HydroGeosim: A water purification geosimulation modelling platform

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Preface:

The Alberta Biodiversity Monitoring Institute (ABMI) is an arm's-length, not-for-profit scientific organization. The primary goal of the ABMI is to provide relevant scientific information on the state of Alberta's biodiversity to support natural resource and land-use decision making in the province.

In the course of monitoring terrestrial and wetland ecosystems across the province, the ABMI has assembled a massive biodiversity database, developed reliable measurement protocols, and found innovative ways to summarize complex ecological information.

The ABMI undertakes focused projects to apply this capacity to specific management challenges, and demonstrate the value of the ABMI's long-term monitoring data to addressing these challenges. In some cases, these applied research projects also evaluate potential solutions to pressing management challenges. In doing so, the ABMI has extended its relevance beyond its original vision.

The ABMI continues to be guided by a core set of principles – we are independent, objective, credible, accessible, transparent and relevant.

This report was produced in support of the ABMI's Ecosystem Service Assessment project, which is developing systems to assess and map ecosystem services across Alberta to better understand how planning and management decisions affect the landscape and increase benefits to Albertans. "Ecosystem services" are the benefits provided by natural systems that contribute to our well-being and health. They support our basic needs like clean water, food, and raw materials for building, or they can be more intangible benefits like recreational opportunities and aesthetic value. Some ecosystem services have a clear, well-known economic value, but the value of most services is harder to calculate, though no less important. Given the essential role that ecosystem services play in our lives, it is important to map, measure, and value these services. Powered with this information, Albertans can make the best possible decisions about how to manage our landscape.

The views, statements, and conclusions expressed in this report are those of the author and should not be construed as conclusions or opinions of the ABMI. The ABMI is a value-neutral organization committed to the application of high quality science to natural resource management in Alberta.

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HydroGeosim: Model Documentation

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1 Context

Ecosystem services are increasingly becoming a construct for policy makers, scientists and practitioners to conceptualize nature as a natural system within and foundational to a socio-economic system. The ecosystem services concept emphasizes the role that healthy ecosystems play in the sustainable provision of human well-being, economic development and poverty alleviation…"[1]

According to the Business for Social Responsibility network there are five emerging global trends in ecosystem service-related policy.[2]

1. National governments around the world are exploring expansion of gross domestic product (GDP) measures to include natural capital
2. Public sector exploration of ecosystem service valuation is on the rise
3. Governments around the world are showing interest in attracting investment in ecosystem services
4. Public sector funding research on ecosystem services is on the rise
5. Engagement between public and private sectors on ecosystem services is limited but it has grown each year

As the importance and acceptance of the ecosystem service concept grows there is an increasing need to develop a science-based approach to defining and assessing ecosystem services. Turner and Daily (2008) argue that information is lacking at scales useful for decision makers on how people benefit from specific services, and that better integrated approaches are required for modelling, mapping and valuing ecosystem services.

The Alberta Biodiversity Monitoring Institute (ABMI) and its consortium of collaborators in the Ecosystem Service Assessment for Environmental Innovation and Competitiveness project are advancing the capacity to conduct ecosystem service assessments in Alberta. This document contributes to the challenge of developing an integrated approach to model, map and assign value to ecosystem services in Alberta. This document and the subsequent sections describe an integrated water purification model.

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[1] Turner, R. K. and Daily, G. C. (2008). The ecosystem services framework and natural capital conservation. Environmental & Resource Economics 39(1): 25-35.

[2] Business for Social Responsibility. (2013). Global Public Sector Trends in Ecosystem Services, 2009-2012. Available online http://www.bsr.org/en/our-insights/report-view/global-public-sector-trends-in-ecosystem-services-2009-2012

1.1 Water Purification

The model documentation below summarizes the data, variables and assumptions required to capture how water purification services are provided across landscapes in Alberta. Water purification in this context captures water quality and quantity.

Water purification services act by absorbing or filtering pollutants or by preventing erosion. The processes related to these services may take place during overland flow, during infiltration and leaching, during ground water passage, or in wetlands or water bodies.[3]

Ecosystem processes involved in water purification services range from physical processes, such as vegetation preventing erosion, to biochemical processes by microorganisms in soil, water or wetlands. The benefit of the service consists inter alia of decreasing water treatment costs, increasing the aesthetic value of water for swimming and tourism, and supporting fish stocks harvested for commercial or recreational purposes.[4]

The water purification services in the model outlined below capture many of the physical processes associated with how vegetation interacts with overland flow, water bodies, and wetlands, etc. The current model, however, does not capture ground water passage or related interactions, nor does it fully depict the biochemical processes that result in the transport and deposition of nitrogen and phosphorus with overland flow. Future research and modelling is required to capture these processes as they relate to water purification services.

1.2 Document Overview

This document provides a comprehensive overview of the water purification geosimulation modelling platform. The document is structured as follows:

Overview	This section provides an overview of the model, introduces the model interface and outlines the primary research questions that drove model development.
Methods	The various steps for setting up and programing the model are summarized in this section, along with descriptions of the various model algorithms that provide the main model functioning.
Results	This section highlights the preliminary results and demonstrates the model's capabilities.

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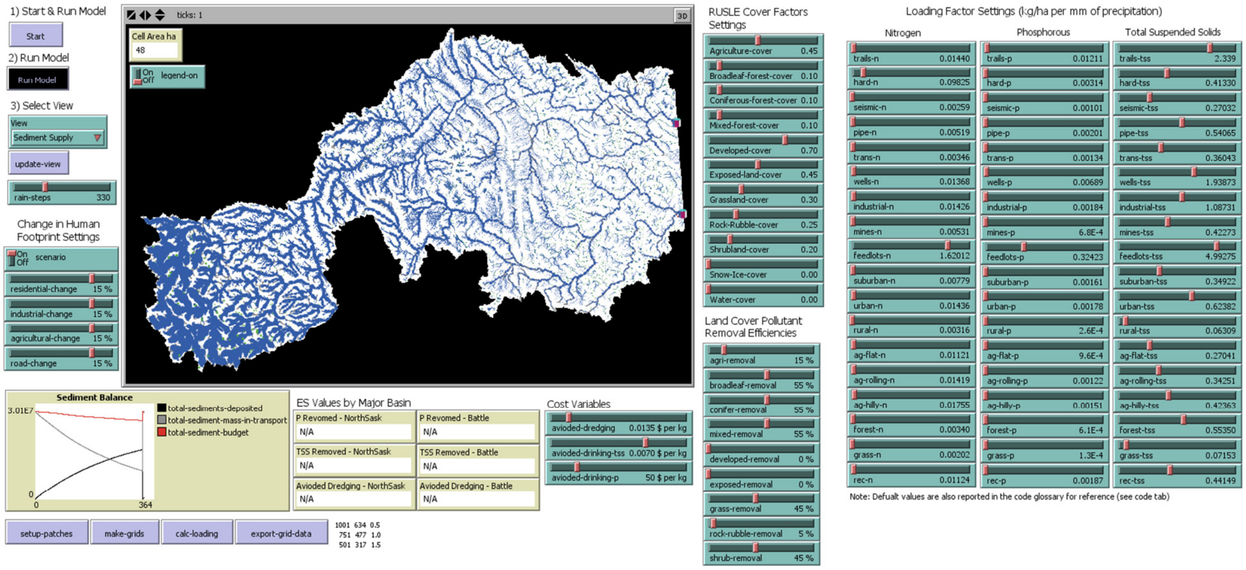
[3] Lautenbach et al. (2012). Mapping water quality-related ecosystem services: concepts and applications for nitrogen retention and pesticide risk reduction. *International Journal of Biodiversity Science, Ecosystem Services & Management* Vol. 1, Issue 1 1-15.

[4] *Ibid*, 2012.

Limitations	Some of the current limitations of the model are described in this section.
Future Directions	Identified in this section are the potential future directions that could be explored to further advance the model.

2 Overview

HydroGeosim is a spatially explicit simulation model that represents hydrological processes and their interaction with topography and landscape composition. The model is executed in Netlogo software (Wilenski, 1999) and is classified as a complex systems model. Specifically, it is a combination of an agent-based model (ABM), cellular automata, and a network model. Each of these model components represents features of the hydrological cycle. Figure 1 below demonstrates the model interface.



View: Sediment Supply
rain-steps 330
Cell Area ha: 48
legend-on: Off
scenario: On
residential-change 15 %
industrial-change 15 %
agricultural-change 15 %
road-change 15 %

P Revomed - NorthSask: N/A
P Revomed - Battle: N/A
TSS Removed - NorthSask: N/A
TSS Removed - Battle: N/A
Avioded Dredging - NorthSask: N/A
Avioded Dredging - Battle: N/A

avioded-dredging 0.0135 $ per kg
avioded-drinking-tss 0.0070 $ per kg
avioded-drinking-p 50 $ per kg

```
1001 634 0.5
 751 477 1.0
 501 317 1.5
```

Agriculture-cover 0.45
Broadleaf-forest-cover 0.10
Coniferous-forest-cover 0.10
Mixed-forest-cover 0.10
Developed-cover 0.70
Exposed-land-cover 0.45
Grassland-cover 0.30
Rock-Rubble-cover 0.25
Shrubland-cover 0.20
Snow-Ice-cover 0.00
Water-cover 0.00

agri-removal 15 %
broadleaf-removal 55 %
conifer-removal 55 %
mixed-removal 55 %
developed-removal 0 %
exposed-removal 0 %
grass-removal 45 %
rock-rubble-removal 5 %
shrub-removal 45 %

Nitrogen		Phosphorous		Total Suspended Solids	
trails-n	0.01440	trails-p	0.01211	trails-tss	2.339
hard-n	0.09825	hard-p	0.00314	hard-tss	0.41330
seismic-n	0.00259	seismic-p	0.00101	seismic-tss	0.27032
pipe-n	0.00519	pipe-p	0.00201	pipe-tss	0.54065
trans-n	0.00346	trans-p	0.00134	trans-tss	0.36043
wells-n	0.01368	wells-p	0.00689	wells-tss	1.93873
industrial-n	0.01426	industrial-p	0.00184	industrial-tss	1.08731
mines-n	0.00531	mines-p	6.8E-4	mines-tss	0.42273
feedlots-n	1.62012	feedlots-p	0.32423	feedlots-tss	4.99275
suburban-n	0.00779	suburban-p	0.00161	suburban-tss	0.34922
urban-n	0.01436	urban-p	0.00178	urban-tss	0.62382
rural-n	0.00316	rural-p	2.6E-4	rural-tss	0.06309
ag-flat-n	0.01121	ag-flat-p	9.6E-4	ag-flat-tss	0.27041
ag-rolling-n	0.01419	ag-rolling-p	0.00122	ag-rolling-tss	0.34251
ag-hilly-n	0.01755	ag-hilly-p	0.00151	ag-hilly-tss	0.42363
forest-n	0.00340	forest-p	6.1E-4	forest-tss	0.55350
grass-n	0.00202	grass-p	1.3E-4	grass-tss	0.07153
rec-n	0.01124	rec-p	0.00187	rec-tss	0.44149

Note: Defualt values are also reported in the code glossary for reference (see code tab)

Figure 1: Model interface, depicting a spatially-explicit landscape (land cover) with the river network and outlets. Views can alternate to present different database GIS layers. Plots report model data, exported to spreadsheet for analysis.

