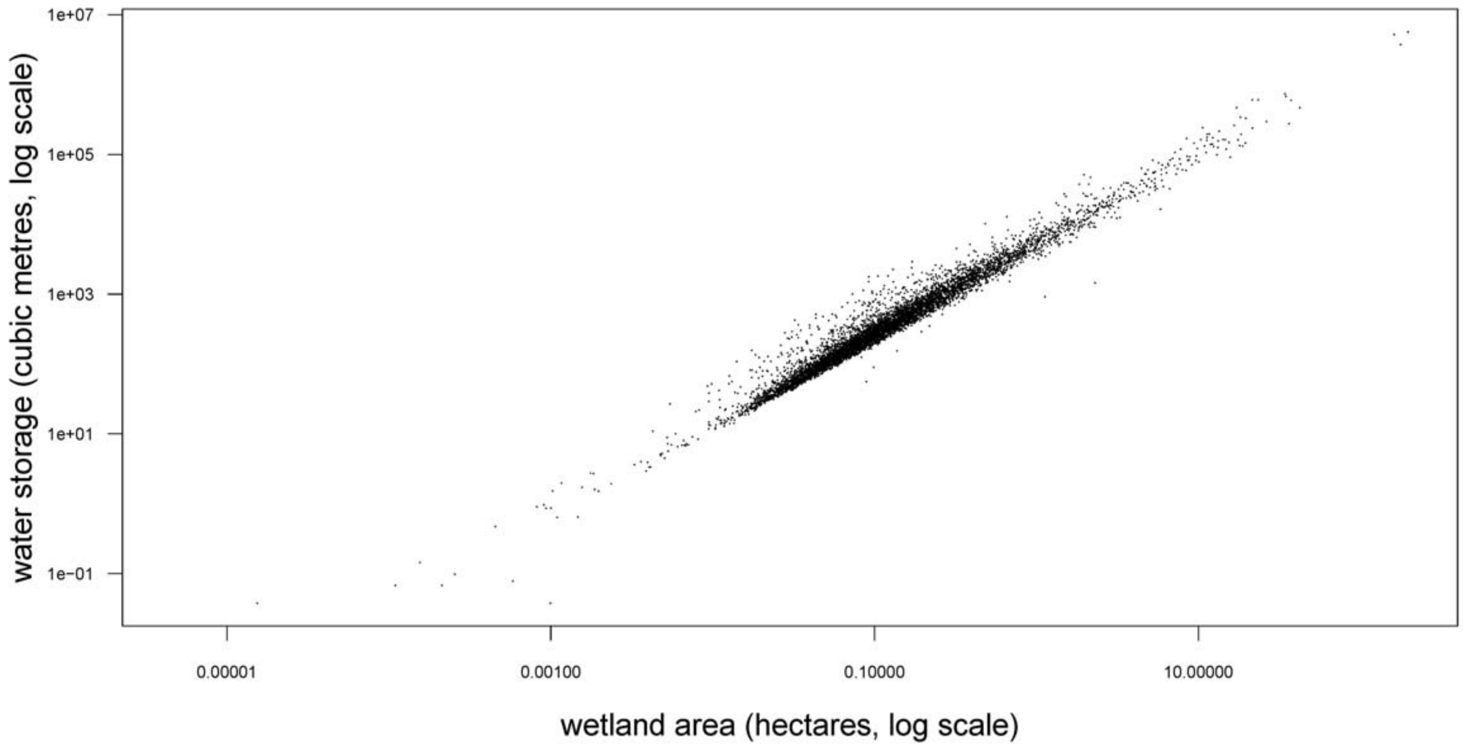


Figure 5.2. Relationship between water storage volume and wetland area (log scale)

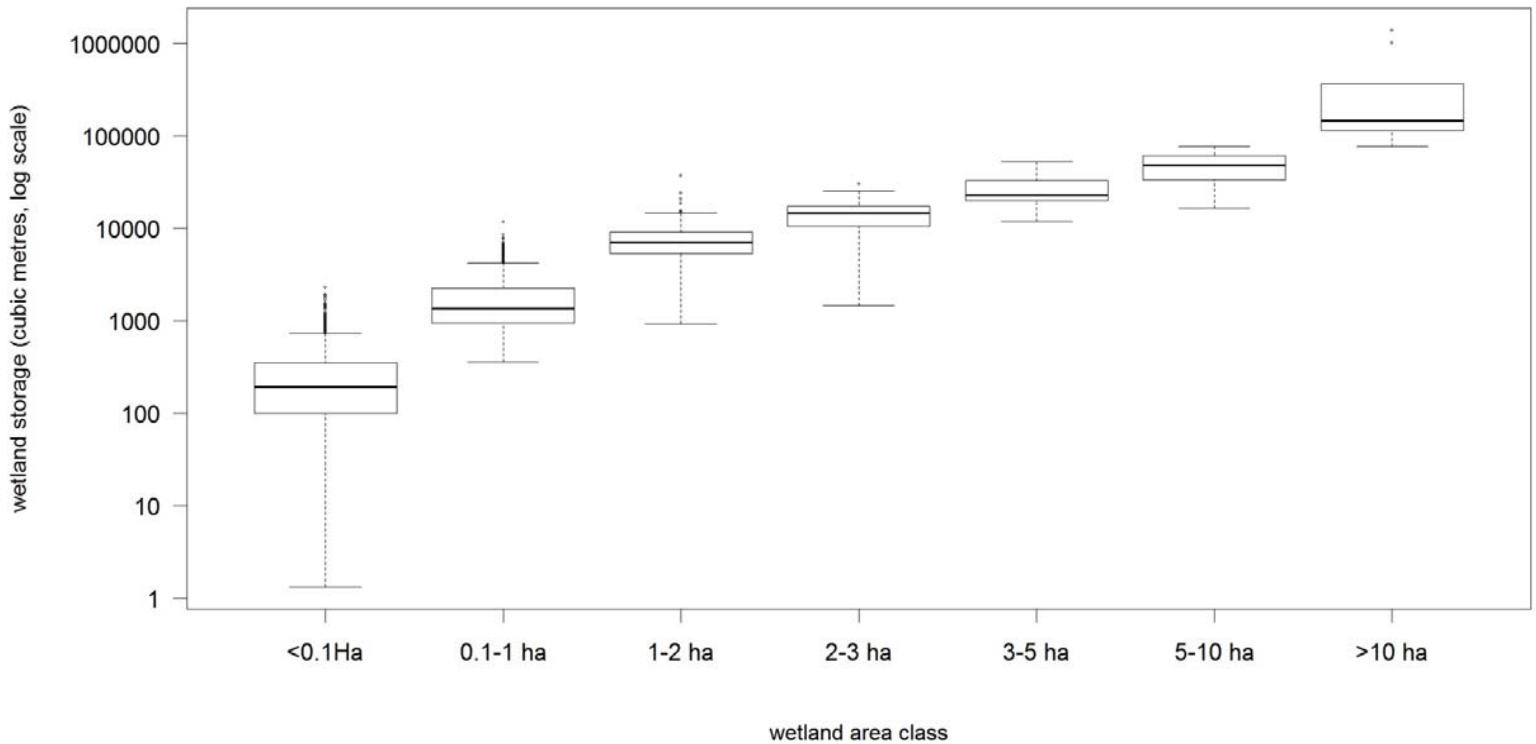


Figure 5.3. Box plots of wetland storage by wetland area

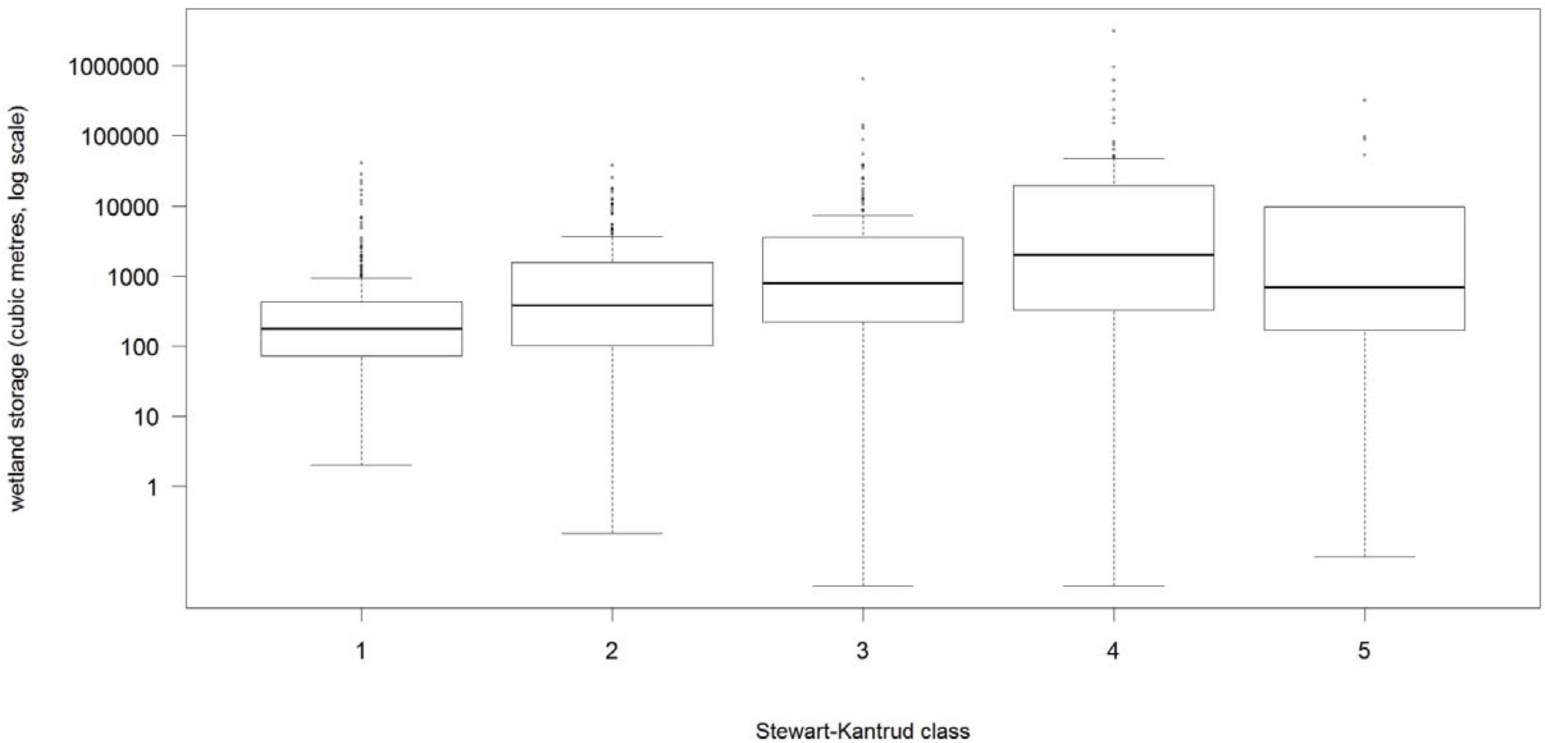


Figure 5.4. Box plots of wetland storage by Stewart-Kantrud wetland class

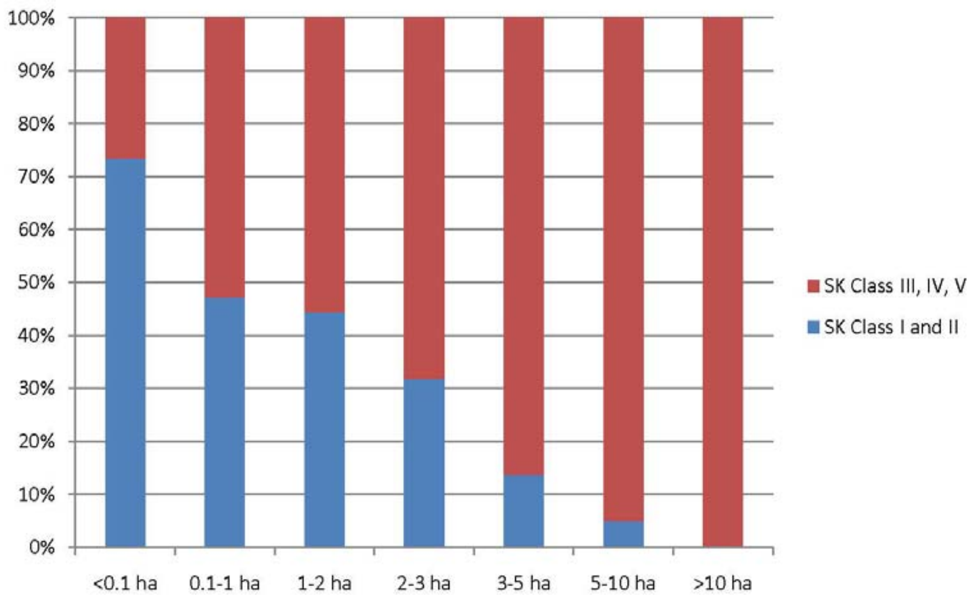


Figure 5.5. Relationship between Wetland Area and Stewart-Kantrud Wetland Class

For interest's sake, the relationship between area and Stewart-Kantrud Class where available is shown in Figure 5.5. Notably, the vast majority of wetlands smaller than 1 ha are likely to be either Class I or Class II wetlands. It is also the case that most of the unknown/missing values for wetland class are smaller than 1 ha in size (Table 5.2). Therefore, it should not necessarily be concluded that Class I and II wetlands have negligible water storage capacity functions, as such wetlands can provide substantial water storage when regional cumulative effects are considered.

5.3 Trend Analysis

A trend analysis of wetland storage capacity was conducted by determining the amount of storage capacity lost from 1965-2005 due to wetland drainage.

Using the available data and methods, the estimated total storage capacity lost due to wetland drainage over the 1965-2005 time period is 9.2 million m^3. Water storage capacity in 1965 was calculated as 45.5 million m^3. This represents a 20 per cent decrease in available water storage capacity in the study area over this time frame. Areas where Ducks Unlimited identified drained wetlands are also shown on the map "*Area of Drained Wetlands (1965-2005)*". In addition, the map "*Change in Waters Storage by W4 Subwatershed"* shows total losses of storage capacity due to wetland drainage over 1965-2005 in each storm subcatchment at the W4 subwatershed scale.

