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Establishing a Foundation for Ecological Infrastructure Investments in the Red River Basin

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August 2010

RED RIVER BASIN COMMISSION

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Executive Summary

The Red River Basin (RRB), which drains a total area of 116,500 square kilometres in parts of Manitoba, North Dakota and Minnesota, has become one of the most productive breadbaskets of the world due to its rich, fertile and productive soils. The conversion of its landscape to support agricultural activity has led to important economic opportunities but also to chronic and acute problems for its citizens. Regular flooding events have resulted in significant infrastructure damages and agricultural losses. Water quality has degraded across the basin and Lake Winnipeg has become the most eutrophied large lake in the world. Efforts to clear and drain land to give way to agriculture have led to natural environmental losses that, at times, have exacerbated these problems.

Finding a better balance between human-altered and natural environments while maintaining or enhancing the overall long-term socioeconomic viability and well-being of the communities within the RRB is the underlying objective of the Building Capacity for Ecological Infrastructure Investments[1] in the Red River Basin[2] initiative. The Red River Basin Commission (RRBC) and the International Institute for Sustainable Development (IISD) initiated this project to provide the municipalities and counties of the RRB with the ability to examine ecological infrastructure investments within and outside their jurisdictions to provide cost-effective services to their citizens.

This report provides foundational research required to develop a comprehensive decision support system (DSS) that would assist municipalities and counties in the RRB examine the cost and benefits associated with ecological infrastructure investments so they can be compared with hard infrastructure investments. It is expected that the DSS will enable a more thorough exploration of local government investment options, consequently leading to a better balance between human-altered and natural landscapes in the basin.

The project can be divided into two phases. The first phase consisted of establishing a multidisciplinary, basin-wide project advisory committee, building partnerships with various organizations and obtaining letters of support; we completed a data gap analysis, organizing and hosting a modelling workshop and selecting case studies. The second phase will consist of developing and disseminating the DSS to the watershed management community in the RRB. The activities undertaken and findings associated with the first phase of the project are described below.

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[1] Ecological infrastructure investments are defined as expenditures in conserving and restoring natural environments to provide services.
[2] The project name was modified to *Building Capacity for Multi-Purpose Land and Water Investments in the Red River Basin* to better convey the purpose of the initiative to various audiences.

Building partnership activities consisted of outreach and presentation activities to familiarize and gain support from key organization in the RRB and to establish a project advisory committee to adequately guide the various activities of the first phase. A number of presentations were made to stakeholders across the basin and letters of support were received from key organizations. A project advisory committee consisting of representatives from North Dakota, Minnesota and Manitoba was assembled to provide expertise in the areas of water supply, water quality, flood management and conservation and overall guidance for the project.

A data gap analysis was completed to identify biophysical, infrastructure and socioeconomic information required to build an effective ecological infrastructure investments DSS. The majority of the biophysical information to develop the DSS is available (land cover, soils and bedrock). Nevertheless, comprehensive elevation data needed to accurately characterize the hydrology of the basin's flat topography is lacking. Light Detecting and Ranging (LIDAR) data (with a vertical accuracy of 15 cm) has been collected for the majority of the basin but large tracts are missing in Canada. A coordinated effort to collect the missing LIDAR data could lead to significant savings (an expenditure of US$0.9 million instead of C$3.4 million). Providing water-related and other infrastructure information, which is generally available, in a more centralized and coherent fashion would make it more accessible to the public and feasible to identify ecological infrastructure investments opportunities. Socioeconomic data is readily available for the development of the DSS but may have to be disaggregated or aggregated from census divisions to basin and watershed boundaries for it to be useful.

A modelling workshop was organized and hosted by IISD and the RRBC to bring together technical and policy-making expertise on both sides of the border. The workshop opened with an update on the ecological infrastructure investments project, an overview of Integrated Watershed Management initiatives and various models that are currently and could potentially be used in the RRB. Strategic questions sent to the participants prior to the workshop were discussed and a number of key directions and insights were obtained with respect to developing the DSS:

- A lack of an overarching vision with defined goals and objectives is an obstacle to developing an effective DSS for ecological infrastructure investments. However, the technical aspects of the DSS can still be worked on as objectives are being formulated.
- Significant knowledge gaps (better understanding of biophysical processes) need to be filled so that an accurate and reliable DSS can be developed (i.e., water retention on the landscape and dissolved phosphorus dynamics).
- Harmonized data sets are needed to develop a basin-wide DSS. Establishing shared protocols for gathering and processing data will ensure that it remains compatible across state and provincial boundaries. A study on data-gathering protocols in each jurisdiction to identify harmonization opportunities would be a positive step towards compatibility.

- There are important ongoing data collection (Group on Earth Observation—soil moisture and crop mapping) and compatibility (International Red River Board—hydrological stream network compatibility) efforts that must be capitalized on for developing the DSS.
- The DSS will have to build on existing models and tools. This may require the development of middleware or translation software so that the various models, tools and databases can work together. The OPEN MI protocol provides some guidance as to how this could be achieved.
- The DSS should be designed so that it is useful for a number of users (local as well as higher levels of governments) at various spatial and temporal scales and it should be educational as well as insightful for decision-making. For this reason, it should have an excellent interface that communicates the information visually and allows the users to provide feedback.
- The DSS should be easily accessible (potentially online) and freely available. To achieve these goals, the designers should take advantage of new networking capabilities, such as cloud computing, to improve performance and cut costs.
- The DSS should have functionalities to facilitate integrated natural resources management and have a wide range of capabilities so that it is useful and relevant for a broad range of potential users (flood and drought forecasting, water quality, water supply, ecosystem management, infrastructure cost and benefit analysis).
- A DSS with the ability to evaluate various scenarios would be useful to facilitate proactive instead of reactionary integrated watershed management and ecological infrastructure investment decisions.
- The project needs to establish stakeholder advisory groups that can provide technical as well as governance expertise.
- The DSS should be designed in a stepwise fashion by first identifying suitable locations for developing and piloting the DSS.
- A long-term maintenance plan for the DSS must be formulated at the beginning of the project so that the system does not become irrelevant.

The participants agreed to an outreach piece for the general public so they can be made aware of the initiative. They also committed to continue working on the project and a letter of commitment was to be drafted and shared with politicians to gain support for the initiative.

Potential ecological infrastructure investment case studies were identified and examined across the basin. Three case studies—one in Canada, one in the United States and a U.S. federal program—were chosen based on their biophysical, infrastructure and socioeconomic characteristics. The Seine Rat River Conservation District La Coulee sub-watershed project was chosen, as its watershed is a nutrient hot spot and the project location, the former Giroux Bog, is prone to flooding resulting in agricultural losses. The project aims to restore the Giroux Bog for water retention during the spring melt and summer rainfall events, thus slowing floodwaters and allowing nutrients and sediment to settle out in the retention area. The Palmville project in the international Roseau River watershed was chosen as it has been regularly subjected to flooding and has experienced significant wetland losses. The project will aim to restore and conserve the Palmville Fen to retain more water and filter nutrients and sediments. This work will help protect the downstream cities of Roseau and Wannaska from flooding events and avert the need to build flood protection structures. The Agricultural Water Enhancement Project (AWEP) is a federal program administered by the United States Department of Agriculture (USDA). A major AWEP initiative has been planned for the RRB, which will be coordinated by the RRBC. A basin-wide DSS that can facilitate ecological infrastructure investments may assist the AWEP with prioritizing resources more effectively to improve water quality within the basin.

The following general recommendations are made for building ecological infrastructure investment capacity in the RRB as a result of this foundational research:

- Build upon ongoing and planned compatible initiatives such as the development of the DSS by the International Water Institute.
- Initiate the collection of missing LIDAR data in the Canadian portion of the basin in a coordinated manner, as opposed to a piecemeal fashion to save cost.
- Develop a coordinated system for tracking infrastructure information in the basin.
- Request the collection of socioeconomic information disaggregated and aggregated at the watershed and basin scales.
- Develop harmonized data-gathering and processing protocols to ensure compatibility among all three jurisdictions
- The DSS should be easily accessible and freely available and designed for multiple users so that it can be useful for various spatial and temporal scales.
- The development of the DSS must be compatible with existing models and tools used for integrated watershed management and must build on ongoing data collection and compatibility efforts in the basin.
- The DSS should have a wide range of functionalities (flood and drought forecasting, water quality, water supply, ecosystem management, infra-structure cost and benefit analysis, scenarios exploration) to facilitate proactive integrated natural resources and watershed management.
- The DSS should be designed so that it can be useful for planning ecological infrastructure investments within municipalities and counties at the watershed scale and to assist with effective government programming related to agricultural and infrastructure efforts.

It is expected that the Building Capacity for Ecological Infrastructure Investments in the Red River Basin initiative will lead to the development of a DSS that will allow local governments to enhance their fiscal effectiveness while rehabilitating natural environments. This expectation is exemplified by New York City's multi-billion dollar cost-saving decision to enhance their water supply's watershed instead of building a new water filtration plant. Delivering cost-effective services through ecological infrastructure investments will lead to more resilient natural environments, which are indispensible for the long-term well-being of the RRB's communities.

Table of Contents

List of Acronyms

AAFC	Agriculture and Agri-Food Canada
ASTER	Advanced Spaceborne Emissions and Reflection Radiometer
ATTAINS	Assessment, TMDL Tracking and ImplementatioN System
AWEP	Agricultural Water Enhancement Program
BEACH	Beaches Environmental Assessment, Closure & Health
BMP	Best management practices
BWG	Basin Working Group
CAR	Census Agricultural Region
CD	Conservation District
CDL	Census division level
CHRM	Cold Regions Hydrological Model
CSO	Combined sewer overflow
CWNS	Clean Watersheds Needs Survey
DDS	Decision support system
DEM	Digital Elevation Models
EC	Environment Canada
EOSD	Earth Observation for Sustainable Development
EQIP	Environmental Quality Incentives Program
ESV	Ecosystem Service Valuation
FEMS	Farm Environmental Management Survey
FFDT	Flood Forecast Display Tool
GEO	Group on Earth Observations
GIS	Geographic Information System
GRTS	Grants Reporting and Tracking System
GSFLOW	Groundwater and Surface Water Flow Model
HRU	Hydrological response unit
IJC	International Joint Commission
IISD	International Institute for Sustainable Development
IRRB	International Red River Board
IWI	International Water Institute
IWM	integrated watershed management
LDC	Legacy Data Center
LES-P	Lake Winnipeg Ecosystem Service Platform
LIDAR	Light Detecting and Ranging
MBWS	Manitoba Water Stewardship

MODFLOW	Modular Groundwater Flow Mode
MPCA	Minnesota Pollution Control Agency
NASS	National Agricultural Statistics Service
NAD	National Assessment Database
NAWQA	National Water Quality Assessment Program
NDZ	No-Discharge Zone
NLFW	National Listing of Fish and Wildlife Advisories
NGO	Non-governmental organizations
NPDES	National Pollutant Discharge Elimination System
NPRI	National Pollutant Release Inventory
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
NTTS	National TMDL Tracking System
NWIS	National Water Information Service
Open MI	Open Modelling Interface
P	Phosphorus
PAC	Project Advisory Committee
PCS	Permit Compliance System
PRBAB	Pembina River Advisory Board
PRMS	Precipitation-Runoff Modeling System
PVCD	Pembina Valley Conservation District
RM	Rural Municipality
RMSE	Root mean square error
RRB	Red River Basin
RRBC	Red River Basin Commission
RRBDIN	Red River Basin Decision Information Network
RRJWRD	Red River Joint Water Resource District
RRWD	Roseau River Watershed District
SDWA	Safe Drinking Water Act
SDWIS	Safe Drinking Water Information System
SPARROW	SPatially-Referenced Regression On Watershed attributes
SRRCD	Seine-Rat River Conservation District
SRTM	Shuttle Radar Topography Mission
SSO	Sanitary sewer overflows
SSURGO	Soil Survey Geographic Database
STATSGO2	United States General Soil Map Database
STORET	Storage and Retrieval
SWAT	Soil and Water Assessment Tool

TMDL	Total maximum daily load
WP	Transboundary Water Opportunities
U.S.	United States
USDA	United State Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WATERS	Watershed Assessment, Tracking and Environmental ResultS
WQSDB	Water Quality Standards Database
WTP	Water treatment plant

1.0 Introduction

To solve our infrastructure and affordability problems, we need to think in terms of the services offered and the needs to be addressed, instead of business-as-usual pipes and pavement.

—Mary Trudeau, Engineers Canada

The Building Capacity for Ecological Infrastructure Investments in the Red River Basin[3] (RRB) project is a research initiative developed by the International Institute for Sustainable Development (IISD) in partnership with the Red River Basin Commission (RRBC). The project can be described and examined by casting a spatial and political lens at the macro (Red River Basin), meso (state and provincial portions of the basin) and micro (municipalities) scales. Examining the RRB using these lenses provides a way to better understand the environmental and socio-political dynamics unfolding in the basin.

At the macro scale, the RRB is a complex multi-jurisdictional international basin that lacks a coherent and integrated basin wide management plan. This need was accentuated by the 1997 flood, which devastated parts of North Dakota and Manitoba.[4] Subsequent to the flood, a number of agencies worked towards developing tools and approaches to minimize flooding impacts of the RRB. The International Joint Commission Red River Task Force created the Red River Basin Decision Information Network (RRBDIN), which provides useful data sets through an online map interface tool for local decision-makers. In addition, the RRBC developed and published a natural resources management framework in 2005 that lays out a vision and general method to implement a more integrative approach to managing the natural resources within the basin.

This basin-wide plan is often overlooked and superseded by government policies and economic activities carried out at the meso scale. Manitoba, North Dakota, South Dakota and Minnesota have varying policies for dealing with development and environmental protection. Agriculture is an important part of their economies and it has had a marked impact on the landscape and the water resources across the basin. It is estimated that the RRB contributes 60 per cent of the phosphorus load that flows into Lake Winnipeg, which has become the most eutrophic large lake in the world. Once again, the need to implement a more cooperative and integrated watershed resource management approach has been heightened.

[3] The project name was modified to Building Capacity for Multi-Purpose Land and Water Investments in the Red River Basin to better convey the purpose of the initiative to various audiences.
[4] The Red River Basin is a natural disaster hot spot due primarily to flooding events on both sides of the border. The basin has received a high proportion of presidential disaster declarations from 1964 to 2007 when compared with the rest of the United States (Federal Emergency Management Agency, Undated).

At the micro scale, municipalities responsible for upholding their citizens' quality of life by delivering services face a number of fiscal, political and environmental context-specific challenges. Municipalities are on the front lines of having to implement cost-effective solutions to deal with flooding and water quality issues. The services provided by natural environments or ecological infrastructure[5] offer municipalities with opportunities to provide cost-effective services that can be evaluated using an ecosystem services approach. Mary Trudeau of Engineers Canada states: "To solve our infrastructure and affordability problems, we need to think in terms of the services offered and the needs to be addressed instead of business-as-usual pipes and pavement" (Mastromatteo, 2008, p. 47). Implementing an integrated watershed resource management plan across the basin could be achieved by way of municipal investments for the preservation and restoration of ecological infrastructure on the landscape.

Beyond the micro scale, private land owners pay property taxes enabling municipalities to deliver important services to their residents. Restoring natural environments through ecological infrastructure investments may impact a municipality's tax base by lowering living space and agricultural land. The cost-benefit analysis for ecological infrastructure projects within a given municipality will have to take this important aspect into consideration to determine whether or not it will provide a net benefit.

The primary purpose of the *Ecological Infrastructure Investments in the Red River Basin* project is to jointly develop with municipalities and relevant stakeholders methodologies and decision-making tools that will build the capacity to examine the costs and benefits associated with ecological infrastructure (or natural environments) investments within and outside municipal jurisdictional boundaries. We expect the final outcome of the project to result in a comprehensive DSS that will enable ecological infrastructure investments to be examined and explored.

RRBC and IISD were awarded funding through Environment Canada's Lake Winnipeg Basin Stewardship Fund to initiate the project. As part of the work plan, partnerships have been established, a data gap analysis was completed, a modelling workshop was organized and hosted, and potential case studies were identified. This report details the activities undertaken and findings associated with this work plan.

[5] Ecological infrastructure is defined by the natural environments, assets and capital that provide us with a variety of services (carbon sequestration, flood control, biodiversity, clear water, etc.) that are imperative for our collective well-being.

2.0 Building Partnerships

The "building partnerships" component of this project included creating a Project Advisory Committee and building partnerships among various entities across the Red River Basin for the project. The organizations that found the project favourable were asked to generate letters of support for the project.

2.1 Project Advisory Committee

During the months of April, May and June 2009, project staff from RRBC and IISD met to discuss and plan the creation of a multi-stakeholder Project Advisory Committee (PAC). The purpose of this committee is to provide guidance, input and quality control (i.e., review of progress and reports) for the project.

Twelve jurisdictional leaders from RRBC Working Groups (water quality, water supply, flood management, Natural Resources Conservation) representing Manitoba, North Dakota and Minnesota were asked to sit on the PAC (see Appendix A). On June 23, 2009, project staff from the RRBC and IISD met with the PAC in Grand Forks. During this meeting, the PAC was provided with a detailed description of the project concept, work plan, goals and objectives.

The PAC provided important input and guidance on numerous project elements, including potential project partners, data acquisition and technical issues, including tool/model development. Project staff subsequently met the PAC on May 25, 2010 to obtain feedback on the data gap analysis, the modelling workshop agenda and content, as well as the PAC Terms of Reference (see Appendix A). Members of the PAC receive project updates via teleconferences and email correspondence.

In addition to receiving guidance from the PAC, the project has been presented to the RRBC Board[6] on several occasions (in 2009 and 2010). The purpose of these presentations has been to familiarize the Board with the project's concept, work plan and progress. The Board, which includes members from the PAC, has been very pleased with the project's progress and has provided important guidance and input.

[6] The RRBC board represents local, county, city, and watershed structures and state governments. Federal agencies are included as ex-officio board members. The 41 board members represent the states of Minnesota, North Dakota and South Dakota and the Province of Manitoba.

2.2 Partnership Building and Letters of Support

Building partnerships with basin stakeholders is a fundamental and critical component of this project as collaboration and support from decision-makers is required at all levels of government. In the Red River Basin, partnership building is a complex and difficult undertaking due to the vast area of the basin (116,000 km^2); the complex nature of the political, governance and institutional structures; and transboundary differences including standards, priorities and terminology. Consequently, the RRBC and IISD have allocated a significant time and resources to this process, which includes:

- Identification of suitable partners
- Scheduling, planning and attending meetings throughout the basin
- Developing presentation, project and meeting materials
- Follow-up meetings to discuss specific project elements, potential areas of collaboration and to provide project updates

A number of partnership building activities have been completed and, to date, project staff have obtained letters of support from 12 agencies and organizations (see Appendix A). The following agencies have confirmed their support:

- Association of Manitoba Municipalities
- Manitoba Conservation Districts
- North Dakota Red River Joint Water Resource Districts
- Minnesota Red River Watershed Management Districts
- Agriculture and Agri-Food Canada
- U.S. Geological Survey
- University of Manitoba
- University of Minnesota
- Minnesota Centre for Environmental Advocacy
- International Water Institute

3.0 Data Gap Analysis

The data gap analysis surveyed the information currently available to determine what information needs to be generated to develop an ecological infrastructure investment decision support system for the RRB. The data gap analysis was framed based on the information required to develop a sophisticated decision support system for ecological infrastructure investments in the RRB. Consequently, the following information categories were examined:

- Biophysical: A good understanding of the biophysical characteristics of the landscape and its hydrology is required to identify where natural environments could be restored and maintained to provide important services and benefits to local populations.
- Infrastructure: The location and condition of human built environments can assist with identifying opportunities for ecological investments.
- Socioeconomic: Demographic and economic information could provide insights for the suitability of ecological infrastructure investments within a particular context.

The biophysical, infrastructure and socioeconomic data sources that were examined in the Canadian (Manitoba) and the United States (Minnesota, North Dakota and South Dakota[7]) portions of the RRB are described in the subsequent sections of this report.

3.1 Biophysical

A landscape is defined by its biophysical characteristics. The biophysical information examined for this study was limited to elevation, bedrock, soils and land cover. Elevation data is invaluable to understanding how water flows on the landscape, soils erode and vegetation evolves in a particular environment. Soils data provides information on water infiltration, geomorphological processes and types of vegetation that have evolved in an area. Bedrock provides some idea on the subsurface dynamics that impact soil formation and hydrological flows. Land cover information is required to identify existing natural environments and their connectivity, which allows for assessing opportunities to restore ecosystems that can provide particular benefits.

A number of biophysical spatial datasets can be accessed for Minnesota and North Dakota through the USGS geospatial partnerships programs.[8] The program has dedicated USGS staff providing

[7] Limited information sources were examined for South Dakota, as less than 1 per cent of the total surface area of the basin, which drains into the headwaters of the basin in North Dakota, is located in the state.
[8] See http://liaisons.usgs.gov/geospatial/Minnesota and http://liaisons.usgs.gov/geospatial/NorthDakota

assistance with locating and accessing various datasets. The Manitoba Land Inventory website[9] provides access to various provincial biophysical data sets. These resources provide guidance and insights for locating and accessing a variety of biophysical spatial datasets, including the ones discussed in more detail in the following subsections.

3.1.1 Elevation

The elevation data sets examined where chosen based on the level of resolution and coverage that they offer. The Advanced Spaceborne Emissions and Reflection Radiometer (ASTER), Shuttle Radar Topography Mission (SRTM) and Light Detecting and Ranging (LIDAR) data sets available for the RRB were identified as potential sources of elevation data that could be useful for developing communication and decision-support systems.

The ASTER dataset provides elevation data for the entire Red River Basin. The global data set, which was collected by the Terra satellite in 1999, has been available since 2007. Each scene covers approximately 60 square kilometres and data were acquired and georeferenced to the WGS84 datum and Universal Transverse Mercator projections. The data were collected at three different resolutions:

1) Latitude, longitude resolution 15 x 15 m
2) Latitude, longitude resolution 30 x 30 m
3) Latitude, longitude resolution 90 x 90 m

The data can be used to derive digital elevation maps with 20 m elevation at 95 per cent confidence (MicroImages Inc., 2009). Hirano, Welch and Lang (2003) state that Digital Elevation Models (DEMs) with 30 to 150 metre postings with a root mean square error of +/- 7 to 15 m were derived using the Desktop Mapping System. According MicroImage Inc. (2009) the ASTER dataset should only be used as experimental or research-grade data as it does not resolve topographic features accurately. Furthermore, they state the spatial detail that is resolvable by the ASTER DEM is estimated between 100 and 120 m (MicroImages Inc., 2009). The data for the Red River Basin is available for free and can be obtained from the following website: http://wist.echo.nasa.gov/wist-bin/api/ims.cgi/u421317#SCROLL (see Appendix B for an Elevation ASTER map of the RRB).

The SRTM was an international effort that aimed to generate digital elevation models on a near-global scale. Thus far, SRTM datasets have been released for the United States at 30-metre resolution and globally at 90-metre resolution. The data was collected by the space shuttle Endeavour during an 11-day mission in February 2000. The Interferometric Synthetic Aperture

[9] http://mli2.gov.mb.ca/about_us/projectdetails.html

Radar was used to collect the information. The SRTM radar collected data sets using two antenna panels, a C-band and an X-band, which are being processed by the Jet Propulsion Laboratory and the German Aerospace Centre respectively. The data was georeferenced using the WGS84 datum and Universal Transverse Mercator projection. The absolute horizontal and vertical accuracy of the C-band and the X-band data is 20 m and 16 m, respectively (Deutsches Zentrum fur Luft- und Raumfahrt, 2009; Jet Propulsion Laboratory, 2005). A rigorous assessment of data collection errors was completed and it was deemed that the data product exceeded expectations (Farr et al., n.d.).

Unfortunately, 30-metre resolution SRTM data has not been released for Canada. Therefore, a complete high resolution SRTM dataset for the entire RRB cannot presently be accessed.[10]

LIDAR technology uses airborne laser and global positioning technology to generate accurate elevation data. LIDAR can provide elevation data with a vertical accuracy of 15 cm and a horizontal accuracy of 0.91 m (Red River Basin Commission, n.d.). It provides the highest vertical and horizontal resolution of the elevation datasets examined.

LIDAR has been collected for the entire U.S. potion of the Red River Basin and parts of the Canadian portion (2,883 square kilometres in the Red River Valley of Southern Manitoba) (Manitoba Remote Sensing, 2005). Due to the elevated costs associated with generating LIDAR data, they are being collected on the Canadian side only when deemed absolutely essential.