A range of hydrological models exist and can be classified based on the amount of detail that is endogenously represented within them. On one side of the spectrum are relatively simple models that represent aggregated information, such as static loading coefficients applied to land use categories, sometimes referred to as 'screening' models. On the other end of the spectrum are highly detailed models which represent fine-resolution processes, termed 'mechanistic' or 'fully-distributed' models. Mid-range models are 'semi-distributed' models which represent sufficient detail to address research questions at appropriate temporal and spatial scales. HydroGeosim would be considered a semi-distributed model, with some processes represented at the micro-scale (e.g. overland flow) and others aggregated (e.g. loading coefficients).

The model has gone through a number of iterations that experiment with the application of routines at various scales. Provincial-scale models proved unable to sufficiently capture the level of detail needed. Finer scales focusing on watersheds proved most suitable. However, with the ultimate objective of being able to map water purification-related ecosystem services across the province of Alberta and to inform land use policy, the model has been applied to the land-use framework (LUF) boundaries. However, a watershed-based modelling process made it impossible to apply the model to the exact LUF boundaries. Figure 2 demonstrates how the major basins across the province are imprecisely linked to LUF scale boundaries.

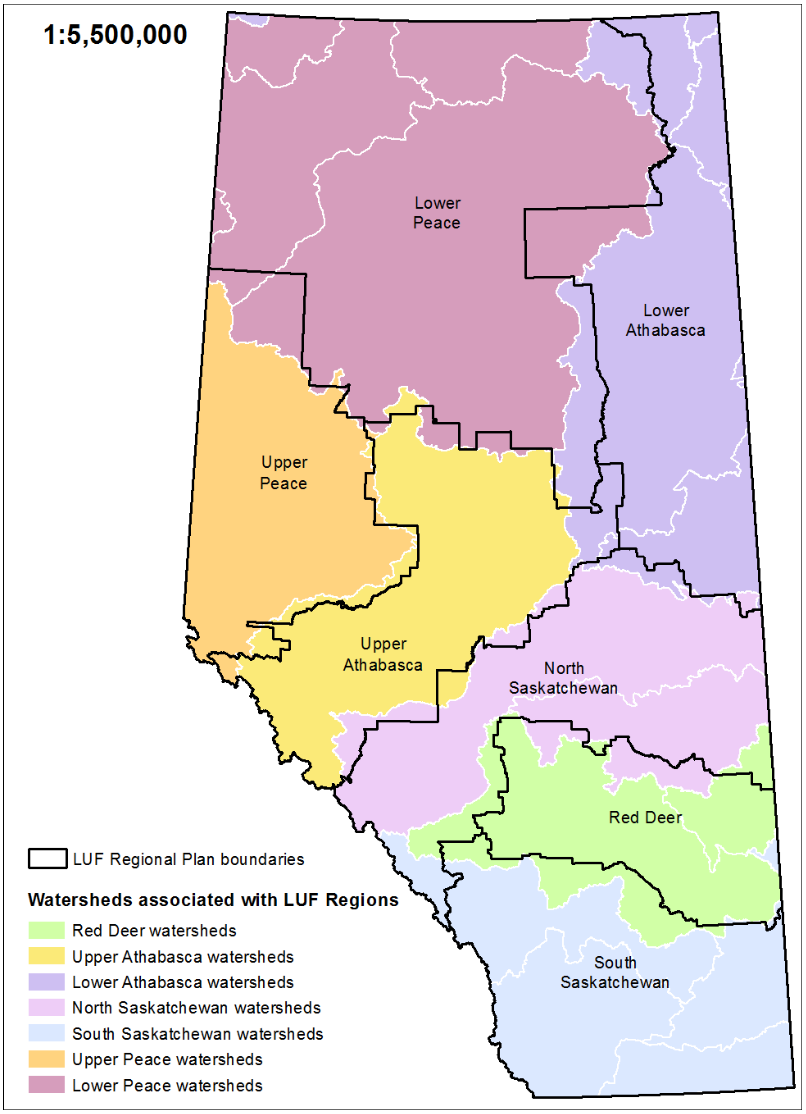


Figure 2: Proposed watershed groupings to run the model at a LUF region scale

The current version of the model is applied to the major basins of the North Saskatchewan LUF boundary. At this scale the model has a 48 ha resolution. HydroGeosim operates at an annual time step and has a variable spatial scale. The model represents overland flow, stream flow and spatially explicit nitrogen (N), phosphorus (P), total suspended sediments (TSS) loading, routing and deposition functions (Figure 3).

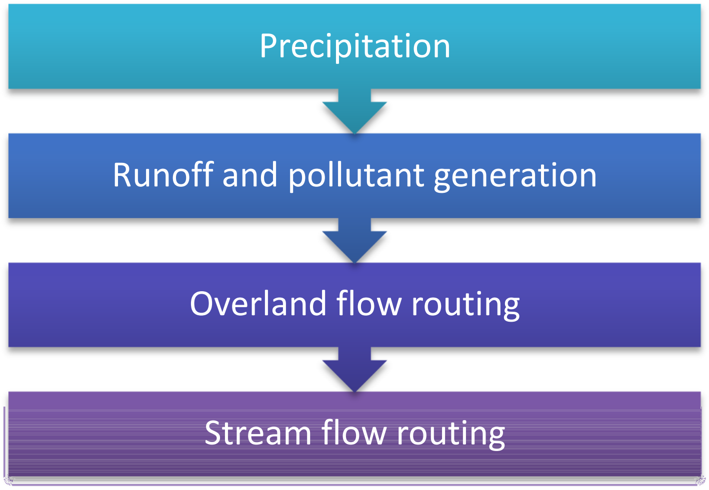


Figure 3: Model process figure

Two methods are presented for representing loading: (1) estimating dynamic and fine-scale hillslope sediment generation, and (2) applying broad-scale loading coefficients for N, P, and TSS. The model imports GIS data and creates a watershed delineation that represents cells (as a gridded landscape), agents (climate stations, outlets, mobile units of water) and networks (stream links / reaches).

The objective of developing HydroGeosim is to provide a base hydrological model that can be expanded to include other agent based routines. For instance, future research could assign land manager agents spatial properties, include crop rotation changes over time, or apply a range of best management practices. Farm-level economic models of land use change and best management practice adoption could also be incorporated. Once the base HydroGeosim model is validated against other hydrological models, research can proceed to represent changes in landscape configuration and management.

2.1 Research questions

The development of the model had been designed to address two key research questions in order to set the stage for future research using an ABM modelling approach.

1. How do precipitation, topography and landscape composition affect overland flow and stream flow?
2. Where are nitrogen, phosphorous and total suspended sediments generated, how are they routed through the hydrological system, and where do they end up?

These research questions guide the level of detail required to develop the model. Screening models do not sufficiently track flow and pollutant routing and a fully-distributed model is not needed for these research questions. In comparison to existing models, SWAT and APEX (http://swat.tamu.edu/documentation/) are commonly used semi-distributed models that are sufficient to address the identified research questions. However, future research directions include the incorporation of detailed ABM of land manager behaviour, so HydroGeosim is developed in Netlogo software with the goal of interfacing with other ABM. With this modelling process in place we can start to explore the value of water purification services on different landscapes.

3 Methods

HydroGeosim represents hydrological processes including precipitation, runoff, overland flow routing, stream flow routing, pollutant generation routing and deposition. To calculate these functions, GIS data is inputted and a hydrological landscape is created using the Netlogo GIS extension.

HydroGeosim inputs a repository of hydrological and landscape data. Import data are raster, polygonal and point GIS data, as well as text files with time series data. GIS layers include static data for elevation, precipitation over time, stream links, and initial land cover. Other data layers are derived either within Netlogo or in external GIS software Saga (Cimmery, 2010). Data preparation was conducted with ArcGIS 10 and imported using Netlogo’s GIS extension.

3.1 GIS Pre-processing and Data Preparation Steps

The foundation of the model is the geospatial database which contains most of the data items needed to run the model. The following provides the steps taken to process the information for modelling. Metadata is provided for each item in Appendix B.

1) ABMI Human Footprint
    a. Clipped data to area of interest
    b. Dissolved on FP_NAME field
    c. Projected data to common coordinate system
2) SectionPoints
    a. ATS sections polygon clipped data to area of interest
    b. Overlaid Human Footprint and section data sets
    c. Summarized area of human footprint by each section
    d. Created a point data file where each point represent it’s sections central location and attributed the summarized area from step b to each point.
    e. Projected data to common coordinate system
3) RiverStreamNetwork
    a. Clipped data to area of interest
    b. Simplified the river network by:
        i. Selecting features based on the stream class (lakes, rivers, perennial streams) and anything with a name
        ii. Selecting features that are connected (i.e. that form a network) and identifying network gaps using ArcGIS topology tool
        iii. Using additional stream classes to fill in any gaps

        iv. Any streams that were identified as standalone (i.e. not in proximity to the main network) were deleted (these were all lower class streams)
    c. Projected data to common coordinate system

4) WetlandsDissolved
    a. Created data set from the Land Cover data
    b. Clipped data to area of interest
    c. Added field (WETFLAG) to denote any feature with a code in the “WET” field
    d. Dissolved data on WETFLAG
    e. Projected data to common coordinate system
5) ChannelElevation
    a. Created using SAGA software (Terrain Analysis tools as per Bohner and Selige 2006)
    b. Exported from SAGA
    c. Projected data to common coordinate system
6) DEM
    a. Clipped data to area of interest
    b. Projected data to common coordinate system
7) ABMI LandCover rasters
    a. Clipped data to area of interest
    b. Converted from polygon to raster at different resolutions (10m, 100m, 500m)
    c. Projected data to common coordinate system
8) LS_Factor
    a. Created using SAGA software (Terrain Analysis tools as per Bohner and Selige 2006)
    b. Exported from SAGA
    c. Projected data to common coordinate system
9) PPT_Annual
    a. Downloaded data from http://www.ualberta.ca/~ahamann/data/climatewna.html
    b. Imported data into 12 rasters (1 per month)
    c. Clipped data to area of interest
    d. Added rasters to create annual precipitation raster
    e. Projected data to common coordinate system
10) TopoWetnessIndex
    a. Created using SAGA software (Terrain Analysis tools as per Bohner and Selige 2006)
    b. Exported from SAGA
    c. Projected data to common coordinate system

3.2 Model Agents, Patches, and Variable Summary

The model contains a number of components (e.g. agents and patches) and a large range of variables in order to simulate pollutant (N, P, TSS) loadings, overland flow, and water purification service values. Tables 1 and 2 summarize all model components and variables.

Table 1: Model components (agents and patches)

Component Name	Type	Description
land-patches	Patch agent set	A subset of the NetLogo "world" patches that represent only those patches within the LUF basins area
outlet	Patch agent set	A subset of patches where the river system exists the area of interest
raindrops	Agent	An agent representing the flow volume from each patch (i.e. net run-off generated by precipitation falling on a given patch). Raindrops track flow volume and sediment it's transporting, as well as interacts with land-patches and river networks to flow downstream.
rivers	Network	A linked network representing the primary river drainage system of the major basins. The network contains a series of parent child relationships connected through a series of nodes used to route raindrops downstream to the basin outlet.
stations	Agent	Stationary agents representing water monitoring stations, ultimately to be used to validate simulated results with existing monitoring data. Currently, the stations are reference points for calculating and outputting measures of water flow and quality.
grids	Agents	Stationary agent representing the central point location of each ATS section within the area of interest. This central point is attributed percent of each AMBI human footprint feature corresponding ATS section. The grid agents are used to more efficiently allocate detailed human footprint information to patches by minimizing computer processing.