It should be noted that climate trends have the potential to confound a trend analysis of wetlands. Ducks Unlimited does attempt to control for climate variability in its wetland assessments by selecting dates within periods of similar climate trends, as well as looking for ancillary evidence of drainage using 3D stereo imagery (Lyle Boychuk, personal communication). The 1960-1965 period clearly shows very comparable climate trends as the period 2000-2005 (see Figure 5.6 showing a graph of P-PET over time). 1960 and 1961 were slightly drier than average, 1962 was much drier than average, 1963 and 1964 were slightly drier than average, and 1965 (the year of assessment) was wetter than average. Very similarly, 2000 was slightly drier than average, 2001 was much drier than average, 2002 was drier than average, 2003 and 2004 were slightly drier than average, and 2005 was wetter than average.

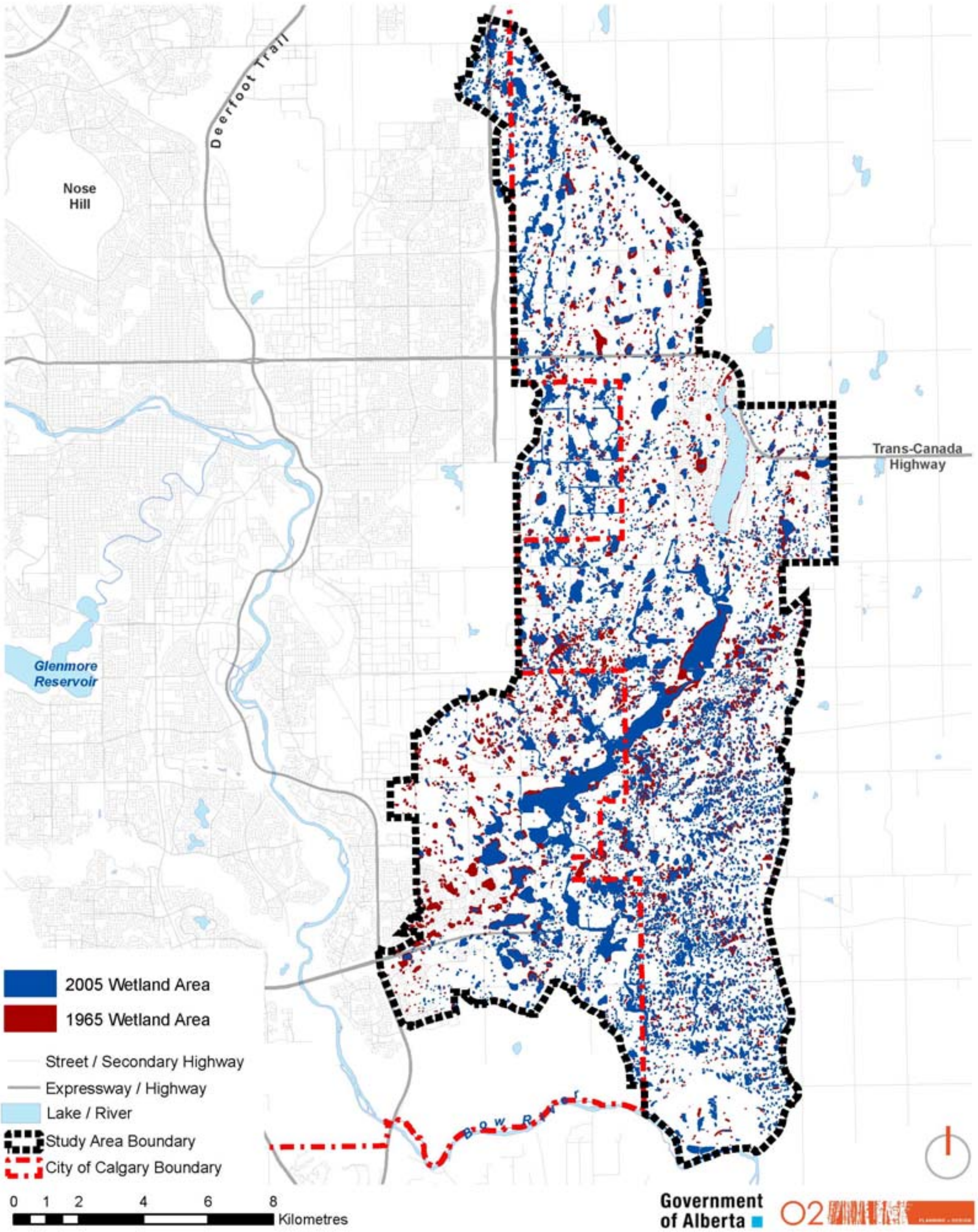
Trends in losses of wetland storage capacity from the map show hotspots of wetland storage loss. Although these occur in many parts of the study area, notable hotspots include:

- Wetlands that historically occurred in The City of Calgary, but are no longer present in the southwest corner of the study area;
- An 11 ha wetland that used to occur along the Shepard Ditch just south of the large Shepard Slough complex inside Rocky View County, which appears to have been drained during Shepard Ditch upgrades sometime during the trend analysis period;
- A large wetland within The Town of Chestermere;
- Several wetlands along the 84th St. industrial corridor north of Shepard; and
- Several wetlands east of the Hamlet of Janet on the east side of the Janet Slough complex.

The map "*Change in Wetland Storage 1965-2005 by W4 Subwatershed"* indicates that losses in wetland water storage were concentrated in the central Shepard Slough areas, although major changes were also observed on the western margins where new City of Calgary subdivisions have been built. One smaller catchment actually showed a small increase in water storage overall. The small increase of approximately 30,000 m^3 in the northernmost catchment may be related to the recent installation of some compensation wetlands with high storage volumes.

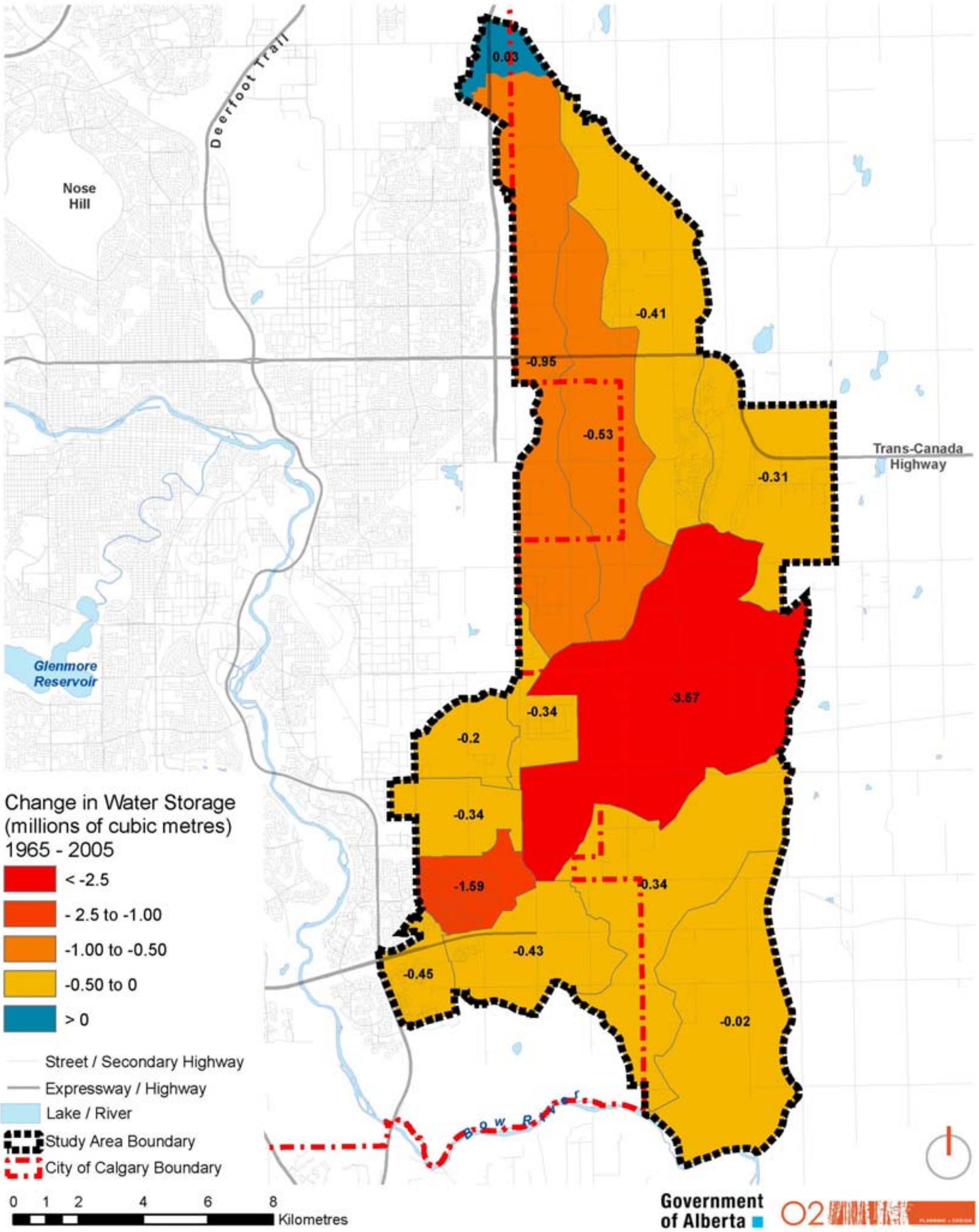
Area of Drained Wetlands (1965 - 2005)

August 2011



Change in Water Storage by W4 Subwatershed

August 26 2011 (FINAL)



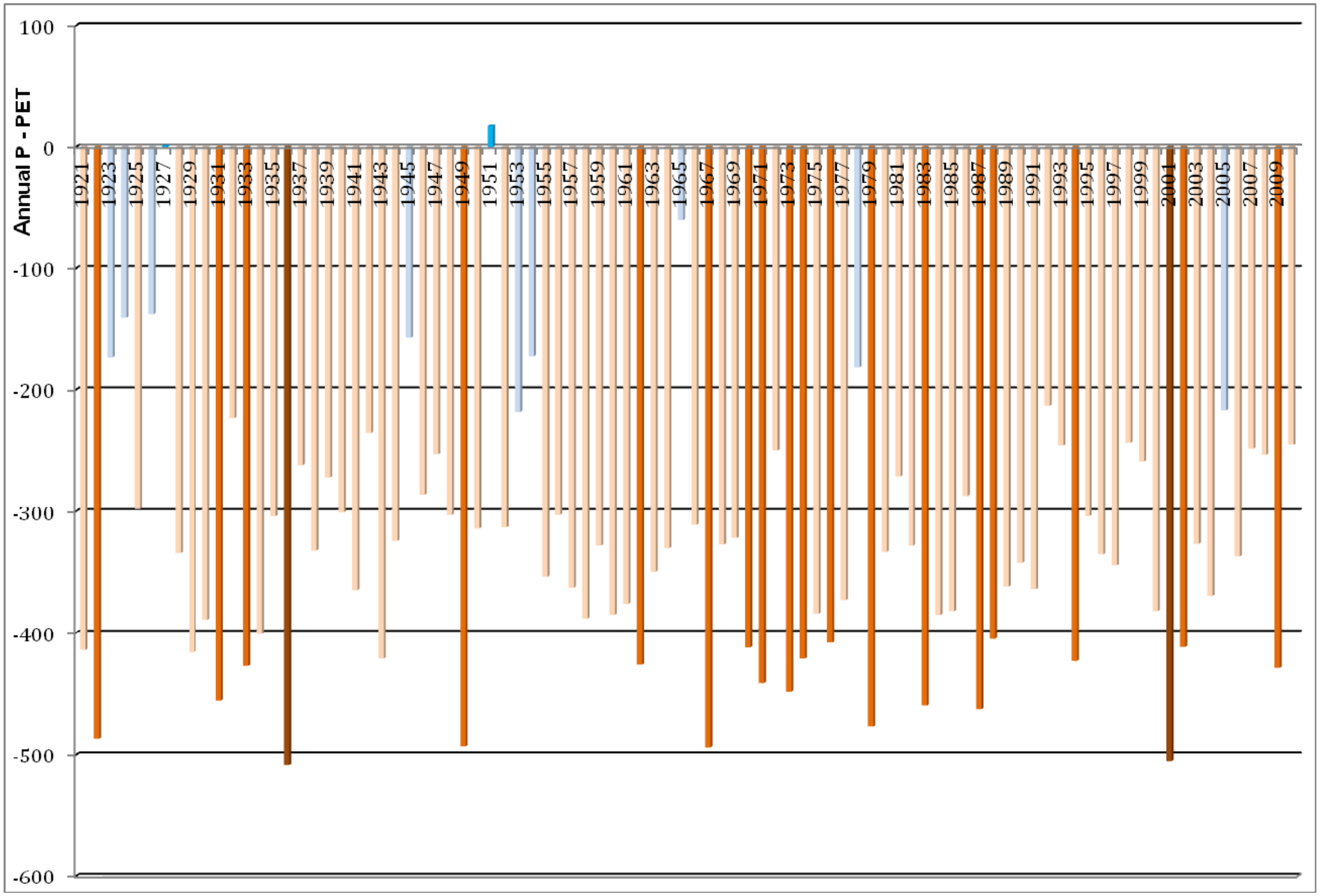


Figure 5.6. Index of Annual Average Wetness / Dryness in Calgary: Precipitation-Potential Evapotranspiration (PET): 1921-2010

Precipitation data from Environment Canada; PET data based on available empirical data by ESRD Hydrology Branch

5.4 Discussion of Ecosystem Services and Beneficiaries

Several potential beneficiaries of wetland water storage and supply services were assessed as below.

5.4.1 Supporting and Regulating Services

Supporting and regulating ecosystem services are essential components provided by water storage in wetlands. Without local water storage, all other wetland-related ecosystem services would not be present. Therefore, water storage is perhaps the most critical ecosystem service of wetlands.