The LIDAR data on the United States portion of the basin are currently being used by the International Water Institute to develop flow networks and identify potential opportunities for water storage on the landscape. The high resolution of the information allows for more accurate modelling of hydrological flows within the basin.

The raw classified and filtered bare earth data collected has an accuracy of <15 cm root mean square error (RMSE), resulting in a 1 metre bare earth digital elevation model georeferenced as NAD 88/NAD 83. All the data on the United States side has been verified for accuracy.

[10] SRTM data can be obtained free of charge from the following website: http://dds.cr.usgs.gov/srtm

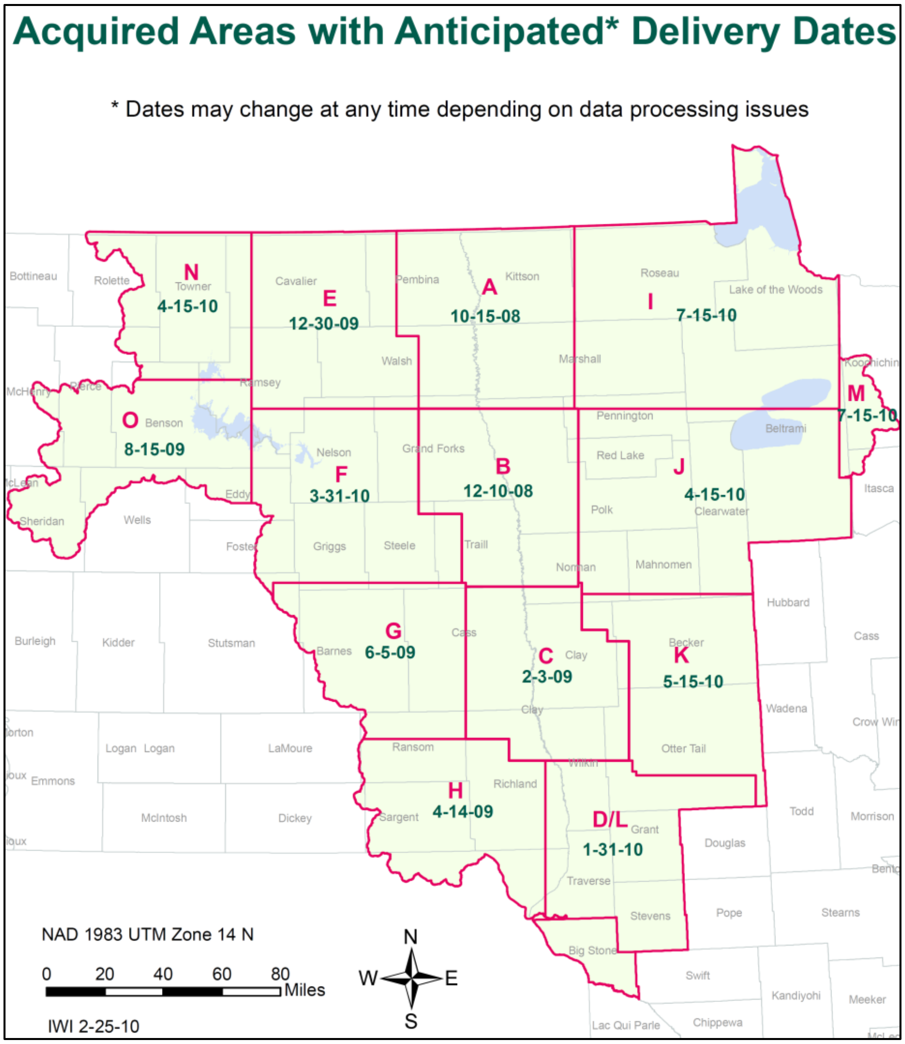

Figure 1 – International Water Institute Red River Basin LIDAR Mapping Initiative.

On the Canadian side, the ground-truthed LIDAR data showed a vertical accuracy of 11 cm (68 per cent) and 20 cm (95 per cent), or a RMSE of 10 cm with a horizontal accuracy of 0.3 m RMSE or better (Aeroscan International, Lasermap Image Plus Inc., Prairie Farm Rehabilitation Administration & Manitoba Conservation, 2005).

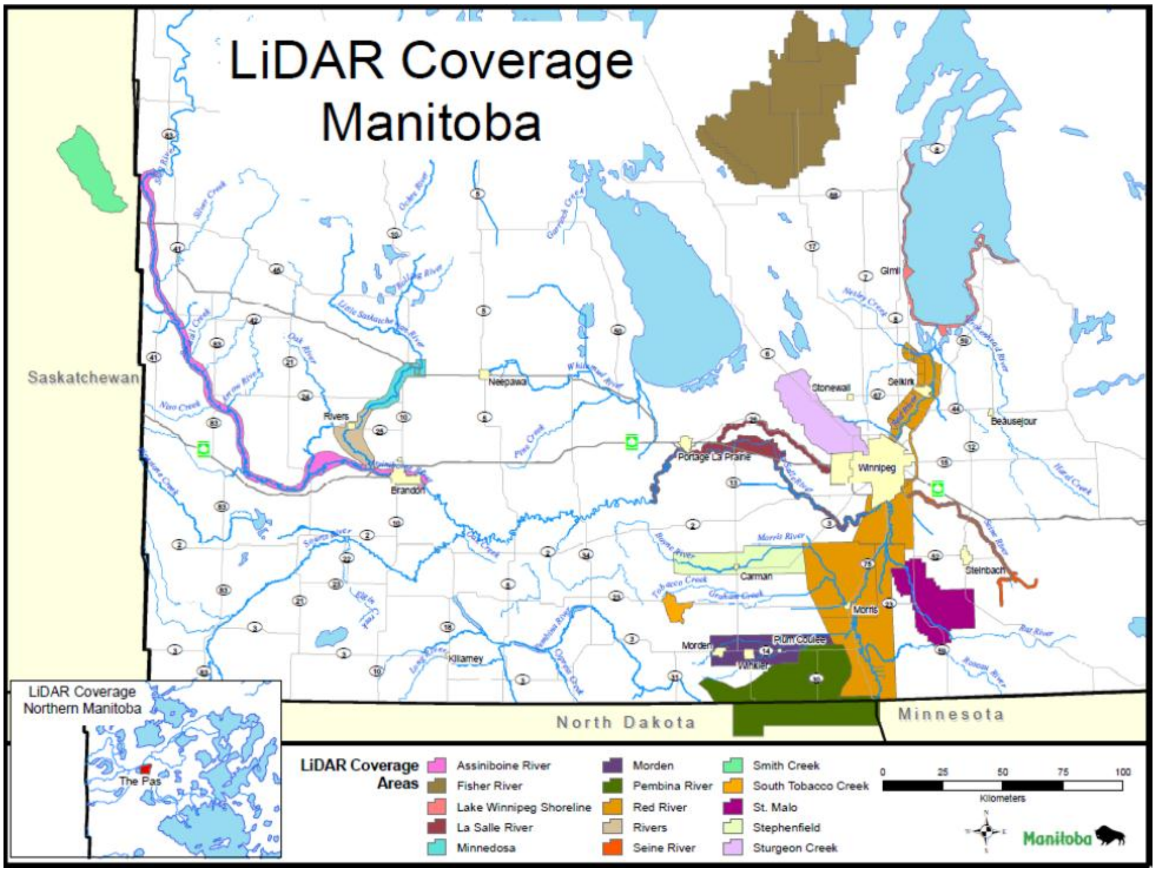

Figure 2 –LIDAR data collection in Manitoba.

LIDAR data for the United States portion of the basin can be obtained from the International Water Institute[11] and the United States Geological Services.[12] LIDAR viewers can be accessed at:

http://iwi.houstoneng.com/iwi_lidar/iwi.html and
http://lidar.cr.usgs.gov/LIDAR_Viewer/viewer.php.

LIDAR data in Canada can be obtained from the Manitoba Land Inventory.[13]

The International Water Institute collected LIDAR data at the cost of approximately US$46 per square kilometre in the United States. Applying this cost to the rest of the areas lacking data represents an investment of approximately US$0.9 million to the get LIDAR coverage of the Red River Basin. This price could increase or decrease substantially depending on economies of scale and

[11] www.internationalwaterinstitute.org/lidar_specs.htm
[12] http://lidar.cr.usgs.gov/
[13] http://mli2.gov.mb.ca/about_us/index.html

the cost of LIDAR collection. For instance, the SRRCD priced a LIDAR collection effort for an area within their territory to be approximately C$174 per square kilometre. Applying this figure to the areas in the Red River Basin would give a total cost of C$3.4 million.

Due to the uniform characteristic of the landscape, the elevation data that is most appropriate for developing a decision support system for ecological infrastructure investments in the RRB is LIDAR information. Unfortunately, the data is missing for substantial portions of the basin. The ASTER data is the only complete elevation dataset available, but it is of insufficient resolution to develop accurate models. Nevertheless, it may be helpful for communicating the potential benefits associated with ecological infrastructure investments. Developing watershed planning models of high accuracy can be achieved by focusing on watersheds that have LIDAR coverage. Missing high resolution DEM information can also be generated using photogrammetry technology, which can have some advantages over LIDAR data and from satellite stereo imagery, which costs approximately C$40/ square kilometre unprocessed.

3.1.2 Land Cover

High-quality land-cover land-use information is imperative to investigate and plan for ecological infrastructure investments. This information provides the lay of the land that can be used to identify opportunities to protect and restore ecosystems that are beneficial to local communities.

The best widely available land-cover layer for Manitoba is the Earth Observation for Sustainable Development (EOSD) layer, which is based on LandSat imagery collected between 1999 and 2001. The data has a resolution of 30 m and has 23 land cover classifications.[14]

Land cover information available for the United States is more varied and can be accessed via the USGS land cover institute website (http://landcover.usgs.gov/landcoverdata.php#na). The NASA Warehouse Inventory Search Tool (https://wist.echo.nasa.gov/api) is a one stop shop where one can access and download a variety of spatial information including land cover data.

Land cover information of higher resolution (0.5 to 0.6 m) can be obtained by purchasing the information via Global Mapping Solutions[15] and Satellite Imaging Corporation.[16] Quickbird provides highly accurate land-cover information for specific parts of the basin. Worldview provides information for the entirety of the basin's surface area.

[14] See the Manitoba Land Inventory website: https://mli2.gov.mb.ca/landuse/index.html
[15] www.mapmart.com/Products.aspx
[16] www.satimagingcorp.com

Table 1: Remote Sensing Land-Cover Data

Satellite[a]	Launch Year	Resolution (metres)	Information Generated	Data Access and Availability
ALOS	2006	2.5 to 10	DEM, Land Cover	ALOS data is available for scientific Category-1 use and commercial applications.
ASTER	1999	15 to 90	DEM, Land Cover	Publicly available via archives of ASTER imagery from around the world.
CARTOSAT-1	2005	2.5	DEM, Land Cover	Commercially available via Satellite Imaging Corporation www.satimagingcorp.com
CBERS-2	2001	20 to 260	Land Cover	Publicly available via INPE www.dgi.inpe.br/CDSR
FORMOSAT-2	2004	2 to 8	Land Cover and Environmental Data	Commercially available via Satellite Imaging Corporation www.satimagingcorp.com and others satellite imaging distribution companies
GeoEye-1	2008	0.41 panchromatic 1.65 multispectral	High Resolution Land-Cover Data for large projects	Commercially available via Satellite Imaging Corporation www.satimagingcorp.com and others satellite imaging distribution companies.
IKONOS	1999	1 panchromatic 4 multispectral	High Resolution Land-Cover Data	Publicly available for Category-1 use through the European Space Agency http://eopi.esa.int/esa/esa?cmd=aodetail&aoname=IKONOS
LANDSAT 7	1999	15 to 90	Land Cover	Publicly available via archives of LANDSAT 7 imagery from around the world.
QuickBird	2001	0.61	High Resolution Land-Cover Data	Commercially available via the Digital Globe Company www.digitalglobe.com and others satellite imaging distribution companies.
SPOT-5	2002	2.5 to 5	Land Cover and 3D Terrain Modelling	Publicly available via archives of SPOT imagery from around the world.
Worldview-1	2007	0.55 Panchromatic	High Resolution Land-Cover Data	Commercially available via the Digital Globe Company www.digitalglobe.com and others satellite imaging distribution companies.
Worldview-2		0.55 Panchromatic 1.8 to 2.4 multispectral	High Resolution Land-Cover Data	Commercially available via the Digital Globe Company www.digitalglobe.com and others satellite imaging distribution companies.

[a]All information acquired from www.satimagingcorp.com

A comprehensive RRB land-cover map has been compiled by the Agricultural Environmental

Services Branch of AAFC using LandSat imagery with a resolution of approximately 30 m. The land-cover map reveals that the majority of the basin is covered by croplands followed by forests, wetlands and grasslands (see Appendix B for a LandSat Land Cover Map of the RRB). Generating a land-cover map of higher resolution by sourcing high resolution land-cover data (0.5 to 1 metre in resolution) from remote sensing imagery companies would cost approximately US$1.63 million (Sneil, 2010).

3.1.3 Soils

Soil data is readily available on the United States and Canadian sides of the RRB by regional municipality and county. Since distinct soil taxonomy systems are used in Canada and the United States, soils have to be correlated to compile a consistent soil map for the basin. Soil equivalencies have been established, and a comprehensive reference edited by Krasilnikov, Arnold and Shoba (2009) can be used to correlate both soil taxonomies to the World Reference Base.

The Natural Resources Conservation Service administers the Soil Data Mart,[17] where soil data with two levels of resolution can be freely obtained. The United States General Soil Map Database (STATSGO2) is a national broad-based soil inventory and the Soil Survey Geographic Database (SSURGO) is available for all counties in North and South Dakota as well as most of Minnesota (with the exception of Koochiching County). STATSGO2 was created by generalizing detailed soil survey information and LandSat imagery to give a 1 km resolution soil coverage layer for the United States. SSURGO provides soil data with mapping scales ranging from 1:12,000 to 1:63,360 and was designed to facilitate natural resource management (Zhu, Weindorf, Haggard, Johnson & Chakraborty, 2009).

The Manitoba Land Inventory provides two sets of soil data information for the province of Manitoba:[18] the Soil Map Unit File (SoilMUF) and the Agricultural Interpretive Database (SoilAid). The SoilMUF provides detailed soil property information such as susceptibility to erosion and salinity for each municipality with mapping scales ranging from 1:20,000 to 1:40,000. The SoilAid layer, which is also provided by municipality, provides information such as soil agricultural capability and irrigation suitability.

Adequate spatial soil information is imperative to determine the hydrological flows on the landscape and to assess the vegetation and land uses that it can support. Having a comprehensive soil cover map for the RRB is imperative to develop effective basin-wide natural resource management plans. IISD is compiling a comprehensive soil map of the RRB by using soil information found in Krasilnikov, et al. (2009) (see Appendix B for interim soil maps).

[17] http://soildatamart.nrcs.usda.gov
[18] https://mli2.gov.mb.ca/soils/index.html

3.1.4 Bedrock

The bedrock information of a particular area can be useful to ascertain subsurface hydrological behaviours. A seamless bedrock map for the RRB would provide insights for the development of adequate land and water investments in the basin. The data required for producing such a seamless basin bedrock map were collected as part of this survey.

Geological information at 1:1,000,000 can be found on the Manitoba Land Inventory website.[19] This dataset provides lithotec, unit and subunit geological information. The USGS has spatial bedrock information for every state at scales from 1:100,000 to 1:1,000,000.[20]

Geological data can also be accessed via academic institutions.[21] Bedrock data of higher resolution may be accessible through individual counties, townships and companies, but this information may be proprietary.

3.1.5 Water Resources

Understanding the hydrology of a watershed is primordial to adequately ascertain the potential multi-purpose benefits that could be harnessed from the landscape. Ecosystems can mitigate potential floods by influencing the hydrology of an area and improve water quality by filtering and assimilating pollutants. Federal, state and provincial agencies that monitor water resources within the RRB were examined to determine the types and quality of the hydrological data that is being collected.

The International Joint Commission's (IJC) International Red River Board coordinates international water management efforts across the basin. In the United States, the main agencies that deal with water resources at the federal level include the United States Geological Survey and the United States Environmental Protection Agency, while Environment Canada (EC) is primarily tasked with managing water resources in Canada. Each state and provincial government also has a role in dealing with water quality and quantity issues. This includes giving out permits for water usage and setting regulatory targets for water pollution discharge.

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[19] https://mli2.gov.mb.ca/geology/index_1million.html

[20] See: http://tin.er.usgs.gov/geology/state. A variety of geological information of the United States can be accessed via the following websites: http://ngmdb.usgs.gov/Other_Resources/rdb_es.html, gos2.geodata.gov/wps/portal/gos and www.geocomm.com.

[21] For instance, bedrock data at 1:1,000,000 for the State of Minnesota can be obtained from the following website: www.mngeo.state.mn.us/chouse/metadata/stmaps20_3.html#ordering.

Water Quantity and Quality

In the United States, there are two main federal agencies, the USGS and the U.S. Environmental Protection Agency (USEPA), that provide in-depth information on the data gathered for water quantity (both surface and groundwater) and quality. These agencies provide important raw and interpreted information for federal, state and local government as well as academic institutions and the general public.

The National Water Information Service (NWIS) website provides raw data related to surface and ground water quantity and quality for approximately 1.5 million sites in all 50 states including the District of Columbia and Puerto Rico (United States Geological Survey, 2010b). The site can be searched based on the following categories: Real-Time Data, Site Information, Surface Water, Groundwater and Water Quality. There is also a mapping tool that enables one to view the various kinds of monitoring site locations across the United States. Specific examples of data that can be retrieved include water discharge, temperature, conductance, suspended sediment and dissolved oxygen. Some sites have more information than others based on the types of ongoing measurement activities being carried out.

Initiated by the USGS, the National Water Quality Assessment Program (NAWQA), which is in its second decade, provides status and trends assessments for the eight major river basins in the United States (United States Geological Survey, 2010a). As part of the program, a total of 113 sites will be monitored for water quality and 58 streams will be monitored for aquatic ecological conditions. Some of the issues the program aims to address include nutrient load and concentration predictions, assessment of pesticide use and trends and characterization and prediction of ecosystem health in wadeable streams.

The USGS has developed a number of models supported by the water quantity and quality data that it collects. One example is the GSFLOW model, which simulates groundwater and surface water resources to provide water budgets for a given location. The model was developed based on the Precipitation-Runoff Modeling System (PRMS) and the Modular Groundwater Flow Model (MODFLOW).[22]

The USEPA is responsible for implementing the Clean Water Act and the Safe Drinking Water Act. The agency works with a number of partners and stakeholders to monitor the nation's waters and maintain clean water. To do so, it collects and provides a variety of raw and interpreted information sources to the public. The USEPA administers the databases listed in the table below.

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[22] Find information on the model design and water budget algorithms at www.brr.cr.usgs.gov/projects/SW_MoWS/software/gsflow_s/gsflow.shtml.

Table 3: USEPA water quality and quantity databases

USEPA Office of Water Program[a]	Description
Water Quality Standards	The **Water Quality Standards Database (WQSDB)** contains information on the uses that have been designated for water bodies. Examples of such uses are: drinking water supply, recreation and fish protection. As part of a state's water quality standards, these designated uses provide a regulatory goal for the water body and define the level of protection assigned to it. WQS also includes the scientific criteria to support that use. (www.epa.gov/wqsdatabase)
Integrated Reporting 305(b) Report and 303(d) List	The **Assessment, TMDL Tracking and ImplementatioN System (ATTAINS)** database contains information reported by the states to the USEPA about the conditions in their surface waters. The database is comprised of information on the attainment of water quality standards, sometimes referred to as the Clean Water Act Section 305(b) information; as well as the list of impaired waters that need a Total Maximum Daily Load (TMDL), sometimes referred to as the Clean Water Act Section 303(d) List. ATTAINS is a combination of what was formerly referred to as the National Assessment Database (NAD) and the National TMDL Tracking System (NTTS). (www.epa.gov/waters/ir)
Water Quality Inventory 305(b) Report	The **National Assessment Database (NAD)** contains information on the attainment of water quality standards. Assessed waters are classified as either "Fully Supporting," "Threatened" or "Not Supporting" their designated uses. This information is reported in the National Water Quality Inventory Report to Congress under Section 305(b) of the Clean Water Act. (www.epa.gov/waters/305b)
Total Maxi-mum Daily Load (TMDL) 303(d) List	The **TMDL** Tracking System contains information on waters that are "Not Supporting" their designated uses. These waters are listed by the state as impaired under Section 303(d) of the Clean Water Act. The status of TMDLs are also tracked. TMDLs are pollution-control measures that reduce the discharge of pollutants into impaired waters. (www.epa.gov/waters/tmdl)
Water Quality Monitoring	**STORET** (short for STOrage and RETrieval) is a repository for water quality, biological and physical data and is used by state environmental agencies, EPA and other federal agencies, universities, private citizens and many others. The Legacy Data Center (LDC) contains historical water quality data dating back to the early part of the twentieth century and collected up to the end of 1998. (www.epa.gov/owow/monitoring)
National Pollutant Discharge Elimination System (NPDES) Permits	Discharge of pollutants into waters of the United States is regulated under the **NPDES**, a mandated provision of the Clean Water Act. To assist with the regulation process, state and federal regulators use an information management system called the **Permit Compliance System (PCS)**. PCS stores data about NPDES facilities, permits, compliance status and enforcement activities for up to six years. (www.epa.gov/enviro/html/pcs/index.html)
Safe Drinking Water	The Safe Drinking Water Act (SDWA) requires that states report to the USEPA information about public water systems and their violations of the USEPA's drinking water regulations. These regulations, and their enabling statutes, establish maximum contaminant levels, treatment techniques,

	and monitoring and reporting requirements to ensure that water provided to customers is safe for human consumption. This information is stored in the **Safe Drinking Water Information System (SDWIS)**. (www.epa.gov/enviro/html/sdwis/index.html)
Fish Consumption Advisories	**The National Listing of Fish and Wildlife Advisories (NLFWA)** database includes all available information describing state-issued, tribal-issued and federally issued fish consumption advisories in the United States and Canada. (http://map1.epa.gov)
Nonpoint Source Pollution	The Section 319 **Grants Reporting and Tracking System (GRTS)** is the main reporting vehicle for the Section 319 program. GRTS enables the USEPA and states to describe the progress they have made in implementing the national **Nonpoint Source (NPS) Pollution** program. GRTS electronically tracks projects and activities funded with CWA Section 319(h) funds. (www.epa.gov/nps/Section319/grts.html)
Nutrient Criteria	The **Nutrient Criteria Database** stores and analyzes nutrient water quality data, which will aid in the development of scientifically defensible numeric nutrient criteria. The ultimate use of the data is to derive ecoregional water body-specific numeric nutrient criteria. (www.epa.gov/waterscience/criteria/nutrient/database/index.html)
BEACH program	The Beaches Environmental Assessment, Closure & Health (**BEACH Watch)** database provides information on whether a specific beach is being monitored for water quality, who is responsible for the monitoring, the pollutants that are being monitored, and if advisories or closures have been issued. (http://oaspub.epa.gov/waters10/beacon_national_page.main)
Vessel Sewage Discharge	Vessel sewage discharge is regulated under Clean Water Act Section 312, which mandates the use of marine sanitation devices (on-board equipment for treating and discharging or storing sewage) on all commercial and recreational vessels that are equipped with installed toilets. Under Section 312, states may request a **No-Discharge Zone (NDZ)** designation that prohibits the discharge of sewage from all vessels into defined waters. (www.epa.gov/owow/oceans/regulatory/vessel_sewage/vsdnozone.html)
Clean Watersheds Needs Survey	The **Clean Watersheds Needs Survey (CWNS)** provides information on publicly owned wastewater collection and treatment facilities, facilities for control of sanitary sewer overflows (SSOs), combined sewer overflows (CSOs), stormwater control activities, NPSs and programs designed to protect the nation's estuaries. Information obtained from the survey is maintained in the CWNS database. (www.epa.gov/owm/mtb/cwns/index.htm)

[a]All the information in this table was obtained directly from: http://epamap32.epa.gov/radims.

The Watershed Assessment, Tracking and Environmental ResultS (WATERS) online database is a one-stop shop for gathering water data quality administered by the USEPA (United States Environmental Protection Agency, 2008). The database combines a number of previously independent water-quality information sources so that the public can determine whether or not water is safe to drink, fish is safe to eat, water bodies are safe to swim in and watersheds are healthy.