Table 2: Model variables

Variable	Variable Type	Description	Units
basin-dataset	Global	GIS raster data input of the major basins that make up the area of interest	Nominal
sediment-dataset	Global	GIS raster data input of the length slope factor (or LS factor) of RUSLE equation, estimated using SAGA	Ratio of soil loss at a given site to a standardized soil loss
land-cover-dataset	Global	GIS raster data input of ABMI wall to wall land cover data	Nominal
precip-dataset	Global	GIS raster data input of annual precipitation data based on WMA climate data	mm per year
rivers-dataset	Global	GIS polyline data input of a simplified river system	Nominal

channels-dataset	Global	GIS raster data input of channel elevation estimated using SAGA	Metres above sea-level
elevation-dataset	Global	GIS raster data input of elevation model based on DEM data	Metres above sea-level
Infiltration-dataset	Global	GIS raster data input of infiltration estimated using SAGA	mm per year
qs-dataset	Global	GIS point data input of each ATS section's central point, each point contains area of human footprint for the corresponding ATS section	Hectares
area	Global	Sets the area per patch for the models current resolution	Hectares
total-sediment-mass-in-transport	Global	Tracks the total sediment mass being transported at each step, calculated by summing the sediment mass of all raindrop agent	kg
total-sediments-deposited	Global	Tracks the total sediment mass deposited to each patch, calculated by summing the deposited sediment of all land-patches	kg
mx	Global	Used for mapping the various spatial data and represents the maximum attribute value for each map	NA
mn	Global	Used for mapping the various spatial data and represents the minimum attribute value for each map	NA
basin	Patch	Delineates the major basins within the area of interest. In this case 1 = North Saskatchewan and 2 = Battle	Nominal
flow	Patch	Tracks the flow volume of raindrop agents on the each land-patch at each step	m^3
rainfall	Patch	Annual precipitation data from precip-data set applied to patches	mm
elevation	Patch	DEM data from elevation-dataset applied to patches	Metres above sea-level
channel-elevation	Patch	Channel elevation data from channel-dataset applied to patches. A more refined elevation that better captures channel features	Metres above sea-level
hydro-elevation	Patch	Modified elevation data derived to averaging elevation and channel-elevation	Metres above sea-level
slope	Patch	Slope at each patch as measured using elevation-dataset	NA
cover	Patch	Used to store each patches corresponding C factor value (for RUSLE calculations) based on values entered on the model interface	
land-cover-type	Patch	Numerical value representing ABMI land cover types applied from the land-cover-dataset	Nominal

land-cover	Patch	String variable translating the land-cover-type numerical values to their text names	Text
potential-sediment	Patch	LS factor (for RUSLE calculations) applied to patches from the sediment-dataset	Same as sediment-dataset
hillslope-sediment-generated	Patch	Sediment generated from each patch based on the RUSLE calculation (see section 3.5)	kg
sediments-deposited	Patch	Variable that tracks the amount of sediment deposited to each patch	kg
removal-rate	Patch	Each patch is allocated a removal rate based on assumed removal efficiencies inputted on the interface by the user for each land cover type	percent
p-deposited	Patch	Amount of phosphorous mass deposited to each patch	kg
n-deposited	Patch	Amount of nitrogen mass deposited to each patch	kg
tss-deposited	Patch	Amount of suspended solid mass deposited to each patch	kg
is-land-patch	Patch	Variable used to establish land-patches agent set	Dichotomous
original-land-cover	Patch	Variable that maintains the initial land cover category. Currently this is equivalent to land-over-type, but is maintain in anticipation of building in land-use change algorithms	Nominal
is-river	Patch	Variable used to establish patches associated with rivers-dataset and to grow the river network	Dichotomous
evapotrans	Patch	A random normal variable based on the mean and standard deviation of evapotranspiration for the Alberta	mm
infiltration	Patch	Infiltration data from infiltration-dataset applied to patches	mm
runoff	Patch	Net runoff for each patch estimate by either (i) subtracting infiltration or evapotranspiration from precipitation; or (ii) applying the runoff-coefficient to precipitation.	mm
runoff-coefficient	Patch	The percentage of rainfall that produces runoff specific to landuse / landcovers	Percent
flow-supply	Patch	Amount of flow volume from each patch that reached the outlet	m^3
sediment-supply	Patch	Amount of sediment mass from each patch that reached the outlet	Tonnes / ha
p-supply	Patch	Amount of phosphorous mass from each patch that reached the outlet	kg / ha
n-supply	Patch	Amount of nitrogen mass from each patch that reached the outlet	kg / ha
tss-supply	Patch	Amount of suspended solid mass from each	kg / ha

		patch that reached the outlet	
hf-area1… 14	Patch	A series of 14 variables that group the area human footprint into categories corresponding with loading factor estimates (see section 3.5)	Hectares
thf	Patch	Percent of total human footprint in each patch	Percent
hf-load-N1… 14	Patch	A series of 14 variables that represent each patch's total N loading for the corresponding load category	Kg
hf-load-P1… 14	Patch	A series of 14 variables that represent each patch's total P loading for the corresponding load category	Kg
hf-load-TSS1… 14	Patch	A series of 14 variables that represent each patch's total TSS loading for the corresponding load category	Kg
load-{N, P, TSS}	Patch	Sum N, P, and TSS loads of all land cover and human footprint categories	Kg
lc-load-{N, P, TSS}	Patch	Sum N, P, and TSS loads of all land cover categories	Kg
hf-load-{N, P, TSS]	Patch	Sum N, P, and TSS loads of all 14 human footprint categories	Kg
load-{N,P,TSS}-perha	Patch	Each patches average N, P, and TSS load per ha	Kg per ha
lc-load-{N,P,TSS}-perha	Patch	Each patches average N, P, and TSS load per ha from land cover only	Kg per ha
hf-load-{N,P,TSS}-perha	Patch	Each patches average N, P, and TSS load per ha from human footprint only	Kg per ha
Sum-my-drops	Agent	As raindrops move across the landscape, when more than 3 agents are on the same patch one agent assumes the values of the others and the others die. sum-my-drops is used to keep a tally of the number of raindrops within an agent.	Number of agents
flow-volume	Agent	Tracks the total volume of each raindrop agent	m^3
sediment-mass	Agent	Tracks the mass of sediment that each raindrop carries	Tonnes
p-mass	Agent	Tacks the mass of phosphorous that each raindrop carries	kg
n-mass	Agent	Tacks the mass of nitrogen that each raindrop carries	kg
tss-mass	Agent	Tacks the mass of suspended solids that each raindrop carries	kg
my-home	Agent	Tracks the source patch of each raindrop agent	NA
my-route	Agent	Tracks and generates and patch set comprising the patches the raindrop agent	NA

		traverses	
parent	Network	A variable used by the river network to identify flow direction. Parent is the source of the next network link. Since the network grows from the outlet (the first parent) all parents are down stream of children.	NA
children	Network	A variable used by the river network to identify flow direction children grow from a pre-existing parent. Since the network grows from the outlet (the first parent) all children are up stream of parents.	NA
is-outlet	Network	A variable used to identify the outlet locations	NA
my-flow	Network	Used to track the flow volume within each network link	m^3
my-contributing-patches	Network	A patch set used to keep track of the patches contributing flow and sediment to each network link	NA

3.3 Overland flow and routing

The overland flow algorithm calculates flow routing using an ABM representing flow dynamics of units of water. Each unit of water is a mobile agent that interacts with other agents, the cellular landscape, and the river network.

Overland flow is calculated as:

$$OF_{j,t} = \sum_{FS} R_i$$

where $OF_{j,t}$ is overland flow [mm year^{-1}] for cell $j=1..n$ as the sum of runoff $R_{i,t}$ for all water agents[5] $i=1..m$.

The model is capable of calculating runoff using to different approaches. The first approach follows the process described in Donahue (2013):

$$R_i = P_J * Ppt_J * R_v$$

where P_J is precipitation [mm year^{-1}], Ppt_J is the fraction of annual rainfall events that produce runoff (set to 0.9), and R_v is a runoff coefficient specific to landuse or landcover *v.*

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[5] Water agents are the “raindrops” as described in Table 1.

Table 3: Runoff Coefficients by Landuse and Landcover Categories (Source: Donahue, 2013)

Landuse / Landcover Category	**R_v**
Highways	0.8
High-density development	0.69
Moderate compaction	0.38
Compacted	0.35
Unmaintained	0.3
Turf	0.25
Maintained	0.2
General Ag (Flat)	0.4
General Ag (Rolling)	0.5
General Ag (Hilly)	0.62
Wooded	0.3

The alternative runoff calculation can be described as follows:

$$R_i = P_J - E_J - I_J$$

where E_J is evapotranspiration [mm year^{-1}], and I_J is infiltration [mm]. E_J requires further calibration as it is current allocated randomly across the landscape based on the provincial mean [364 mm year^{-1}] and standard deviation [27 mm year^{-1}] of evapotranspiration as reported by Alberta Government (2013). I_J also requires further calibration and is approximated using SAGA wetness index noted in section 3.1.[6]

$OF_{j,t}$ is calculated for all ‘flow steps’ FS which are sequenced events representing travel distance of one cell from the runoff generation point to either the sub-basin outlet or a stream link, where overland flow becomes stream flow. Units of water are routed down slope according to elevation, which including water height, such that the target cell $TC_{FS,i}$ to which the water is routed can be described by:

$$TC_{FS,i} = \min \sum_{NB} \left(EV_j + \frac{\sum R_{i,t}}{1000} \right)$$

---

[6] This implies that the net runoff estimates are not properly calibrated and as result has implications for flow and sediment outputs of the model. However, loading factors for N, P, and TSS are not affected as their calculations are driven by total precipitation, not overland flow.

where NB denotes cell neighbors and EV_j is elevation [m]. If water units are on or adjacent to stream links, they are routed downstream 1 cell per FS until reaching the sub-basin outlet. Water units record their current position, and sequentially record a list of cells traversed which is their route to the outlet, thereby maintaining the information necessary to calculate the pathway of flow from source to outlet.

3.4 Stream flow routing

Stream flow SF_j is calculated similarly to overland flow as:

$$SF_r = \sum_{FS} R_i$$

but is calculated for each node in the river network $r = 1 \ldots z$

3.5 Pollutant generation and routing

As mentioned above two separate processes are used to estimate pollutant generation within the model: (1) applying broad-scale loading coefficients for N, P, TSS; and (2) dynamic and fine-scale estimation of hillslope sediment generation.