5.4.2 Provisioning Services: Water Licenses and Wetlands

Direct use of water in prairie wetlands is uncommon, as wetland water quality generally has taste and odour issues and in some cases presents health concerns due to faecal coliforms or cyanobacterial toxins (CAESA 1998; AARD 2002). However, some wetlands may still supply water for domestic, commercial, industrial, or agricultural uses. In some cases wetlands also indirectly supply water through water storage during the wet season and a gradual release downstream during the dry season. This process can provide a natural ecosystem service of water storage and supply.

However, no major users of wetland water supply occur in the study area, either directly or indirectly. Urban developments in The City of Calgary are on piped water supplies from the Bearspaw and Glenmore reservoirs far upstream from the study area. Residential areas in the Town of Chestermere are on piped regional water supply from The City of Calgary. Virtually all residential and industrial developments within Rocky View County, including the hamlet of Conrich and 84th St. industrial zones, obtain water from groundwater wells in deep sandstone aquifers with little to no connection to surface waters. Study area wetlands do not provide irrigation water supplies; the Western Irrigation District (WID) obtains water from the Bow River just downstream from the confluence with Nose Creek.

Alberta Environment and Sustainable Resource Development water licensing data was analyzed in GIS. *Only a few water licenses occur in the study area, and none of these intersect directly with wetlands although some are close to wetlands.* The map titled "*Surface Water Licenses and Potential Associated Wetlands*" summarizes the analysis of water licensees in the study area:

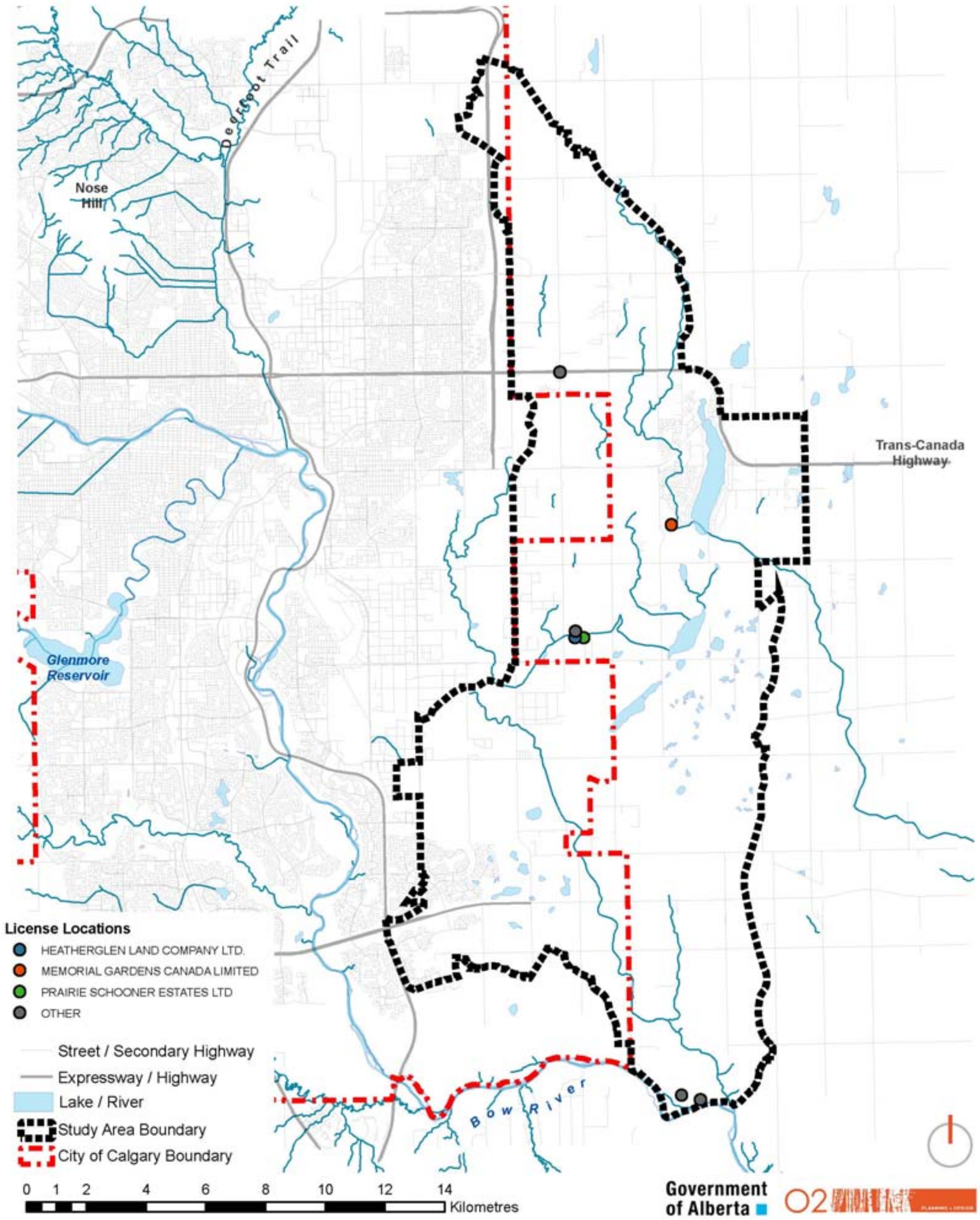
- The largest *potential* indirect user of wetland water supply is Memorial Gardens Canada Ltd. However, the location of the Memorial Gardens Canada Ltd. Mountain View Cemetery is suspiciously several km northwest of the location of the license in the water licensing data. Further investigations are necessary to determine whether this stakeholder is actually using wetland water storage or not. If they are using the water license at the location, it is highly likely that the stream from which they draw water is supplied to some extent by hydrologically connected wetlands upstream. Their license allocation (but not necessarily usage) is 74,000 m^3/ year.

- Prairie Schooner Estates Ltd., a country residential subdivision of about 30 housing units, has a maximum licensed annual diversion rate of 37,000 m^3 for commercial use. It is speculated that this volume is for open space and tree/shrub irrigation. However, it is also unclear exactly where their water comes from and whether wetlands play a significant role or not.
- Heather Glen Land Company Ltd., which operates the Heather Glen Golf Club, has a maximum licensed diversion rate of 96,679 m^3 for commercial use. This volume seems to be the correct amount required for irrigation of a golf course of this size. However, it remains unclear where their water comes from and whether wetlands play a significant role or not.
- The Lutheran Church of Canada along 17th Ave. has a surface water license from a "tributary to surface runoff" of 12,335 m^3 for municipal use. However, this does not appear to be related to wetlands.
- The largest water licenses are for aggregate mining operations in the Bow River Valley, which draw water directly from the Bow River and have no relationship to study area wetlands.

Comment [G1]: Do we have permission to mention these companies in this report?

Surface Water Licenses and Potential Associated Wetlands

August 2011



5.4.3 Provisioning Services: Livestock Watering and Wetlands

Cattle are almost certainly the most common user of wetland water storage and supply in the study area. A large proportion of cattle may drink from wetlands, including dugouts as well as other wetlands. Cattle use of wetland water storage was estimated as follows:

- Agriculture Canada soil landscape unit 798002 (NLWIS 2011), which includes the study area, has a total cattle number of 115,624 over 2,500 km^2, which is a density of 45 cattle/ $km^{2;}$
- Cattle were assumed to occur at the same relative density on that portion of the study area that has not been developed to residential, commercial, or industrial uses (214 km^2 total);
- Consequently the estimated total cattle in the study area is:
  45 cattle / km^2 x 214 km^2 of non anthropogenic land cover=9,600 cattle;
- Average water consumption of beef cows ranges from 38 to 45 L/day, which is roughly equivalent to an estimated average value of 15 m^3/year (BCMAL 2006);
- Therefore, the total water demand of cattle in the study area is approximately:
  9,600 x 15 m^3=144,000 m^3 / year;
- It is unknown what proportion of cattle water requirements are met by wetlands vs. other sources (groundwater, streams), so the true value will be some fraction of the above calculated value, although it is clear that cattle do use local wetlands (Figure 5.7); and
- It should also be stressed that cattle use of wetlands is not always desirable and may degrade other ecosystem services. The "Cows and Fish" program in Alberta has been promoting cattle watering systems such as nose pumps to conserve riparian and wetland health for many years.

Horses and other livestock may also use water storage for drinking. Due to the generally high socioeconomic value of horses in Alberta, a similar calculation was done for horses as follows:

- Agriculture Canada soil landscape unit 798002 that includes the study area has a total horse number of 2,157 horses over 2,500 km^2 or 0.86 horses / km^2, which is:
  0.86 horses / km^2 x 214 km^2 of non anthropogenic land cover=184 horses;
- Assuming similar water consumption of horses as for cattle, which is reasonable (NDSU 1999), total water demand of horses in the study area is approximately:
  184 x 15 m^3/ year =2,760 m^3 / year;

Figure 5.7. Cattle drinking from a wetland east of Calgary *(Credit: G. Roman, O2)*

5.4.4 Provisioning Services: Crop and Hay Production

Ephemeral and temporary wetlands are often cultivated for crop production. The enhanced soil moisture within these wetlands can enhance crop yields, particularly in dry years. Subsurface storage of water is a crucial determinant of crop yields the following growing season (Schroeder and Bauer 1984). Hay production within wetlands is also common, particularly in the low prairie and wet meadow zones of all wetland types. However, agricultural production within wetlands may impact other wetland functions and values. In addition, it is also often the case that excessive moisture in spring as well as wetland soils high in clay may work against water availability to actually reduce crop yields in cultivated wetlands.

Crop and hay in surrounding upland vegetation may also benefit from shallow groundwater movement out of wetlands into surrounding upland vegetation in a buffered fringe surrounding the wetland (Schroeder and Bauer 1984; Gilbert et al. 2006). This may also benefit trees and shrubs in addition to crop and hay. The distance of the active fringe zone where wetlands strongly influence upland water supplies and storage is difficult to determine, and requires more thorough research prior to applying an adequate buffer distance for GIS measurement purposes. Closer involvement of Alberta Agriculture and Rural Development staff and ideally producers as well will help with coming up with reasonable and acceptable assumptions.

However, saline wetlands on the contrary may not benefit hay and crop production. Therefore, when measuring potential benefits of wetlands to upland water balances, water quality within wetlands should be considered using geospatial information on salinity (e.g., salinity 10TM layer and/or AGRASID soils layer and/or MacMillan 1987 soils layers do have some information on salinity of wetlands).

6. FLOOD CONTROL ASSESSMENT

This section describes the methods applied, results, and ecosystem service beneficiaries for the flood control assessment. Section 6.1 summarizes the methods applied. Section 6.2 outlines the results. Section 6.3 provides the trend analysis assessment. Section 6.4 discusses potential beneficiaries of ecosystem services and potential next steps for the socioeconomics subtask team.

6.1 Methods

The modelling approach for this indicator is largely based on the Cobbaert et al (2011) Industrial Heartland GIS model. Several modifications and improvements have been made to account for study area characteristics as well as to help improve the scaling of the relationship of the indicator to actual peak flow (m^3/s) reductions. The information below provides a summary of the approach for modelling flood control ecosystem services using a GIS-based indicator approach. Predictor variables H1 to H7 are described below, maintaining general consistency with the labeling of Cobbaert et al. (2011). More detailed step-by-step GIS processing instructions will also be adapted/created for the study area and included as GIS metadata.

6.1.1 H1. Water Storage Capacity

The first predictor variable is based on the fact that a wetland with a larger water storage capacity will provide much more flood attenuation than a small wetland with less storage capacity. Therefore, values calculated for water storage capacity in section 5.0 above were also used for the flood control assessment. However, these were rescaled into intervals for the purposes of the assessment as follows:

- >1,000,000 m^3 (1.0)
- 100,000 – 1,000,000 m^3 (0.8)
- 10,000 – 100,000 m^3 (0.6)
- 1,000 – 10,000 m^3 (0.4)
- 100-1,000 m^3 (0.2)
- <100 m^3 (0.1)

The map "*H1 Water Storage Volume in Cubic Metres*" presented in Section 5 shows H1.

6.1.2 H2. Wetland Catchment (W6) Impervious Surfaces

Impervious surfaces cause significantly greater runoff than vegetated areas, because infiltration and evapotranspiration are prevented or inhibited. Consequently, impervious surfaces in a catchment tend to result in higher and more rapid peak discharge (Figure 6.1) (Schueler 1992).

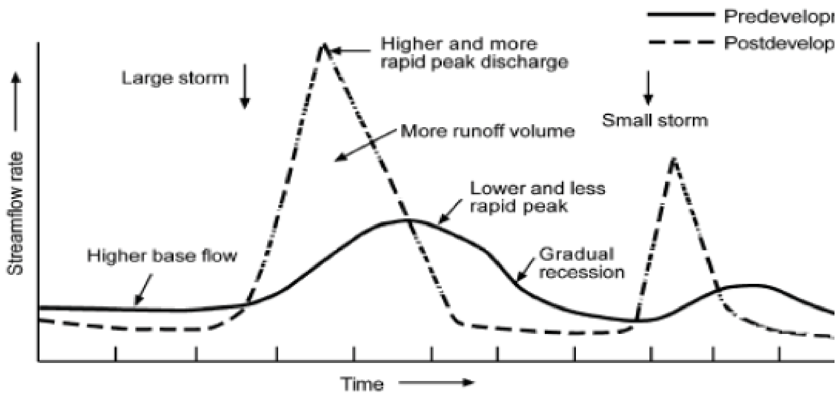


Figure 6.1. Changes in hydrology due to urbanization and impervious surfaces *(Schueler 1992)*

Therefore, a wetland within a watershed composed primarily of impervious land cover types will have the opportunity to mitigate the flood wave coming off impervious areas upstream. Although it is possible that this predictor variable is more applicable to areas with a stream network, it is also the case that stormwater drainage systems exist in the area and more are planned for the future (AECOM 2011). Therefore, it was decided that this predictor variable can still be included and that the rationale is still valid. However, it should also be noted that increased water inputs to a wetland from developed impervious surfaces typically leads to water quality degradation and reduced use by wildlife.

Impervious surface values assigned to different land cover types based on the extensive statistical analysis conducted by O2 for The City of Calgary (O2 2009). Mean values include:

- Industrial land use: 79 per cent impervious;
- Urban residential communities, including typical distribution of roads, buildings, municipal reserve, schools, and commercial buildings: 61per cent impervious; and
- Country residential land uses, though not part of the City of Calgary study, were assigned an impervious value of approximately 20 per cent which is consistent with a typical country residential community.