It must be noted that a number of state, local and tribal agencies assist the USEPA with the collection of water quality data, which is fed into various USEPA programs and databases. To meet its obligations under the Clean Water Act, Minnesota monitors water quality[23] twice every five years within the 10 sites on the mainstem of the Red River and at the confluences of large tributaries (International Red River Board, 2008). Water quality information is provided via the Minnesota Pollution Control Agency.[24] North Dakota contracts out the USGS to carry out water quality monitoring at 18 sites[25] within the basin. Pesticide concentrations[26] were measured at six sites in 2006 and biomonitoring was conducted within 50 wadeable stream and rivers to assess ecosystem health from 2005 to 2008. A number of water quality and aquatic ecosystem health monitoring programs are ongoing within both states.

EC's *Water Survey* program, in partnership with provincial agencies, monitors water quantity and provides hydrometric information. There are currently 2,844 active water-level and streamflow stations across the country (1,648 sites have the capability of transmitting near real-time information) (Environment Canada, 2009). In Manitoba, there are 199 stations providing near real-time data accessible online.[27] Real-time as well as historic data can be accessed for each station. Functionality is provided to perform basic statistical calculations and to display the data. In addition to hydrometric information, some stations also have sediment measurements that can be accessed via the Archived Hydrometric Data site.[28]

Water quality within the Canadian portion of the RRB is collected primarily by EC, Manitoba Water Stewardship (MBWS) and the City of Winnipeg (International Red River Board, 2008). EC has been tasked by the international Red River Board to monitor water quantity and quality at the

[23] The water is assessed for ammonia, dissolved oxygen, turbidity, e-coliform, as well as chlorides and, where streamflow data is collected, chlorophyll-A, total suspended solids, total phosphorus and biological oxygen demand (International Red River Board, 2008).

[24] See: www.pca.state.mn.us/index.php/topics/environmental-data/eda-environmental-data-access/eda-surface-water-searches/eda-surface-water-search-conditions.html.

[25] Parameters Measured: temperature, pH, specific conductance, hardness, alkalinity, dissolved oxygen, total dissolved solids, TSS, carbonate, bicarbonate, sodium, ammonia, nitrate-nitrite total Kjeldahl nitrogen, total nitrogen, total phosphorus, potassium, organic carbon, E. coli fecal coliform, Enterococcus sp., arsenic, aluminum magnesium antimony, calcium, barium, manganese, beryllium, iron, boron, chloride, cadmium, sulfate, chromium, copper, lead, hydroxide, nickel, silver, selenium, thallium, zinc.
Monitoring Sites: Bois de Sioux near Doran; Red River at Brushville; Wild Rice River near Abercrombie; Red River at Fargo; Red River near Harwood, Sheyenne River at Warwick; Sheyenne River 3 mi east of Cooperstown; Sheyenne River below Baldhill Dam; Sheyenne River at Lisbon; Sheyenne River near Kindred; Maple River at Mapleton; Goose River at Hillsboro; Red River at Grand Forks; Turtle River at Manvel; Forest River at Minto; Park River at Grafton; Pembina River at Neche; Red River at Pembina

[26] Sixty-one types of pesticides are being measured within three location on the Red River, two sites on the Sheyenne River and one site on the Goose River.

[27] See: http://scitech.pyr.ec.gc.ca/waterweb/formNav.asp.

[28] See: http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=mainStation_e.cfm

international border. Samples are collected at Emerson, Manitoba and assessed for a variety of water quality parameters.[29] EC also measures water quality at four sites within the basin as part of the Canadian Environmental Sustainability Indicators program. MBWS measures water quality[30] monthly at two locations on the mainsteam (upstream and downstream of the City of Winnipeg at the mouth of the Floodway and at Selkirk). The City of Winnipeg also monitors water quality bi-weekly at six locations[31] on the mainstem of the Red River within and outside the city. In addition, samples are collected and analyzed[32] four times a year on five major tributaries feeding off the Red River. The list below summarizes the locations within the RRB in Manitoba where water quality is monitored on an ongoing basis:

- Pembina River, Windygates
- Red River, Emerson
- Roseau River, near Dominion City
- Rat River at Otterburne
- La Salle River, downstream of La Barrier
- Red River (upstream of Winnipeg)
- Seine River (south of Winnipeg)
- Cooks Creek at Springfield
- Red River (downstream of Winnipeg – close to Lake Winnipeg)
- Brokenhead River near Scantebury
- Assiniboine River at Headingly
- Assiniboine River downstream of Portage La Prairie
- Assiniboine River upstream of Portage La Prairie
- Boyne River at Carman

Benthic macro-invertebrates have also been collected at these sites to assess ecological health. To access this water quality data EC, MBWS and the City of Winnipeg need to be contacted directly. MBWS is planning on making their water quality data accessible online in the near future.

In addition to ongoing water quality monitoring, the Province of Manitoba has initiated a number of water-improvement programs that are of particular importance. The Lake Winnipeg Action Plan aims to lower nitrogen and phosphorus loads below pre-1970s levels, representing a reduction of 10

[29] These include dissolved oxygen, total dissolved solids, chlorides, chlorophyll-A, sulphates, fecal coliform.
[30] The parameters examined include suspended solids, bacteria, industrial organics, trace elements, plant nutrients and agricultural chemicals.
[31] The parameters examined include general chemistry, plant nutrients, suspended sediments and chlorophyll-a.
[32] General physical and chemical parameters are assessed as well as suspended solids, bacteria, industrial organics, trace elements, plant nutrients and agricultural chemicals.

and 13 per cent respectively. The Nutrient Management Regulation and the Livestock Manure and Mortalities Management Regulation are driving the need to improve nutrient management approaches to improve water quality. The Water Protection Act has facilitated the need to develop integrated watershed management plans within Manitoba watersheds. The LaSalle River and Seine River watersheds have developed their plans and are in the process of implementing them.

Climate

Extensive climate data is accessible online on both sides of the border. EC's Meteorological Services Canada collects and archives climate data across the country. In Manitoba alone, archived climate data from 552 stations can be accessed online.[33] Temperature, precipitation, wind speed and snow depths from a variety of years can be accessed depending on the station. In addition to this information, archived weather radar images can be obtained. The United States Department of Commerce's National Climatic Center provides online climate data.[34] Information on temperature, precipitation, drought, snow and ice, as well as a variety of climate-related reports and products such as documents and maps on extreme events and climate regions and divisions are also available.

Water Consumption

Water consumption information is tracked within various levels of government in Canada and the United States. In addition to government sources, the private sector and public entities (non-government organizations, community groups) also monitor water usage. Depending on the jurisdiction, governments will be involved in controlling and limiting water usage via a defined water allocation system, and water consumption information can also be accessed through water allocation agencies.

Statistics Canada[35] and Environment Canada provide vital water consumption information for various sectors at the federal level, for instance, Statistics Canada's report on industrial water use in 2005[36] detailing the water intake and discharge of manufacturing, mining and thermal-generating industries. Statistics Canada also collects water consumption data within the agricultural sector, which is a significant consumer of the resource. The agricultural water use survey compiles information on water use, irrigation methods and practices and sources and quality of water used.[37] (A report entitled *Estimation of water use in Canadian agriculture*, published in 2001, provides detailed water consumption information for the agricultural sector [Beaulieu, Fric, C. & Soulard, 2007].)

[33] http://climate.weatheroffice.gc.ca/Welcome_e.html
[34] www.ncdc.noaa.gov/climate-monitoring/index.php#networks
[35] www.statcan.gc.ca/pub/16-401-x/2008001/5003964-eng.htm
[36] "The Industrial Water Survey, 2005 was conducted by Statistics Canada in partnership with Environment Canada and Health Canada and is the successor to the Water Use Survey last conducted by Statistics Canada for Environment Canada in 1996. This survey will be a biennial survey with the next version collecting data for 2007" (Statistics Canada, 2010).
[37] www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5145&lang=en&db=imdb&adm=8&dis=2

Environment Canada provides in-stream and withdrawal water consumption information at various levels. For instance, a variety of general national-level information on water consumption is provided on their website with municipal links.[38] Environment Canada also produces the municipal water-use and wastewater survey, which provides water use and pricing statistics[39] for all municipalities with populations over 1,000 people and a sample of municipalities with populations under 1,000 people (excluding First Nations) every two to three years dating back to 1983[40] (this information is accessible online and work to complete the 2009 survey is currently underway).[41]

The USGS provides national-level,[42] county-level[43] and HUC8-level (only for the Great Lake region) water usage estimates. Information is available for a variety of years (1985, 1990, 1995, 2000 and 2005). The data are fairly comprehensive and include variety of information on water consumption. The 2005 report included the following information at the state level: public supply (surface and groundwater) and total population served, domestic, irrigation (crop and golf courses), livestock, aquaculture, industrial, mining, and thermoelectric-power water use.[44]

Manitoba water law is based on both prior appropriation doctrine and water-use class priority (domestic, municipal, agricultural, industrial and irrigation). "The class priority system is a secondary allocation mechanism used when multiple licenses are issued within the same precedent date. Uses with higher priority classes can cause the rescinding of licenses of lower class priorities" (HDR Engineering Inc., 2009, p. 41).

Manitoba Water Stewardship Water Licensing Branch is the authority responsible for allocating the use of water resources in Manitoba under the *Water Rights Act*. Those wanting to use water for industrial or municipal purposes or any other use requiring more than 25,000 litres (5,500 imperial

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[38] www.ec.gc.ca/eau-water/default.asp?lang=En&n=96F2B222-1

[39] "The survey collects data on water sources, water use, water conservation, wastewater treatment level and water and wastewater pricing at the municipal level. The ongoing trend-line analyses and extensive data made available provide information that supports water management decisions in the broader context of ecosystem management, thus contributing to Canada's goal of promoting wise and efficient management and use of water" (Environment Canada, 2010a).

[40] www.ec.gc.ca/eau-water/default.asp?lang=En&n=ED7C2D33-1

[41] "Raw data from the Municipal Water and Wastewater Surveys: The raw data files available for download below contain the survey results exactly as they were entered into the online version of the survey at the time the survey was closed. These files do not include any quality-checked data or data gathered after the official close of the survey to fill gaps. For quality-checked data please see the files downloadable from the Publications page" (Environment Canada, 2010b).

[42] http://pubs.usgs.gov/circ/1344

[43] http://water.usgs.gov/watuse/data/2005

[44] State data files can be viewed or downloaded in Excel spreadsheet formats at: http://water.usgs.gov/watuse/data/2005/index.html

gallons) of water per day must first obtain permission from the Water Licensing Branch (Manitoba Water Stewardship, n.d.-a).

Water rights licenses in Manitoba require water users to install metering or timing devices on the water source and require that records are kept and periodically submitted to the Water Licensing Branch to meet the reporting requirements of water use under water rights license (Manitoba Water Stewardship, n.d.-b). "Since funding has historically been limited resulting in sparse actual use information, Manitoba Water Stewardship has suggested the use of permitted amounts as an estimate for actual use" (HDR Engineering Inc., 2009, p. 42). Permitted amounts may have to be assumed to equal actual use since comprehensive reported actual use information is not available at this time.

CONTACT:
Manitoba Water Stewardship
Main Office
Box 11, 200 Saulteaux Crescent,
Winnipeg MB R3J 3W3
1-800-282-8069 (toll-free)
1-204-945-6398
email: wsd@gov.mb.ca
http://www.gov.mb.ca/waterstewardship/licensing/index.html

In Minnesota, water-related laws are based on a riparian doctrine. "Under this doctrine, those using the public waters can do generally so provided that impacts to other users are avoided. Minnesota has developed a priority system which includes prioritization of the water use during shortages […]. Lower priority water uses must avoid impacts to higher priority uses" (HDR Engineering Inc., 2009, p. 40).

The Department of Natural Resources Division of Waters is responsible for permitting or licensing water use in Minnesota. "A water use permit is required for all water users in Minnesota withdrawing more than 10,000 gallons of water per day, from surface or groundwater, or 1 million gallons per year" (Minnesota Department of Natural Resources, 2010). Water permit holders are required to submit actual use information every year. "Minnesota has reported actual use information for each permit since 1988" (HDR Engineering Inc., 2009, p. 42).

CONTACT:
Department of Natural Resources Division of Waters
500 Lafayette Road - Box 32
St. Paul, MN 55155-4032
phone: (651) 259-5700
fax: (651) 296-0445
http://www.dnr.state.mn.us/waters/index.html

The Minnesota Department of Natural Resources also provides water consumption information at: www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html.

In North Dakota, water consumption laws are based on prior appropriation. "Under this system, later permitted water users are sequentially denied water in favour of earlier appropriators in times of water shortage" (HDR Engineering Inc., 2009, p.40). The State Water Commission is responsible for allocating water resources in North Dakota. Water permit holders are required to submit actual use information every year. "North Dakota reported actual use information is available from 1970, although there appears to be some missing information prior to 1976" (HDR Engineering Inc., 2009, p. 42).

CONTACT:
North Dakota State Water Commission
900 East Boulevard Avenue, Dept 770
Bismarck, ND 58505-0850
(701) 328-2750
swc@nd.gov
http://www.swc.state.nd.us/4dlink9/4dcgi/redirect/index.html

The North Dakota State Water Commission provides water use information via its Map Data & Resources website:
www.swc.state.nd.us/4dlink9/4dcgi/GetCategoryRecord/Map%20and%20Data%20Resources

3.2 Infrastructure

Various sources of water related and other infrastructure information were examined to determine their status and the need to develop a decision support system for ecological infrastructure investments. Information on infrastructure can typically be accessed at various levels of government depending on jurisdictional responsibilities. Information sources for potable and sewage water treatment facilities within the RRB were first examined followed by flood prevention and drainage infrastructure. Other types of infrastructure such as manufacturing and industrial facilities impacting natural environments and human well-being were also examined as they may offer additional opportunities for ecological infrastructure investments.

3.2.1 Water-Related Infrastructure

Water-related infrastructure includes water treatment, flood prevention, and water conveyance and drainage systems. Government agencies at various levels are typically involved in managing and maintaining this infrastructure, which eventually must be upgraded or replaced. Canada and the United States are both faced with having to replace decaying infrastructure.[45] In addition, more frequent and extreme climate change-induced weather events are expected to lower the lifespan of existing hard infrastructure (Axworthy, 2008; Research and Analysis Division, Infrastructure Canada, 2006).

The USEPA provides a range of information on water treatment facilities online.[46] For instance, the Small Communities section of the website features general comparative information on population, housing, sewage disposal and plumbing systems at the State and Small Community levels based on a 1990 census.[47]

Drinking water supply infrastructure[48] information in Minnesota can be found on the Minnesota Health Department website. A general search on water treatment or water infrastructure provides a number of related documents. The People and Environment section of the website provides more focussed additional information on water and health, which may provide some information on water-related infrastructure.[49]

The Minnesota Pollution Control Agency compiles and manages information on wastewater treatment systems, septic fields and stormwater across the state.[50] Information gathered as part of the NPDES permits covers all the wastewater treatment facilities in Minnesota except for ones located on tribal lands.[51]

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[45] Mirza (2007) reports that C$123 billion in expenditures will be required to restore Canada's decaying municipal infrastructure.
[46] www.epa.gov/owm/index.htm
[47] www.epa.gov/owm/mab/smcomm/factsheets/census/census_tbl1.htm
[48] There are four municipalities in the Minnesota portion of the basin that draw their drinking water from surface water: Thief River Falls and East Grand Forks use the Red Lake River, Moorhead uses the Red River and Fergus Falls uses Wright Lake and a diversion of the Otter Tail River through Hoot Lake to Wright Lake.
[49] www.health.state.mn.us/people.html
[50] www.pca.state.mn.us
[51] There are four facilities located on the White Earth Reservation and probably one facility on the Red Lake Reservation.

Watershed districts in Minnesota provide important information regarding water treatment infrastructure.[52] The watershed districts that are located in the RRB coordinate their efforts under the Red River Management Board.[53] The depth of information available for each watershed district varies. Some, such as the Red Lake Watershed District, provide very detailed information, which conveys details on water retention and drainage projects online.[54]

In North Dakota, water supply distribution system information can be accessed via the North Dakota State Water Commission[55] primarily through meeting minutes and the North Dakota Department of Health website.[56] Wastewater infrastructure information can be obtained from the North Dakota Department of Health.[57]

Water Resources Districts in North Dakota play the same role as watershed districts in Minnesota. The majority of water resource districts are established based on county boundaries, and cooperation is often required to adequately manage water resources crossing political boundaries. For this reason, the North Dakota Legislature enacted the Joint Exercise of Powers Statute to enable the formation of joint water resource districts in 1975. The Red River Joint Water Resource District (RRJWRD) was the first joint district created in 1979 to address flooding problems in the Red River Valley. Made up of 14 water resource districts, the RRJWD provides coordinated approaches to water management in the North Dakota portion of the basin. Information can be found on various infrastructure projects such as the Maple Dam River project and the Red River Valley Water Supply project online.[58]

The RRJWD also provides information on existing and proposed water infrastructure, such as supply, drainage and retention structures.[59] A number of online searchable tools provide access to a range of water related infrastructure information. For example, the searchable tools for drainage and retention[60] structures provide information on their exact locations (longitude and latitude), dimensions and the tributaries they affect.[61] The site also has information on water retention structures in the Devils Lake area.[62]

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52 www.mnwatershed.org/index.asp?Type=NONE&SEC={EC4561E7-5A37-4381-A983-E192911452C6}
53 www.rrwmb.org
54 www.redlakewatershed.org/engineering.html#pdfmaps
55 www.swc.state.nd.us/4dlink9/4dcgi/redirect/index.html
56 www.ndhealth.gov/wq
57 www.ndhealth.gov/WQ/WasteWater/WasteWaterProgram.htm
58 http://rrjwrd.tripod.com
59 www.swc.state.nd.us/4dlink9/4dcgi/GetCategoryRecord/Map%20and%20Data%20Resources
60 Retention structures as categorized by their purpose: debris control, fish and wildlife, flood control, hydroelectric, irrigation, livestock, mining, navigation, water supply, waste lagoon, recreation, other.
61 www.swc.state.nd.us/4dlink9/4dcgi/GetCategoryRecord/Map%20and%20Data%20Resources
62 www.swc.state.nd.us/4dlink9/4dcgi/GetSubCategoryRecord/Map%20and%20Data%20Resources/Published%20Maps

The South Dakota Department of Environment and Natural Resources provides detailed reports online on water-related topics (e.g., compliance with regulations by different categories of infrastructure).[63] Information on water-related infrastructure is also provided in the form of databases (groundwater tanks, spill events) and maps (public water supply intakes, rural water system coverage).[64]

Canadian water treatment information can be accessed via the EC Water Survey initiative.[65] Data on water distribution, water treatment, water pricing and finance, sewer systems, wastewater treatment facilities and wastewater pricing and finance can be accessed online. The information is somewhat difficult to decipher as abbreviated codes are used as table headings. Nevertheless, it represents a wealth of accessible water-related infrastructure information.

In Manitoba, basic information on the existence or non-existence of municipal water and sewage treatment systems in rural municipalities (RMs) and communities are available through www.communityprofiles.mb.ca. To access this information, the user must select an RM or community, and then select "utilities" from the side-bar on the web page. Under the utilities link, information for all communities can be found on the following topics:

- Communities in an RM serviced by municipal wastewater systems
- Whether or not the systems are shared between municipalities
- Major sources of water (e.g., which source provides water to the communities)
- Percent of population increase that could be served from the current system
- Rated capacities and peak demands of the water system
- Quality of the treated water
- Name of owner(s) of water system
- Availability and quality of potable groundwater (e.g., alkaline)
- Remaining capacity of existing sewage systems at current growth rate
- Locations of lagoon/treatment facilities
- Type of sewage service
- Rated capacities of the lagoons/treatment facilities
- Capacities and peak demand of facilities
- Locations where septic pump-out trucks unload effluent

[63] http://denr.sd.gov
[64] See: http://denr.sd.gov/tech.aspx and www.sdgs.usd.edu
[65] www.ec.gc.ca/Water-apps/MWWS/en/export_tables.cfm

Cities tend to have the most information online regarding water and sewage treatment. For wastewater, information often includes suspended solids license requirement, aeration basin capacity, biological oxygen demand license requirement, treatment methods, type of sewage system. For water treatment, information such as treatment methods, water plant capacities, daily production and reservoir capacities may be provided. In addition, annual reports on public water systems are provided, which go into finer detail, providing, for instance, future expansion plans. However, not all cities in the Manitoba portion of the RRB provide detailed information (i.e., Morris). Some examples of city water treatment websites include:

- Winnipeg (www.winnipeg.ca/WaterandWaste/water/default.stm, www.winnipeg.ca/WaterandWaste/sewage/default.stm)
- Selkirk (www.cityofselkirk.com/assets/brochures/selkirk%20water%20brochure.pdf, www.cityofselkirk.com/assets/brochures/wastewater%20treatment%20plant.pdf)
- Winkler (www.cityofwinkler.ca/infrastructure.html)
- Steinbach (www.steinbach.ca/city_services/water_works)
- Morris (www.town.morris.mb.ca/bylaws.html)
- Pembina Water Valley Coop (www.rmofmorris.com/Reports/Annual%20Report%202007.pdf)

Some towns also provide fairly detailed information on water treatment (e.g., Altona, www.townofaltona.com/provisioner/articles/index.php?ArticleID=183&PreviousArticleID1=39&PreviousArticleID0=3; Morden, www.mordenmb.com/residents/waterquality.shtmls). However, smaller municipalities typically have very little information online regarding water treatment (e.g. Carman, www.townofcarman.com/index.html; Rural Municipality of Stuartburn, rmofstuartburn.com/index.php?option=com_frontpage&Itemid=1). This information can likely be accessed by contacting the municipal offices directly and making a request for information.

In municipalities where the majority of the population uses septic fields and personal groundwater wells, this information could be harder to obtain. For instance, the Rural Municipality of Rockwood is carrying out a "well-mapping program" to locate and manage all active and abandoned wells in its area to protect the aquifer from contamination.[66] It is very likely that comprehensive information for drinking water wells is not available for all municipalities. Septic fields are not well documented in Manitoba. It is estimated that there are between 20,000 and 30,000 sceptic fields located in the Red River corridor between the City of Winnipeg and Lake Winnipeg, but no exact count exists (Welch, 2007). The province is in the midst of a three-year septic field inspection in the Red River corridor, which will provide a more accurate count of functioning and malfunctioning septic fields.

[66] See www.rockwood.ca/environmental_services.asp

The Government of Manitoba provides general and dated (1998–1999) information on drainage.[67] The more recent Manitoba Water Strategy is also low in infrastructure details.[68] However, detailed information was likely used to create the strategy. Tile drainage information, on the other hand, seems to be non-existent, as it may not be adequately documented in the province.

Drainage infrastructure information can also be found on RM, city, town and village websites. By-law documents, council minutes and annual reports are examples of documents that often contain information on such infrastructure. However, this information is typically not centralized, can be difficult to find and often lacks detail (i.e., Winnipeg does not provide detailed online drainage information[69]).

The majority of information on drainage, water retention and flooding infrastructure in rural areas in Manitoba is generally available from CDs through a variety of reports and maps. There is a varying degree of drainage-related information on the different CD sites. There are five CDs with land within the RRB:

1) Seine-Rat River CD
2) Cooks Creek CD
3) La Salle-Redboine CD
4) Pembina Valley CD
5) East Interlake CD

The table below provides examples of the information available.

[67] www.gov.mb.ca/waterstewardship/reports/planning_development/land_drain_review.pdf
[68] www.gov.mb.ca/waterstewardship/waterstrategy/pdf/index.html
[69] www.winnipeg.ca/waterandwaste/drainageFlooding/default.stm

Table 4: Examples of infrastructure information provided by CDs

Conservation District	Map/Report/Link Name	URL	Description
La Salle-Redboine	Designation of Drains Maps	www.lasalleredboine.com/drainage_information.htm	Links to 12 "dated" (some have not been updated since the 1980s) aerial photographs and watershed maps that detail drainage.
	District Vitals	www.lasalleredboine.com/district_maps.htm	Links to detailed sub-district maps showing infrastructure such as dikes, dams and disposal/sewage beds.
	State of the Watershed Report (2007)	www.lasalleredboine.com/images/LaSalle%20River%20S%20of%20W/La_Salle_Watershed_State_of_the_Watershed_Report_(duplex).pdf	Report providing information on sections of drainage systems, dams and pump stations, water treatment plants and rural water pipelines. Information relevant to other sections of this data gap analysis are also presented (e.g., licensed manure storage facilities, pesticide container storage sites, soil types, hydrology, demographics).
Seine-Rat River	Waterway Network and Historic Annual Runoff within the Seine River Watershed	www.srrcd.ca/specialprojects/documents/050h_provwat.pdf	Map detailing drainage in the Seine River watershed.
	Seine River Integrated Watershed Management Plan (2008)	www.srrcd.ca/specialprojects/documents/Sections1to4April1.pdf	Document providing a discussion of the drainage network in the Seine River watershed.
Pembina Valley (PVCD)	Pembina River Integrated Watershed Management Plan (2010)	www.pvcd.ca/2010-02-01PembinaRiverIWMPDraft.pdf	Report that discusses the surface water management goals of the CD. The PVCD site also includes plans for watersheds within the Pembina Valley (e.g., Coleman, Goudney, Pembina River)
	Pembina Valley Watersheds	www.pvcd.ca/pembinaWatersheds.html	Interactive map that provides infrastructure details and links to reports.
East Interlake	Netley-Grassmere Integrated Watershed Management Plan (2010)	www.eicd.net/assets/watershed%20characterization%20report.pdf	Document that describes the drainage network and a related map (pp. 49–55).
Cooks Creek	Programs – Drain Infrastructure	www.cookscreekcd.com/default.asp?cat_ID=3&sub_ID=18	Specific drainage infrastructure information is not available yet.