Broad-scale loading coefficients

Pollutant loading surfaces are generated using event mean concentration estimates based on landscape composition. Loading coefficients are drawn from static parameters from Donahue (2013) and simplified to a set of 18 human footprint or land cover types which receive unique loading coefficients, resulting in a spatially assigned loading L_j for nitrogen, phosphorus and total suspended sediments calculated as:

$$L_j^{N,P,TSS} = \sum \beta^k \cdot AreaLC_j^k \cdot P_j + \beta^k \cdot AreaHF_j \cdot P_j$$

where $AreaLC_j^k + AreaHF_j^k = 1$, and β^k are annual chemical load factors (CLF) for each of the 18 categories measured in kg/ha per mm of total annual precipitation (detailed in Table 3). $AreaLC_j^k$ is the cell area by land cover category, and $AreaHF_j^k$ is area human footprint. Loading coefficients measure the amount of pollutant loading in kg/ha per mm of annual precipitation.

Table 4: Annual Chemical Load Factors Used (Source: Donahue, 2013)

ID	Load factor category	NetLogo Code Name[7]	N	P	TSS
			(kg/ha) per mm of annual precipitation		

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[7] In the NetLogo code each land cover or footprint time has three variables one for each of N, P, and TSS. The variable name in the code listed in this column where x = N, P, or TSS.

1	Trails	trails-x	0.01440	0.01211	2.88900
2	Hard roads (paved)	hard-x	0.09825	0.00314	0.41330
3	Seismic line	seismic-x	0.00259	0.00101	0.27032
4	Pipeline	pipe-x	0.00519	0.00201	0.54065
5	Transmission line	trans-x	0.00346	0.00134	0.36043
6	Well pad	wells-x	0.01368	0.00689	1.93873
7	Industrial plants	industrial-x	0.01426	0.00184	1.08731
8	Surface mines	mines-x	0.00531	0.00068	0.42273
9	Feedlots	feedlots-x	1.62012	0.32423	4.99275
10	Urban (Suburban)	suburban-x	0.00779	0.00161	0.34922
11	Urban (City Core)	urban-x	0.01436	0.00178	0.62382
12	Rural Residential	rural-x	0.00316	0.00026	0.06309
13	General Ag (Flat)	ag-flat-x	0.01121	0.00096	0.27041
14	General Ag (Rolling)	ag-rolling-x	0.01419	0.00122	0.34251
15	General Ag (Hilly)	ag-hilly-x	0.01755	0.00151	0.42363
16	Wooded	forest-x	0.00340	0.00061	0.55350
17	Open space / grass	grass-x	0.00202	0.00013	0.07153
18	Recreation	rec-x	0.01124	0.00187	0.44149

The high-resolution spatial data of the ABMI human footprint data was handled by calculating the percentage area of various human footprint categories for each ATS section and applying these to associated patches in the model. The percentage area of total human footprint is removed from the land cover type and each CLF loading coefficient is correspondingly applied by area of human footprint type. This allows the separation of the source of pollutants from loadings generated by land cover composition and those from human footprint. Table 4 shows how the human footprint and land cover categories where linked to the load factor categories and corresponding variables in the NetLogo code.

Table 5: Linking AMBI Human Footprint and Land Cover Categories to Pollutant Loading Factors

ABMI Human Footprint / Land Cover Feature	Assigned Loading Category	NetLogo Code Name
Urban	Urban (Suburban)	Urban
Rural (Residential/Industrial)	Rural residential (acreage yard)	Rural
Other Disturbed Vegetation	Recreation	Other
Industrial Site Rural	Industrial Plants	IndSiteRural
High Density Livestock	Feedlots	HD_Livesto

Peat Mine	Surface Mines - disturbed	PeatMine
Well Site	Well pads	WellSite
Mine Site	Surface Mines - disturbed	MineSite
Road – Hard Surface	Hard roads (paved)	RoadHard
Rail – Hard Surface	Hard roads (paved)	RailHard
Pipeline Area	Pipelines	Pipeline
Transmission Line	Transmission lines	TransLine
Seismic Line	Seismic lines	Seismic
Road/Trail (Vegetated)	Trails	RoadTrail
Road – Vegetated Verge	Trails	RoadVerge
Rail – Vegetated Verge	Trails	RailVerge
Borrow-Pits, Dug-outs, Sumps	General Ag (Flat, Rolling, or Hilly)	BorrowPits
Municipal (Water and Sewage)	NA	MuniWater
Reservoirs	NA	Reservoirs
Canals	NA	Canals
Cultivation (Crop/Pasture/Bare Ground)	General Ag (Flat, Rolling, or Hilly)	Cultivatio
Cut Blocks	Wooded	CutBlocks
Water	NA	20
Snow/Ice	NA	31
Rock/Rubble	NA	32
Exposed Land	Open Space / Grass	33
Developed	Urban (City Core)	34
Shurbland	Open Space / Grass	50
Grassland	Open Space / Grass	110
Agriculture	General Ag (Flat, Rolling, or Hilly)	120
Coniferous Forest	Wooded	210
Broadleaf Forest	Wooded	220
Mixed Forest	Wooded	230

Dynamic estimate of hillslope sediment

Sediment generation is also calculated based on the RUSLE method, calculating hillslope sediment generation (measured in tonnes) as:

$$HS_j = R_j \cdot K_j \cdot LS_j \cdot C_j$$

Where R_j is the rainfall factor, K_j is the soil erodibiity factor, LS_j is a slope and length factor derived using Saga GIS (Cimmery, 2010), C_j is the cover factor, set via the model interface for each land cover type[8]. For a more detailed treatment of RUSLE factors see Appendix A.

Pollutants are transported via mobile water units from their point of generation, along a transport route according to overland flow and stream flow, and are delivered to outlets.

3.6 Pollutant routing and removal

Pollutants are transported via mobile water units from their point of generation, along a transport route according to overland flow and stream flow, and are delivered to sub-basin outlets. In this stage of model development pollutants are removed based on removal coefficients applied to land cover types. As water units traverse a cell, a given percentage of loading in transport for nitrogen, phosphorous and total suspended sediment is removed, such that:

$$L_{i,FS}^{N,P,TSS} = \sum_{FS} LD_J^{N,P,TSS} \cdot LR_j^{N,P,TSS}$$

where $L_{i,FS}^{N,P,TSS}$ is pollutant [n, p, tss] mass in transport (measured in kg) for each flow step to the sub-basin outlet, LD_J is the loading at the runoff source J, and LR_j is the loading removal coefficient set via the model interface.

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[8] Default values are established based on results from the literature; see Appendix A for detailed discussion.

4 Results

Outcomes from the model are presented here for each of the four sub-models described above; overland flow and routing, stream flow routing, pollutant generation and pollutant routing and removal.

4.1 Overland flow, stream flow and routing

The routing algorithm is depicted in Figure 4. Here three water units are exaggerated in size and colored magenta, red and green. Their route via overland flow, stream flow and to their sub-basin outlet is highlighted in their respective colors.

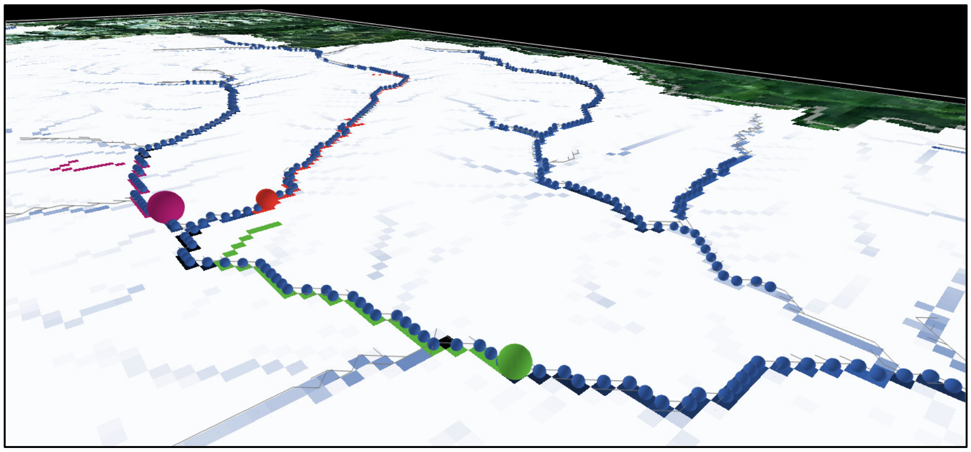


Figure 4: Depiction of model routing process

Total flow (overland and stream flow) can be mapped across the area of interest (Figure 5).

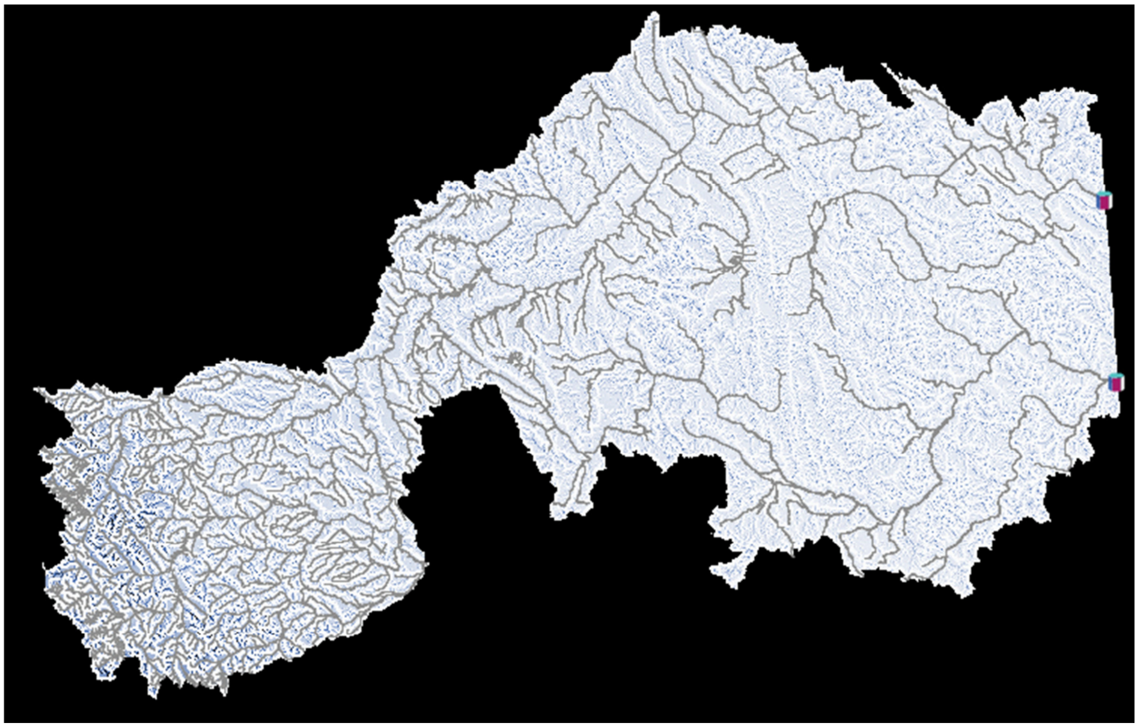
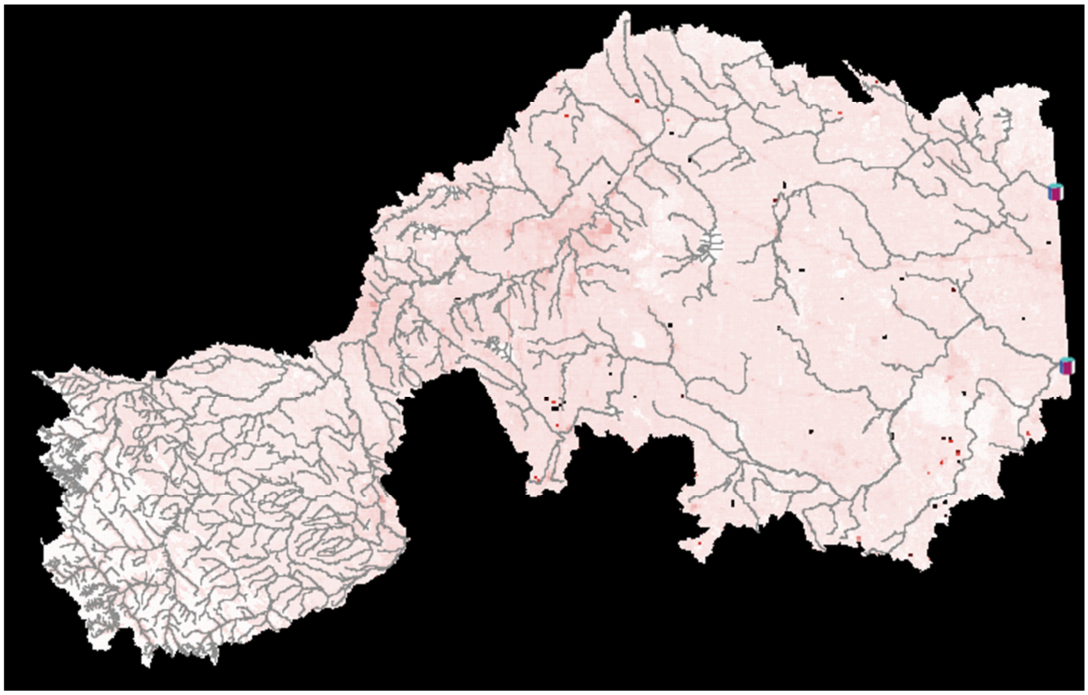