The map entitled "*H2: Percentage of Impervious Surface in W6 catchment"* displays the results for this variable. Scores assigned for this criterion were based on a modification of Cobbaert et al. (2011), using documented values related to imperviousness, peak flows, and watershed dynamics (CWP 2001; Leitao et al. 2006) that in turn are based on a synthesis of a large body of research as follows:

- >25 per cent of the wetland catchment (W6) is made up of impervious surfaces (1.0)

- 10-25 per cent of the wetland catchment (W6) is made up of impervious surfaces (0.8)
- 1-10 per cent of the wetland catchment (W6) is made up of impervious surfaces (0.5)
- <1 per cent of the wetland catchment (W6) is made of impervious surfaces (0.1)

In the future, if similar exercises are done, a linear scaling factor could also be developed and applied as opposed to intervals. Average curve numbers based on the catchment land cover, including different values assigned to pasture vs. cropland, could also be developed in future editions as per Gilbert et al. (2006).

6.1.3 H3. Wetland Catchment: Wetland Ratio

The rationale for this predictor is that more runoff will enter a wetland from a large watershed than a small watershed; therefore, a wetland with a proportionately larger local catchment will have a greater opportunity to store water and desynchronize flood flows (Adamus et al. 1991; Cobbaert et al. 2011). If wetland size is held constant as watershed size increases, the opportunity for the wetland to perform this function also increases because of the increased runoff amount entering the wetland. Scores assigned to this variable included:

- Wetland catchment (W6): wetland area ratio is > 20 (1.0)
- Wetland catchment (W6): wetland ratio is 4 to 20 (0.6)
- Wetland catchment (W6): wetland ratio is < 4 (0.1)

The map entitled "*H3: Catchment to Wetland Area Ratio"* shows the results for this predictor variable. In the future, this method could be improved by applying a linear scaling function as opposed to fixed intervals.

6.1.4 H4. Amount of Wetland Subwatershed (W5) Comprised by Upslope Wetlands

The rationale for this predictor is that the wetland's opportunity to perform flood flow alteration will be reduced if upslope wetlands have already performed this function to a significant degree during flood events (Adamus et al. 1991).

The method applied was to calculate the area of upslope wetlands (higher elevation) in the wetland's W5 subwatershed, as a proportion of the total wetland area in that W5 subwatershed. The map "*H4: Amount of Upslope Wetlands in W4 Subwatershed"* shows the results for this variable.

Values assigned to this were based on Cobbaert et al. (2011) including:

- Upslope wetlands comprise < 5% of the wetland's W5 subwatershed (1.0)
- Upslope wetlands comprise 5 to 10% of the wetland's W5 subwatershed (0.7)
- Upslope wetlands comprise 10 to 15% of the wetland's W5 subwatershed (0.3)
- Upslope wetlands comprise > 15% of the wetland's W5 subwatershed (0.1)

6.1.5 H5a. Wetland Position in the W5 Subwatershed

This predictor accounts for a wetland's landscape position by selecting those wetlands located in a subwatershed's more upper reaches. Headwater wetlands will tend to desynchronize flood flows more than wetlands located in the lower reaches of the watershed. If headwater wetlands are lost, flooding will be exacerbated because local runoff to wetlands in the lower reaches of the watershed can be synchronized with the arrival of surface flows from higher in the watershed (Adamus et al. 1991).

The method applied was to categorize the wetland's position within defined W5 subwatersheds into quartiles based on the LiDAR elevation. The map entitled "*H5a: Wetland Position in the W5 Subwatershed"* shows the results for this variable. Scores were applied as follows:

- Wetland occurs in upper quarter of the wetland's W5 subwatershed (1.0)
- Wetland occurs in the third quarter of the wetland's W5 subwatershed (0.7)
- Wetland occurs in the second quarter of the wetland's W5 subwatershed (0.3)
- Wetland occurs in the lowest quarter of the wetland's W5 subwatershed (0.1)

6.1.6 H5b. Wetland Position in the W4 Subwatershed

It was also felt that wetland contribution to flood control at multiple scales in the watershed hierarchy should be considered. Therefore, similar as for H5a, the wetland position in the W4 watershed within the region at a broader scale in the hierarchy was also considered. The rationale is similar, that headwater wetlands will tend to desynchronize flood flows more than wetlands located in the lower reaches of the watershed. If headwater wetlands are lost, flooding will be exacerbated because local runoff to wetlands in the lower reaches of the watershed can be synchronized with the arrival of surface flows from higher in the watershed (Adamus et al. 1991).

The method applied was to categorize each wetland's position within defined W4 watersheds into quartiles of the watershed based on the LiDAR elevation. The map entitled "*H5b: Wetland Position in the W4 Subwatershed"* shows the results for this variable. Scores were assigned as follows:

- Wetland occurs in upper quarter of the wetland's W4 subwatershed (1.0)
- Wetland occurs in the third quarter of the wetland's W4 subwatershed (0.7)
- Wetland occurs in the second quarter of the wetland's W4 subwatershed (0.3)
- Wetland occurs in the lowest quarter of the wetland's W4 subwatershed (0.1)

6.1.7 H6. Wetland Connected to Surface Waters Through Natural or Artificial Drainage Systems

A wetland without a permanent outlet will store most precipitation or runoff that enters it, preventing the water from entering the stream network and increasing flood flows. Any reduction in flow from a wetland to the surface water network will facilitate desynchronization (Cedfeldt 2000).

The methods applied to determine whether a wetland was connected to natural or artificial drainage systems was to:

- Identify wetlands that intersect any of the identified streams in the ESRD Strahler stream order database;
- Identify wetlands connected to the available City of Calgary stormwater infrastructure vector data (drains/ponds);
- Identify wetlands completely surrounded by urban land cover (e.g., within Town of Chestermere) (it was assumed that these must be connected to stormwater infrastructure given lack of storm engineering vector data available from the Town of Chestermere); and
- Identify historical wetlands in the Ducks Unlimited drained wetlands inventory that are currently more than four times smaller than they were in 1965, which provides a strong indication that drainage from outlet construction or tile drain installation has occurred.

The results of this assessment are shown in the map "*H6: Wetland Connection to Surface Waters".* Scores were assigned as follows:

- Wetland is isolated with no outflows, may have inflows (1.0)
- Wetland is connected to surface water network with a natural or artificial outflow (0.1)

6.1.8 H7. Subsurface Storage Potential Based on Groundwater Vulnerability Measures

Areas where soil and surficial geology are highly permeable also tend to be areas of high groundwater vulnerability. Therefore, more vulnerable areas are associated with potentially very large subsurface water storage capacities that may play an important role in flood control. Therefore, it makes sense to include information on groundwater vulnerability as a predictor variable for the flood control ecosystem service indicator.

Although groundwater vulnerability maps in other portions of the province such as the Industrial Heartland have been based on a scale from 23 to 230, in the study area only the categories "Low" and "Medium" occur, with a small portion of "Very High" occurring in the Bow River Valley. Methods applied to the context of the study area were as follows and results are shown in the attached map "*H7*: *Groundwater Vulnerability"*:

- Groundwater vulnerability underlying wetland is very high (1.0)
- Groundwater vulnerability underlying wetland is high (0.7) (note: this category does not occur within the study area)
- Groundwater underlying wetland is medium (0.3)
- Groundwater underlying wetland is low (0.1)

6.1.9 Combining Predictor Variables (H1 to H7) for the Flood Control Indicator

Cobbaert et al. (2011) applied equal weightings to each of the predictor variables H1 to H7. Many different ways of combining the predictor variables were explored and compared with one another by staff at O2. The final flood control indicator value was based on the most direct and simple way of combining the variables as a simple weighted average as follows:

$$\textit{Wetland Index of Flood Control} = \frac{H1 + H2 + H3 + H4 + H5a + H5b + H6 + H7}{8}$$

6.2 Results

Maps have been created for each predictor variable (H1, H2, H3, H4, H5a, H5b, H6, H7). The maps illustrate trends across the study area for each individual indicator. A final map representing the flood control indicator value for each wetland has also been included.

Table 6.1 shows mean flood control values for each wetland interval class. Table 6.2 shows mean flood control values for each Stewart-Kantrud wetland class. There are no clear trends for flood control values across either Stewart-Kantrud classes or size classes. The conclusion is that high or low flood control values depend far more on landscape context than on wetland size or class.

Table 6.1. Flood Control Value in Study Area by Wetland Area Class Intervals

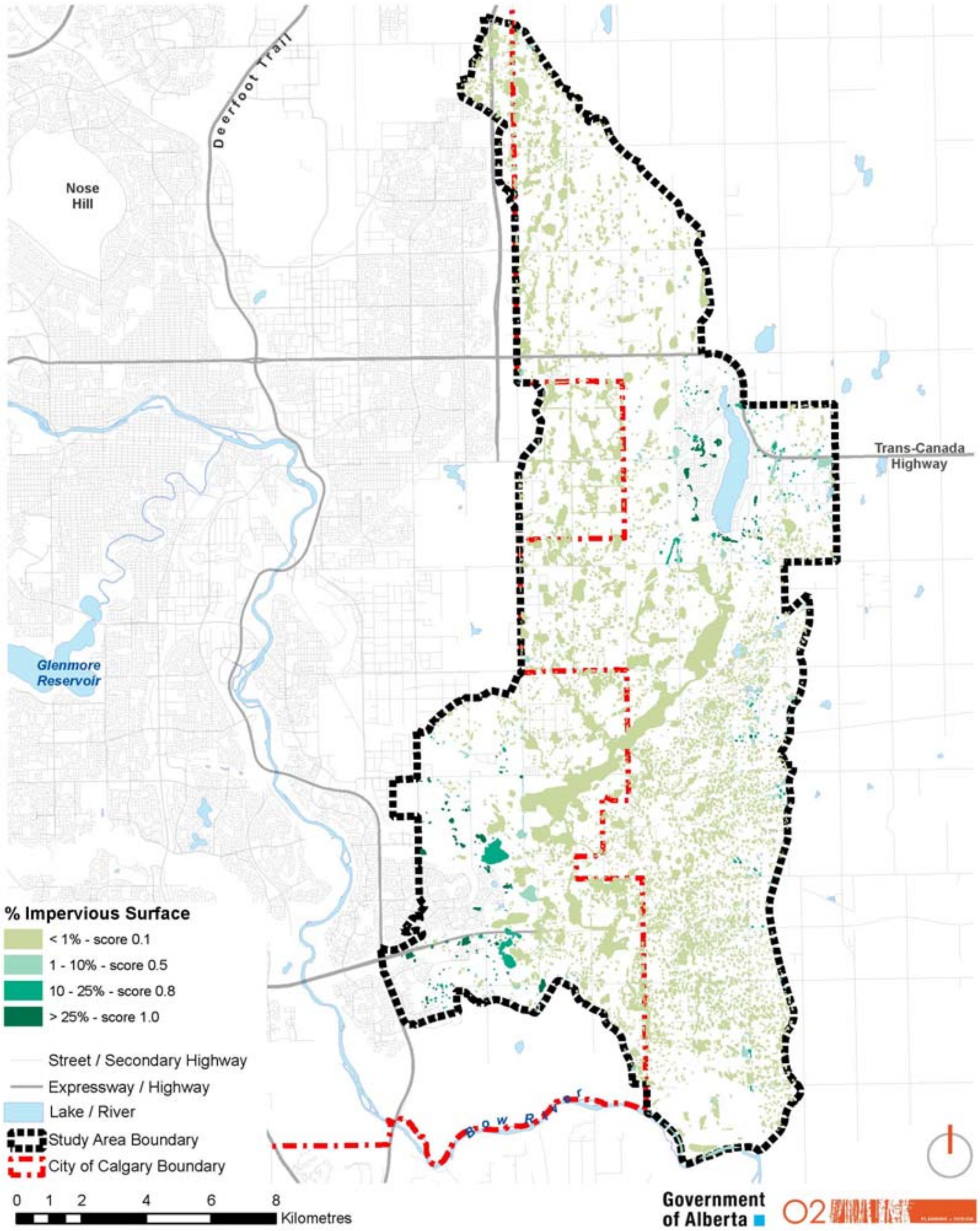
Variable	Wetland Area Class Intervals (ha)						
	<0.1 ha	0.1-1 ha	1-2 ha	2-3 ha	3-5 ha	5-10 ha	>10 ha
Total number in study area (n)	4621	1510	199	74	45	44	43
Mean flood control index (unitless)	0.50	0.49	0.45	0.41	0.46	0.41	0.40
Standard deviation of flood control index	0.12	0.11	0.11	0.10	0.10	0.09	0.09

Table 6.2. Flood Control in Study Area by Stewart-Kantrud Wetland Class

Variable	Stewart-Kantrud Wetland Classification (where available)					
	Class I	Class II	Class III	Class IV	Class V	Unknown/ Missing
Sample size (n)	253	206	152	131	27	5799
Mean flood control index (unitless)	0.42	0.42	0.42	0.38	0.40	-
Standard deviation	0.12	0.10	0.10	0.09	0.08	-