Numerous documents on the City of Winnipeg Red River Floodway are available online from the Province of Manitoba[70] and the Manitoba Floodway Authority.[71] Detailed information can be found, such as hours of operation per year, amount of water diverted and expanded floodway capacity.

Combined sewage systems are also important infrastructure systems that may offer opportunities for investigating and implementing ecological infrastructure investments. For instance, Winnipeg storm-water combines with its sewage system and information on sewer overflow[72] updates is provided on the city's website.[73]

3.2.2 Other Infrastructure

Other infrastructure includes facilities that could have direct or indirect environmental impacts on watersheds. These include industrial and manufacturing facilities such as mines, petroleum storage facilities and existing contaminated sites as well as large agricultural operations such as feedlots and hog barns.

The USEPA provides a wide scope of information on infrastructure, industrial pollutants and their regulations.[74] This website provides links to reports, data, regulation summaries, costing analyses and other information on topics such as types of manufacturing,[75] food processing, hospitals, landfills, paving materials, pulp and paper, power generation and waste combustors. Information on Minnesota, South Dakota and North Dakota can be found through links on the USEPA website.

The USEPA tool "Envirofacts Warehouse" allows for targeted information searches based on topics such as water, waste, land, toxics, facilities and compliance.[76] For instance, a search for water-related facts for Fargo, North Dakota yields information on 16 facilities that discharge water, ranging from sewage systems to industrial buildings. Data on the amounts of substances produced are not always available.

The USEPA also allows users to search for facility regulation compliance.[77] Infractions can be searched based on regulation (e.g., Clean Water Act), and searches can be narrowed to the county, city or zip code level. One interesting search feature is that facilities with combined sewer systems can be specified during a search related to the Clean Water Act.

70 www.gov.mb.ca/waterstewardship/reports/index.html#floods
71 www.floodwayauthority.mb.ca/home.html
72 At times of heavy rainfall, the system may become overwhelmed and lead to raw sewage entering the river system.
73 www.winnipeg.ca/waterandwaste/sewage/overflow/present.stm
74 www.epa.gov/waterscience/guide/industry.html#exist
75 Examples of manufacturing operations include asbestos, battery, cement, iron and steel, nonferrous metals, pesticide chemicals, phosphate, soaps and detergents, pharmaceutical production, etc.
76 www.epa.gov/enviro/index.html
77 www.epa-echo.gov/echo

The EPA also provides information on Superfund sites, which are infrastructure-related locations that contain hazardous waste slated for cleanup due to their environmental and/or health risks. These contaminated sites include landfills, drum sites, abandoned barrels, metal finishing sites and various manufacturing sites.[78] Searches can be done by state, county or zip code, which can be displayed online in table format or downloaded in Microsoft Excel format. To find specific information on the amount of toxins released, it is necessary to look at the reports relevant to the sites, if they are available.

Toxmap Environmental Health Maps is another national resource that shows toxin release sites, that is, amounts of pollutants released with their sources and location (e.g., refineries, power stations, mining activities, pharmaceutical activities). Data is available online going back to 1988.[79]

Information on infrastructure is also available at the state level. For instance, the Minnesota Pollution Control Agency (MPCA) provides a variety of data on infrastructure and water quality. For instance, incidents of leaking above-ground and underground petroleum storage tanks are identified.[80] Specific information is provided, such as the type of petroleum product released (e.g., fuel), the location (often the name of a business), the date of the leak, whether or not contamination occurred (e.g., to soil, offsite areas).

The MPCA's "What's in My Neighbourhood" search tool allows users to carry out map and text searches for contaminated sites.[81] Users can view the locations of sites such as feedlots, hazardous waste locations, water facilities, tanks and leaks, solid waste locations, investigation and cleanup, and sites with "multiple activities." Users can click on the dot corresponding to a site to view basic information and download data if it is available. This map includes interactive functions such as the ability to draw on the map, measure distances and conduct radius queries. The text search allows users to search counties or cities for locations such as feedlots, hazardous waste, industrial stormwater, landfills, leak sites, petroleum brownfields, Superfund sites and wastewater discharge.

Similar websites for North Dakota and South Dakota are the North Dakota State Water Commission,[82] North Dakota Department of Health – Environmental Health Section[83] and the South Dakota Department of Environment and Natural Resources.[84]

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78 http://cfpub.epa.gov/supercpad/cursites/srchsites.cfm
79 http://toxmap.nlm.nih.gov/toxmap/facilities/navigate.do
80 www.pca.state.mn.us/programs/lust_pSearch.cfm
81 www.pca.state.mn.us/wimn/index.cfm
82 www.swc.state.nd.us/4dlink9/4dcgi/redirect/index.html
83 www.ndhealth.gov/ehs
84 http://denr.sd.gov/documents.aspx

Information on large industrial sites may be better accessed through the National Pollutant Release Inventory (NPRI).[85] Potentially useful information from the NPRI includes:

- The Facility Location Table, with spatial coordinates for facilities reporting to the NPRI[86]
- An online search tool[87] that allows users to narrow searches using the following parameters: substance name, location (province, postal code, major urban centre or community), facility name and industrial sector (e.g., pulp and paper, mining, wastewater treatment[88])
- A user-friendly Google Earth tool that maps out information on facilities in a number of industrial sectors[89] (2008 and 1994-2008 data are both available as .kmz formats).

Manitoba CD websites also often offer information on other types of infrastructure, such as the locations of livestock operations, storage facilities, mining activities, mining claims and quarries. The *La Salle-Redboine State of the Watershed Report* (2007) is particularly thorough on such data, including maps on:

- Licensed manure storage facilities by township (includes the type of manure stored—i.e. chicken, dairy, hogs or mixed)
- Licensed pesticide container storage sites
- Licensed petroleum container storage sites
- Licensed solid and liquid waste storage sites
- Locations of livestock operations
- Impacted and/or contaminated sites within the La Salle River watershed

The report indicates that much of this data was found in the Portage district office, indicating that these offices likely store such information. The La Salle Redboine CD also provides an online map showing where mines are active, inactive and abandoned, as well as the substances mined, though

85 www.npri.ca
86 http://ec.gc.ca/inrp-npri/default.asp?lang=En&n=20DE1DC2-1
87 www.ec.gc.ca/pdb/websol/querysite/query_e.cfm
88 For instance, a search for wastewater facilities in Winnipeg returns information on all treatment facilities in the city, and provides information on substances emitted by each facility (e.g., ammonia, arsenic, copper, lead, nitrates, phosphorus) and the amounts of these substances.
89 Cement, lime and other non-metallic minerals; oil and gas pipelines and storage; water and wastewater systems; chemical storage; metals (except aluminum, iron and steel); iron and steel; aluminum; mining and quarrying; oilsands and heavy oil; petroleum and coal products refining and manufacturing; plastics and rubber; pulp and paper; transportation equipment manufacturing; wood products; electricity infrastructure (e.g., hydro generating systems); other manufacturing; other (non-manufacturing).

this information is available only for the Stephenfield Lake watershed.[90] The Seine Rat River CD also provides a mining and quarrying map.[91]

As noted in the sewage and drainage section, municipal websites may also contain some information on infrastructure, but, as with sewage and drainage information, it may be necessary to comb through council meeting minutes and by-laws. Rarely do municipalities seem to concisely compile this information or provide data on the exact locations of facilities.

3.3 Socioeconomic

Socioeconomic statistics related to demographics and agricultural practices in the RRB are important as they paint the picture of opportunity for ecological infrastructure investments in the basin. For instance, growing populations within particular regions will strain current town and municipal infrastructure systems requiring expenditures for expansion. Marginal agricultural lands that may be better suited for restoring natural environments and farmers that could adopt farm management practices that could improve natural environments and water quality could be identified. This information is fundamental to developing an effective decision support system for multi-purpose land and water investments.

3.3.1 Demographics

The United States Census Bureau administers and disseminates information in the United States. There are various demographic surveys that have been carried out, the most thorough of which is the decennial population census, which collects data "for every household in the U.S. and its territories."[92] The most recent census was completed in 2000 and the next is scheduled for 2010.

Data are available at national, state, county and places (e.g., cities and towns) levels of aggregation. The user inputs the desired city/town or county into the search utility[93] to receive general demographic statistics. The resulting table of information depicts age breakdowns with gender divisions. Both total number and percentage values are provided. Each Fact Sheet divides information into four characteristic categories: general, social, economic and housing. Table 5 shows selected topics of interest based on grouping.

[90] www.lasalleredboine.com/SLWMP_15.htm
[91] www.srrcd.ca/specialprojects/documents/SeineRiverLeases.pdf
[92] http://factfinder.census.gov/jsp/saff/SAFFInfo.jsp?_submenuId=aboutdata_1&_pageId=censuses_surveys
[93] http://factfinder.census.gov/home/saff/main.html?_lang=en

Table 5: United States demographic information

Grouping	General Information	Detailed Information
General	Total population Age and gender breakdown Race (single race and mixed-race breakdowns) Households by type (e.g., married, single female householder, living alone) Occupancy characteristics (e.g., occupied, tenure, average household size)	
Social	Educational attainment (population over 25) Marital status Disability status Population mobility Immigration status Languages spoken at home	*Educational attainment divisions:* Less than 9th grade 9th to 12th grade, no diploma High school graduate (includes equivalency) Some college, no degree Associate degree Bachelor's degree Graduate or professional degree
Economic	Employment status (over 16 years) Commuting type Occupation Industry Median household income	*Occupation divisions:* Management, professional, and related occupations Service occupations Sales and office occupations Farming, fishing, and forestry occupations Construction, extraction, and maintenance occupations Production, transportation, and material moving occupations *Industry divisions:* Agriculture, forestry, fishing and hunting, and mining Construction Manufacturing Wholesale trade Retail trade Transportation and warehousing, and utilities Information Finance, insurance, real estate, and rental and leasing Professional, scientific, management, administrative, and waste management services Educational, health and social services Arts, entertainment, recreation, accommodation and food services Other services (except public administration) Public administration
Housing	Number units in structure Year structure built Number of vehicles Housing heating type (e.g. utility gas, fuel oil, etc.) Cost (house price, mortgage or rent)	

The U.S. Census Bureau also collects data on an annual basis through the American Community Survey and presents the information in accessible tables. The data are derived from measurements of approximately 3 million housing units annually from every county. Margins of errors are provided for the estimates. The measurement categories are similar to those of the decennial census.

One-year estimates of data are available "for geographic areas with a population of 65,000 or more" and three-year estimates are available for those with populations of 20,000 or more (United States Census Bureau, n.d.). For areas with populations lower than 20,000, the Census Bureau is preparing five-year estimates, the first of which will be produced in 2010.

For the estimates requiring higher populations, there are limitations to the availability of data in the RRB. For instance, in the three-year estimates, there are data for only seven of 53 counties in North Dakota and only three of these seven counties are in the RRB.

The U.S. Census Bureau's Population Estimates Program provides information on past and projected populations on nation, state and county levels. Measurements include age, sex, race and number of housing units. The data are provided in various formats. For instance, Excel files are available that detail changes over a period of seven years (July 2000 to July 2007) in the populations of individual counties.[94] The same information is provided on a macro level for states.[95]

Geographic Information System (GIS) cartographic boundary files available online[96] allow for mapping at a target scale range of 1:500,000 to 1:5,000,000. Census tables can be downloaded as batch files, and are available at the county level (Census Tract level). The tables can be joined to the cartographic boundary file.[97] Most information from the characteristic groupings are available and comprehensive coverage of population, housing and ethnicity for all census takers is provided.

Searches using the Fact Finder function of the website can also help users locate specific information from the American Community Surveys. For instance, a search for "North Dakota AND Agriculture" returned tables on industries by occupation in different counties. Data related to agriculture are included in these tables. However, it should be noted that the margins for error can be quite large for some estimates. For instance, data provided for Cass County, North Dakota, indicated that there were 1,484 workers in the "agriculture, forestry, fishing and hunting and mining" fields, but that the margin of error was +/-597.[98]

94 See: www.census.gov/popest/counties/CO-EST2007-01.html
95 See: www.census.gov/popest/states/NST-ann-est2007.html
96 www.census.gov/geo/www/cob/index.html
97 The table search utility is available at http://factfinder.census.gov/servlet/DownloadDatasetServlet?_lang=en
98 See: http://factfinder.census.gov/servlet/STTable?-geo_id=05000US38017&-qr_name=ACS_2005_EST_G00_S2407&-ds_name=ACS_2005_EST_G00_

The most recent Canadian census was in 2006, and the next is scheduled for 2011. Statistics Canada disseminates community demographic information through its Community Profiles.[99] The information is presented in html tables and includes breakdowns based on gender and age groupings. Many of the data categories links are included to bar charts that visually illustrate the findings. Html tables can also be custom built to suit one's interest. Information on the specific community is presented on the left-hand side of the table, while the data for the province of Manitoba is presented on the right-hand side, allowing for some basic comparison.[100]

Table 6: Canadian demographic information

General Information	Detailed Information
Total population	
Population breakdown based on age, gender	
Total dwellings and percentage by type (e.g. single detached)	
Family characteristics (e.g. married, average size, median income, etc.)	
Household characteristics (e.g. median income, type of household)	
Languages spoken	
Immigration status	
Mobility of population	
First Nations population	
Educational attainment and major field of study.	*Educational attainment:* No certificate, diploma or degree High school certificate or equivalent Apprenticeship or trades certificate or diploma College, CEGEP or other non-university certificate or diploma University certificate or diploma below the bachelor level University certificate, diploma or degree *Major field of study:* No post-secondary certificate, diploma or degree Education Visual and performing arts, and communications technologies Humanities Social and behavioural sciences and law Business, management and public administration Physical and life sciences and technologies Mathematics, computer and information sciences Architecture, engineering, and related technologies

[99] Searchable online at: www12.statcan.gc.ca/census-recensement/2006/dp-pd/prof/92-591/index.cfm?Lang=E
[100] Demographic information is retrievable online from Statistics Canada at www12.statcan.gc.ca/census-recensement/index-eng.cfm.

Employment (e.g., occupation class, industry, employed/unemployed, place of work, mode of commute, median earnings, volunteerism)	*Occupation class divisions:* Management occupations Business, finance and administration occupations Natural and applied sciences and related occupations Health occupations Occupations in social science, education, government service and religion Occupations in art, culture, recreation and sport Sales and service occupations Trades, transport and equipment operators and related occupations Occupations unique to primary industry Occupations unique to processing, manufacturing and utilities *Industry divisions:* Agriculture and other resource-based industries Construction Manufacturing Wholesale trade Retail trade Finance and real estate Health care and social services Educational services Business services Other services
Visible minorities (excluding First Nations)	
Mode of transportation to work	

3.3.2 Agriculture

The United States Department of Agriculture's National Agricultural Statistics Service (NASS) is the main recorder of agricultural data in the United States. Hundreds of surveys are conducted each year on a multitude of topics. In addition, a Census of Agriculture is conducted every five years.[101] Data are collected at the national, state and county levels. In select cases, information from the NASS is presented by watershed or other environmental boundaries. Custom statistical information requests can be accommodated by the NASS for a fee.

The NASS website has an online function called "Quick Stats" for retrieving county-level information.[102] For example, one can design a custom search to find out the number and size of hog facilities in the county of Kittson, Minnesota during the years 2000 through 2008.

The most recent Census of Agriculture occurred in 2007.[103] Given that the RRB does not follow state boundaries, county-level data is most ideal for analysis. County profiles and maps are available

[101] www.nass.usda.gov/About_NASS/index.asp
[102] www.nass.usda.gov/Data_and_Statistics/Quick_Stats/index.asp

online with statistics such as number and average size of farms and market value of products sold by commodity groups.[104] More detailed information can be obtained in the *2007 Census of Agriculture Volume 1, Chapter 2: County Level Data*.[105] Tables provide an information breakdown for each state and its counties. Tables of particular interest produced for each state include:

- Table 8: *Farms, Land in Farms, Value of Land and Buildings, and Land Use: 2007 and 2002* (e.g., cropland harvested, pasturage, fallow land, woodland area breakdown, land enrolled in conservation programs)
- Table 10: *Irrigation: 2007 and 2002* (e.g., land in irrigated farms based on land use)
- Table 11: *Cattle and Calves – Inventory and Sales: 2007 and 2002* (e.g., number of farms holding and total animals)
- Table 12: *Hogs and Pigs – Inventory and Sales: 2007 and 2002* (e.g., number of farms holding and total animals)
- Table 26: *Field Crops: 2007 and 2002* (e.g., breakdown by crop type reported as bushel yield, includes total harvested and total from irrigated farms)
- Table 42: *Fertilizers and Chemicals Applied: 2007 and 2002* (e.g., cropland and pastureland acres fertilized, for what target were chemicals used, manure versus commercial fertilizer). However, there is no information on application rate.
- Table 43: *Organic Agriculture: 2007* (e.g., number of farm acres in organic production, type of product [crop, livestock or poultry], acres in the process of being converted to organic agriculture)

The NASS also produces other relevant reports and surveys that contain valuable information. The *2008 Farm and Ranch Irrigation Survey* provides important information at the national and state levels, and by general water resource region.[106] The tables of interest identified below are available via this web page:

- Table 3: *Land Use on Farms with Irrigation: 2008 and 2003* (e.g., cropland, pastureland or woodland by acres irrigated)
- Table 4: *Land Irrigated by Method of Water Distribution: 2008 and 2003* (e.g., acres irrigated by gravity, sprinkler, drip or sub-irrigation systems)
- Table 8: *Estimated Quantity of Water Applied Using Only One Method of Distribution: 2008 and 2003*
- (e.g., gravity by acres irrigated and average acre-feet per acre)
- Table 11: *Estimated Quantity of Water Applied by Source or Supplier: 2008 and 2003*

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103 www.agcensus.usda.gov
104 www.agcensus.usda.gov/Publications/2007/Online_Highlights/County_Profiles
105 www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_County_Level
106 www.agcensus.usda.gov/Publications/2007/Online_Highlights/Farm_and_Ranch_Irrigation_Survey/index.asp.

- (e.g., acres irrigated, average acre/feet applied, by water source [on-farm surface, off-farm surface, ground])
- Table 12: *Irrigation by Estimated Quantity of Water Applied: 2008 and 2003* (e.g., acres irrigated and acre-feet of water applied)
- Table 35: *Irrigated Farms by Percent of Total Sales from Irrigated Crops and Livestock: 2008 and 2003* (e.g., irrigated crop versus non-irrigated)
- Table 40: *Energy and Water Conservation Improvements: 2008 and 2003* (e.g., effects of improvements such as reduced energy cost, reduced water applied, reduced labour costs, reduced pesticide or fertilizer loss, reduced soil erosion, reduced tailwater by number of farms, acres irrigated and acre-feet applied)
- Table 41: *Barriers to Making Improvements to Reduce Energy Use or Conserve Water: 2008 and 2003* (e.g., not a priority, risk, physical limitations)
- Table 42: *Source of Irrigation Information Relied on to Reduce Irrigation Costs or to Conserve Water: 2008 and 2003* (e.g., extension agents, private consultants, irrigation equipment dealers)

Data from the *2007 Census of Agriculture* for 38 different land characteristics (e.g., number of irrigated acres, fertilizer usage, chemical usage) are published in the *2007 Census of Agriculture: Watersheds* report. According to the USGS, the United States is divided into 20 Water Resource Regions, which are further divided into 221 subregions and 376 basins.[107] Information for the Souris-Red-Rainy watershed is available in the census, which contains data such as land use, irrigated land, usage of fertilizers and chemicals, usage of manure, crops grown and livestock raised (National Agricultural Statistics Service, 2007).

Agricultural chemical usage and chemical distribution rates have been captured since December 2005. Information on the usage and distribution of chemicals (herbicides, insecticides, fungicides and other pesticides) to selected fields and vegetable crops is presented as an active ingredient for per cent of acres treated, number of applications, rates of application and rate per crop year. These parameters are monitored for selected Program States.[108] The 2005 reports are available online,[109] while accessing more current data requires subscription by selecting the *Reports by Email* link in the page header. Similar reports in the series that may be of use include:

- *Agricultural Chemical Usage: Field Crops 1992-2008* (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do;jsessionid=B5AD9F5D74B89B9695132C9C9C6C60D5?documentID=1560

[107] The Census by Watershed report is available at: www.agcensus.usda.gov/Publications/2007/Online_Highlights/Watersheds/index.asp.
[108] Further details on the data sources at: www.nass.usda.gov/Statistics_by_Subject/Environmental/index.asp
[109] http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1579

- *Agricultural Chemical Usage: Livestock and General Farm Use 1999-2007* (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do;jsessionid=B5AD9F5D74B89B9695132C9C9C6C60D5?documentID=1569)
- *Agricultural Chemical Usage: Swine and Swine Facilities 2001-2006* (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do;jsessionid=B5AD9F5D74B89B9695132C9C9C6C60D5?documentID=1658)
- *Agricultural Chemical Usage: Dairy Cattle and Dairy Facilities 2002-2007* (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do;jsessionid=B5AD9F5D74B89B9695132C9C9C6C60D5?documentID=1700)
- *Agricultural Chemical Usage: Cattle and Cattle Facilities 2000* (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1707)
- *Agricultural Chemical Usage: Sheep and Sheep Facilities 2001* (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do;jsessionid=B5AD9F5D74B89B9695132C9C9C6C60D5?documentID=1656)

It should be noted that state-level governments also gather agricultural statistics. However, these efforts are often coordinated with the NASS. The Minnesota Department of Agriculture, the North Dakota State University Extension Service and Experiment Station, the North Dakota Department of Agriculture, the South Dakota Department of Agriculture and South Dakota State University all play a role in collecting various types of agricultural statistics within their respective states. These bodies, however, do not appear to provide information in as detailed and accessible forms as does the NASS, with state and university websites only highlighting basic statistics, or linking directly to the NASS.

Agricultural census data in Canada are collected by Statistics Canada as part of the Census of Agriculture. The most recent census occurred in 2006, the same year as the most recent Census of the Population. This is done for ease of data collection and analysis as demographic and agricultural information can then easily be linked. Data are collected from farmers regarding a variety of products including field crops, vegetables, livestock, eggs and milk products. The information recorded can be accessed online[110] and includes (Statistics Canada, 2009):

- Size (area) of operation
- Land use and tenure
- Area and type of crops
- Land management practices
- Number and type of livestock
- Total gross farm receipts

[110] www.census2006.ca/census-recensement/2006/ref/dict/overview-apercu/ag1-eng.cfm

The data is tabulated at national, provincial and three sub-provincial levels (census agricultural region, census division and census consolidated subdivision). The *Census Agricultural Regions Boundary Files of the 2006 Census of Agriculture 92-174-X* provides data for census agricultural regions (Census Agricultural Regions [CARs] in .zip format containing ESRI .shp files which delineate the 82 CARs[111]). The reference guide for the CARs[112] provides information on the limitations and potential uses of the CAR information.

The agricultural ecumene delineates areas of significant agricultural activity in Canada as indicated by the 2006 Census of Agriculture to the census division level (CDL).[113] A reference guide for this feature is available at www.statcan.gc.ca/pub/92-175-x/92-175-x2007000-eng.htm. Three boundary .shp files are included: (1) the agricultural ecumene (with integrated census division polygons), (2) all census divisions in Canada and (3) the provinces and territories.

Both CARs and CDLs can be viewed on a .pdf reference map, which presents the geographic boundaries, codes and names for all geographic areas appearing in the data tables for the 2006 Census of Agriculture. Information specific to Manitoba can be obtained at www.statcan.gc.ca/ca-ra2006/reference_map-carte-eng.htm#mb.