Figure 5: Total flow surface estimated

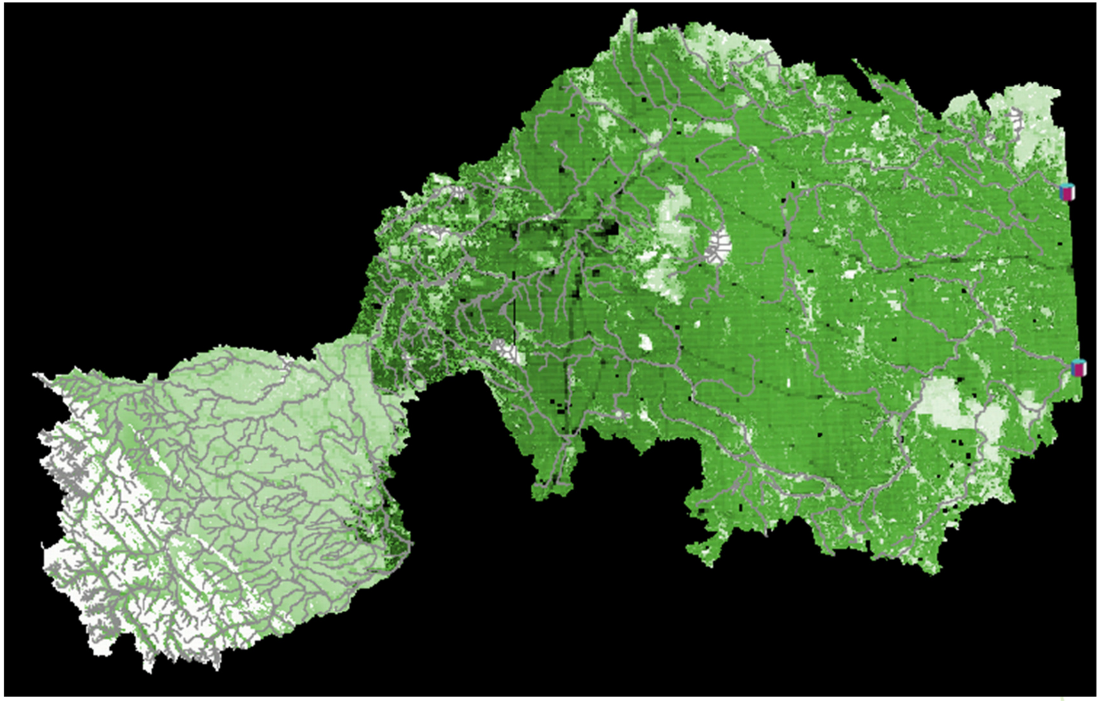
4.2 Pollutant loading

Figure 6 demonstrates pollutant loading results for phosphorus loading, nitrogen loading, total suspended sediments and hill slope sediment generated. Note the difference between (b) TSS and (d) hillslope sediment generated is the pollutant generation process used to calculate loading.

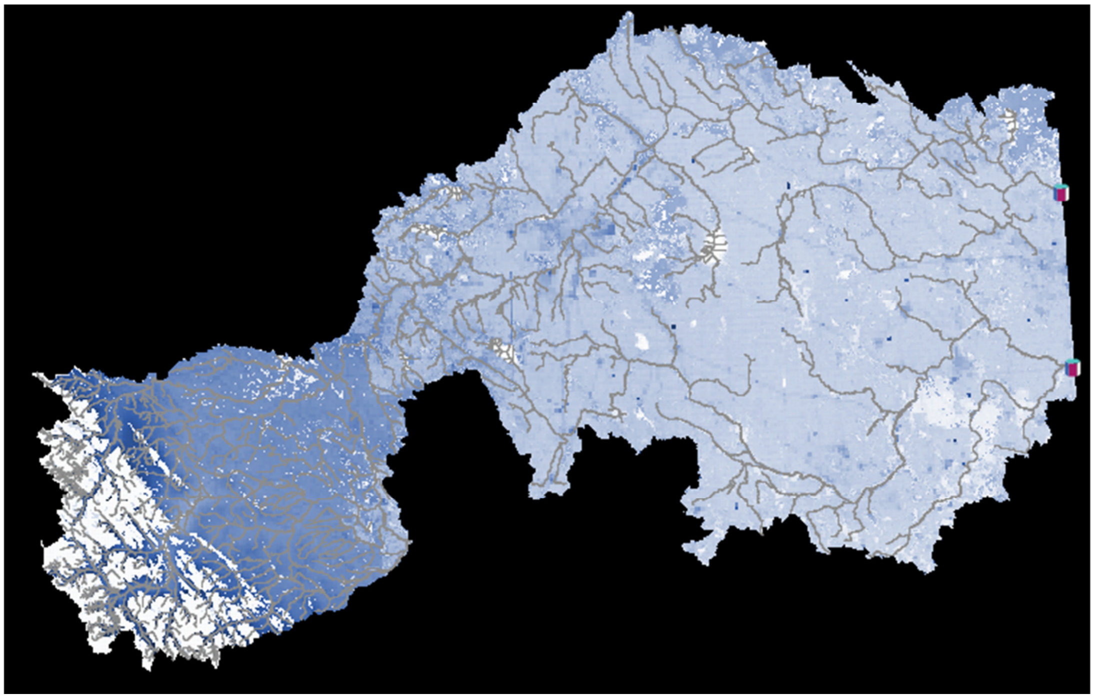
(a) Phosphorous (P) Loading



(b) Nitrogen (N) Loading



(c) Total Suspended Solids (TSS) Loading



(d) Hillslope sediment generated

Figure 6: Pollutant loading maps for (a) Phosphorous (kg ha^{-1} yr^{-1}), (b) Nitrogen (kg ha^{-1} yr^{-1}), (c) Total Suspended Solids (kg ha^{-1} yr^{-1}), and (d) Hillslope sediment generated (kg ha^{-1} yr^{-1})

Using the method described in the previous section, pollutant loading and sediment surfaces are generated. The spatial distribution of these surfaces is depicted in Figure 6. These maps essentially depict how much pollutant and sediment is generated from each parcel of the land base, based on the existing land use and land cover configuration. It is important to note the distinction between total suspended solids loading (Figure 6c) versus the hillslope sediment generated (Figure 6d). Hillslope sediment is estimated using the RUSLE equation described above and estimates soil erosion, a measure of sediment yield. TSS is a measure of the amount of fine sediment particles suspended in water. TSS loading factor calculate the contribution of suspended solids from each land cover and human footprint type. Thus, while related, hillslope sediment generated and TSS loading maps depict different concerns. Also, when comparing Figure 6c and 6d, it is important to note that for TSS there is currently no loading factor for the exposed rock / rubble land cover in the model and the hillslope sediment is estimating erosion based on RUSLE. For this land cover the loading approach underestimates loading and the RUSLE approach likely overestimates erosion. This is the primary reason why Figure 6c and 6d appear so different in the extreme western portion of the study area.

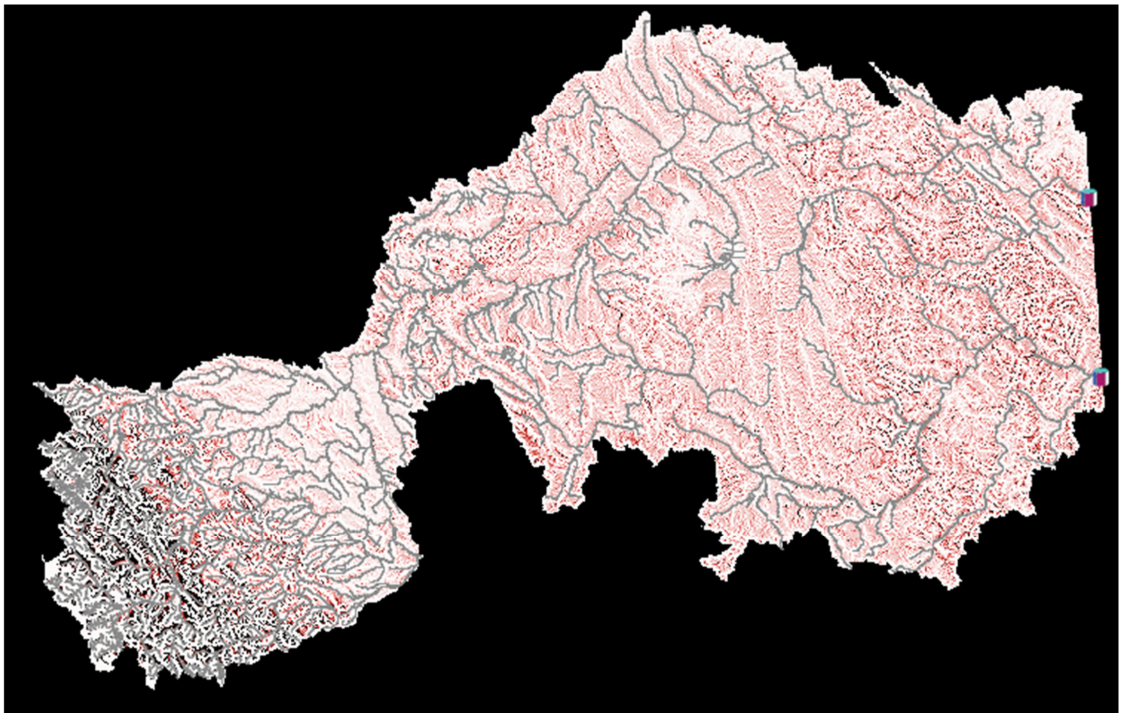


Figure 7: Removal / deposition of sediment.