H2: Percentage of Impervious Surface in W6 Catchment

August 2011



H3: Catchment to Wetland Area Ratio

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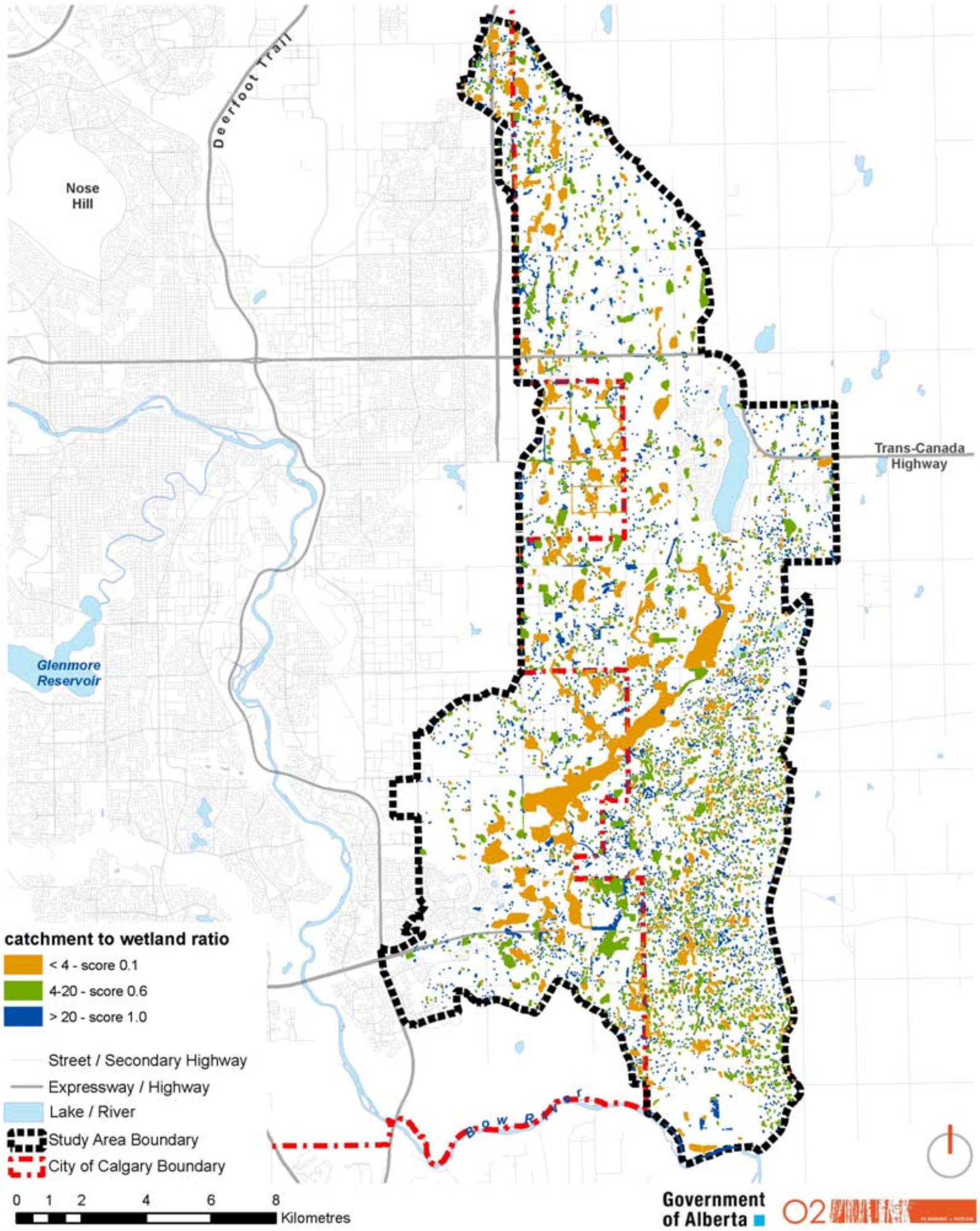

H4: Amount of Upslope Wetlands in W4 Subwatershed

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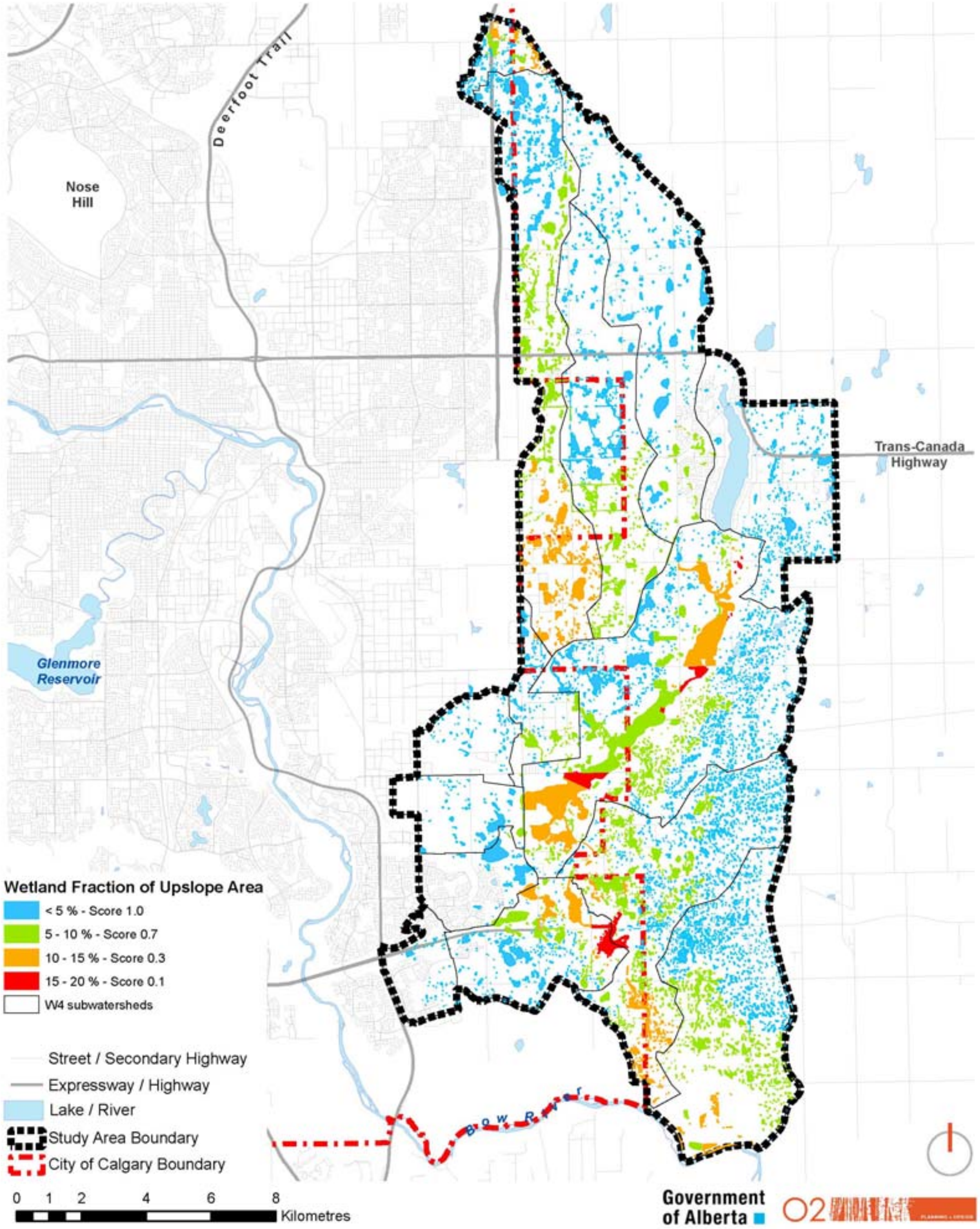

H5a: Wetland Position in the W5 Subwatershed

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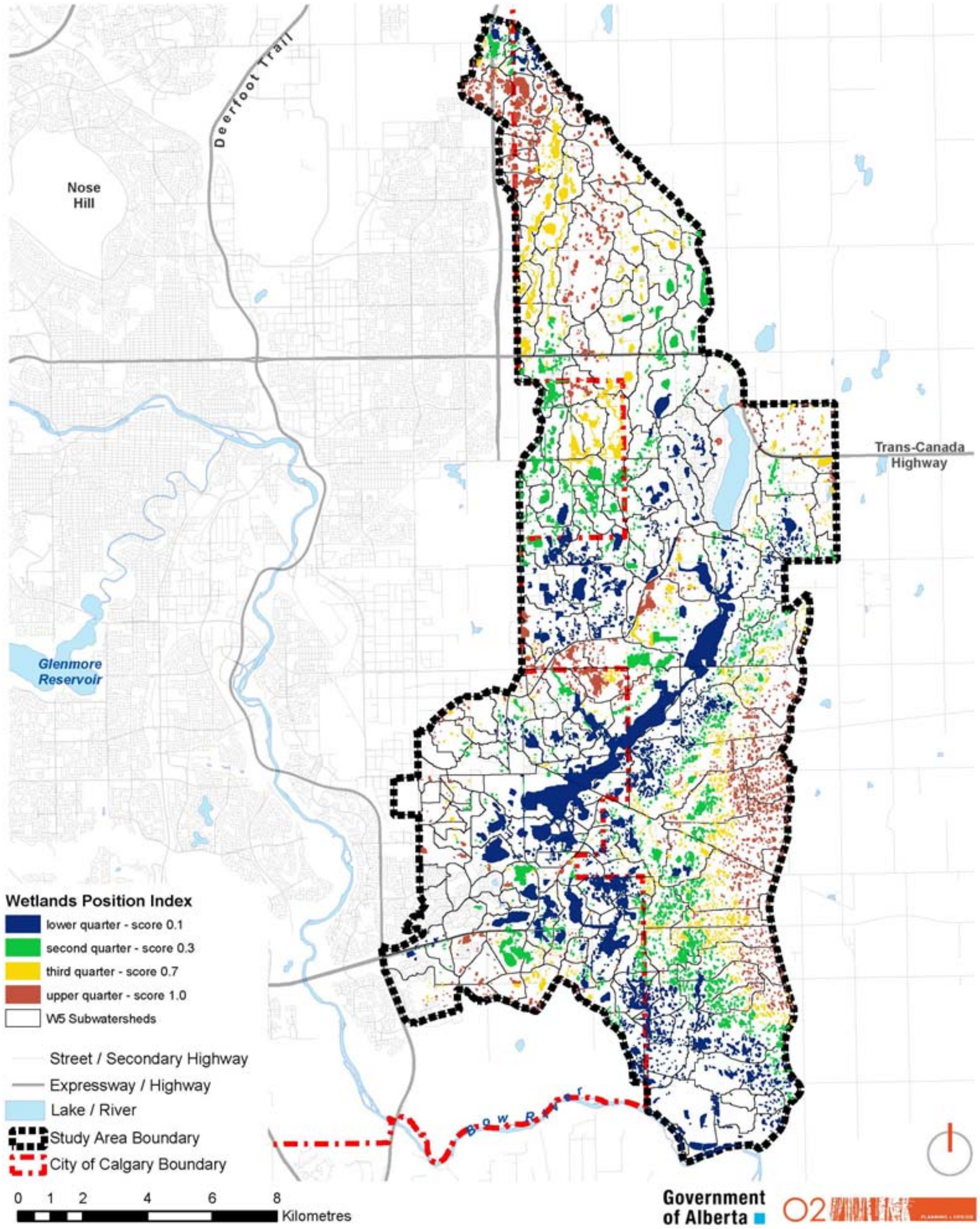
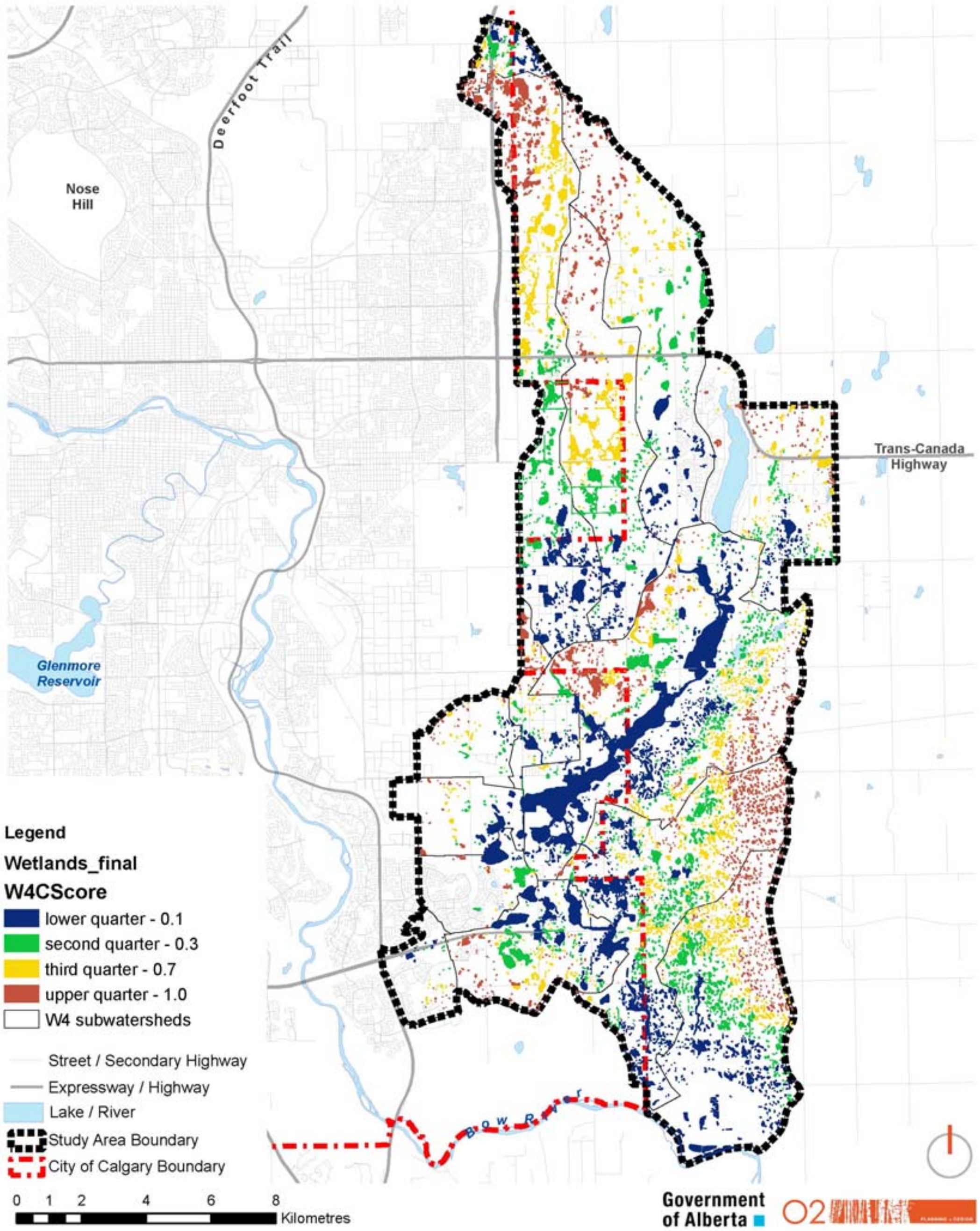


