Modelling climate impacts on hydrologic and nutrient transport processes in the Lake Winnipeg watershed

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Introduction

The quality of water in Lake Winnipeg has deteriorated due to excess nutrient loading from non-point sources in the watershed. According to an analysis by Jones and Armstrong (2001), total nitrogen and total phosphorus loads to Lake Winnipeg has increased by 13 % and 10 % respectively, over the last three decades.

While nutrient transport from non-point sources to the lakes is driven by complex hydrologic and biochemical processes, the large-scale variability in the hydro-meteorologic regime play a key role in nutrient delivery to the lakes. Climate change is expected to influence the hydro-meteorologic regime in the Prairies region, which will also affect the nutrient transport processes. Previous studies on nutrients loading indicate that Red and Assiniboine basins are the major source of nitrogen and phosphorus loading into Lake Winnipeg (Bourne *et al*., 2002). Therefore, the present study focuses on climate impacts on hydrologic and nutrient transport processes in the two representative sub-watersheds of the Red and Assiniboine basins.

Study Area

The study considers the upper Assiniboine catchment in Saskatchewan and Morris catchment in Manitoba (Figure 1) for a detailed assessment of climate impacts on hydrologic and nutrient transport processes. Both of these catchments are dominated by agricultural land use and can be considered suitable for understanding the climate impacts on non-point nutrient loadings.

The upper Assiniboine catchment covers an area of about 13500 km^2, upstream of the Lake of Prairies (Shellmouth reservoir) in Saskatchewan. The topography is gently to moderately undulating with the higher relief in the north-east of the catchment. Major tributaries are the Whitesand River, Shell River, Lilian River and Yorkton Creek. The catchment is dominated by agricultural land use (about 55 %) with mixed grain and wheat as primary crops (Environment Canada, 2000).

The Morris river is a tributary of Red River with a catchment area of about 4300 m^2. The catchment is located in southern Manitoba with the headwaters located on the north-eastern edge of the Pembina Hills region (Jones and Armstrong, 2001). The Boyne river and Tobacco creeks are the major tributaries, which drain into a network of man-made channels before flowing into Morris River. The catchment is dominated by agricultural land use (about 80 %) with the river water extensively used for irrigation.

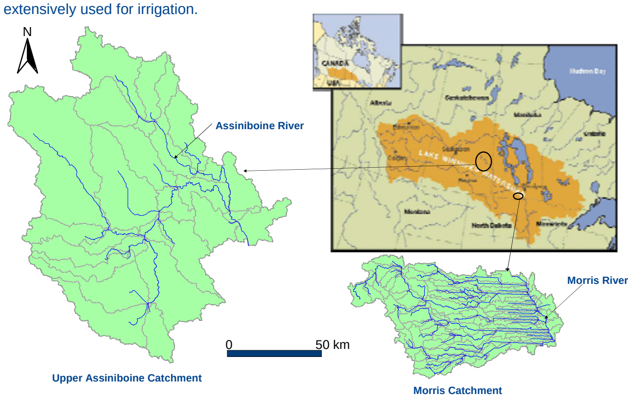


Figure 1: Location Map of Upper Assiniboine and Morris Catchments

Project Components

The project consists of the following components:

- Selection of representative basins in the Lake Winnipeg watershed
- Analysis of current and future precipitation regimes for representative regions in the watershed
- Selection of different GCM/RCMs that best replicates the current climate of this region
- Assessment of different landscape hydrology/nutrient transport models for application in representative regions
- Ensemble prediction of future climate scenarios by combining GCM/RCM outputs with hydrologic/nutrient transport model.

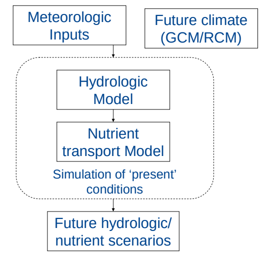


Figure 2: Model Components for Simulation of Present and Future Scenarios

Hydrologic/Nutrient Transport Model

Soil Water Assessment Tool (SWAT) (Arnold *et al*., 1998) is a process-oriented, semi-distributed continuous model developed by the United States Department of Agriculture- Agriculture Research Service (USDA-ARS). SWAT is developed for assessing the impacts of management and climate on water supplies, sediment, and agricultural chemical yields in watersheds and large river basins. The main components of the model include hydrology, weather, erosion, soil temperature, crop growth, nutrients, pesticides, and agricultural management.