Using the removal function as described in the previous section, deposition / removal surfaces are calculated. Figure 7 depicts this removal and can be interpreted as the total annual amount of the pollutants removed from each cell, based on the existing land use and land cover configuration.

4.3 Valuing Water Purification Services

From the combined processes of loading, deposition, and routing, as well as supply calculations, the value of water purification services can be explored. This can be done in a number of ways with varying degrees of complexity. The current approach follows a process similar to that used in InVEST (Kareiva et al. 2011), where the value of water purification is equated to the amount of sediment or pollution retained by the ecosystem and multiplied by the avoided treatment costs per unit of sediment or pollution. Future work will explore more in-depth approaches that more accurately capture the marginal value associated with changes in water purification services, fully capturing the demand side of the equation (i.e. the use of purification services by end user). The current valuation process draws on a range of existing values in published literature that focuses on avoided dredging costs and avoided drinking water treatment costs.

Avoided dredging costs are based on 14 different estimates from across North America. While dredging costs are likely to vary by location and site specific details, the maximum, minimum, and average values from the literature should provide a reasonable approximate and range of potential dredging costs. The average dredging costs were estimated to be $0.0135 per kg of sediment, with a min value of $0.0005 per kg and a max value of $0.0527 per kg (Moore and McCarl, 1987; Waxmonsky, 1997; Sohngen, 2001; Hansen and Hellerstein, 2004; Texas Water Development Board, 2005). All values reported have been adjusted to 2012 CAD.

Avoided drinking water treatment costs can be dealt with in a similar way. Holmes (1988) examined 430 water treatment facilities across the United States and found the average treatment ranged from $0.00003 to $0.00008 per kg of sediment. More recent estimates report costs as high as $0.0095 per kg (Hansen and Ribaudo, 2008). Overall, 10 estimates were found averaging $0.0071 per kg of treated sediment. Removal of phosphorous was found to be significantly more expensive, with a much wider range in values from $43.78 to $2,455.56 per kg depending on the water treatment facility (Sano et al. 2011; Wisconsin Department of Natural Resources, 2012). All values reported have been adjusted to 2012 CAD.

It should be noted that this is an overly simplistic approach to attributing values to water purification services. Value is driven by the interaction of supply and demand. The current models described in this document attempt to capture and map the supply of water purification services. A more comprehensive approach should also account for the demand side factors: who is benefiting, where are they located, and how much of the ecosystem service supply is being utilized by a beneficiary. In addition, valuing ecosystem services, such as water purification, should be done in the context of a change in state. For example, determining the marginal value derived by a given beneficiary for a specific improvement or decline in the supply of ecosystem services.

One of the exciting opportunities of this modelling approach is the ability to spatially link the beneficiaries to changes in pollutant conditions at a given location, and map the value of those changes back to the landscape parcels that provided those values. While further research and model development is required to properly capture the supply and demand of water purification services, the current model provides a proof-of-concept of this potential. Figure 8 demonstrates how for any given point on the landscape (in this case the provincial boundary of the North Saskatchewan and the battle river), we can track pollutant source and therefore the impact of landscape change to particular beneficiaries.

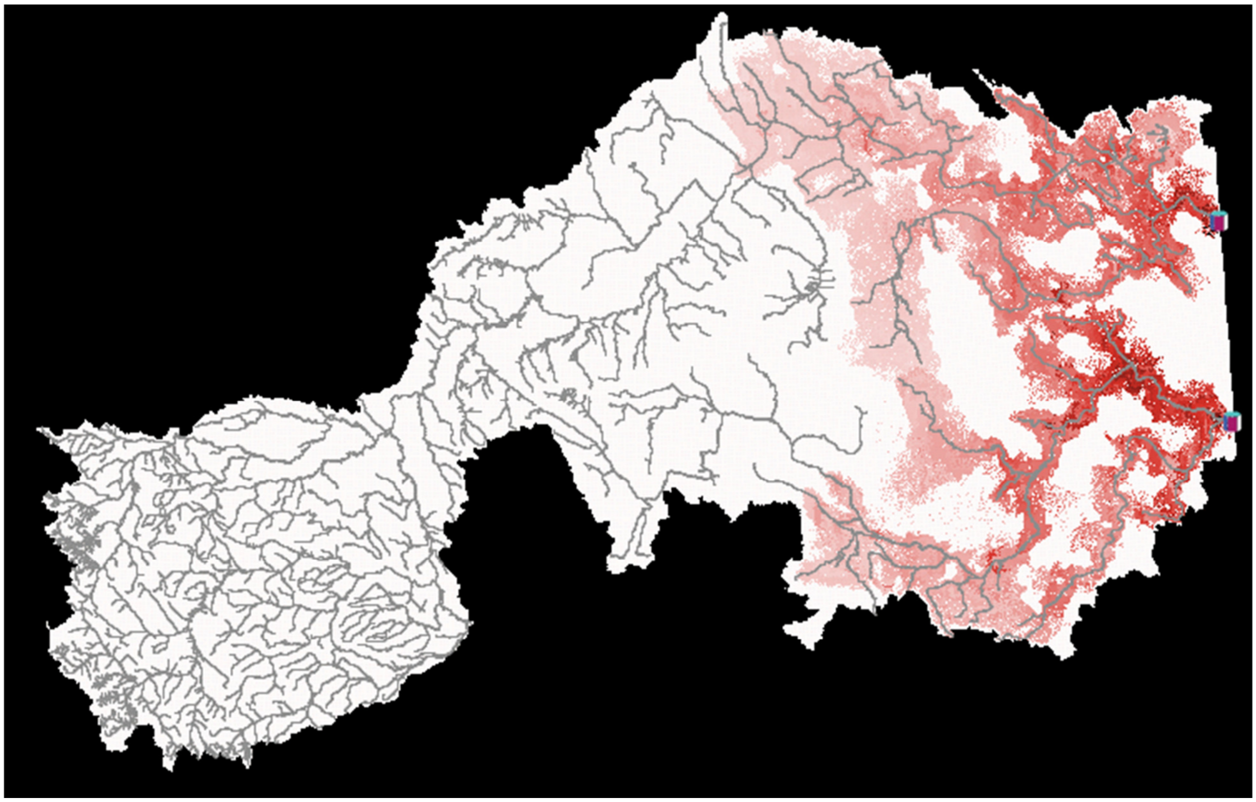


Figure 8: Example of the Valuation Mapping Potential from Sediment Supply

Specifically, Figure 8 maps the average amount of pollutants (per ha) reaching the outlet. In this way, changes in these values provide a relative assessment the supply of water purification services. Most importantly, it provides a basis for allocating and mapping values experienced by beneficiaries (at any given location) back to the land base.

5 Limitations

The model contains a few limitations and simplifying assumptions that should be aware of when interpreting any outputs from the model. They can be summarized as follows:

- Runoff procedures
    - The primary limitation of the model is the way runoff is generated and modelled. Currently, a full water balance model is not implemented, and future research will apply a method consistent with SWAT and imWebs (Yang et al. 2007; Liu and De Smedt, 2004).
    - Overland flow and stream flow routing require further work after the water balance model is implemented. The current model does not account for freezing conditions, so a rainfall event in the winter produces more flow than would be expected. Results are expected to calibrate well once water balance (and, more specifically, base flow) can be represented.
- Loading and Removal Efficiencies
    - The movement of P, N, and TSS involves complicated chemical relationships that have not been modelled.
    - Removal of P, N, and TSS is currently based on assumed removal efficiencies for different land covers. Removal efficiencies need to be calibrated. As a result of data limitations, removal efficiencies are assumed. As well, for a given land cover, the current model uses the same removal efficiency all three pollutants.
- Interpreting pollutant removal
    - Since pollutant removal calculations are based on assumed removal efficiencies, they should only be interpreted when aggregated to the sub-watershed or watershed level. Pixel-scale representation is provided to demonstrate the proof-of-concept. However, they should not be used to understand hydrologic processes or inform decision making.

6 Future Directions

With further changes to assumptions, calibration and validation, HydroGeosim could be used to determine the extent that best management practices and alternative land use change scenarios can alter water quality at both the landscape scale and at specific monitoring points. This will allow for modelling investment prioritisation in best management practices to achieve water quality targets at least cost. Future directions also include connection to climate change modelling.

7 Version Notes:

V1 developed in (ACEAS). V2 applied in Heckbert (2013), Heckbert et al. (in press). V3 applied in Canada with ALCES Group Ltd. 2012. V4 developed for North Saskatchewan River, Canada with Green Analytics 2013. V5 developed for Sheep River, Canada with Green Analytics and University of Guelph 2013. V6 develop for major basins linked to the North Saskatchewan Land Use Framework boundary.

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Appendix A. Background on RUSLE Method

Understanding sediment yields is integral to understanding various soil and water conservation planning processes. The universal soil loss equation (USLE) was originally designed to assess soil loss from agricultural land in the United States in particular predicting long-term average annual soil loss (Wischmeier and Smith, 1978). The revised universal soil loss equation (RUSLE), while retaining the basic structure of the USLE, was updated to incorporate a more comprehensive process for evaluating USLE factors (Renard et al., 1997). The process has also been adapted for specific application in Canada (Wall et al. 2002).

The basic equation can be represented as follows:

$A = R * K * LS * C * P$

where:

A is the long term average annual soil loss in tonnes per hectare per year (originally in tons per acre per year)
R is the rainfall factor
K is the soil erodibiity factor
LS is the slope length and steepness factor
C is the cover and management factor
P is the support practice factor

While, originally developed for agricultural purposes, in recent years RUSLE has been applied to a range of situations such as construction of highways (Alberta Transportation, 2003), modelling erosion at natural gas well sites (Wachal et al. 2009), forest management (Dissmeyer and Foster, 1981), and mining reclamation lands (Toy et al. 1999).

The following sections summarize how each factor was estimated for the water purification model.

R Factor

The R factor is a measure of the average annual erosivity, measured in erosion index (EI) units, and is generally influenced by storm energy and intensity, annual distribution of erosive precipitation, winter precipitation, and snowmelt (Wall et al. 2002). Wall et al. (2002) outline appropriate R factor values to be used in various locations across Canada. According to Wall et al. (2002) this value varies somewhat across Alberta ranging from slightly below 300 EI to slightly above 350 EI. In central Alberta, the R factor, adjusted for winter conditions, is reported to be 350 EI. This was the value used in the model.

K Factor

The K factor represents the rate of soil loss per unit area and is a quantitative measure of soil's inherent susceptibility (or resistance) to erosion (Wall et al., 2002). Soil texture, organic matter, structure, permeability and seasonality can all affect the K factor.

In the US, the calculation of K is based on an equation established by Wischmeier and Smith (1978) and relies on 5 key parameters:

1. Percent silt and very fine sand
2. Percent sand greater than 0.10mm
3. Percent organic matter
4. Soil structure
5. Permeability class

For Canada, Wall et al. (2002) reports a range of K values for common soil types that are based on information obtained from 1600 samples collected in Southern Ontario (see Table 5). As an interim approximation the K factor is set to 0.0288, the average of all soil erodibility values. Future calibration of the model will capture more location specific information.