H5b: Wetland Position in the W4 Subwatershed

August 2011



H6: Wetland Connection to Surface Waters

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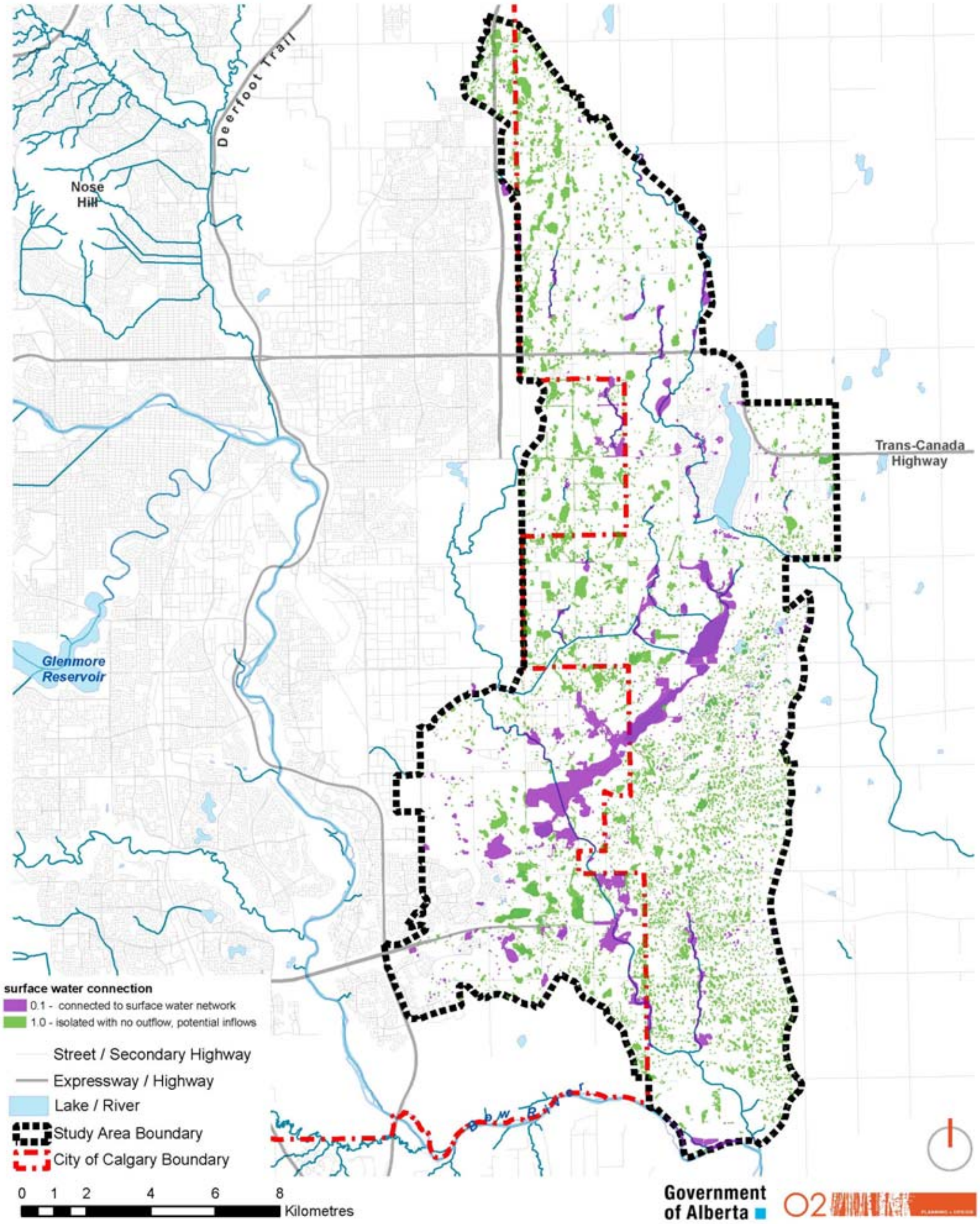

H7: Groundwater Vulnerability

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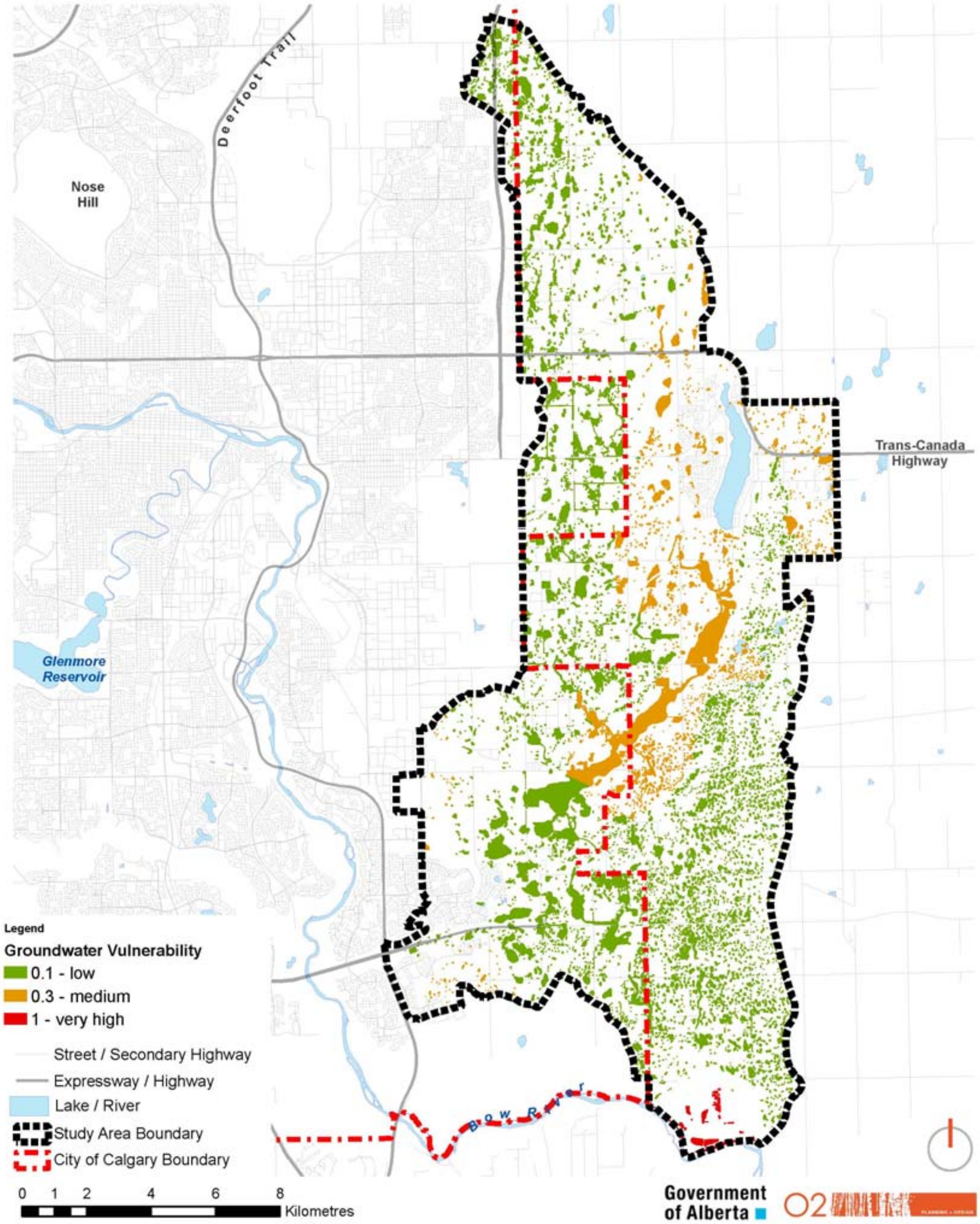
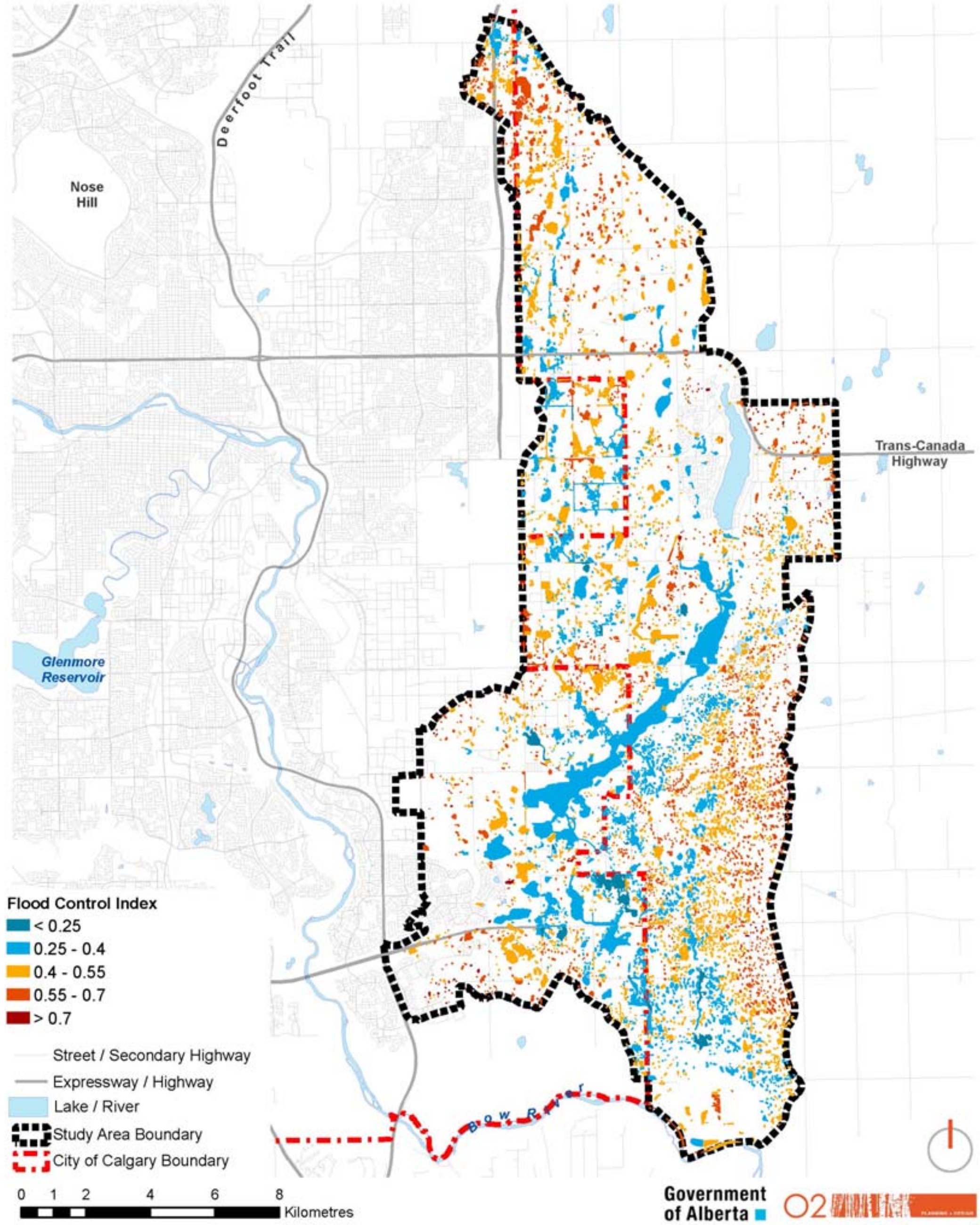


Wetland Flood Control Index

August 2011



The final index of wetland flood control indicates that many medium and small wetlands at high landscape positions provide considerable flood control benefits. This makes sense, particularly on a cumulative effects basis, as all of these small wetlands add up to a large physical quantity of flood peak desynchronization and reduced peak flows in terms of m^3/s at catchment outlets.

A large cluster of wetlands near the north boundary of the study area came out as very high for flood control benefits. Other “hotspots” of high flood control services occurred east of Chestermere and in the north half of the Belvedere Area Structure Plan area within The City of Calgary. However, smaller areas of wetlands with high flood control indicator values also occur dispersed throughout the study area.

It is worth noting that all wetlands have the potential to provide some measure of flood control ecosystem services, but to differing degrees. In addition, many wetlands exhibit very different scores for different flood control predictor variables (H1 through H7). The large wetlands in the central Shepard Slough complex have large storage capacities (H1), but low scores for many other predictor variables.

The way that separate predictor variables are combined and weighted may affect the overall interpretation. O2 examined many different ways to combine H1 through H7, although only the best method according to several rounds of expert review and judgement are shown in this report. Some wetlands, such as the large Shepard Slough complex wetlands, are sensitive to the way the different predictor variables are weighted and combined. Other wetlands are not sensitive and come out as high for virtually all indicators. This includes the largest wetlands in the northern component of the study area, the largest wetlands east of the Town of Chestermere, and several wetlands in the Belvedere Area Structure Plan area within Calgary. It is also worth noting that the chosen method to combine variables for the flood control index value was similar to several alternative weighting systems. For example, the correlation of the chosen flood control index method of equal weightings with an alternative method using the H6 variable (presence/absence of a natural or artificial drainage outlet) as a multiplier was very high at 0.8.

6.3 Trend Analysis

Replicating the flood control analysis was not considered feasible at this time, due to methodological and data completeness issues. However, the map “*Areas of Drained Wetlands: 1965-2005”* show areas where wetlands had been providing flood control ecosystem services but are now lost. With reference to this map, of particular note in terms of wetlands that have been lost include:

- Wetlands that historically occurred in The City of Calgary, but no longer are present in the southwest corner of the study area;
- An 11 ha wetland that used to occur along the Shepard Ditch just south of the large Shepard Slough complex inside Rocky View County, which appears to have been drained during Shepard Ditch upgrades sometime during the trend analysis period;

- A large wetland within The Town of Chestermere;
- Several wetlands along the 84^{th} St. industrial corridor north of Shepard; and
- Several wetlands east of the Hamlet of Janet on the east side of the Janet Slough complex.