The 2006 Census was expanded to include several topics that are relevant to water resource management by including irrigation (type of irrigation system and total land irrigated), manure management (production, use, method of application, suitability of land), land tenure and organic production.[114] Specific market information is collected more frequently, on a quarterly or annual basis. Various specialized and specific reports or related surveys are also compiled and posted online.[115]

Specific socioeconomic and agricultural data are collected and disseminated as CANSIM tables, which are available online. While some CANSIM data is available free of charge, most of it can be obtained on a sliding cost scale depending on the order size. Tables are easily located by using the CANSIM search utility.[116]

The following are examples of tables pertinent to basin-wide investigation. Geographic level of evaluation and some content headers are supplied. Further details require payment. Yield is only

111 www.statcan.gc.ca/bsolc/olc-cel/olc-cel?lang=eng&catno=92-174-X
112 www.statcan.gc.ca/pub/92-174-g/92-174-g2007000-eng.pdf
113 www.statcan.gc.ca/pub/92-175-x/92-175-x2007000-eng.htm
114 www.statcan.gc.ca/ca-ra2006/about-apropos/new-nouveau-eng.htm
115 www.statcan.gc.ca/ca-ra2006/index-eng.htm
116 http://cansim2.statcan.gc.ca/cgi-win/CNSMCGI.EXE?LANG=Eng&Dir-Rep=CII/&CNSM-Fi=CII/CII_1-eng.htm

presented and discussed at a provincial level, but should be available at a finer scale due to the data collection at the CAR and CD levels.

Table 7: Examples of Canadian agricultural statistics

Table Number:	Table 003-0004
Table Name:	*Number of hogs on farms at end of quarter, quarterly (head)*
Date:	years 1971–2009, last updated on February 15, 2009
Geography:	Data presented aggregated nationally or at provincial level
Data Content:	Hogs, total; Breeding stock, 6 months and over; Boars, 6 months and over; Sows and gilts, 6 months and over; etc.
Online Source:	cansim2.statcan.ca/cgi-win/cnsmcgi.pgm?regtkt=&C2Sub=&ARRAYID=30004&C2DB=&VEC=&LANG=E&SrchVer=&ChunkSize=&SDDSLOC=&ROOTDIR=CII/&RESULTTEMPLATE=CII/CII_PICK&ARRAY_PICK=1&SDDSID=&SDDSDESC=
Notes:	Only describes number, age and class of hog/boar.

Table Number:	Table 003-0031
Table Name:	*Number of sheep and lambs on farms, annual (head), 1906 to 2010*
Date:	years 1906–2010, last updated early 2010
Geography:	Data presented aggregated nationally or at provincial level
Data Content:	Sheep and lambs, total; Sheep, 1 year or older; Rams; Ewes and wethers; Lambs, under 1 year; Lambs for breeding; Lambs for marketing; etc.
Online Source:	cansim2.statcan.ca/cgi-win/cnsmcgi.pgm?regtkt=&C2Sub=&ARRAYID=30031&C2DB=&VEC=&LANG=E&SrchVer=&ChunkSize=&SDDSLOC=&ROOTDIR=CII/&RESULTTEMPLATE=CII/CII_PICK&ARRAY_PICK=1&SDDSID=&SDDSDESC=
Notes:	Only describes number, age and class of sheep/lambs.

Table Number:	Table 003-0032
Table Name:	*Number of cattle, by class and farm type, annual (head), 1931 to 2010*
Date:	years 1931–2010, last updated early 2010
Geography:	Data presented aggregated nationally or at provincial level
Data Content:	Total cattle; Bulls, 1 year and over; Dairy cows; Beef cows; Total heifers; Heifers for dairy replacement; Total beef heifers; Heifers for beef replacement; Heifers for slaughter; Steers, 1 year and over; Calves, under 1 year; etc.
Online Source:	cansim2.statcan.ca/cgi-win/cnsmcgi.pgm?regtkt=&C2Sub=&ARRAYID=30032&C2DB=&VEC=&LANG=E&SrchVer=&ChunkSize=&SDDSLOC=&ROOTDIR=CII/&RESULTTEMPLATE=CII/CII_PICK&ARRAY_PICK=1&SDDSID=&SDDSDESC=
Notes:	Only describes number, age.

Table Number:	Table 153-0058
Table Name:	*Selected agricultural activities, Canada, ecozones and ecoregions with agriculture, every 5 years (square kilometres unless otherwise noted)*
Date:	years 1971–2006, last updated on December 29, 2009
Geography:	Data presented by ecozone, with subdivisions within each ecozone per province; e.g. Southern Arctic ecozone; Maguse River Upland

Data Content:	Total area; Number of farm units; Agricultural land area; Average farm unit size; Agricultural land as a share of total area (percent); Cropland area; Improved pasture area; Hay area; Number of cattle; Cattle density (number per square kilometre); Chemical product expenses (1992 constant dollars); Chemical product expenses per total area (1992 constant dollars per square kilometre); Fertilizer expenses (1992 constant dollars); Fertilized land area; Fertilizer expenses per total area (1992 constant dollars per square kilometre); Trucks on farms (number); Tractors on farms (number); Automobiles on farms (number)
Online Source:	cansim2.statcan.gc.ca/cgi-win/cnsmcgi.pgm?Lang=E&RootDir=CII/&ResultTemplate=CII/CII_ASUM&ARRAY_SUMM=1&ARRAYID=1530058

Table Number:	Table 003-0089
Table Name:	*Hogs statistics, number of farms reporting and average number of hogs per farm, quarterly, Jan 2000 to Jan 2010*
Date:	years 2000–2010, last updated early 2010
Geography:	Data presented aggregated nationally or at provincial level
Data Content:	Number of farms reporting hogs; Average number of hogs per farm reporting; etc.
Online Source:	cansim2.statcan.gc.ca/cgi-win/cnsmcgi.pgm?regtkt=&C2Sub=&LANG=E&C2DB=&C2USER=&C2PASS=&C2APASS=&C2USEWRK=&SDDSLOC=//www.statcan.gc.ca/imdb-bmdi/*.htm&ROOTDIR=CII/&VEC=&RESULTTEMPLATE=CII/CII_ASUM&ARRAY_SUMM=1&SDDSID=&DRILLFILE=&ARRAYID=30089
Notes:	Only describes number, age.

Table Number:	Table 153-0038
Table Name:	*Selected agricultural activities, all major drainage areas and sub-drainage areas with agriculture, every 5 years (square kilometres unless otherwise noted)*
Date:	2006
Geography:	Data presented aggregated by major and sub-drainage areas
Data Content:	Total area; Number of farm units; Agricultural land area; Average farm unit size; Agricultural land as a share of total area (percent); Cropland area; Improved pasture area; Hay area; Number of cattle; Cattle density (number per square kilometre); Chemical product expenses (1992 constant dollars); Chemical product expenses per total area (1992 constant dollars per square kilometre); Fertilizer expenses (1992 constant dollars); Fertilized land area; Fertilizer expenses per total area (1992 constant dollars per square kilometre); Trucks on farms (number); Tractors on farms (number); Automobiles on farms (number); etc.
Online Source:	cansim2.statcan.gc.ca/cgi-win/cnsmcgi.pgm?Lang=E&RegTkt=&C2Sub=&Array_Pick=1&RootDir=CII/&Vec=&ResultTemplate=CII/CII_Pick&ArrayId=1530038&C2DB=PRD
Notes:	No RRB explicitly, but Lake Winnipeg and Red River subdivisions of the Nelson River major drainage area exist.

Table Number:	Table 153-0040
Table Name:	*Manure production, Canada, major drainage areas and sub-drainage areas, every 5 years (tonnes), 2001 to 2006*
Date:	2001–2006
Geography:	Data presented aggregated by major and sub-drainage areas

Data Content:	Manure production; Phosphorous production; Nitrogen production; etc.
Online Source:	http://cansim2.statcan.ca/cgi-win/cnsmcgi.pgm?Lang=E&RegTkt=&C2Sub=&Array_Pick=1&RootDir=CII/&Vec=&ResultTemplate=CII/CII_Pick&ArrayId=1530038&C2DB=PRD
Notes:	No RRB explicitly, but Lake Winnipeg and Red River subdivisions of the Nelson River major drainage area exist

Other tables of potential interest include:

- 001-0004 (Estimated summerfallow areas, annual [hectares])
- 001-0010 (Estimated areas, yield, production and average farm price of principal field crops, in metric units, annual)
- 001-0017 (Estimated areas, yield, production, average farm price and total farm value of principal field crops, in imperial units, annual)
- 001-0018 (Estimated areas, yield, production, average farm price and total farm value of selected principal field crops: sugar beets, tame hay and fodder corn, in imperial units, annual)
- 001-0019 (Estimated area, yield, production, average farm price and total farm value of selected major speciality field crops, in imperial units, annual)
- 001-0020 (Estimated area, yield, production, average farm price and total farm value of selected principal field crops: dry beans [white and coloured], in imperial units, annual)
- 001-0040 (Stocks of grain and oilseeds at March 31, July 31 and December 31, 3 times per year [tonnes])
- 001-0041 (Supply and disposition of grains in Canada as of March 31, July 31, August 31 (soybeans only) and December 31, 3 times per year [metric tonnes])
- 001-0042 (Supply and disposition of corn in Canada and selected provinces as of March 31, August 31 and December 31, 3 times per year [metric tonnes])
- 001-0043 (Farm supply and disposition of grains as of March 31, July 31, August 31 [soybeans only] and December 31, 3 times per year [metric tonnes])

The *2006 Census of Agriculture* includes informative farm data and operator data tables. Of greatest interest to this review are those tables included under the title of *Land use, tenure and land management practices.*[117] Table data are available online and presented at the provincial, CAR, CD and census consolidated subdivision levels of aggregation. Information is listed by number of farms, acres and hectares.

[117] www.statcan.gc.ca/pub/95-629-x/2007000/4182415-eng.htm

Table 8: 2006 Census of agriculture[118]

Land use	
4.3-1	Total area of farms, census years 2006 and 2001
4.3-2	Land in crops (excluding Christmas tree area), census years 2006 and 2001
4.3-3	Summerfallow land, census years 2006 and 2001
4.3-4	Tame or seeded pasture, census years 2006 and 2001
4.3-5	Natural land for pasture, census years 2006 and 2001
4.3-6	All other land (including woodlands, wetlands and Christmas tree area), census years 2006 and 2001
4.3-7	Area in Christmas trees, woodlands and wetlands, census year 2006
4.3-8	All other land, census year 2006
Historically comparable tenure of land reported	
4.4-1	Total area, census years 2006 and 2001
4.4-2	Area owned, census years 2006 and 2001
4.4-3	Area leased from governments, census years 2006 and 2001
4.4-4	Area rented or leased from others, census years 2006 and 2001
4.4-5	Area crop-shared from others, census years 2006 and 2001
Tillage practices used to prepare land for seeding	
4.7-1	Total land prepared for seeding, census years 2006 and 2001
4.7-2	Tillage incorporating most of the crop residue into the soil, census years 2006 and 2001
4.7-3	Tillage retaining most of the crop residue on the surface, census years 2006 and 2001
4.7-4	No-till or zero-till seeding, census years 2006 and 2001
Land inputs	
4.8-1	Herbicides, 2005 and 2000
4.8-2	Insecticides, 2005 and 2000
4.8-3	Fungicides, 2005 and 2000
4.8-4	Commercial fertilizer, 2005 and 2000
4.8-5	Lime, 2005
Manure and manure application methods	
4.9-1	Farms classified by manure produced or used on the agricultural operation, 2005
4.9-2	Number of farms reporting composted manure incorporated into soil, by area and land use, 2005
4.9-3	Number of farms reporting composted manure not incorporated into soil, by area and land use, 2005
4.9-4	Number of farms reporting solid manure incorporated into soil, by area and land use, 2005
4.9-5	Number of farms reporting solid manure not incorporated into soil, by area and land use, 2005
4.9-6	Number of farms reporting liquid manure injected or incorporated into soil, by area and land use, 2005
4.9-7	Number of farms reporting liquid manure not incorporated into soil, by area and land use, 2005
4.9-8	Number of farms reporting liquid manure applied by irrigation, by area and land use, 2005
Soil conservation practices	
4.10-1	All farms and crop rotation, census years 2006 and 2001
4.10-2	Winter cover crops and plowing down green crops, census years 2006 and 2001
4.10-3	Windbreaks or shelterbelts, census years 2006 and 2001
4.10-4	Rotational grazing and buffer zones around water bodies, census year 2006
Forms of weed control used on summerfallow land	
4.11-1	Chemfallow only, census years 2006 and 2001
4.11-2	Summerfallow, tilled only, census years 2006 and 2001
4.11-3	Chemical and tillage weed control on the same land, census years 2006 and 2001

[118] Tables listed in Table 8 can be found at: www.statcan.gc.ca/pub/95-629-x/2007000/4182415-eng.htm

Irrigation	
4.12-1	All irrigation use, 2005 and 2000
4.12-2	Irrigated field crops and Irrigated hay and pasture, 2005
4.12-3	Irrigated vegetables and Irrigated fruits, 2005
4.12-4	Other irrigated areas (nursery, sod, etc.), 2005

Farm type (North American Industry Classification System) also provides valuable information on trends within the agricultural sector.[119]

Table 9: Agricultural statistics classified by industry group

Farms classified by industry group	
3.1-1	Cattle ranching and farming and hog and pig farming, census years 2006 and 2001
3.1-2	Poultry and egg production and sheep and goat farming, census years 2006 and 2001
3.1-3	Other animal production and oilseed and grain farming, census years 2006 and 2001
3.1-4	Vegetable and melon farming and fruit and tree-nut farming, census years 2006 and 2001
3.1-5	Greenhouse, nursery and floriculture production and other crop farming, census years 2006 and 2001

The *2006 Farm Environmental Management Survey* (FEMS) focuses on livestock and crop operations. The FEMS survey "collects farm-level information on manure management practices, sustainable grazing systems, crop nutrient management, pesticide application practices, land and water management practices (including irrigation farming practices), and whole farm environmental management" (Grimard, 2007). Sampling was done by province and ecoregion to create a total of 27 agriculture subdivisions. Data tables are not yet provided online and only information from the 2001 FEMS is available, which includes the following five short reports with tables of data aggregated at the national or provincial levels:

- 21-021-MWE Volume 3, number 1: *Water Management on Canadian Farms* "examines practices for the protection of natural water sources and those for management of water directly used on Canadian farms, both in farming and household activities. This article presents information on the maintenance of vegetation in areas adjacent to natural sources of water, the practices used by dairy farmers who store liquid manure and dispose of their milkhouse wash water into liquid manure storage systems, as well as use of water for irrigation and the testing of domestic water."[120]
- 21-021-MIE Volume 2004, Issue 4: *Grazing Management in Canada* "presents information on various characteristics of livestock grazing management as practiced on Canadian farms."[121]
- 21-021-MIE Volume 2004, Issue 3: *Fertilizer and Pesticide Management in Canada* "presents information on the various practices used to manage chemical inputs, specifically chemical fertilizers and pesticides, on Canadian farms."[122]

[119] Available at: www.statcan.gc.ca/pub/95-629-x/2007000/4123852-eng.htm.
[120] www.statcan.gc.ca/pub/21-021-m/21-021-m2007001-eng.htm
[121] www.statcan.gc.ca/pub/21-021-m/21-021-m2005001-eng.htm

- 21-021-MIE Volume 2003, Issue 1: *Manure Storage in Canada* "presents various characteristics of the manure storage systems on Canadian farms, with particular attention to the dairy, beef and hog sectors."[123]
- 21-021-MIE Volume 2001, Issue 2: *Manure Management in Canada* "presents information on various characteristics of manure management as practised on Canadian farms."[124]

Data from the *2007 Agricultural Water Use Survey* are also available from Statistics Canada on a request-only basis. This survey records data such as "volumes of water used for irrigation, irrigated areas, irrigation practices and the quality of water used for agricultural purposes" (Poirier, 2009). The *Methodology Report*[125] presents methods of survey and generalized data tables based on regions.

3.2 Summary

In general, the majority of the biophysical, infrastructure and socioeconomic information required to develop a sophisticated decision support system for ecological infrastructure investments in the RRB is available. The information that is missing, such as high quality DEM information in the form of LIDAR data, can be acquired. Acquisition costs for missing data sets ranges widely and may or may not be required depending on the context where the DSS is being developed or tested.

3.4.1 Biophysical

Overall, the majority of the biophysical information to undertake the development of decision support systems for multi-purpose land and water investments in the RRB is available. Land cover data has been assembled into a comprehensive map and the information required for compiling a soil map is available. IISD is in the process of compiling a comprehensive soil and bedrock map for the RRB. Nevertheless, accurate elevation data for the basin is lacking. Although LIDAR data has been acquired for the U.S. portion of the basin and parts of the Canadian portion, there are still substantial areas in Canada that do not have coverage. It was estimated that collecting data for the rest of the basin could cost anywhere from US$0.9 million to $3.4 million, which could be acquired affordably if the total cost is shared amongst a number of government agencies and other entities interested in the data.

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[122] www.statcan.gc.ca/pub/21-021-m/21-021-m2004002-eng.htm
[123] www.statcan.gc.ca/pub/21-021-m/21-021-m2003001-eng.htm
[124] www.statcan.gc.ca/pub/21-021-m/21-021-m2004001-eng.htm
[125] www.statcan.gc.ca/pub/16-001-m/16-001-m2009008-eng.htm

3.4.2 *Infrastructure*

Water-related and other infrastructure information is generally regularly gathered and archived by the various government agencies that are responsible for them. This information is often available to the public and accessed online. Nevertheless, the information is managed in many different ways and can be difficult to track down. For instance, it could be necessary to sift through reports and meeting minutes to access the information that is being sought. Providing this information through a centralized website accessible to the public would make it more feasible to identify opportunities for ecological infrastructure investments in the RRB. The possibility of hosting this information in a centralized manner on an existing website should be investigated.

3.4.3 *Socioeconomic*

Socioeconomic data is readily available for the development of the decision support system for ecological infrastructure investments in the RRB. A variety of statistics describing demographics and the agricultural sector can be accessed through Statistics Canada and the U.S. Census Bureau online. Although the information is available, it may have to be adequately disaggregated or aggregated from census divisions to basin and watershed boundaries for the information to be useful. This may require a substantial amount of data processing, which typically can be completed by Statistics Canada and the U.S. Census Bureau for a nominal fee.

4.0 Modelling Workshop

The primary purpose of the Building Capacity for Ecological Infrastructure Investments in the Red River Basin project is to jointly develop with relevant stakeholders a decision support system (DSS) that will build capacity to examine the costs and benefits associated with natural capital (or natural environments) conservation and restoration investments at the basin scale and within municipalities and counties.

A number of shared issues (flooding, water quality and supply) are being faced by the residents of the RRB on both sides of the border. Well-structured tools can assist with communicating the interconnectedness of these issues and provide a systems perspective that can help open up new possibilities for discourse and policy-making pathways. An integrated high-resolution DSS at the right scales (basin-wide and watershed scales) could improve the overall communication and decision-making within the basin. An underlying objective of this workshop is to continue fostering cooperation among the residents of the basin to jointly solve trans-boundary issues. The workshop will address the following objectives:

1. Generate insights and a plan for developing a state-of-the-art DSS for the RRB;
2. Develop a plan to build consensus for implementing a comprehensive DSS;
3. Identify partnerships to establish the technical and financial capacity required to complete the project;
4. Obtain feedback on proposed DSS architecture.

The workshop was designed to generate a spectrum of approaches for large-scale basin modelling in support of integrated watershed management.[126] Twenty-eight participants (13 in Canada and 15 in the United States) from across the RRB with modelling and policy-making expertise participated in the workshop. They discussed the specifics of designing a sophisticated DSS for ecological infrastructure investments within the RRB by building on existing models and tools. Due to the international nature of the project and tight international travel budgets of many collaborating organizations, it was necessary to have two nodes for the workshop: a Canadian node in Winnipeg, Manitoba and a U.S. node in Fargo, North Dakota, which were connected by video-conferencing.

[126] "Integrated Watershed Management is the process of managing human activities and natural resources on a watershed basis. This approach allows us to protect important water resources while at the same time, addressing multiple critical issues such as the current and future impacts of rapid growth and climate change. Effective Integrated Watershed Management ultimately leads to better decision-making, smarter priority setting, opportunities to pool existing resources and increased efficiency between a variety of stakeholders such as government, residents, agencies and businesses—especially important in today's economic and environmental climate" (Conservation Ontario, 2010).

To achieve a candid illuminating discussion, it was decided that no comments throughout the workshop will be ascribed to specific individuals in order to facilitate an open conversation.

4.1 Format

Pre-workshop materials (see Appendix B) that were sent to the participants focused on some of the challenges facing the basin, important ongoing projects in the RRB, integrated watershed management (IWM) initiatives and selected IWM models and tools.

The Next Generation Red River Basin Decision Information Network, which will provide local decision-makers with water management tools, and the Red River Basin Commission – Agricultural Water Enhancement Program, which will coordinate flood mitigation and water quality improvement projects, were briefly presented, as they are foundational initiatives for developing a transboundary DSS.

IWM initiatives in the Willamette River Basin, Mississippi River Basin and the Chesapeake Bay, which have relied on various models and tools for its implementation, were then be presented. A selection of these models were described to initiate reflection on how they could be applied within the context of an overarching DSS for ecological infrastructure investments in the RRB.

The following strategic questions were sent to the participants ahead of time so they were prepared to discuss them during the workshop:

1. What are some of the key design elements and or functionalities that you would include to ensure that the DSS is useful and relevant?
2. What existing DSSs and tools currently used in the basin should be built on to develop the proposed DSS?
3. What are the barriers to implementing a basin-wide DSS? Why don't we have a similar system in place already (technological, political, other obstacles)?
4. What is the process that you would follow to develop the proposed DSS?

The workshop opened up by presenting its objectives and agenda (see Appendix C) and then provided a quick introduction to the project itself and the progress made to date. A rationale for the development of tools for IWM was presented and examples of where modelling and decision support tools have been implemented successfully was discussed.

A quick overview of the existing models being used in the basin and implemented for IWM was provided by the participants. The presentation enabled the participants to get a sense of the various tools and models that are being used and how they could be implemented within the RRB.

Strategic questions one to three were discussed in small breakout groups to enhance interactions among the participants. Each breakout group recorded their insights and presented back to the participants. An open discussion concerning the strategic questions with the overall group ensued.

A basic DSS architecture for IWM and the Open MI (Open Modelling Interface) concept was presented (see Appendix B). The participants were then asked to discuss and critique the architecture presented within their breakout groups. The discussions were reported back to the overall group.

To save time, an open discussion on strategic question four followed. Both the American and Canadian groups provided a number of insights and strategies for developing DSS for ecological infrastructure investments.

The workshop concluded with a short summary of the discussions and an agreement to draft a letter of commitment to continue working on this initiative to be composed by the IISD and the RRBC.

4.2 Proceedings

A summary of the minutes taken during the workshop are provided below. The discussion following the presentations on foundational initiatives, international water resources management and water management models were recorded. The insights generated during the strategic questions and proposed DSS architecture discussions in the breakout and collective groups were captured.

4.2.1 Foundational Initiatives

Ongoing compatible initiatives being carried out in the basin will be leveraged. Two initiatives of note are the International Water Institute (IWI) Next Generation Red River Basin Decision Information Network (RRBDIN) and the Red River Basin Commission (RRBC) Agricultural Water Enhancement Program (AWEP). The ecological infrastructure investments project will ultimately build on these initiatives.

The IWI is in the process of completing a project entitled the RRBDIN, which will support local decision support in the United States portion of the RRB. The RRBDIN will provide tools for Flood and Water Quality Forecasting, Development & Permitting and Emergency Management. The system will be built on a geospatial platform and will take advantage of social networking and cloud computing.

The RRBC is currently in charge of administering a large AWEP in the basin. This initiative consists of large-scale agricultural projects aiming to improve water quality in the RRB. The lessons learned throughout this project could help with developing the DSS and the development of the DSS could potentially provide the AWEP with a tool to coherently target projects across the basin that offer the most cost efficiency.

4.2.2 *Integrated Water Resources Management*

The Transboundary Water Opportunities (TWO) analysis aims to create win/win situations for addressing systematic problems within transboundary basins and watersheds. "By jointly managing a river, riparians can generate public goods and drought protection, increased biodiversity and improved conservation, enhanced water quality, and even greater possibilities for peace and regional stability" (Phillips, et al., 2008). TWO analysis looks at five factors of development and categories of water to give us a framework for identifying win-win opportunities for the residents of a transboundary basin.

The general philosophy is to first treat a basin or watershed as an ecosystem as a whole and then add the borders. Many transboundary basins share similar issues that are being tackled in various parts of the world. Therefore, the RRB is not completely unique compared with other large transboundary basins.