Table 6: Soil erodibility values (K factor) for common soil types

Textural Class	**Organic Matter Content**		
	< 2%	>2%	Average
Clay	0.032	0.028	0.029
Clay Loam	0.044	0.037	0.040
Coarse Sandy Loam		0.009	0.009
Fine Sand	0.012	0.008	0.011
Fine Sandy Loam	0.029	0.022	0.024
Heavy Clay	0.025	0.020	0.022
Loam	0.045	0.038	0.040
Loamy Fine Sand	0.020	0.012	0.015
Loamy Sand	0.007	0.005	0.005
Loamy Very Fine Sand	0.058	0.033	0.051
Sand	0.001	0.003	0.001
Sandy Clay Loam		0.026	0.026
Sandy Loam	0.018	0.016	0.017
Silt Loam	0.054	0.049	0.050
Silty Clay	0.036	0.034	0.034

Textural Class	Organic Matter Content		
	< 2%	>2%	Average
Silty Clay Loam	0.046	0.040	0.042
Very Fine Sand	0.061	0.049	0.057
Very Fine Sandy Loam	0.054	0.044	0.046

LS Factor

The LS factor, also known as the slope length factor, accounts for the effect of slope angle and length on erosion. For the purpose of the water purification model, the LS factor for a given landscape was estimated using a geoprocessing tool within SAGA[9]. The tool calculates slope length (LS) factor based on user inputted digital elevation data and allows the user to select from three different calculation approaches based on: (i) Moore et al. (1991); (ii) Desmet and Govers (1996); and (iii) Böehner and Selige (2006). The current model used the Böehner and Selige (2006) approach. However, any of the three could be used.

C Factor

The C factor is arguably the most important RUSLE factor since it represents conditions that can be managed to reduce erosion. Under RUSLE, the c factor is determined from a range of subfactors. These subfactors include:

- Canopy cover
- Raindrop fall height
- Surface cover
- Roughness
- Root biomass
- Prior land use
- Soil-moisture

Standardized c factors have been determined for a wide range of agricultural crop and management types for a wide range of geographies. In Canada, Wall et al. (2002) provide generalized c factors for various regions across Canada. Of relevance to this research, Wall et al. (2002) provide detailed c values for the prairie Region. However, to utilize this information requires detailed information on cropping

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[9] SAGA is an open source is a Geographic Information System (GIS) software and can be downloaded free of charge at http://www.saga-gis.org/en/index.html

rotations and tillage practices. However, generalized c values are provided for the province of Alberta. Table 6 summarizes these generalized values.

Table 7: Generalized C Values for Alberta (adapted from Wall et al. 2002)

Crop	Conventional Till	Conservation Till	No Till
Spring Cereals	0.29	0.22	0.15
Fall Cereals	0.14	0.11	0.07
Oil Seeds	0.29	0.22	0.15
Legumes	0.29	0.22	0.15
Buckwheat	0.31	0.23	0.16
Sunflower	0.51	0.38	0.26
Corn Grain	0.53	0.4	0.27
Corn Silage	0.57	0.43	0.29
Potatoes	0.42	0.32	0.21
Sugar Beats	0.5	0.38	0.25
Tame Hay	0.01	0.01	0.01
Mixed Grain	0.31	0.23	0.16
Summer Follow	0.69		
Other Fodder Crops	0.3	0.23	0.15

While the c factor values have been well documented and detailed for agricultural areas, much less information is available for non-agricultural land covers. Some research has explored the use of remote sensing to attribute c values to a range of vegetation covers based on normal difference vegetation index (NDVI) data (Wang et al. 2002; Rompaey et al. 2005; Karaburun, 2010).

However, in the absence of detailed NDVI data and corresponding equation relating NDVI to C factors, we used published C factors from literature to approximate the default C factors values for each ABMI land cover class. Table 7 below summarizes the literature not reported Table 6. Based on information from Table 6 and 7, assumed default C factors are as follows: 0.45 for agriculture cover, 0.1 for all forest covers (coniferous, broadleaf, and mixed), 0.45 for exposed land cover, 0.3 for grassland cover, 0.25 for rock/rubble cover, 0.2 for shrubland, and 0 for water and snow/ice covers. All factors are adjustable by the model user on the model interface and can be adjusted to the users' preferred C factors.

P Factor

The P factor captures the effects of practices designed to modify the flow pattern, grade, or direction of surface runoff in order to reduce erosion (Wall et al. 2002). Such practices typically include cross slope cultivation, contour farming, or strip cropping. For the purpose of the current model the P factor was not included.

Table 8: Summarized C Factor values from literature

Land Cover Type	Detailed Specification	C factor high	C factor	C factor low	Region	Source
Natural vegetation	NA		0.003		NSW, AU	Simms et al (2003)
Agriculture / grazing	NA		0.45		NSW, AU	Simms et al (2003)
Complete clearance	NA		0.45		NSW, AU	Simms et al (2003)
Logging	NA		0.34		NSW, AU	Simms et al (2003)
Undisturbed Forest	20% to 40% canopy cover	0.003		0.009	Generic	Misir and Misir (2012)
Undisturbed Forest	45% to 70% canopy cover	0.002		0.004	Generic	Misir and Misir (2012)
Undisturbed Forest	75% to 100% canopy cover	0.0001		0.001	Generic	Misir and Misir (2012)
Tallgrass and weeds	0 to 25% canopy cover	0.003		0.45	Michigan, US	MSU (2002)
Tallgrass and weeds	25% to 75% canopy cover	0.003		0.36	Michigan, US	MSU (2002)
Brush	25% to 75% canopy cover	0.003		0.4	Michigan, US	MSU (2002)
Trees with no brush	25% to 75% canopy cover	0.003		0.42	Michigan, US	MSU (2002)
Undisturbed Forest	20% to 35% canopy cover	0.003		0.009	Michigan, US	MSU (2002)
Undisturbed Forest	40% to 70% canopy cover	0.002		0.004	Michigan, US	MSU (2002)
Undisturbed Forest	90% to 100% canopy cover	0.001		0.0001	Michigan, US	MSU (2002)
Forest	Logged / clearcut		0.115		Southeast US	Dissmeyer and Foster (1981)
Forest	Untilled selective cut		0.004		Southeast US	Dissmeyer and Foster (1981)

Appendix B. Metadata

Human footprint data

Layer

File name: ABMI_HumanFootprint

File type: Vector Polygon Shapefile

Description

This layer contains arc representation of cutlines within the North Saskatchewan LUF planning region of Alberta

Credits

Alberta Biodiversity Monitoring Institute, Alberta Sustainable Resource Development, Government of Alberta

Use Limitations

Government of Alberta departments and authorized agencies may conditionally use this data for internal business purposes which includes conditional sharing of the data with other third parties (i.e. contractors, stakeholders) if necessary for reasonable use of the data relating to the provision of services to the Crown as represented by each Ministry. Spatial Data Warehouse Ltd. (SDW) Mapping Data: Redistribution of the SDW information in whole or in part, whether alone or as part of a value added product, is not permitted without the prior written authorization of SDW, or AltaLIS Ltd. as agent for SDW. Prior to using SDW licensed information, Alberta Sustainable Resource Development (ASRD) personnel should be familiar with the contents of the document "Guidelines for Using Spatial Data Warehouse Ltd. (SDW) Mapping Data", available online on the Resource Information Management Branch website. ASRD personnel should also review the "Data Display Best Practices Guide", available online on the Resource Information Management Branch website for the appropriate accreditation that is required when using SDW data for display purposes.

Geographic Extent

North Saskatchewan planning region of Alberta

Spatial Reference Information

Type: Projected

Projection: Transverse_Mercator

Projected Coordinate System:

NAD_1983_10TM_AEP_Forest

False Easting: 500000.0

False Northing: 0.0

Central Meridian: -115.0

Scale Factor: 0.9992
Latitude of Origin: 0.0
Linear Unit: Meter (1.0)

Geographic Coordinate System:
GCS_North_American_1983
Angular Unit: Degree
Prime Meridian: Greenwich
Datum: D_North_American_1983
Spheroid: GRS_1980
  Semimajor Axis: 6378137.0
  Semiminor Axis: 6356752.314140356
  Inverse Flattening: 298.257222101

Spatial Data Properties
Data type: Vector
Geometry: Polygon
Object Count: 685,555 polygons

Area of Interest (AOI) data

Layer
File name: AOI
File type: Vector Polygon Shapefile

Description
This layer contains the boundary file for the two major basins within North Saskatchewan LUF planning region of Alberta

Credits
Silvacom, Alberta Sustainable Resource Development, Government of Alberta

Use Limitations
None

Geographic Extent
North Saskatchewan planning region of Alberta

Spatial Reference Information
Type: Projected
Projection: Transverse_Mercator

Projected Coordinate System:
NAD_1983_10TM_AEP_Forest
False Easting: 500000.0

False Northing: 0.0
Central Meridian: -115.0
Scale Factor: 0.9992
Latitude of Origin: 0.0
Linear Unit: Meter (1.0)

Geographic Coordinate System:
GCS_North_American_1983
Angular Unit: Degree
Prime Meridian: Greenwich
Datum: D_North_American_1983
Spheroid: GRS_1980
  Semimajor Axis: 6378137.0
  Semiminor Axis: 6356752.314140356
  Inverse Flattening: 298.257222101

Spatial Data Properties
Data type: Vector
Geometry: Polygon
Object Count: 1 polygon

Channel elevation data

Layer
File name: ChannelElevation_500m
File type: Raster dataset

Size
2.42 MB

Description
This layer contains channel elevation data in the North Saskatchewan LUF planning region of Alberta, derived from the DEM raster layer

Credits
Green Analytics

Use Limitations
None

Geographic Extent
North Saskatchewan planning region of Alberta
West: -117.513532
East: -109.804195

North: 54.493800

South: 51.542098

Spatial Reference Information

Type: Projected

Projection: Transverse_Mercator

Projected Coordinate System:

NAD_1983_Transverse_Mercator

False Easting: 500000.0

False Northing: 0.0

Central Meridian: -115.0

Scale Factor: 0.9992

Latitude of Origin: 0.0

Linear Unit: Meter (1.0)

Geographic Coordinate System:

GCS_North_American_1983

Angular Unit: Degree

Prime Meridian: Greenwich

Datum: D_North_American_1983

Spheroid: GRS_1980

  Semimajor Axis: 6378137.0

  Semiminor Axis: 6356752.314140356

  Inverse Flattening: 298.257222101

Spatial Data Properties

Data type: Raster

Number of rows: 634

Number of columns: 1000

Cell size: 500, 500

Digital elevation data

Layer

File name: DEM_500m

File type: Raster dataset

Size

2.42 MB

Description

This layer contains digital elevation model data in the North Saskatchewan LUF planning region of Alberta

Credits

Green Analytics

Use Limitations

None

Geographic Extent

North Saskatchewan planning region of Alberta
West: -117.513532
East: -109.804195
North: 54.493800
South: 51.542098

Spatial Reference Information

Type: Projected
Projection: Transverse_Mercator

Projected Coordinate System:
NAD_1983_Transverse_Mercator
False Easting: 500000.0
False Northing: 0.0
Central Meridian: -115.0
Scale Factor: 0.9992
Latitude of Origin: 0.0
Linear Unit: Meter (1.0)