6.4 Discussion of Ecosystem Services and Beneficiaries

There are many possible beneficiaries of flood control ecosystem services which occur at multiple scales. This section has been separated into three sections addressing several different scales, including: localized flood control within the study area, flood control related to the Western Headworks Canal, and flood control related to the Bow River.

6.4.1 Localized Flood Control

Localized flooding has been identified as an issue within the study area itself. Several anecdotal sources of information indicate that flooding has been a problem in the area. There are reports that in the early 20th century, the CPR railway east of the Hamlet of Shepard was flooded. Flooding of industrial lands along the 84th St. corridor north of Shepard also occurs with some regularity. The 2001 *Shepard Plan* (City of Calgary and Rocky View County 2001) noted that:

- Drainage and flooding have been identified as issues in the area;
- The Hamlet of Shepard, which contains a community hall, residences, and industrial uses, is located in an area with a high water table, a history of flooding, and water quality problems;
- Stakeholders were interested in how the Shepard Plan could address ditch grading, flooding, flood protection, high moisture problems, high water tables, and water wells; and
- Stakeholders also expressed concern about road drainage, particularly culverts that are clogged and in poor locations, and water that remains "trapped in ditches".

Some of the historical flooding is likely natural, due to the predominance of wetlands and a high water table. However, it is well established that the existence of wetlands at one location reduces flooding downgradient at other locations. In many cases, wetland drainaqe and development can cause hydrological changes and undesirable local flooding that was not present prior to development. Although stormwater management systems are typically built to mitigate these impacts, they are very expensive to design and build. For example, the total cost of future stormwater servicing for planned infrastructure in the study area is $270 million (AECOM 2011); this does not include expenditures to date which likely number many tens of millions of dollars already. In addition, in prairie pothole landscapes, if large development footprints are installed, there will be unavoidable increases in discharge rates from property parcels pre- and post-development. For example, the established discharge rate of 0.8 L/s/ha in the area (AECOM 2011), although fairly low by urban development standards, is higher than a typical prairie pothole non-contributing drainage area, which will, under normal circumstances (1:2 year events), contribute no flow at all downstream. In addition, stormwater systems can be subject to failure. By definition, almost all stormwater systems near Calgary will fail and result in flooding of property if a precipitation event larger than the calculated 1-in-100 year storm event (based on historical data) occurs.

Another issue to consider is that, in some cases, irrigation canals bisecting the study area can rupture or leak into adjacent properties. For example, the WID “A Canal”, which begins in the study area near the south east corner of Lake Chestermere, has previously been observed to have collapsed in over 50 locations, permitting water to escape and flood adjacent areas (Decision Report 2001). Without wetlands and other open space to help absorb this unpredictable infrastructure failure, property or crops will flood instead.

Related to this, the Town of Chestermere has identified a “Drainage Constraint Area” on the southern and eastern ends of Lake Chestermere, where potential flooding would occur following a dam breach or overtopping from Lake Chestermere. They also state that “*Any development proposals in this area will need to address the Drainage Constraints to the satisfaction of the Town and the Western Irrigation District*.” Therefore, wetlands within this Drainage Constraint Area, of which there are several, may be able to absorb some of this potential flooding and therefore provide a high potential for ecosystem service economic values for flood control.

Notwithstanding the above discussion, assessing local flood control benefits of wetlands in a more quantitative manner was found to be very problematic and convoluted, without applying a very large number of questionable assumptions, mostly because:

- There is no 1-in-100 year floodplain data available within the study area;
- Quantifying which properties are protected from localized flooding due to the existence of wetlands is very difficult without a detailed hydraulic model that indicates where flood flows are routed during extreme events; and
- When wetlands are removed, the current regulatory system requires stormwater management systems that prevent flooding through release rate targets and conveyance infrastructure; residual impacts to hydrology or the chance of stormwater infrastructure failure causing destructive flood damages are both very difficult to quantify objectively.

6.4.2 Flood Control and the Western Headworks Canal

Discharge of urban stormwater into the Western Headworks Canal has been a major issue in the Calgary Region for several decades. In 1980, a moratorium on any additional storm sewer outfalls into the canal from lands north of the WH Canal was imposed by Alberta Environment and Sustainable Resource Development, due to concerns over damage to the canal, flooding in Chestermere Lake, and water quality concerns.

To enable continuing development within the study area while avoiding the problems with flooding and drainage that occurred in the past, The City of Calgary (under threat of legal action from downstream parties) built the Shepard Stormwater Diversion project. The project included 5 phases including:

- *Phase 1:* Underdrain under the WH Canal to bypass stormwater flows under the canal system *and* a wasteway structure in the canal itself that can divert high flows out of the canal;
- *Phase 2:* Diversion channel from the WH canal west of the Hamlet of Shepard into the Shepard Constructed Wetland;
- *Phase 3:* CPR Rail crossing of the diversion channel;
- *Phase 4:* Construction of the Shepard Wetland; and
- *Phase 5:* Upgrades to the Shepard Ditch and a Discharge structure to the Bow River.

The total cost of this project, which is now complete, was approximately $60-70 million. The City also expended considerable political capital and required lawyers to deal with conflicts related to the expropriation of lands along the Shepard Ditch to expand its capacity. Other ecosystem values such as duck habitat and aesthetics also appear to have been degraded by the Shepard Constructed Wetland.

It is worth noting that the loss of wetland cover and installation of impervious surfaces north of the WH Canal is what ultimately caused the documented flooding problems in the irrigation canal system itself. If development patterns and designs could mimic pre-development hydrology adequately by retaining high wetland cover and open space while also implementing aggressive Low Impact Development stormwater practices, increased discharge to the WH Canal would not occur. Essentially, the historical past conversion of wetlands within north east Calgary to industrial and residential lands with typical efficient stormwater servicing drainage south into the canal system led to flooding problems. If less development had occurred and more wetlands had been historically retained in developed areas, expenditures related to the Shepard Stormwater project may not have been necessary.

Although this would have required public acceptance of new and creative development patterns incorporating wetlands, as well as potential additional costs to developers and potential increased risks of localized flooding of communities during extreme events, it appears that nobody has done full cost accounting to see whether retaining the wetland flood control ecosystem services and avoiding the engineering solutions would have been more cost efficient in the long run.

In any case, it is not a stretch to say that the economic value of wetland flood control services north of the WH Canal is equivalent to a minimum value of $60 million**.** As the bypass structure only deals with a limited quantity of peak flow (16 m^3/s maximum capacity) (City of Calgary 2009), flood control services of all wetlands north of the canal are likely much higher since additional bypass structures would need to be built in the future. Total flood control services of wetlands north of the WH Canal may be closer to the total value of the projected infrastructure requirements of additional drainage shown in AECOM (2011) ($270 million), plus the existing expenditures related to the Shepard Stormwater Project ($60 million), for a total economic value of $330 million. This may still be on the low end since expensive stormwater systems such as pipes and stormwater ponds will also still need to be integrated into new developments on top of the drainage infrastructure in order to meet the low runoff release rate targets that have been established for the area so that downstream conveyance channels will be able to handle increased stormwater flows without requiring additional expansions.

6.4.3 Flood Control and the Bow River

Ultimately, the study area drains to the Bow River, especially since the construction of the underdrain to bypass areas to the north under the WH Canal. All of the analysis below is a very rough, first order, back of the envelope estimate and further detailed research should ideally be undertaken to validate the assumptions and calculations.

An interesting question is how many cubic metres per second (m^3/s) are not reaching the Bow River during a peak flood due to wetland flood attenuation that would otherwise discharge there. An accurate answer to this question would require complex coupled hydrology and hydraulics models and this would need to be performed to have higher confidence in the estimates. However, a rough answer can be estimated based on the difference between current area hydrology and current and future drainage capacity planned for the study area (AECOM 2011). Trends can also be estimated based on what we know about the study area's hydrology. The context of peak flows from the study area are also expressed as a percentage of the maximum daily peak discharge rates that occurred in the past, based on hydrometric data from the Bow River at Calgary (Station 05BH002). Although peak instantaneous discharges have been measured as high as 1320 m^3/s in June 1929 and 791 m^3/s in June 2005, the average annual maximum daily peak discharge in the Bow River at Calgary is 365 m^3/s (Environment Canada 2011).

Pre-1900s: In pre-development times, almost the entire study area was a large area of internal drainage with no natural surface outlet to the Bow River. Under these conditions, wetlands would have experienced major fluctuations in water levels in response to seasonal and interannual climate variations. Discharge to the Bow would have been very limited and in most years would have approached zero, although it is likely that some surface flows did still reach the Bow River. However, as this would have been very limited, the peak discharge to the Bow River from the study area was considered to be only a maximum of about 1 m^3/s. In comparison to average maximum daily discharge, this represents only 0.3 per cent of the flow in the Bow River.

Mid 1900s: The Shepard Ditch drainage canal was constructed in the early part of the 20th century. The Shepard Ditch drained the area by conveying water south to the Bow River, particularly during high water events. The original capacity of the Shepard Ditch at the outlet to the Bow River, though not readily available in reports, is unlikely to have been capable of exceeding about 4 cms at the outlet to the Bow River. Therefore, circa 1950, peak discharge from the study area to the Bow River can be estimated to be about:
4 cms + 1 cms natural discharge = 5 m^3/s. In comparison to average maximum daily discharge, this represents only 1.4 per cent of the flow in the Bow River.

Early 2000s: After the Shepard Ditch had been upgraded post 2008, the capacity at the discharge structure to the Bow River is now about 25 cms. However, only about half this value is currently active, and of this, about 46 per cent originates from WH Canal water and not from water originating in the study area. Therefore, the peak flow originating from the study area today through the Shepard Ditch to the Bow River is approximately *25 cms x 0.5 x 0.54 = 7 cms*. Therefore, the total estimated peak flow into the Bow River from the study area today is estimated as:
1 cms + 7 cms + = 8 m^3/s. In comparison to average maximum daily discharge, this represents about 2.2 per cent of the flow in the Bow River.

Projected future value: Once the Shepard Ditch is at full capacity, it will be likely discharging 25 cms, of which 54 per cent will originate from stormwater within the area. Additional drainage capacities are also planned, such as the secondary conveyance channels, which will augment this further by an additional 3 cms (AECOM 2011). Therefore, assuming these canals are full once development occurs in the future, the total future estimated peak flow into the Bow River from the study area will be:

1 cms +25 cms + 3 cms = 29 m^3/s. In comparison to average maximum daily discharge, this represents an increase of +8 per cent of the flow in the Bow River at Calgary, which starts to be substantial. Peak discharge rates this much higher may have impacts on downstream landowners due to increased flooding and erosion of property, including buildings, land, crop, hay, and pasture. The City of Medicine Hat, several hundred kilometers downstream, may even be affected by higher flood risk, although the flow of the South Saskatchewan River here is at least four times higher and the increased peak flow would be a much smaller fraction.

Projected value if all wetlands were drained: The above value depends on the low release rate target specified for the Shepard Drainage Plan area (0.8 L/s/ha), which actually will necessitate a large area of stormwater ponds for evaporation and constructed wetlands in comparison to a more conventional development in an area where outfall construction is more feasible. The actual flood peak that would occur in the Bow River if all wetlands were suddenly drained would be much higher than this value. For example, a typical release rate established for areas with streams in southern Alberta is 5 L/s/ha. Although it is not possible for development to this release rate to occur any time in the near future, applying this across the entire study area, the peak discharge under this hypothetical discharge rate would be:

(5 L/s/ha x 100 ha/km^2 x 267 km^2)/(1000 L / m^3) = 134 m^3/s

So what are the ecosystem services of study area wetland flood control in the context of the Bow River? In comparison to average maximum daily discharge, the increase in peak flow that would occur if wetlands were not present at all would be over 37 per cent, with average peak flows increasing from 365 m^3/s to 499 m^3/s. This is a considerably greater flood risk. In comparison to the June 2005 peak flood, the peak flow in the Bow River of 791 m^3/s would have been increased to well over 925 m^3/s (+17%), with concomitant higher flooding and erosion risk to downstream landowners. The economic value of this increased flood risk is a more difficult question to answer.

Disaggregating the total increased peak flow to the Bow into individual wetland contributions is also a more difficult question, since stormwater ponds will end up replicating a large portion, though not all, of wetland flood attenuation functions, particularly due to the low release rate target specified for the area of 0.8 L/s/ha.

What implications reduced flood peaks has downstream on the Bow River is a much trickier question that will be difficult to answer, especially if a quantitative answer is desired for economic valuation.

Another point to note is that between station 05BH002 and the Bow River within the study area, several additional inputs of water to the Bow River occur from various stormwater outfalls as well as Fish Creek and Pine Creek. Therefore, the percentage values calculated above are likely to slightly overestimate the actual value in the Bow River near the study area.

In addition, the mouth of the Highwood River occurs just downstream of the study area and peak flood flows in this river near the mouth are substantial. For example, the exceptionally high June 2005 maximum instantaneous discharge in the Highwood was 1340 m^3/s (Environment Canada 2011). Consequently, Bow River flood flows downstream of the confluence with the Highwood River during June 2005 were likely to exceed 2,000 m^3/s. Therefore, if study area wetlands did not exist, increased flood flows in the Bow River downstream of the confluence with the Highwood River would be increased by approximately seven per cent.

7. COMPARISON AND DISCUSSION OF GIS AND WESPUS MODEL RESULTS

This section compares the results of two different models that applied different approaches and different indicators:

- Site-scale rapid assessment of wetland "water storage and delay" using the Wetland Ecosystem Services Protocol for the United States (WESPUS) (O2 2011)
- Broad-scale GIS-based models (from this report) calculating water storage values (m^3) and a flood control index for all wetlands in the study area

Table 7.1 shows the compiled table for all sites where both site-scale field WESPUS field assessments and broad-scale GIS assessments of values have been completed. Figure 7.1 shows a scatterplot of wetland storage capacity vs. WESPUS water storage and delay scores; figure 7.2 shows the same data using a log scale. Figure 7.3 shows a scatterplot of the flood control index values vs. WESPUS water storage and delay scores. Note that the WESPUS wetland sample size is low; increased sampling of wetlands for WESPUS field scores would improve the analysis and may change some interpretations.