A number of integrated transboundary watershed initiatives have been implemented in various basins and watersheds. The following initiatives were discussed:

- Willamette River Watershed: Extensive work was done to determine the impacts of various development scenarios. An agent-based model was developed for a sub-watershed of the Willamette to examine how various policy and agent decision-making parameters would affect the landscape.
- Mississippi River Basin: *From the Corn Belt to the Gulf* is a study that examined various scenarios in a couple of sub-watersheds in the Mississippi River Basin to improve the water quality of the Gulf of Mexico. It examined how these landscape scenarios would impact water quality using SWAT. One of the interesting outcomes of the research was the desirability of the agricultural producer community to embrace environmentally friendly landscapes based on a landscape picture survey. This kind of research in the Gulf of Mexico led to increased funding from the USDA for agri-environmental programs in the basin to lower nutrient flows originating from the basin impacting the Gulf.
- Chesapeake Bay Basin: Point and nonpoint nutrient pollutants were examined using the SPARROW model. This work identified the nutrient hot spots on the landscape to better target nutrient management plans.

4.2.3 *Existing Models*

A selection of models currently being used within the RRB and for IWM was discussed. The notes capturing the presentations and discussions are provided below.

SWAT Modelling: The Soil and Water Assessment Tool (SWAT) was developed by the USDA. The model is free and is continuously updated (at least one to two times per year). It uses topography, land use and soil types to evaluate water quality. It is used to predict the impact of land-management practices on water, sediment and agricultural chemical yields on a daily, monthly or yearly time-step. The hydrological cycle and water balance are the driving force in model simulation. The hydrological portion is split into two components:

- Land phase: Controls amount of water, sediment, nutrient and pesticide loading to the main channel in each sub-basin.
- Routing phase: Defines the movement of water, sediment, nutrients, etc., through the channel network of the watershed to the outlet. The water quality component is a modified version of QUAL2E.

SWAT divides a basin into smaller sub-basins based on topography that can then be divided again into hydrologic response units. The model is typically used to look at larger watersheds but can be used in concert with APEX to examine smaller scales (applying it to an area smaller than 5 m^2 will not be beneficial). The base layers are the limiting factors. The model is user friendly as far as determining water quality impacts from a variety of agricultural management practices (crop types and crop rotation, etc.).

It factors in streambed erosion but is limited in its ability to take into consideration dissolved nutrients from flooding events. For instance, evaluating whether or not water retention areas may contribute to increased dissolved nutrients cannot be explored with the model. SWAT has limited functionality for assessing snow dynamics on the hydrology of a watershed. Snow movement and depth are difficult to model due to variable wind patterns. It could be useful to evaluate its snow modelling component with other models such as the CHRM. SWAT models have been developed for 70 per cent of the watersheds in the basin.

HMS HEC-RAS Modelling: The model is essentially a hydraulic routing flow model (both for steady and unsteady flow conditions). It is very useful for flood forecasting and to examine water retention potential on a square-mile section. It can be used to examine many different flood management strategies such as floodplain storage and has built-in economic models to examine flood damages and drainage costs. Most recently, it has been applied in the Fargo-Moorehead area to examine river diversion alternatives. It is also used to examine various hydropower operating procedures and the hydrology of the waffle project. It is very useful to examine the potential economic and risk trade-offs associated with the hydraulic management of water resources within a given basin or watershed.

HMS is still widely used in the basin because the U.S. Army Corps of Engineers are required to use it. The national weather system is moving to using different models. Government officials are looking to update the HMS model. The model still uses base data for channels in the RRB passed down from surveys in the 1970s and 1980s, and developed for the 2003 assessment report. Channel sections have been cut and incorporated in the model to update it.

The model needs to build out its water quality modelling functionality. It was used to look at dissolved solids coming from water storage sites and it found that there was a decrease in nitrogen but a slight increase in phosphorus. HMS is superior to SWAT for flood forecasting but is inferior for water quality. There are advantages to using multiple models.

MIKE-11 Modelling: This is a hydrological model and a planning tool commonly used by Manitoba Hydro. The model is proprietary and powerful but expensive to use. Nevertheless, DHI provides good support, which can be worth the cost (it can cost $8,000/month). It has an excellent routing model and it uses a triangular mesh of 1 to 5 m in resolution. It uses long-term average values of water characteristics using non-linear regression to calculate parameters. The model can be used to coarsely identify water retention sites and has functionality to factor in groundwater. It has the capability to distinguish between urban and non-urban wastewater contributions, which can be helpful. The model can be applied to a few to thousands or millions of square kilometres. Therefore the model can be used to undertake 50-year runs to examine water storage and water quality at a very fine scale.

The RRBC is developing a flow reduction strategy that would reduce flood damages throughout the basin by reducing the flood volume enough to reduce peak flows along the entire length of the Red River by 20 per cent. The flow would be reduced primarily by storing floodwater within the contributing watersheds. The amount of flow reduction required was estimated by the RRBC using the Mike-11 model based on the flow conditions of the 1997 spring flood.

Telemac 2D Modelling: Developed by the Laboratoire National d'Hydraulique, a department of Electricité de France's Research and Development Division, the model was built on FORTRAN sub-routines and is now used by over 170 agencies around the world.

It is currently being applied in the Pembina River Watershed to examine various flood management scenarios (set back dikes, diversions). Acquiring high resolution elevation LIDAR data was necessary to ascertain the flow patterns on the landscape. Culvert locations was supplied by the RRBC. The model was calibrated with a high level of accuracy. The model is more accurate along streams and roads where more data is available but less accurate further away from these features (i.e., fields). The model examines how water moves through the landscape without human intervention.

SPARROW Modelling: The model, which was developed by the USGS and updated in 2008, uses statistical methods to estimate water quality measurements based on a network of monitoring stations and watershed spatial attributes. For this reason, it can be used in areas with little monitoring. In general terms, it was developed to:

- Utilize existing data to better explain the factors that affect water quality;
- Examine the statistical significance of contaminant sources, environmental factors and transport processes in explaining predicted contaminant loads;
- Provide statistical basis for estimating stream loads in unmonitored locations.

Specifically, SPARROW can be used to: establish links between water quality and constituent sources, track transport of constituents to streams and receiving waters, assess the natural processes that attenuate constituents as they are transported from land and downstream, predict changes in water quality that may result from management actions or changes in land use.

The SPARROW model is deterministic in nature since it incorporates nonlinear physically-based functions, mass-balance requirements and simulations of certain physical processes. It is also statistical in nature in the way they are calibrated—using established statistical procedures designed to optimize model fit by minimizing error between model predictions and measured water-quality data.

The Mississippi River Basin Healthy Watersheds Initiative (a multi-state, multi-agency effort) utilized SPARROW to identify high-priority watersheds for mitigating nutrients and other pollutants. The model allowed for a rapid assessment and visual depiction of the watersheds (at the HUC 8 level) and their nutrient contributions to the Gulf of Mexico. The visual output of the model proved to be a powerful tool for explaining nutrient and sediment impacts on a watershed-by-watershed basis to state and local workgroups. The model allows for the separation of urban and non-urban contributions. Agencies working in various settings identified focus areas for applying other models at various scales. It is currently being applied to the RRB.

EcoServ Modelling: The model was developed at the USGS Northern Prairie Centre in partnership with EROS Sioux Falls. It is used to examine how ecosystem services change with land use and climate change. It uses fine-scale detailed data to assess a number of ecosystem factors and landscape functions. For instance, it can model the carbon sequestration of the landscape and examine how water levels can impact the provision of ecosystem services. The model has only been applied on a 200 mi^2 area within South Dakota to examine the impacts of a climate scenario on a variety of ecosystem functions from 1990 to 2040.

Linking the EcoServ model with a hydraulic model could be useful and a logical next step for its development. Additional functionality could include in-stream flow needs and the ability to examine the spread of diseases. For instance, it could be used to examine how mosquitoes could spread the West Nile virus as the climate warms. The model does not have an economic functionality to estimate, for instance, the financial benefits of asking someone to store 500 acre-feet of water on their land. The model needs to be flexible enough to provide insights at different scales.

INVEST Modelling: The model was developed by the Natural Capital Project (World Wildlife Fund; The Nature Conservancy; Woods Institute, Stanford University). It is an ArcGIS toolbox enabling the examination of the ecosystem services measured biophysically and monetarily that could be derived from a given landscape (carbon sequestration, drinking water, irrigation water, native pollination, hydropower, commercial timber, flood mitigation, non-timber forest products, recreation and tourism, cultural and aesthetic, biodiversity, real estate). The model provides a high-level biophysical and economic analysis of selected ecosystem services. Building in the economic valuation capability of the INVEST model into the EcoServ Model could be useful. There is currently a proposal submitted by the University of Minnesota to do an INVEST study within the RRB.

CANWET Modelling: The model, which was developed by a research group at the University of Guelph and Penn State, is a lumped, continuous, semi-distributed, standalone GIS-based watershed model (written in VB.net). It simulates watershed hydrology and sediment, particulate and dissolved nutrients, and pathogens transport from sub-catchment levels up to sub-watershed and larger watershed scales. The joint U.S./Canadian-based model was enhanced to a assess a range of watershed characteristics and account for seasonal variations.

The model was designed based on simplified hydrological equations to lower computational time and enhance the ease of use. The database structure allows for simple input/output of parameters and results. Very few calibration efforts are required to use the model. It assesses water quality based on estimations of point and nonpoint sources. The parameters can be adjusted on a monthly basis to account for seasonal variations and nutrient application rates.

The model is unique, as it calculates the costs and benefit of adopting various agricultural best management practices (BMPs), which can provide insights for targeting which catchments to prioritize for their implementation. It uses daily time steps at the catchment level to provide water management insights. The model could be enhanced by increasing the spatial resolution to a grid-cell level, which could then be applied to the RRB as a showcase watershed. The goal would be to provide predictive capabilities and facilitate real-time planning for the adoption of agricultural BMPs.

To summarize, CANWET is a simplified, semi-distributed, database-driven, land-use model that is more user-friendly than SWAT. The PREDIT function provides cost-benefit ratios that are built into the model to assess various management strategies.

Future developments of the CANWET model should include the web-based Decision Making Framework, a grid cell-based model to account for variable source hydrology, allow for event-based and predictive simulations, factor in nutrient trading and climate change. The model could take advantage of "cloud" storage of spatial and observed data.

Redeveloping the model using a "bottom-up approach" would improve the model's ability to link into data from agricultural equipment for improved precision and analysis. This would greatly improve the model's predictive capabilities and would provide valuable insight to agricultural producers (i.e., optimal times for applying inputs to their fields). The model could then provide real-time information allowing land managers to make critical decisions at the right time (an online grid scale, web-based model that could be used to identify where the vulnerable areas and actual levels of impairment are).

We would like to use the RRB as a showcase watershed to illustrate to farmers how their land is contributing to environmental issues. The Tobacco Creek watershed could provide a good case study.

We need models that will allow us to identify an opportunity for change so that we can be more resilient. Tools that allow us to identify key watersheds that require improvements can be helpful. Furthermore, identifying hot spot areas will allow us to examine which BMPs should be applied from a scientific and producer-acceptability standpoint.

CHRM Modelling: The model, which was developed by the University of Saskatchewan, uses hydrological algorithms for cold climates. It requires basin and hydrological response unit (HRU) physical characteristics (i.e., soil and vegetation) and interpolates meteorological data to the HRU using adiabatic relationships and saturation vapour pressure calculations. It has simplified algorithms to factor in transport and sublimation, rainfall and snowfall interception (i.e., forest canopies snow interception).

HSPF Modelling: It was suggested that this would be another model to examine (water quality component is modified from HSCS and SWAT).

4.2.4 Strategic Questions 1 to 3

The following strategic questions were discussed in breakout groups:

1. What are some of the key design elements and or functionalities that you would include to ensure that the DSS is useful and relevant?
2. What existing DSSs and tools currently used in the basin should be built on to develop the proposed DSS?
3. What are the barriers to implementing a basin-wide DSS? Why don't we have a similar system in place already (technological, political, other obstacles)?

The U.S. node discussed the questions as one group while the Canadian node broke into two separate groups. Three independent conversations were reported back to the overall group.

U.S. Breakout Group

There is a need to clearly define what this system is going to do. What will the system be capable of? We still do not have common goals throughout the basin. These would be needed to develop a coherent DSS for the basin. We do not have clarity on desired future conditions that we should strive for. There is not a common, consistent vision for the future and there should be. Nevertheless, the absence of targets is not a reason not to develop a useful and comprehensive DSS.

The DSS needs to build on foundation products across all jurisdictions. A seamless integration of these products with the DSS would be necessary. The development of the DSS could reveal a number of data gaps, which would enable us to deal with them. For instance, ground water and some surface water information is unknown due to limited measurement and monitoring efforts. For instance, mapping and aquifers recharge many springs in the upper parts of the basin. In general, recharge and discharge points are relatively unknown. We also need to think about who will be responsible for the long-term maintenance of the DSS.

This tool could be used to establish parameters for programs like AWEP, examine hydrology, water quality, biodiversity, impacts on aquatic species, and provide economic evaluations. The model will have to include provisions to assess climate change impacts. For example, it should be able to assess how severe drought and flooding conditions could be dealt with. The DSS should be designed to accommodate basin-wide and field-scale analysis. For example, the model could assess how a variety of local actions would affect a watershed.

Canadian Breakout Group 1

Important information gaps need to be filled to adequately model the landscape and develop a DSS that will provide useful and accurate information (LIDAR, culvert inventory, soil phosphorus concentrations and digitized stream network). Some of the data requirements could potentially be filled through academic efforts and by engaging the public. Remote sensing information is useful but extensive ground truthing needs to be done to ensure that it is of good quality. The data will also have to be harmonized between Canada and the United States. Groundwater is another major data gap. Although the mapping of aquifers is pretty well done, groundwater recharge and discharge needs more work. Climate change exploration is also needed.

Along with additional data, watershed processes also need to be better understood. We do not understand dissolved nutrient load dynamics very well and it is imperative that we understand this. Are small dams having a nutrient reduction impact? The transport of nutrients through sedimentation is fairly well understood but in-depth knowledge on the transport of dissolved nutrients is lacking. The lowlands of the RRB are big producers of nutrients (both in solid and dissolved forms). With respect to the delivery of the nutrients, there is a distinction between the Red River and its tributaries that needs to be better understood.

We need to push for more research to fill these gaps in our knowledge related to water quality. A structured plan to look at the questions, perhaps by examining comparative watersheds, would enable us to look at two issues simultaneously. Although we have been monitoring water quality, the research and data needs to be worked on with the dissolved nutrient question in mind, while co-benefits are systematically examined.

Phosphorus concentrations in Lake Winnipeg are lower during periods of drought and increase substantially during floods (as evidenced by the flood of 1997). Although agriculture contributes nutrient to the lake, high flow levels also drive nutrient concentrations. There is a need to determine what percentages of nutrients originate from sedimentation. We may or may not be increasing nutrient concentrations from ponding on the land. We do not have models to examine these processes adequately.

There is also a need for model harmonization, although it will be difficult to pick a model that is suitable for Canada and the United States. Selecting one model may make sense for investigating certain parameters and issues (i.e., flooding). There needs to be a stronger inter-agency collaboration, which has not been happening as much as it should—hence the ongoing need for more data and model harmonization.

Funding and liability are key barriers to developing and implementing the DSS. Acquiring funding for international projects seems to be difficult, although there are ongoing funded international initiatives. Liability is a very important issue, as designers may become liable when a product is shared with the public. Engineers only have licenses to operate in certain regions (province/state).

In general terms, the DSS will have to be flexible and have a life of its own so that it can remain relevant and useful over time, as it can become outdated quickly. An ongoing maintenance plan will have to be in place to ensure that the information and system continue to be updated frequently. The ecological infrastructure investments project needs to think long term with respect to this initiative.

In terms of functionality, the DSS should provide support for a number of the primordial issues in the basin (flooding, drought, water quality, climate change impacts and changing policies). For instance, the DSS should allow for exploring various climate scenarios, such as increased summer rainfall and less snowfall, and how these could impact flooding in the basin. Additionally, the flood forecasting functionality should build on the RRBDIN and must have a provision for flood-induced landscape modifications. Drought needs to be considered as well so that coping strategies can be explored. It should also have the ability to examine the water-quality impacts of various levels of manure production from livestock operations (hog and cattle feedlot) and how certain manure management policies could improve or worsen water quality. The DSS should have an ecosystem services functionality similar to the EcoServ and INVEST models, although selecting the services may be challenging.

The DSS should be easy for various stakeholders to use (farmers, policy-makers, watershed planners, etc.). It should be designed in such a way that it can build trust between producers and watershed managers. It should be an information-sharing platform where everyone can input data into the system and generate information for their decision-making. The ecological infrastructure investments project needs to have a two-way flow so that users can help improve its design and keep the system relevant, as well as have provisions to undertake the analysis at the watershed as well as the jurisdictional (county, municipality, etc.) scales. For this analysis to be useful, the data must be available at an appropriate level of resolution.

Canadian Breakout Group 2

The tools that we have now were built in the 1970s and 1980s. We need our current decisions to be broadly compatible with future needs and technological developments. Current knowledge and data gaps push us to work at the policy level and make it tough to adopt a bottom-up process.

The DSS could help affect positive change, as policies are not always successful in initiating change. To affect change, it will need to link various scales and help policy-makers understand hydrological responses. We will need the support from the top levels of government to prioritize this initiative so that they will encourage us to go out and design it.

There is a lack of data (i.e., LIDAR elevation data in Manitoba) and a lack of harmonization among existing datasets (watershed boundaries, soils, land cover, land use) that could limit interoperability. Can we assemble a seamless dataset of the entire basin, as Canada does not have the same datasets as the United States? This question should be posed at the International Joint Commission (IJC) meeting next week. In addition, protocols and methodological standards vary from organization to organization. There is a need to design a shared data portal for the basin.

The SWAT model has been around for a long time and is pretty accurate, although the snow process component needs work. The model has also been applied to some parts of Manitoba, although calibrating it has been difficult. Accuracy and calibration are issues that need to be considered. The CanWET approach could be useful with the inclusion of a bottom-up approach that would involve agricultural producers. The model would include both economic and ecosystem levels, which are absent from other models. EcoServe is an interesting, multifaceted model requiring more work.

The design of the DSS will have to build on existing models and consider which ones will work best for a given region. It will have to take into account jurisdictional constrictions (traditional and institutional restrictions, international, all government levels, CDs, private, academic, etc.). The system should be relevant at multiple scales (basin wide, watershed as well as intricate levels).

Many projects are well designed and implemented but fall apart because they are not supported at the information and technology levels. This can be a resource or cultural problem, as some information and technology departments have the attitude of "your systems are not built to our specifications so we will not support."

The DSS will have to take into account water quality and quantity (specifically this would include sediment erosion, dissolved nutrients and freeze thaw cycles). Downstream flow requirements and upstream retention for aquatic flow (in-stream needs) will have to be included for the Red River and its tributaries. Water temperature and how it is influenced by industrial operations needs to be considered. Both the urban and rural contexts will need to be included in the design. Functionality for assessing and managing ecosystem services is important. Most of the ecosystems within the basin have been highly modified and ecological services generally get left out.

The models built into the DSS will have to be well calibrated with as much information as possible. Many of the current models on which we base decisions do not include important information such as evapotranspiration, etc. A nutrient footprint calculator providing the economic value of those nutrients should be included. The DSS should have a high-resolution topographic feature tool to determine which areas are contributing and which are not contributing to the nutrient loads (i.e., small dams and diversions).

The DSS should be built to support the implementation of CD IWM plans and empower CD managers. The DSS will need to have the capability to provide guidance for funding conservation programs that have the biggest bang for the buck. It will need to provide the user with the ability to track and monitor a program so that it can be assessed (i.e., are you having the effect you want?).

4.2.5 *Potential DSS Architecture*

A potential DSS Architecture was presented by IISD. The Canadian and U.S. nodes then discussed the architecture presented separately and reported their conversations back to the rest of the group. The presentation is summarized, followed by the overall feedback provided by the group on the architecture.

IISD Presentation

The cluster of issues in the RRB deserves a first-class computational approach that takes advantage of new environmental software developments. IISD responded to this challenge by proposing a flexible DSS that builds upon the ecological infrastructure investments project and Environment Canada's Lake Winnipeg Basin Portal to the Lake Winnipeg Basin Stewardship Fund. IISD designed a general framework for the DSS with two goals in mind: to move into the next era of modelling at the basin level and to be to be agnostic about particular models.

The DSS would provide functionality to optimize the benefits you can receive from the landscape. We need to develop a comprehensive ecosystem management model to move into the twenty-first century. For example, adding an economic valuation element to the EcoServe model would provide important natural resources management insights.

The DSS architecture relies on the Open MI concept, which is a programming protocol that allows data to be separated from models and data to move between models. This allows for transferability between datasets and models. CANWET separated its database structure from its modelling engine. Models should be separated from the source data. Instead of getting data locally, it should come from an Internet source.

The logic for using Open MI is that a number of different models used across the basin are firmly entrenched in certain organizations or regions. The DSS needs to be compatible with all models used in the region. Trying to compel developers to write to that translator may not be easy. If we are to conform to Open MI, it will be easier over the long term. Some conformance work is being done already but there is still a long way to go. Within AAFC, applications are being built to be compatible agency-wide instead of locally run. Environment Canada is starting to work with Open MI (Dr. David Swain is a proponent).

Group Feedback

There are underlying data issues that are being worked on that could be an important foundation on which to build (CDN/US Group on Earth Observations – Test Beds: Great Lakes Management, North American Drought Monitoring, Rocky Mountains, Red River Basin; International Joint Commission). Although the RRB is seen as a priority transboundary region, the Great Lakes region has been prioritized thus far. AAFC has raster datasets depicting soil carbon, pH, and so forth at a pretty coarse resolution for the basin. The IJC is currently working on harmonizing streams and watershed boundaries across the border. Federal agencies need to make more of an effort to pass the information onto the states and provinces.

If an organization has a slow network, this whole idea falls apart. Many have the data locally because it is a slow process to retrieve it from a server. However, it is not always the performance of the internet connection that counts but how the information is archived. Cloud computing may help by providing more networking power and flexibility, as it allows you to use band width when you need it. The data should be housed in one location with one entity that would be responsible for it. Environment Canada's Lake Winnipeg Basin Data Portal will be web based.

Architecture matters because it can make work a lot easier. Collaboration and data management are critical for success. If you get it right, it opens a lot of potential. Enterprise GIS being used within AAFC across Canada facilitates the establishment of integrated teams. Nevertheless, data management can be a nightmare. There are still data silos across the country and bilingualism in Canada needs to be considered. This brings us back to more foundational work, which needs to be done really well to ensure the next levels will be successful.

We could pilot the ecological infrastructure investment project in a representative watershed so it can be replicated. Large-scale benefits are achievable with the right tools. Environment Canada (EC) seems willing to move forward at the small watershed scale.

EC has a funding program to reduce nutrient loads into Lake Winnipeg—the Lake Winnipeg Stewardship Fund. In terms of allocating their funds, they have no way to measure which programs will work. A prioritization tool, which has not yet been developed, could help them. Without strong regional interest, EC will take their time to develop management tools. They are interested in management tools and recognize that they need some support there, but they were not ready to support the large project that this group proposed. They are currently using SWAT, which is not perfect. We should start looking at other models and build on what they have proposed.

From a provincial perspective, resources are limited and a tool that would allow governments to identify where we can get the biggest bang for our buck would be very useful. In the past, funding has not been an allocated based on priority, but rather who applies first. This cannot happen anymore.

A data conversion tool will be absolutely necessary to use different models. Basic datasets are required, and we should not reinvent hydrologic models and datasets that have already been done.

The International Red River Board (IRRB) is looking at various models to standardize their model use. Their work could help with selecting the right tools at the right scale for the job. We must start experimenting with some of these models on a pilot scale. Perhaps we could pick a watershed and use three different models to compare their performances. This exercise could start by checking with the IRRB to find out what they are working on. We should also check with the University of Minnesota, United State Geological Survey and Earth Resources Observation System.

We must determine: who is our audience, who will fund the development of the DSS and who will own it once it has been completed? If it is useful for water managers and they value it, there should be a way to fund it. The IRRB would be committed to helping this move forward if it is useful to water managers. The product should also be relevant for CDs in Manitoba. Supporting institutions would help secure the required funding.

The ecological infrastructure investment project could get a letter out to political leaders. The content should consist of a two-page fact sheet explaining the advantages and disadvantages of the proposed project. Someone should compose a first draft and the group can move forward from there.

Allowing models to access datasets can be an onerous task. There are a number of ways to link multiple disparate systems. We created a language bus called "middleware," which allows each system to talk to each other or connect to databases. It is a translation module that allows you to be on the language bus.