Geographic Coordinate System:
GCS_North_American_1983
Angular Unit: Degree
Prime Meridian: Greenwich
Datum: D_North_American_1983
Spheroid: GRS_1980
  Semimajor Axis: 6378137.0
  Semiminor Axis: 6356752.314140356
  Inverse Flattening: 298.257222101

Spatial Data Properties

Data type: Raster
Number of rows: 634
Number of columns: 1000
Cell size: 500, 500

10m land cover data

Layer
File name: LandCover_10m
File type: Raster dataset

Size
1.56 GB

Description
This layer contains land cover data down to 10m in the North Saskatchewan LUF planning region of Alberta

Credits
Alberta Biodiversity Monitoring Institute

Use Limitations
None

Geographic Extent
North Saskatchewan planning region of Alberta

Spatial Reference Information
Type: Projected
Projection: Transverse_Mercator

Projected Coordinate System:
NAD_1983_Transverse_Mercator
False Easting: 500000.0
False Northing: 0.0
Central Meridian: -115.0
Scale Factor: 0.9992
Latitude of Origin: 0.0
Linear Unit: Meter (1.0)

Geographic Coordinate System:
GCS_North_American_1983
Angular Unit: Degree
Prime Meridian: Greenwich
Datum: D_North_American_1983
Spheroid: GRS_1980
  Semimajor Axis: 6378137.0
  Semiminor Axis: 6356752.314140356
  Inverse Flattening: 298.257222101

Spatial Data Properties

Data type: Raster

Number of rows: 32,997

Number of columns: 50,855

Cell size: 10, 10

100m land cover data

Layer

File name: LandCover_100m

File type: Raster dataset

Size

16 MB

Description

This layer contains land cover data down to 100m in the North Saskatchewan LUF planning region of Alberta

Credits

Alberta Biodiversity Monitoring Institute

Use Limitations

None

Geographic Extent

North Saskatchewan planning region of Alberta

Spatial Reference Information

Type: Projected

Projection: Transverse_Mercator

Projected Coordinate System:

NAD_1983_Transverse_Mercator

False Easting: 500000.0

False Northing: 0.0

Central Meridian: -115.0

Scale Factor: 0.9992

Latitude of Origin: 0.0

Linear Unit: Meter (1.0)

Geographic Coordinate System:

GCS_North_American_1983

Angular Unit: Degree

Prime Meridian: Greenwich

Datum: D_North_American_1983
Spheroid: GRS_1980
Semimajor Axis: 6378137.0
Semiminor Axis: 6356752.314140356
Inverse Flattening: 298.257222101

Spatial Data Properties
Data type: Raster
Number of rows: 3300
Number of columns: 5085
Cell size: 100, 100

500m land cover data

Layer
File name: Landcover_500m
File type: Raster dataset

Size
655.49 KB

Description
This layer contains land cover data down to 500m in the North Saskatchewan LUF planning region of Alberta

Credits
Alberta Biodiversity Monitoring Institute

Use Limitations
None

Geographic Extent
North Saskatchewan planning region of Alberta

Spatial Reference Information
Type: Projected
Projection: Transverse_Mercator

Projected Coordinate System:
NAD_1983_Transverse_Mercator
False Easting: 500000.0
False Northing: 0.0
Central Meridian: -115.0
Scale Factor: 0.9992

Latitude of Origin: 0.0
Linear Unit: Meter (1.0)

Geographic Coordinate System:
GCS_North_American_1983
Angular Unit: Degree
Prime Meridian: Greenwich
Datum: D_North_American_1983
Spheroid: GRS_1980
  Semimajor Axis: 6378137.0
  Semiminor Axis: 6356752.314140356
  Inverse Flattening: 298.257222101

Spatial Data Properties
Data type: Raster
Number of rows: 660
Number of columns: 1017
Cell size: 500, 500

Land slope data

Layer
File name: LS_Factor_500m
File type: Raster dataset

Size
2.42 MB

Description
This layer contains land slope factor data in the North Saskatchewan LUF planning region of Alberta

Credits
Green Analytics

Use Limitations
None

Geographic Extent
North Saskatchewan planning region of Alberta
West: -117.513532
East: -109.804195
North: 54.493800
South: 51.542098

Spatial Reference Information

Type: Projected

Projection: Transverse_Mercator

Projected Coordinate System:

NAD_1983_Transverse_Mercator

False Easting: 500000.0

False Northing: 0.0

Central Meridian: -115.0

Scale Factor: 0.9992

Latitude of Origin: 0.0

Linear Unit: Meter (1.0)

Geographic Coordinate System:

GCS_North_American_1983

Angular Unit: Degree

Prime Meridian: Greenwich

Datum: D_North_American_1983

Spheroid: GRS_1980

Semimajor Axis: 6378137.0

Semiminor Axis: 6356752.314140356

Inverse Flattening: 298.257222101

Spatial Data Properties

Data type: Raster

Number of rows: 634

Number of columns: 1000

Cell size: 500, 500

Annual precipitation data

Layer

File name: PPT_Annual_500m

File type: Raster dataset

Size

1.21 MB

Description

This layer contains annual precipitation data in the North Saskatchewan LUF planning region of Alberta, downloaded from http://www.ualberta.ca/~ahamann/data/climatewna.html

Credits

Silvacom, Green Analytics, Hamann, A.

Use Limitations

None

Geographic Extent

North Saskatchewan planning region of Alberta
West: -117.513532
East: -109.804195
North: 54.493800
South: 51.542098

Spatial Reference Information

Type: Projected
Projection: Transverse_Mercator

Projected Coordinate System:

NAD_1983_Transverse_Mercator
False Easting: 500000.0
False Northing: 0.0
Central Meridian: -115.0
Scale Factor: 0.9992
Latitude of Origin: 0.0
Linear Unit: Meter (1.0)

Geographic Coordinate System:

GCS_North_American_1983
Angular Unit: Degree
Prime Meridian: Greenwich
Datum: D_North_American_1983
Spheroid: GRS_1980
  Semimajor Axis: 6378137.0
  Semiminor Axis: 6356752.314140356
  Inverse Flattening: 298.257222101

Spatial Data Properties

Data type: Raster
Number of rows: 634
Number of columns: 1000
Cell size: 500, 500

River and stream data

Layer

File name: RiverStream
File type: Vector polyline shapefile

Description

20K base feature data depicts rivers and streams as well as other wetland areas within the two major basins in the North Saskatchewan LUF planning region of Alberta

Credits

Alberta Biodiversity Monitoring Institute, AltaLIS

Use Limitations

Data should not be used or distributed except for the advancement of the Ecosystem Services Assessment project, as contributed by Silvacom, Green Analytics, Alberta Innovates Technology Futures and Alberta Biodiversity Monitoring Institute

Geographic Extent

North Saskatchewan planning region of Alberta

Spatial Reference Information

Type: Projected
Projection: Transverse_Mercator

Projected Coordinate System:
NAD_1983_10TM_AEP_Forest
False Easting: 500000.0
False Northing: 0.0
Central Meridian: -115.0
Scale Factor: 0.9992
Latitude of Origin: 0.0
Linear Unit: Meter (1.0)

Geographic Coordinate System:
GCS_North_American_1983
Angular Unit: Degree
Prime Meridian: Greenwich
Datum: D_North_American_1983
Spheroid: GRS_1980
  Semimajor Axis: 6378137.0
  Semiminor Axis: 6356752.314140356
  Inverse Flattening: 298.257222101

Spatial Data Properties

Data type: Vector
Geometry: Polyline
Object Count: 100,764 polylines

Land section data

Layer
File name: SectionPoints
File type: Vector point shapefile

Description
This layer contains points depicting the location and characteristics of quarter section cells within the North Saskatchewan LUF planning region of Alberta

Credits
Alberta Biodiversity Monitoring Institute, Alberta Innovates Technology Futures, AltaLIS

Use Limitations
Data should not be used or distributed except for the advancement of the Ecosystem Services Assessment project, as contributed by Silvacom, Green Analytics, Alberta Innovates Technology Futures and Alberta Biodiversity Monitoring Institute

Geographic Extent
North Saskatchewan planning region of Alberta
West: -117.512328
East: -109.805774
North: 54.493557
South: 51.544550

Spatial Reference Information
Type: Projected
Projection: Transverse_Mercator

Projected Coordinate System:
NAD_1983_10TM_AEP_Forest
False Easting: 500000.0
False Northing: 0.0
Central Meridian: -115.0
Scale Factor: 0.9992
Latitude of Origin: 0.0
Linear Unit: Meter (1.0)

Geographic Coordinate System:
GCS_North_American_1983
Angular Unit: Degree
Prime Meridian: Greenwich
Datum: D_North_American_1983
Spheroid: GRS_1980

Semimajor Axis: 6378137.0
Semiminor Axis: 6356752.314140356
Inverse Flattening: 298.257222101

Spatial Data Properties
Data type: Vector
Geometry: Point
Object Count: 32,166 points

Wetlands data

Layer
File name: WetlandsDissolved
File type: Vector polygon shapefile

Description
This layer contains dissolved wetlands data in the North Saskatchewan LUF planning region of Alberta, derived from land cover data from the Alberta Biodiversity Monitoring Institute

Credits
Alberta Biodiversity Monitoring Institute

Use Limitations
None

Geographic Extent
North Saskatchewan planning region of Alberta

Spatial Reference Information
Type: Projected
Projection: Transverse_Mercator

Projected Coordinate System:
NAD_1983_10TM_AEP_Forest
False Easting: 500000.0
False Northing: 0.0
Central Meridian: -115.0
Scale Factor: 0.9992
Latitude of Origin: 0.0
Linear Unit: Meter (1.0)

Geographic Coordinate System:
GCS_North_American_1983
Angular Unit: Degree
Prime Meridian: Greenwich

Datum: D_North_American_1983
Spheroid: GRS_1980
Semimajor Axis: 6378137.0
Semiminor Axis: 6356752.314140356
Inverse Flattening: 298.257222101

Spatial Data Properties

Data type: Vector
Geometry: Polygon
Object Count: 478,321 polygons

Topographic wetness index data

Layer

File name: TopoWetnessIndex_500m
File type: Raster dataset

Size

1.21 MB

Description

This layer contains data from the topographical wetness index in the North Saskatchewan LUF planning region of Alberta, derived from the DEM raster layer

Credits

Green Analytics

Use Limitations

None

Geographic Extent

North Saskatchewan planning region of Alberta
West: -117.513532
East: -109.804195
North: 54.493800
South: 51.542098

Spatial Reference Information

Type: Projected
Projection: Transverse_Mercator

Projected Coordinate System:

NAD_1983_Transverse_Mercator
False Easting: 500000.0
False Northing: 0.0

Central Meridian: -115.0
Scale Factor: 0.9992
Latitude of Origin: 0.0
Linear Unit: Meter (1.0)

Geographic Coordinate System:
GCS_North_American_1983
Angular Unit: Degree
Prime Meridian: Greenwich
Datum: D_North_American_1983
Spheroid: GRS_1980
  Semimajor Axis: 6378137.0
  Semiminor Axis: 6356752.314140356
  Inverse Flattening: 298.257222101

Spatial Data Properties
Data type: Raster
Number of rows: 634
Number of columns: 1000
Cell size: 500, 500