Table 7.1. WESPUS Scores and Water Storage and Flood Control Index Values

Wetland Name	Stewart-Kantrud Wetland Class	WESPUS Water Storage and Delay Function Score (Effectiveness)	WESPUS Water Storage and Delay Score-(Values of the Function)	Water Storage (m^3)	Flood Control Index
Shepard Upland B	II	0.36	1.25	800	0.36
Patton 3	II	0.33	3.00	277	0.25
Shepard Upland A	III	5.00	2.58	3,737,578	0.29
Patton 4	III	7.00	3.00	1602	0.33
Frog Wetland	IV	3.25	2.83	121,268	0.46
Patton 5	IV	3.25	3.00	2187	0.35
City of Calgary Wetland #2	IV	7.00	2.58	196,186	0.51
Patton 1	IV	5.75	2.83	18,629	0.24
Black Dog	IV	4.50	2.33	24,192	0.33
Killdeer Site	IV	3.69	2.08	18,966	0.30
Site 111	IV	2.33	4.33	16,761	0.45
Shepard Upland C	IV	7.00	3.17	11,437	0.39
Site 87 Saline	IV	4.75	2.92	134,031	0.44
Glenmore Wetland	V	3.38	2.42	5,204,178	0.32
Patton 2	V	3.28	3.00	146,237	0.38

City of Calgary Wetland #3	V	6.00	2.83	3130	0.33
Zahmol	V	8.00	3.08	83,052	0.43
Frontier	V	3.25	4.08	140,512	0.38
Country Hills Blvd. and Stoney Trail	V	3.85	3.58	75,940	0.35

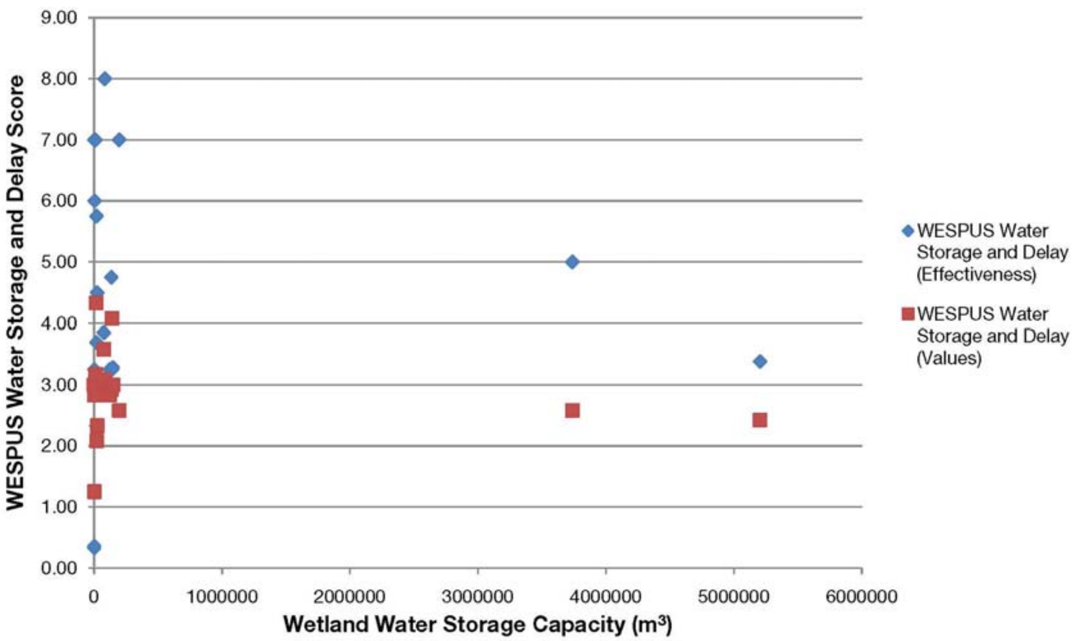


Figure 7.1. WESPUS Hydrologic Function Scores vs. Wetland Water Storage Capacities

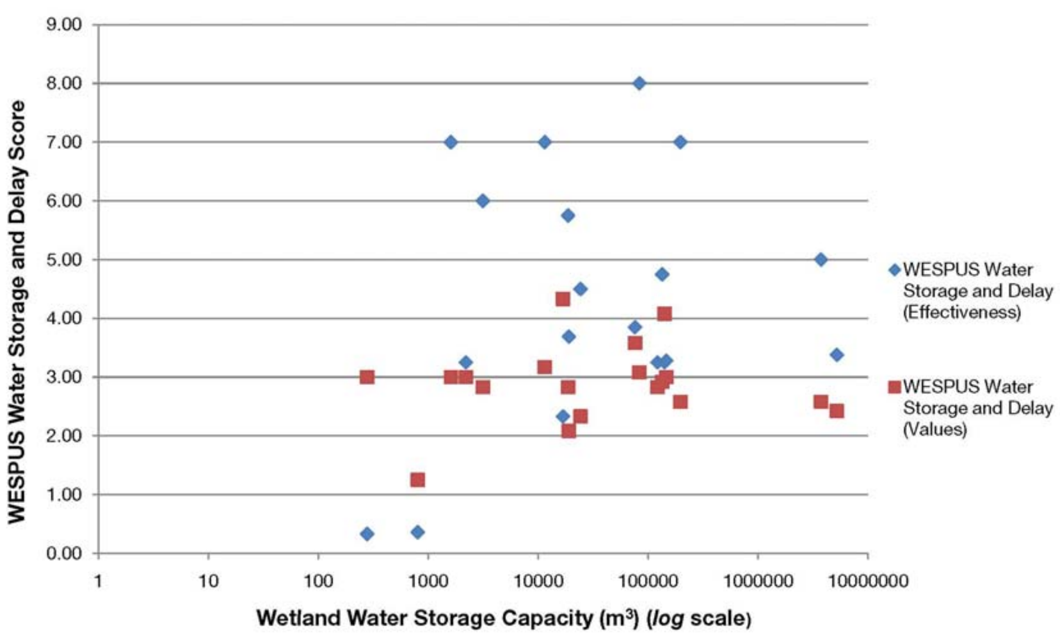


Figure 7.2. WESPUS Hydrologic Function Scores vs. Wetland Water Storage Capacities (log scale)

The scatterplots in Figure 7.1 and Figure 7.2 indicate:

- Very high variability and almost no relationship between the variables being compared overall;
- However, the two small Class II wetlands in the sample displayed the lowest WESPUS hydrologic scores; intuitively this makes a lot of sense;
- The largest wetland assessed ("Glenmore wetland") had a low WESPUS water storage and delay function score (3.38); this data point is an extreme outlier along with the second largest wetland;
- If the two extreme outliers (storage capacity > 1,000,000 m^3) are removed, correlation coefficients of the scatterplots in Figure 7.1 are relatively low at 0.18 and 0.19, respectively;
- The results highlight the caution required when interpreting WESPUS scores, which are more suitable for pre- and post-disturbance assessments of similar wetland acreages where wetland compensation occurs;
- Since the WESPUS water storage and delay scores do not incorporate wetland size, they should not be used to suggest any differences in the actual biophysical quantities of different functions that may be performed by different wetlands which differ in size;
- Therefore, it can be concluded that, although a relationship between water storage volume and the WESPUS hydrologic score does exist, there is a lot of "noisy" variability in wetland systems as well as in the assumptions used for both modelling approaches; and
- WESPUS water storage and *delay* (flood control) are also grouped together; therefore it may be more appropriate to compare these WESPUS scores to the GIS flood control indicator scores.

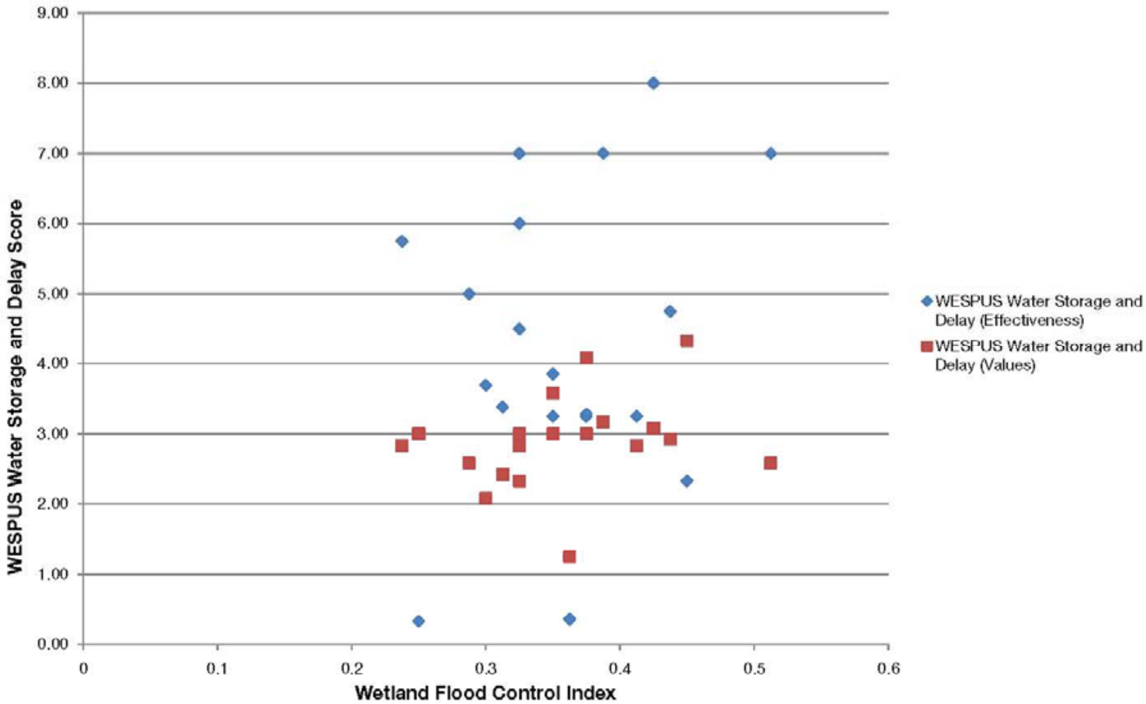


Figure 7.3. WESPUS Hydrologic Scores vs. Wetland Flood Control Index

The scatterplot in Figure 7.3 indicates:

- High variability and a slightly positive relationship between the WESPUS water storage and delay scores and the GIS-based wetland flood control index;
- Correlation coefficients of the scatterplots in Figure 7.3 were approximately:
  - 0.15 between the flood control index vs. the WESPUS water storage and delay “effectiveness” score
  - 0.20 between the flood control index vs. the WESPUS water storage and delay “values of the function” score;
- Outliers occur on the low end of the flood control index range; for example, the Patton 4 wetland with a WESPUS hydrologic function score of 7.00 has a GIS flood control index of only 0.25, and the Patton 1 wetland with a WESPUS hydrologic function score of 5.75 but a GIS flood control index of only 0.24;
- Removing these two lower outliers, the correlation coefficients of the remaining data set are more moderately positive at:
  - 0.43 between the flood control index vs. the WESPUS water storage and delay “effectiveness” score

- 0.25 between the flood control index vs. the WESPUS water storage and delay “values of the function” score;

- When excluding the outliers, there is a moderately positive relationship between the WESPUS model outputs vs. the GIS based flood control indicator values;
- Although there is still considerable “noisy” variability in both natural wetland systems as well as the two alternative modelling approaches, in spite of this variability a reasonable level of correlation between the two modelling approaches occurs;
- However, neither the WESPUS model nor the flood control indicator model represent absolute quantities of biophysical flood mitigation (e.g., m^3/s of flood peak reduced); therefore, caution should be taken when interpreting the meaning of the indicator values; and
- Increased sampling of WESPUS sites and additional analyses would help to increase confidence in the conclusions;

8. CONCLUSIONS

- Study area wetlands provide large water storage functions, with a total capacity of over 36 million m^3, greater than the combined volumes of the Glenmore Reservoir and Lake Chestermere;
- Wetland water storage provides many supporting and regulating ecosystem services upon which depend on all other ecosystem services;
- Much water storage is located in the large central Shepard Slough Wetlands; however, the large number of small wetlands add up to a considerable storage volume on a cumulative basis;
- In the study area, Class IV wetlands tend to store the most water volume, both on a per wetland basis and on a cumulative basis, although variability within the class was very high;
- Class V wetlands also store large volumes, but there are fewer of them and they are less important on a cumulative basis than Class III wetlands overall;
- Class I and II wetlands have very small average wetland volumes, but they can add up to a considerable volume when taken together as a whole;
- A large number of wetlands have been drained in the study area, particularly within urban areas but also in agricultural areas, and the trend calculated over 1965-2005 is a 20 per cent drop in wetland water storage volume;
- Users/beneficiaries of wetland water storage provisioning services are low in the study area;
- Cattle are the largest ecosystem service beneficiary of water storage and supply in the study area, although their use of wetlands may degrade other ecological values; up to 144,000 m^3/year of water may be used by cattle in the study area;
- Eight indicators of flood control, including storage volume, were combined into a flood control index for all study area wetlands;
- The flood control index indicates that many medium and small wetlands at high landscape positions provide considerable flood control benefits. This makes sense, particularly on a cumulative effects basis, as all of these small wetlands add up to a large physical quantity of flood peak desynchronization and reduced peak flows in terms of m^3/s at catchment outlets;
- A large cluster of wetlands near the north boundary of the study area came out as very high for flood control benefits. Other “hotspots” of high flood control services occurred east of Chestermere and in the north half of the Belvedere Area Structure Plan area in The City of Calgary. However, smaller areas of wetlands with high flood control indicator values are dispersed throughout the study area;
- All wetlands have the potential to provide some measure of flood control ecosystem services, but to differing degrees and at different scales;

- According to a rough method of calculation, peak flood flows in the Bow River if all study area wetlands were drained effectively would increase by over 37 per cent, indicating the level of importance of these wetlands at mitigating peak flows in the region;
- Comparisons of the WESPUS site-scale results to the GIS model results showed:
  - very high variability and in particular several outliers highlighting model mismatches
  - WESPUS hydrologic function scores weakly positively correlated with water storage volume
  - WESPUS hydrologic scores moderately positively correlated with the flood control indicator
  - caution is required when interpreting indicator values from WESPUS or GIS models.

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