What happens if one of the base products or datasets gets updated? What if one model, such as SWAT, changes? From a funding standpoint, how much work will be required to deal with these changes? There are no objections to the ecological infrastructure investments concept but no one is clear on the technical level needed to create the DSS proposed. We ball parked the overall effort at C$650,000. The basin and sub-watersheds would not have the same detail.

Will the DSS be a repository for data or a clearing house source to know where to get the data? Will it be just a translation bus? What about provisions for converting metric to imperial units? There is a problem with the base data layers that are not the same between the two states and province. How will we standardize everything? How do we harmonize the data before we attempt a modelling exercise? This was sparked by Environment Canada's effort to build a data warehouse. Let's think about extending this across the border with a model that will not be too onerous to operate. We could also try smaller pilots to see what is working for users.

4.2.6 Strategic Question 4

To move forward with the development of a DSS, the following question was asked to the group: What is the process that you would follow to develop the proposed DSS? The question was sent to the group prior to the workshop so they could present their pre-conceived reflections. The question was discussed as an overall group to save time.

A number of key questions need to be answered: What will be the process for developing the DSS? Who is going to use the DSS? We will need to identify users and their needs. What are the existing tools or tools that need to be developed to meet those needs? What will we need to standardize datasets? How difficult will it be to standardize the input data? What are the data gaps and needs? We need to improve our understanding of processes by filling research gaps (i.e., dissolved versus suspended nutrients). Processes for modelling are still not clearly understood.

These data discussions will help to look at the system as a whole. There are some successes associated with an enterprise deployment of a DSS. We can do this. The DSS needs to serve the needs of many users. We cannot address all users, but we should determine three to five groups of users. We want to develop the right tools at the right time for given users.

Manitoba CDs are making changes on the ground. We want them to be able to use the tool and understand it. We may want to bring them in early so they will buy into it. There is also generally a high turnover in CD offices, which means this must be a simple tool.

Ultimately, every model will need to be calibrated—keeping it simple means not just a little calibration but no calibration (building a model that can be used universally). We want to target conservation as a prioritization ethic. SWAT and CANWET are the same: they cannot tell you what the output might be at that stream level. Simple tools need to be looked into; not all projects need to have significant models.

The premise is that different users with different models and knowledge can work together. We need to cooperate at a meta-level. We need to stand on the shoulders of the projects that came before us.

We need to start experimenting with some of these models on a pilot scale to better understand processes on the landscape and understand how these tools handle each point. It is necessary to examine export coefficients. Some watersheds will be more important than others when looking at nutrient loading. For instance, the Saskatchewan River Basin does not contribute a lot of nutrients to Lake Winnipeg because there is a series of reservoirs leading up to the lake. Many models do not have the correct routing necessary to account for that kind of environment.

Aquatic flow needs can be estimated using an in-stream incremental flow methodology. This method figures out what stream flows are needed for a variety of different species and life stages. Are there models that look at minimum flows to protect the aquatic life?

Who will own the DSS once it is ready to go? Should the DSS be free and open to the public domain? If the DSS will sit on a web portal, where would it sit and who would maintain it? If we want governments to use it, do they have to own it? What are the institutional norms or precedents? These are very important questions that we have not yet answered.

Many agencies are still going to use their own models and not recognize the data generated by the DSS. Then what is the point? Typically if AAFC does not build it, it does not get on our system. There is a catalytic role non-governmental organizations (NGO) can have until the DSS is ready for prime time, and this is a role that IISD could play. The DSS would be online, accessible and free of charge. The NGO would maintain the system temporarily.

How would a farmer use this tool? It could show farmers where on the land they are losing nutrients and which areas are contributing to soil erosion. The technology can be inside the farmer's equipment. Farmers could then claim that they are producing in the most environmentally friendly way to market their products. There is also a strong economic motivation behind this as well.

Disseminating the DSS within the farming community could be achieved through individual farmers or farming associations. Connections to the farming community are necessary to be successful in the RRB. The model will work well at the agricultural producer level. There will always be different users with different goals. Scaling up is absolutely essential. Precision agriculture and conservation are two of the goals of the ecological infrastructure investments project.

We have no specific goals, except for 20 per cent flood reduction, which is a good starting point for long-term basin management planning. In 2004 the IJC made a commitment to reduce nutrient loading across the border by 10 per cent, but there is no plan to achieve this. The RRBC should develop such a plan.

People are interested, but this is new stuff. We are still working on getting beyond our silo issues. We still are working on understanding the Lake Winnipeg nutrient loading dynamics. People get things done when there is a crisis such as flooding. Lake Winnipeg issues are not that well known yet. Until this disconnect is fixed, it will be a hard fight. More education is needed.

There is recognition that integrated data and analysis is important. How can we send this message to policy makers/funders? There is a basic concept that this is important and, if done well, speaks to our common interests across the border. There is value in communicating this message now in the early phases of the project: "this is what the tech guys are working on and the stakeholders are asking for."

Ideas for Moving Forward

There are many first steps to take, but we do not want the various steps to separate into different initiatives and lose track of the greater project. We need to: identify compatible initiatives; check with the IRRB to identify what they are working on and check with the University of Minnesota to see if they are going ahead with their RRB INVEST modelling work; and identify other initiatives that may provide us with leverage to generate resources by working with other people in the basin. The following steps were also proposed in the discussion:

- We are interested in INVEST but not certain whether we could use it, as it may not have enough detail. The idea is to include the qualitative aspect of the landscape and how that impacts the services the landscape can offer. Adding this qualitative functionality to the model would enhance what INVEST has.

- An EcoServe-type of analysis of the ecosystem services in the RRB should be implemented. A good case study that actually generates monetary values would be beneficial. For example, comparing the current versus pre-settlement ecosystem service values can provide important insights and motivation for this work.

- Pick three models and see how they perform in one watershed. Pilot an application and evaluate strengths, weaknesses, discover more gaps and then start working on developing the larger DSS.

- The RRBC-AWEP efforts are primarily concerned with implementing programs on the ground but they would be interested in and benefit from tools that could help them prioritize where the money would best be spent. The DSS could also be used to examine the potential for the waffle water storage approach.

- Designing the platform is one work component but there also is the whole research side of it. This work could lead to research on dissolved nutrients and adopting more effective agricultural beneficial management practices, which could also be a platform for other research.

- If the DSS is a product that water managers use and is valuable to them, there is no reason why it will not continue to be funded. For instance, the Red River Board is committed to maintaining the RRBDIN. We should ensure that CDs will use the DSS by involving them in the design. Is there a possibility to receive funding from them?

- RRBDIN users will be approached to see what is and is not working. We will then be able to revisit the whole structure.

- The development of the DSS should be guided by a stakeholder, governance and technical advisory group. We should include the GEO group in the discussions as they will provide useful information for the project.

- The ecological infrastructure investments project should have two components: a technical component and an educational component that the public can digest and relate to (and that explains what this project is going to do for them).

- A way forward for the ecological infrastructure investments project would be to answer the following question: "What are the consequences of continuing to do business like we did in the past?" The answer is a hodgepodge of issues: continued flooding, research silos and poor coordination. The answer should include equal emphasis on the positive and negative aspects of business as usual.

- We should generate a letter from the agencies around the table indicating that there is a lot of support for this project. The letter would state that the initiative is being worked on and that there is a desire to engage them at their convenience. The project ties in with the RRBDIN, which has already received lots of support. We should compose a 2-page letter to policy-makers with a list of negative and positive aspects to the project and a real, direct application. It should speak to the strategic key priorities of the provincial, state and federal governments. The letter has to include all audiences. Policy-makers and funders will be more willing if they see that the project will benefit multiple users. Funding for this initiative needs to come from the national level on both sides of the border.

4.2.7 *Conclusion*

The notes gathered during the workshop will be compiled and shared with the participants to collect additional comments and missed insights. A letter will be drafted for politicians and government agencies stating our commitment to this initiative. Feedback will be solicited from the participants before they are asked to sign the letter.

4.3 Insights Gained

We need a common vision and a long-term management plan for the RRB so that we can work toward shared goals and garner a high-level political commitment for proactive decision-making, instead of being reactionary. The DSS will be built with this common vision and plan in mind. Its development will have to overcome critical differences such as measurement systems and IT cultural differences within each agency. These cultural differences will have to be considered during outreach activities for the deployment of the DSS. Ultimately the DSS will aim to facilitate integrative modelling in the basin for integrated natural resource management as described in Goal 2 of the RRBC's Natural Resources Management Framework Plan.

The system will have to be compatible with and build upon existing models and DSSs being used in the basin, such as the RRBDIN. The DSS will also have to support models (including the water management models being evaluated by the IRRB) being used in multiple places. Therefore, an intermediate step or middleware (Open Cable Application Platform principles) may be necessary to allow various models using different languages and approaches to use the available datasets and provide insights. Open MI provides the capacity to facilitate inter-model compatibility, which could be very useful for the DSS. Models would have to become Open MI-compliant and there would be a learning curve associated with that. A long-term maintenance and effective plan will have to be developed to ensure that the DSS remains functional and useful over the long term.

Knowledge gaps will have to be filled. Despite being an important large international basin, basic harmonized data sets do not yet exist. Harmonized layers for hydrographic modeling, such as soils, high resolution elevation data and other fundamental cadastral layers, do not currently exist. Along with data gaps, there are also process gaps in our understanding of hydrological processes. For instance, nutrient-water interactions are still not well understood. Impounded water on the land can lead to increased dissolved nutrients. Information on interactions between aquifers and surface water is also lacking. Along with harmonizing existing data sets and efforts to harmonize current and future data collection, efforts would be very useful for future expansions of the DSS and the development of additional tools. Standardization protocols for data inputs into the DSS will be very useful. Perhaps a feasibility study to assess what is required to get data uniformity would be useful.

Nevertheless, there are good examples of transboundary data collection efforts. The Group on Earth Observations (GEO) has assembled soil moisture and agricultural land cover harmonized datasets for the RRB. There are also ongoing transboundary remote sensing initiatives in the Rocky Mountains, RRB, and the Great Lakes. The USGS, USDA, Environment Canada, AAFC as well as the IJC have been involved in developing harmonized datasets for hydrological networks, surface water supply indices and datum systems.

The DSS will have to have a wide range of functionalities so that it can be useful for a variety of stakeholders within the basin. Our ability to assess climate change impacts will be very important in light of the fact that the area has experienced 70- to 80-year droughts. Therefore, a drought forecasting tool needs to be implemented as part of the DSS. Groundwater assessment capabilities and in-stream ecological requirements will also be desirable.

If the DSS is to be an online tool, the speed at which it operates will be a key consideration to its design. The architecture will have to take advantage of new network capacities such as cloud computing. For instance, the implementation of common decision-making platforms have yielded significant improvements in data-sharing and decision-making capacities. A good example is the City of Calgary and U.S. Marine Corp.'s adoption of ESRI's enterprise GIS product.

Determining the audience for the DSS is a key consideration as this will greatly influence how the DSS should be developed and designed. For instance, if the DSS is to be useful for CDs in Manitoba they need to easily understand and use the tools. They would also need to be involved in its design to ensure that it is relevant for their needs. If the DSS is meant to support producers, providing them with the right information at the right times of the year will be important to support precision agriculture and conservation. Ensuring that the DSS provides insights into better managing our water supplies will also be desirable. Flood reduction is an important concern that is shared on both sides of the border. Ultimately, identifying who and what (providing the right tools to address the problems) the DSS is for will be crucial to its design.

Ensuring that the DSS is educational is important. The DSS should be available to a variety of stakeholders so they can access data collected and lessons learned. The DSS should provide unbiased information and the processes and methodologies used to derive the results should be transparent. The DSS must provide results visually in the form of maps and provide various functionalities for exploration through the adoption of various tools. The DSS should also provide mechanisms for users to provide feedback on what they would like to see. There may be issues surrounding intellectual property rights that may need to be addressed.

One way to approach the design of the DSS would be to perhaps use SPARROW to identify which locations across the basin would be suitable and desirable to carry out a pilot. Once the locations have been identified, models could be applied within them and an overarching DSSs could be developed, which would be tweaked so they can remain relevant for the rest of the basin. The applied models could then be assessed in terms of their performance, compared and rated against each other. The design should also build on ongoing initiatives such as the IRRB model evaluation effort, the University of Minnesota INVEST potential modelling work, the USGS EcoServ model development initiative and the work being done by the GEO. Establishing a stakeholder advisory group, technical group and governance group to provide guidance for the design team would be beneficial.

The development of the DSS could also be justified based on the need to better invest limited government financial resources into various development, environmental and agricultural programming initiatives. For instance, the DSS could potentially demonstrate how it would target resources for the AWEP more effectively. Investing money so that future funding could be better spent would be worthwhile. A short-term goal for the DSS could be to provide support for the strategic management of government programs. A long-term goal could include supporting various institutions moving forward with integrated natural resource management efforts.

We need a marketing piece that is easy to understand that could be communicated to the general public and decision-makers. The outreach piece would be a two-page fact sheet that communicates what is required to enhance the management of natural resources and what are the consequences of maintaining business as usual (advantages and disadvantages of not doing anything). It would also provide concrete examples of the benefits that could be achieved through the development and implementation of a comprehensive and flexible DSS. The fact sheet could be tailored to fit within the strategic directions of the departments being targeted. Ultimately, if the DSS is useful for the various user groups, the funding required to develop and maintain the system should be easy to access.

It was determined that a memorandum of understanding expressing a commitment from the technical community to work together for the development of the proposed DSS would be an effective means to communicate to government representatives and politicians that this initiative is important and worthwhile.

5.0 Case Study Selection

The goal of the case study selection process was to select three case study sites to aid in the development of a decision support system that could be used to facilitate ecological investments in the RRB. The case studies were selected based on the following criteria:

- Biophysical characteristics: A good understanding of the biophysical characteristics of the landscape and its hydrology is required to identify where natural environments could be restored and maintained to provide important services and benefits to local populations.
- Infrastructure requirements: The location and condition of human-built environments can assist with identifying opportunities for ecological investments.
- Socioeconomic benefits: Demographic and economic information could provide insights into the suitability of ecological infrastructure investments within a particular context.

The initial goal of the case study selection exercise was to choose suitable case studies to pilot the DSS within a Canadian, American and transboundary watershed. It was later decided to select a Canadian and American watershed as well as a federal program that could benefit from the program prioritization benefits of a comprehensive DSS.

The case study selection process provided the project team with an opportunity to become familiar with the diverse types of programs and projects that are being planned and implemented in the RRB. The following three case studies were selected by consulting stakeholders and conducting site visits:

1. The Seine-Rat River Conservation District's (SRRCD) water management program for the La Coulee sub-watershed of the Seine River
2. The Roseau River Watershed District's Palmville Project
3. The Agricultural Water Enhancement Program (AWEP) – RRB Funding Proposal

Detailed descriptions of the case studies are provided in the following subsections.

5.1 The La Coulee sub-watershed Project[127]

The SRRCD[128] in Manitoba expressed interest in partnering in a case study for the project. The SRRCD organized a site visit of its completed, existing and future projects to help identify potential case study opportunities. The SRRCD manager invited IISD to participate in the development of a water retention project through the restoration of the Giroux Bog.

5.1.1 *Project Description*

The project's overall objective is to develop and implement a water management program involving 46 sections of land (approximately 18 being Crown land) in the southeastern area of the RM of Saint Anne in Manitoba. The project will include rehabilitating natural retention areas that will collect and store water during spring freshet and after major precipitation events, allowing the water to be released at a slower rate and over a longer period of time, effectively lowering the peak flow of water going into the Seine River system.

[127] Information for this project was retrieved from the Seine-Rat River Conservation District, (2010). Lake Winnipeg Basin Stewardship Fund Proposal – Water management program for the La Coulee sub-watershed of the Seine River. Winnipeg.

[128] Established in partnership with RMs and the Province of Manitoba Conservation Districts Program in January of 2002, the SRRCD was formed to provide local people with an entity to set resource management priorities, develop and deliver land and water management programs and assist partners with addressing local issues of sustainably.

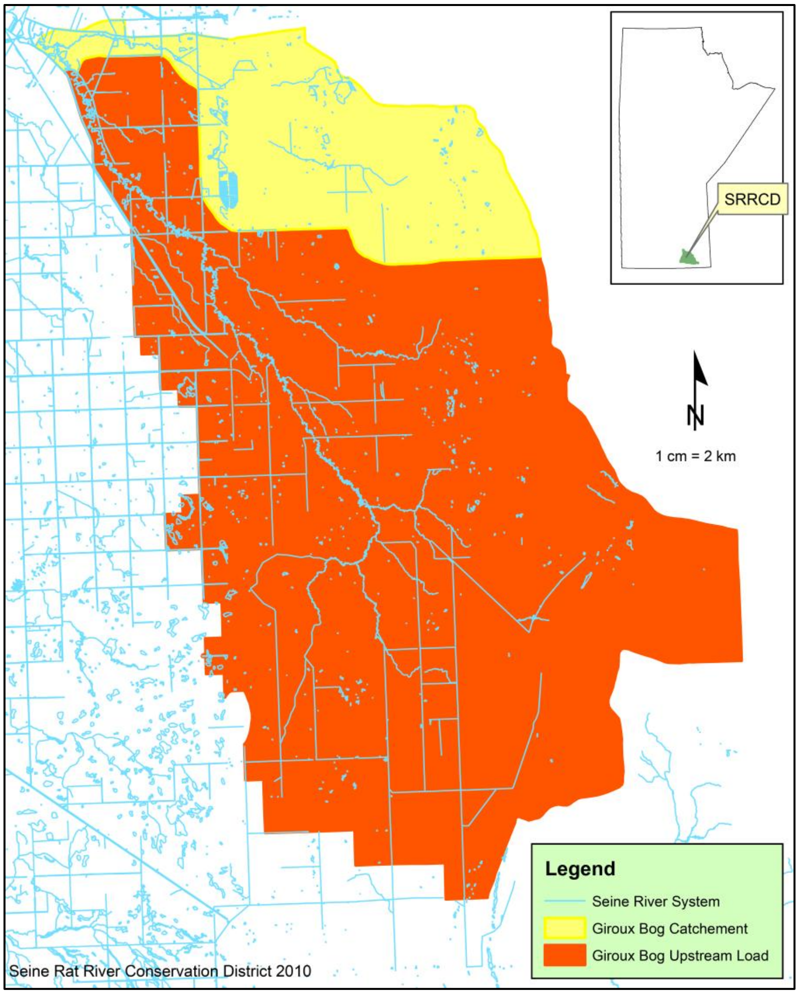

Figure 3 –Map of the Giroux Bog Project Area.

Specifically, this project will reduce nutrient inputs from rural/agricultural sources by rehabilitating the Giroux Bog that support aquatic habitats as well as reduce and sequester nutrients. Retaining water in the bog will also allow for decreased suspended sediment loading and a decrease in nonpoint pollution sources and increased bank stability through flow reduction. The project will also control water movement from retention areas to the natural tributaries of the Seine River, allowing the retention sites to be used as reservoirs while preventing downstream flooding during critical periods.

The project is expected to last three years, consisting first of a topographical survey to identify suitable and sizeable water retention locations, and second, to acquire and install the necessary control structures on the retention sites and ensure that they are compatible with existing rural infrastructure. A passive system for retaining water would be most desirable. Gated culverts with constructed earthen berms would control water at a desired level, and would allow excess water to flow over a rock spillway in a controlled fashion. Gates would be equipped with locking mechanisms, and flow meters could be installed along with pumping equipment if needed. Necessary soil movements such as berms, wall reinforcement or enhancement, etc., will be installed. Water quality will be monitored at inlet and outlet sites to measure pre- and post-project nutrient loads. This would be in addition to the comprehensive water quality testing that the SRRCD currently conducts on the Seine and Rat Rivers, and on the Joubert Creek.

The knowledge generated through this project will improve information and resources available for water-related decision-making. The multifaceted nature of this project is an example of using knowledge, innovation and technology to address a problem in a sustainable manner. This initiative will be a model for communities within the Lake Winnipeg Basin to follow so that ecological infrastructure investments can become more common.

5.1.2 *Selection Criteria*

Biophysical – The Seine Rat Conservation District has a high concentration of livestock operations, making the area susceptible to water quality issues. In addition, the Giroux Bog is located in a flood-prone, low-lying area within the RM of Saint Anne that has been drained for agricultural production and peat extraction operations. Biophysically, it is ideally located, as water can be easily directed to it. In addition, a good portion of the adjoining areas to the bog are designated as crown land.

In using the bog area to retain water runoff from surrounding agricultural fields, water velocity is reduced and nutrients can be filtered/settled out rather than continue downstream to Lake Winnipeg, which is being eutrophied. In addition, slowing the water flowing in the drainage area can achieve a reduction in water and soil erosion as well as help with groundwater recharge. This project would effectively aid in the establishment/rehabilitation of a major wetland area, which would improve habitat quality for aquatic life (fish, waterfowl, benthic invertebrates), and increase biodiversity and ecosystem services.

Infrastructure – In terms of infrastructure, the project could primarily alleviate potential infrastructure needs for flood prevention and stream bank erosion downstream. There are no clear infrastructure investments planned to address flooding in the area.

Socioeconomic – The expected socioeconomic benefits are the mitigation of excess water on arable land to allow landowners and other stakeholders to pursue normal agricultural activities in this potentially productive area. The project is also intended to improve the surface water quality in the Seine River Watershed and in the region by slowing runoff in the area.

The project is also expected to create jobs and sources of revenue through the management and harvesting of wetland plants. Research by the University of Manitoba and IISD in Netley-Libau Marsh has found that cattails produce an average 15,000 kg of dry biomass per hectare, and absorbed 20 to 40 kg of phosphorous per hectare during a single growing season, which can be permanently removed via plant harvesting. The collected biomass provides valuable feedstock for bio-energy production. It can be readily densified for use in a variety of biomass burners.

5.2 The Palmville Project

The Roseau River Watershed District (RRWD)[129] has considerable flooding issues. The district is working towards long-term solutions for reducing flood damage while protecting and enhancing natural resources. Flood damage reduction and natural resource enhancement projects aim to balance economic, environmental and social considerations.

5.2.1 Project Description

Since settlement of the area, drainage programs have removed nearly 56 per cent of the wetlands of Roseau County. The purpose of the Palmville Project[130] is to provide local and regional flood control, as well as the environmental benefit of the wetland restoration. The Palmville Fen is a major wetland area covering approximately 3,000 acres located in the upper watershed of the South Fork of the Roseau River, primarily on land owned and managed by the Minnesota Department of Natural Resources. The fen has been degraded by the construction of judicial and county ditch systems over the last one hundred years.

Almost all of the incoming water from the 85.5 km^2 (33 mi^2) drainage area currently enters the existing channel of the Judicial Ditch 63 (JD 63), where it flows to the South Fork of the Roseau River. The existing conditions allow minimal amounts of 1-year to 10-year runoff events out of the channel banks as surface flow into the surrounding fen. The placement of two proposed stoplog control structures will allow flow to continue down the main channel, maintaining the ditches' existing capacity for all future flood events. Other work to be carried out with this project includes access improvements, ditch cleaning and beaver dam removal. Monitoring the project's benefits will be based on vegetative inventories, surface water flow, ground water and water quality measurements.

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[129] The RRWD was established on June 17, 1963 in the State of Minnesota. The Roseau River Watershed district is a local, special-purpose unit of government that works to solve and prevent water-related problems.
[130] Information for this project retrieved from Dalager, 2007.

5.1.2 *Selection Criteria*

Biophysical – The local area and areas downstream are affected by repetitive flooding on a consistent basis, due to the fact that much of the RRWD is located in the flat ancestral bed of Lake Agassiz, averaging 3 to 5 feet of vertical drop in elevation per mile.

The project is well suited as a case study due to the natural flood-prone topography and the natural habitat loss of the area. The boundaries of the district follow those of the natural watershed and consist of land in which all water flows to one outlet. Fens[131] are among the wetlands that have been removed or degraded in the district. Fens, like bogs, provide important benefits in a watershed, including preventing or reducing the risk of floods, improving water quality, and providing habitat for unique plant and animal communities.

Fen restoration would be accomplished by maintaining a greater depth and duration of surface and subsurface flow to spill from the main channel and seep into the adjacent fen. Restoration of the Palmville Fen will have benefits for the wildlife in the watershed.

Infrastructure – The project alleviates the important need for flood control structures such as ring dikes[132] downstream, particularly for the cities of Roseau and Wannaska. The project is also compatible with a number of planned and existing flood mitigation projects such as the West Interceptor Project, Hay/Creek Norland Project and the Malung Impoundment, which are land-water impoundment projects.[133]

Socioeconomic – Flood control benefits would be provided to immediate areas downstream, the City of Roseau, and the City of Wannaska. Restoration of the fen will also improve water quality for the region and enhance recreational opportunities. The restoration will conserve, manage and restore diversity and viability of native fish and wildlife and open a new area to bird and wildlife viewing.