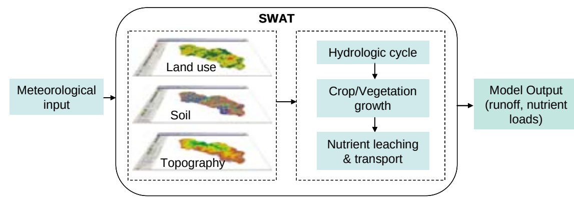


Figure 3: Schematic Representation of Hydrologic and Nutrient Transport Modelling Using SWAT

Discharge and Nutrient Loading

The discharge and nutrient loading in Assiniboine (Figure 4a) and Morris river tributary Boyne river (Figure 4b) show increase in the total load with an increase in discharge. This suggests that nutrient loading during climate change induced extreme events may also be higher.

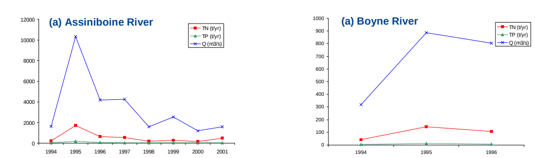
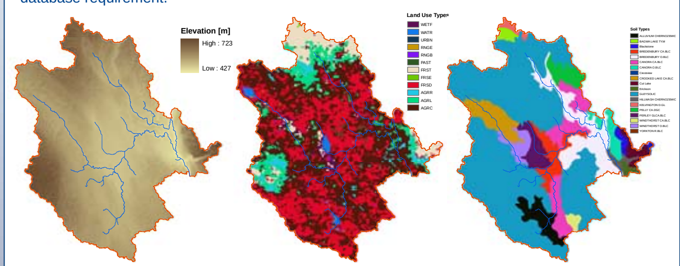


Figure 4: Annual Discharge and Nutrient Loading in (a) Assiniboine River and (b) Boyne River

Model Set Up

Geospatial Data

The SWAT model for both the catchments are set up using 90 m digital elevation model (Figure 4a) from Consultative Group for International Agriculture Research - Consortium for Spatial Information (CGIAR-CSI). The digital land use data (Figure 5b) is taken from Land Cover of Canada (LCC) database with a spatial resolution of about 1 km. The soil database (Figure 5c) from Soil Landscapes of Canada (SLC) version 3.1.1 is used which consists of physical properties of soil at 1: 1 million resolution. The LCC and SLC database are reclassified to match with the SWAT database requirement.



(a) Digital Elevation Model (CGIAR-CSI GeoPortal)
(b) Land Use Classes (Land Cover of Canada)
(c) Soil Types (Soil Landscapes of Canada)

Figure 5: Geospatial Data for SWAT

Meteorologic Data

SWAT requires precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity as meteorologic inputs. The North America Regional Reanalysis (NARR) data is used as input variables to calibrate the SWAT model. The dataset used consists of 45 km spatial resolution and 1 day temporal resolution. The NARR dataset is of the same spatial resolution as the Canadian Regional Climate Model (CRCM) to be used in scenario simulation, so consistency in the input data can be maintained for simulation of present and future climate scenarios.

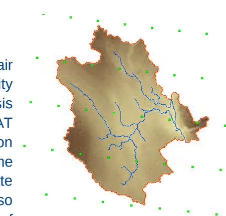


Figure 6: Meteorologic Input Domain

Model Calibration and Uncertainty Analysis

SWAT consists of a large number of model parameters which need to be identified. Most of the parameter values are unknown and highly uncertain. The parameter estimation is further complicated by 'equifinality' problem, as many different parameter sets within a chosen model structure can give similar model performances (Beven and Freer, 2001). Therefore, a systematic methodology for parameter estimation and uncertainty analysis is necessary. The study uses methodologies developed by Van Griensven and Meixner (2006) and Abbaspour *et al*. (2004) for a combined identification of model parameters and uncertainty analysis.

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