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131 A fen is a peat-forming wetland that receives nutrients from sources other than precipitation, such as from upslope sources through drainage from surrounding mineral soils and from groundwater movement.

132 The district is involved with a cost-share ring dike program (87.5 per cent district and 12.5 per cent landowners) to help qualifying landowners construct an earthen levee dike around their homestead that will provide up to 100-year protection. The district has participated in over ten ring dikes so far.

133 The West Interceptor project was completed in 2007 to reduce flood damage to the City of Roseau by re-routing waters that currently flow overland into the city. The project has eliminated flood problems in the city west of the Roseau River, while simultaneously restoring wetlands four miles northwest of the city of Roseau and establishing 170 acres of permanent grassland over its entire length. The Hay Creek/Norland project will provide flood damage reduction with respect to flows from the Hay Creek and Norland drainage areas to help reduce flood flows on the Roseau River, affecting the City of Roseau and areas downstream. The project would consist of setback levees along Hay Creek and an impoundment area that would hold 9,000 acre-feet of gated and ungated storage.
The proposed Malung Impoundment will be upstream of the City of Roseau to provide immediate relief by holding approximately 3,000 to 4,000 acre feet of storage.

The project will also enhance outdoor recreation by restoring the area back to a natural landscape with opportunities to paddle and hike.

5.3 The Agricultural Water Enhancement Program

The Agricultural Water Enhancement Program[134] (AWEP) is a voluntary conservation initiative in the United States that provides financial and technical assistance to agricultural producers to implement agricultural water enhancement activities on agricultural land for the purposes of conserving surface and groundwater and improving water quality. As part of the Environmental Quality Incentives Program (EQIP),[135] AWEP operates through program contracts with producers to plan and implement conservation practices in project areas established through partnership agreements.

Under AWEP, the Natural Resources Conservation Service (NRCS) enters into partnership agreements with eligible entities and organizations that want to promote groundwater and surface water conservation or improve water quality on agricultural lands. After the NRCS has announced approved AWEP project areas, eligible agricultural producers may submit a program application.

In 2010, the RRBC received US$2,615,352 in funding to engage in complementary and compatible land and water activities within the RRB (see Appendix D for a breakdown of expenditures by jurisdictions and projects). They have taken the lead to prepare the partnership proposal and will continue to be involved once funded as the Basin Working Group (BWG) lead in outreach and project coordination.

The projects will be continually monitored by activities currently underway that have established base numbers in many areas. By using the current monitoring efforts, all impaired stream improvements will be evident. Monitoring of activities in various areas of the basin based on strategy sign-ups will be relayed quarterly to and through the BWG. RRBC will track this information and use it in the final report.

5.3.1 Proposed Enhancement Activities

The USDA, in partnership with local and state partner organizations, have begun implementing a five-year project in the RRB, beginning in the spring of 2009, as soon as funding is available. The first year of the project will begin in the southern portion of the RRB. Future years will gradually expand to the remainder of the basin in Minnesota, North Dakota and South Dakota.

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[134] Information for this project was retrieved from Yohe, 2009.
[135] http://www.nrcs.usda.gov/programs/eqip/index.html

The entire project will target the following strategies: 1) Sugar Beet Cover Crop Strategy, 2) Beach Ridge Erosion Reduction Strategy, 3) Restricted Flow Sediment Pool Strategy, 4) Water Flow Retardation Strategy, 5) Stream Bank Erosion Reduction Strategy, and 6) Other Activities Strategy.

These strategies will be implemented in the RRB through existing structures and organizations at the landowner level. These strategies will provide benefits to the local landowner as well as larger watershed benefits. Because of this, multiple producer projects will be considered in all appropriate strategies.

1. Sugar Beet Cover Crop Strategy

The Sugar Beet Cover Crop Strategy will pay producers to plant cover crops to protect sugar beet and other appropriate row-crop land in the spring from wind erosion. This strategy is critical, as this erosion can destroy seeds and newly growing plants, which increases costs and reduces profits, but it also adds soil to drainage and waterway systems at the time of spring runoff and spring rains, thereby having an enormous impact on water quality in the surface water system.

The targeted goal is for 20 producers to participate the first year. They will sign contracts by September 30, 2009, for cover crop practices to be implemented beginning in spring of 2010 (there will also be a fall planting option for planting the previous fall). In the second year, the goal will be to add the three other areas of the basin at 50 producers in each area and to increase the southern end by an additional 30 producers. In each succeeding year, each of the four areas will increase producers until by the end of the fifth year, 580 of the 2,700 sugar beet contracts (and additional row crops) will be enrolled in the program, or around 16 per cent.

Producers will be allowed to enroll up to 480 acres in a three-year contract with the expectation that the average will be around 300 acres. It is expected that during the five-year effort, some 174,000 acres of sugar beets (as well as additional other row crops) will have been in protective spring cover crop to stop wind erosion and improve surface water quality. This strategy will reduce the amount of soil and sediment flow through drainage systems during the spring runoff season as well as during heavy precipitation events.

2. Beach Ridge Erosion Reduction Strategy

Water quality impacts from erosion in the RRB beach ridge areas is one of the major factors in deteriorating surface waterways in the basin, as identified in the 303d Impaired Waters reports directed by the U.S. Congress through the USEPA. The entire eastern, western and southern edges of the basin consist of this topography, which was a result of the formation of the RRB after the last ice age and the resultant Lake Agassiz, which drained north into Hudson Bay. This erosion is directly related to topography, hydrology and farming practices. Excess water in the spring melt or summer rains carries volumes of soil as it drains from the steeper portions of the basin to the lower, flatter portions.

The focus of this strategy is to reduce the speed and force of runoff, which is the cause of the erosion from the old beach ridge areas. The project will improve water quality by reducing erosion and improving impaired waters. Using local partner knowledge and contact areas where there are ravines and similar runoff locations to implement total sediment containment (holding a section at the top, a tile line to the bottom and a grassed waterway if needed) will be identified. The goal will to be to target the highest-priority erosion areas using information from current monitoring efforts and those areas identified as high priorities under 303d Impaired Waters—TMDL maps.

3. Restricted Flow Sediment Pool Strategy

Erosion is an ever-present problem in the RRB, either from wind or water or a combination of the two. The valuable agricultural land in the RRB is protected by extensive drainage and waterway systems to move excess water from spring runoff and summer rains off the land and crops. The RRB is shaped like a large oval bowl that has very steep sides and a wide flat bottom. The water moving off agricultural land into the drainage system carries with it topsoil and chemical nutrients (nitrogen and phosphorus) that cause water quality problems.

The size and location of landowner culverts can have a significant impact on slowing and holding water on a short-term, temporary basis. This will allow sediments and nutrients affecting water quality the time to settle out and remain on the producers' land where they can be recaptured.

The restricted flow sediment pool strategy is a broadly distributed storage strategy that can easily be implemented on each section of land that would provide tremendous water quality benefits to the basin by allowing sediment and nutrients to settle and be recaptured on the land. The construction of a dike is likely to result in permanent upland and wetland habitat. By controlling flows to match downstream channel capacity, breakout flows across adjacent cultivated fields, which often cause severe erosion, will be minimized. In addition, the pool will lower the sedimentation of upstream water bodies.

4. Water Flow Retardation Strategy

Improving water quality by lowering erosion and sedimentation is a major challenge in the RRB. Slowing and holding water though land-use practices such as buffer strips, wetland restoration and cover crops could be used to address this challenge. This strategy involves holding large amounts (10 and 100 acre foot) of water for longer periods of time.

Numerous water flow retardation areas will be implemented within strategic and highly erodible runoff locations to increase water supplies and improve downstream flood protection and water quality. Site selection will be based on modelling tools, elevation data, impaired water information, TMDL goals and potential local, regional and basin-wide benefits. Locations will also be determined by working with local landowners and with assistance of the water boards.

5. Stream Bank Erosion Reduction Strategy

The RRB is a prairie river system with rich topsoil that experiences natural erosion that has been exacerbated by the extensive drainage systems that moves water to increase agricultural production. This is especially true during increased spring flows and during excessive summer rains. It has also been exacerbated by farming practices that have destroyed much of the natural protection along stream banks.

Reducing stream bank erosion will increase water quality in the region as well as lower flood damages by protecting the stream banks of the tributaries feeding into the RRB. This program will focus on reducing tributary stream bank erosion by implementing vegetative buffers and bio-engineering projects.

6. Other Activities Strategy

Other activities that normally apply under EQIP will be utilized as appropriate (i.e., the buffer strip concept and agricultural erosion reduction strategies). These practices will be used to assist the AWEP strategies above and to enhance the strategy's conservation and water quality components where appropriate.

5.2.2 Selection Criteria

The USDA-NRCS selected the projects that would be funded within the proposed enhancement activities. Unfortunately, the selection criteria used remains unknown. A quick survey of the mix of selected practices funded reveals that they were slightly more oriented towards hard infrastructure (dams, dikes, structure for water control, grade stabilization structure) as opposed to ecological infrastructure (cover crops, no till, water and sedimentation basin, pasture and hayland planting, restricted flow sediment pool and grassed waterways) investments (see Appendix D). The AWEP project funding selection process may benefit from an ecological infrastructure DSS, as it would provide additional insights to select projects that yield multiple benefits and consequently maximize return on investment.

5.4 Summary

The three case studies summarized represent a variety of projects/programs going on throughout the RRB. They illustrate the necessity for integrated planning in terms of biophysical, infrastructure and socioeconomic needs within the basin. The development of a DSS for the RRB would be an extremely useful tool for the planning, development and implementation of these projects and programs.

5.5 Other Potential Case Studies

There are many areas across the basin that would be suitable to develop and pilot the ecological infrastructure investments DSS. A number of other potential case studies were also examined as part of Phase 1 and a subset of these projects are described below.

5.5.1 R.M. of Dufferin – Wetlands Tax Credit Program

The RM of Dufferin has examined ways to preserve and conserve wetlands. The wetland preservation program was motivated by an economic downturn in the cattle industry. Farmers were looking for ways to increase their farming acres while lowering their pasture lands. The RM of Dufferin responded by passing a by-law on March 23, 2010 that identifies eligible wetlands for the Dufferin Wetlands Tax Credit Program and passed a resolution for the program on April 20, 2010. The RM is hoping to preserve approximately 365 acres of wetlands within the next three years with a budget of C$25,000. The development and application of the DSS within the RM of Dufferin could assist with strategically identifying the wetland restoration within the landscape that could yield the most benefit.

5.5.2 City of Selkirk Water Treatment Plant Rehabilitation

The City of Selkirk's raw water source was originally derived from wells. Prior to 1970, water treatment of the well water consisted of chlorine disinfection only. In 1970, the city's water treatment plant (WTP) was first commissioned. The addition of a WTP provided the needed treatment of surface water sources. Between 1977 and 1995, the Red River was used to supplement well water. In 1995, the city drilled more wells to supply the city exclusively with well water.

The City of Selkirk currently relies on ground water as its primary source of raw water from four primary wells and a fifth emergency well. They also installed a 9 million litre reservoir to increase their water supply capacity. River water can be used when groundwater cannot meet demands, which is typically mixed (70 per cent well water with 30 per cent river water) to address objectionable taste and odor concerns.

Restoring the natural environments around the City of Selkirk could help recharge groundwater supplies and improve water quality. The ecological infrastructure investment DSS could assist the city with making cost-effective investments in the restoration of the natural environments to secure and enhance their groundwater supply and maintain the water quality of their surface water supply.

5.5.3 The Pelican River Watershed District – Rice Lake Nutrient Reduction Project

From 2003 to 2007, the NRCS–Small Watershed Assistance group conducted an in-depth assessment study of the Rice Lake wetland to analyze best management practices for reducing phosphorus exports. Wetland restoration was selected as the most technically feasible option. The project will include restoration and impoundment of Rice Lake wetland, township road improvement, and implementation of agricultural best management practices. The process used in determining the investment in restoring the Rice Lake wetland could provide insights for the development of the ecological infrastructure investment DSS.

5.5.4 Pembina River Basin Advisory Board – 2D-Telemec Model of the Lower Pembina River

In 2009, the Pembina River Advisory Board (PRBAB) organized a tour and discussions regarding the U.S. (North Dakota)/Canada (Manitoba) border flooding issues. The PRBAB has since collaborated with the relevant provincial, state, federal and international agencies to develop a flood management strategy. River flows, breakouts, impacts of road and railroad bridges, and various model approaches were all part of the discussions to develop a flood management strategy roadmap. These efforts resulted in consensus and strategies for the development of a flood prediction model for the region. The discussions led to the completion of a 2D Telemac model for the Lower Pembina River Basin. The development of the ecological infrastructure investment DSS should build upon the modelling effort conducted Lower Pembina River Basin. The DSS would likely provide additional insight toward developing a comprehensive flood management plan for the basin.

6.0 Conclusions and Recommendations

The Building Capacity for Ecological Infrastructure Investments in the Red River Basin project was initiated by the RRBC and the IISD to enable municipalities and counties in the RRB evaluate the possibility of investing in the conservation and restoration of natural environments to deliver cost-effective services to their citizens. The project is being carried out in two sequential phases. Phase 1 focused on building partnerships, establishing a project advisory committee, conducting a data gap analysis, organizing and hosting a modelling workshop and selecting suitable case studies for the project. Phase 2, which will be initiated once adequate funding has been secured, will focus on developing a comprehensive DSS for the evaluation of ecological infrastructure investments. This report summarizes the activities and insights gained while completing Phase 1.

The project was initiated by undertaking partnership-building activities across the basin with various stakeholder groups. Letters of support were received by a number of key organizations who are likely to become the DSS user community (Association of Manitoba Municipalities, Manitoba Conservation District, North Dakota Red River Joint Water Resource Districts and the Minnesota Red River Watershed Management Districts). In addition to local entities, international, federal, provincial and state agencies were also approached (International Red River Board, Manitoba Water Stewardship, Minnesota Pollution Control Agency, North Dakota Department of Health, Agriculture Agri-Food Canada and USGS). Finally, expertise was sought from academia and the private sector (University of Manitoba, International Water Institute, University of Minnesota, Energy and Environmental Research Centre, IBM and Greenland Technologies).

A 12-member project advisory committee was established to provide the project with basin-wide multi-disciplinary guidance. The states of North Dakota and Minnesota, and the Province of Manitoba are represented in all the sub-groups of the project advisory committee, which provided an expert lens on water quality, water supply, flood management and conservation. Terms of Reference for the project advisory committee have been drafted and reviewed by the committee members. Thus far, two meetings were held to introduce the members to the project and seek feedback and guidance for the data gap analysis and designing the modelling workshop.

In general, the majority of the biophysical, infrastructure and socioeconomic information required to develop a sophisticated DSS for ecological infrastructure investments in the RRB is available. The information that is missing—such as high-quality elevation information in the form of LIDAR data—can be acquired. Acquisition costs for missing data sets ranges widely and may or may not be required depending on the context where the DSS is being developed, tested or applied.

Accurate elevation data for the basin is lacking. Although LIDAR data has been acquired for the U.S. portion of the basin and parts of the Canadian portion, there are still substantial areas in Canada that do not have coverage. It was estimated that collecting data for the rest of the basin could cost anywhere from US$0.9 million if collected in a coordinated manner to US$3.4 million if collected in a piecemeal fashion. The data could be acquired affordably if the total cost is shared amongst a number of government agencies and other entities interested in the data.

Infrastructure information is managed in many different ways across the RRB and can be difficult to track down. Providing this information through a centralized website accessible to the public would make it more feasible to identify and assess opportunities for ecological infrastructure investments. Opportunities to host this information in a centralized manner on an existing website should be investigated. Environment Canada's Lake Winnipeg Portal could potentially provide this function.

A variety of statistics describing demographics and the agricultural sector can be accessed via Statistics Canada and the U.S. Census Bureau online. Although the information is available, it may have to be adequately disaggregated or aggregated from census divisions to basin and watershed boundaries for the information to be useful. This may require a substantial amount of data processing, which typically can be completed by Statistics Canada and the U.S. Census Bureau for a nominal fee.

A modelling workshop was organized and hosted by IISD and the RRBC to bring together technical and policy-making expertise on both sides of the border. Pre-workshop materials were sent to the participants. They were asked to reflect on the following strategic questions prior to the workshop, which focused on the development of a DSS for ecological infrastructure investments in the RRB:

1. What are some of the key design elements and or functionalities that you would include to ensure that the DSS is useful and relevant?
2. What existing DSSs and tools currently used in the basin should be built on to develop the proposed DSS?
3. What are the barriers to implementing a basin-wide DSS? Why don't we have a similar system in place already (technological, political, other obstacles)?
4. What is the process that you would follow to develop the proposed DSS?

The workshop opened with an update on the ecological infrastructure investments project, an overview of IWM initiatives and various models that are currently and could potentially be used in the RRB. The strategic questions were then discussed in small groups and presented back to the group. A basic architecture for the development of the DSS was also presented and critiqued. The discussions were recorded and sent to the participants for their comment. In general terms, the insights generated during the workshop were:

- A lack of an overarching vision with defined goals and objectives is an obstacle to developing an effective DSS for ecological infrastructure investments. However, the technical aspects of the DSS can still be worked on as objectives are being formulated.
- Significant knowledge gaps (better understanding of biophysical processes) need to be filled so that an accurate and reliable DSS can be developed (i.e., water retention on the landscape and dissolved phosphorus dynamics).
- Harmonized data sets are needed to develop a basin-wide DSS. Establishing shared protocols for gathering and processing data will ensure that it remains compatible across state and provincial boundaries. A study on data-gathering protocols in each jurisdiction to identify harmonization opportunities would be a positive step towards compatibility.
- There are important ongoing data collection (Group on Earth Observation—soil moisture and crop mapping) and compatibility (International Red River Board—hydrological stream network compatibility) efforts that must be capitalized on for developing the DSS.
- The DSS will have to build on existing models and tools. This may require the development of middleware or translation software so that the various models, tools and databases can work together. The OPEN MI protocol provides some guidance as to how this could be achieved.
- The DSS should be designed so that it is useful for a number of users (local as well as higher levels of governments) at various spatial and temporal scales and it should be educational as well as insightful for decision-making. For this reason, it should have an excellent interface that communicates the information visually and allows the users to provide feedback.
- The DSS should be easily accessible (potentially online) and freely available. To achieve these goals, the designers should take advantage of new networking capabilities such as cloud computing to improve performance and cut costs.
- The DSS should have functionalities to facilitate integrated natural resources management and have a wide range of capabilities so that it is useful and relevant for a broad range of potential users (flood and drought forecasting, water quality, water supply, ecosystem management, infrastructure cost and benefit analysis).
- A DSS with the ability to evaluate various scenarios would be useful to facilitate proactive instead of reactionary IWM and ecological infrastructure investment decisions.
- The project needs to establish a stakeholder advisory groups that can provide technical as well as governance expertise.
- The DSS should be designed in a stepwise fashion by first identifying suitable locations for developing and piloting the DSS.
- A long-term maintenance plan for the DSS must be formulated at the beginning of the project so that the system does not become irrelevant.

The participants agreed that on an outreach piece for the general public so they can be made aware of the initiative. They also committed to continue working on the project and a letter of commitment was to be drafted and shared with politicians to gain support for the initiative.

Three suitable ecological infrastructure investment case studies were identified based on their biophysical, infrastructure and socioeconomic characteristics. A Canadian and an American case study were selected to examine how an ecological infrastructure investment DSS could be used to facilitate more cost-effective infrastructure investment decisions. A federal agricultural program was selected to demonstrate how the DSS could potentially be used to target program resources more effectively.

The restoration of the former Giroux Bog within the La Coulee sub-watershed project by the Seine Rat River Conservation District in Manitoba was selected, as it is located in a nutrient hot spot and is prone to flooding, causing agricultural losses. The restoration of the Giroux Bog will retain water, thus slowing floodwaters and allowing nutrients and sediments to settle out.

The restoration of the Palmville Fen in the international Roseau River watershed aims to lower flooding events in the area and improve water quality. The project was chosen because it is an area that has lost a significant amount of wetlands and is regularly subjected to flooding. The project is expected to protect the cities of Roseau and Wannaska from flooding events and avert the need to build flood protection structures.

The AWEP is a federal program administered by the USDA focussed on improving water quality within agricultural landscapes. The RRBC has been tasked with coordinating a major AWEP initiative for the RRB. The ecological infrastructure investment DSS may assist the AWEP with prioritizing resources more effectively to improve the basin's water quality.

The following recommendations are made based on the findings of Phase 1:

- Build upon ongoing and planned compatible initiatives such as the development of the DSS by the International Water Institute
- Initiate the collection of missing LIDAR data in the Canadian portion of the basin in a coordinated manner, as opposed to a piecemeal fashion, to save cost
- Develop a coordinated system for tracking infrastructure information in the basin
- Request the collected socioeconomic information disaggregated and aggregated at the watershed and basin scales
- Develop harmonized data gathering and processing protocols to ensure compatibility among all three jurisdictions

- The DSS should be easily accessible and freely available and designed for multiple users so that it can be useful for various spatial and temporal scales.
- The development of the DSS must be compatible with existing models and tools used for integrated watershed management and must build on ongoing data collection and compatibility efforts in the basin.
- The DSS should have a wide range of functionalities (flood and drought forecasting, water quality, water supply, ecosystem management, infra-structure cost-benefit analysis, scenarios exploration) to facilitate proactive integrated natural resources and watershed management.
- The DSS should be designed so that it can be useful for planning ecological infrastructure investments within municipalities and counties at the watershed scale and to assist with effective government programming related to agricultural and infrastructure efforts.

The Building Capacity for Ecological Infrastructure Investments in the RRB initiative is expected to result in the development of a DSS that will enhance local government infrastructure investment options to facilitate improved fiscal effectiveness and rehabilitated natural environments. New York City's multi-billion dollar cost saving decision to enhance their water supply's watershed instead of building a new water filtration plant provides a concrete example of where ecological infrastructure investments led to significant savings. Investments to increase resilient natural environments providing cost-effective services are imperative for the long-term well-being of the basin's communities.

> *"the full extent of the problem is not one of infrastructure renewal, but rather one of reconsideration and reinvention of servicing for sustainable communities."*
>
> *—Mary Trudeau, Engineers Canada (in Mastromatteo, 2008, p.48)*

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Appendix A – Building Partnerships

Current Project Advisory Committee Members

Water Quality:

- Nicole Armstrong, Manitoba Water Stewardship
- Dennis Fewless, North Dakota Department of Health
- Jim Ziegler, Minnesota Pollution Control Agency

Water Supply:

- Bob Harrison, Manitoba Water Stewardship
- Lee Klapprodt, North Dakota State Water Commission
- Bob Bezek, Minnesota Department of Natural Resources

Flood Management:

- Steve Topping, Manitoba Water Stewardship
- Jim Lyons, North Dakota Red River Joint Water Resource District Board
- Dan Wilkens, Minnesota Red River Watershed Management Board

Conservation:

- Ute Holweger, Agriculture and Agri-Food Canada
- Brian Dwight, Minnesota Board of Water and Soil Resources
- Keith Weston, Natural Conservation Service, U.S. Department of Agriculture

Project Advisory Committee Terms of Reference

1.0 Project Overview

This project is being undertaken through a partnership between the Red River Basin Commission and the International Institute for Sustainable Development. The main objective of this project is to develop and implement a basin-wide decision support system that will provide decision-makers with the capacity to assess the costs and multiple benefits of projects aimed at maintaining and restoring natural environments. Multiple benefit projects are those that simultaneously address improvements in the areas of water quality, water supply, flood damage reduction and soil conservation. Ultimately, the tools will allow decision-makers to weigh the costs and benefits of hard infrastructure investments and natural environment restoration investments so that they can deliver services to the communities of the Red River Basin in the most cost-effective manner. The general project rational, background and objectives are described below.

Rationale

- Protecting, restoring, and conserving ecological infrastructure (or natural environments) can provide cost-effective alternatives to conventional water resources infrastructure for water treatment and supply and flood protection.
- Ecosystem services provided by ecological infrastructure are an important component of natural resources planning frameworks associated with integrated water resource management.
- The Red River Basin is well suited to demonstrate how an ecosystem services approach can be used to support natural resources planning frameworks and provide cost-effective infrastructure investment options for municipalities as its landscape has been highly altered by humans.
- Stakeholders at multiple scales in the basin need to be engaged to evaluate ecosystem service options.

Background

- Flood mitigation is the historic focus of international cooperation within the Red River Basin, which was galvanized by the destructive flood of 1997.
- The Red River Basin Commission's development and promotion of a natural resources planning framework in the basin was motivated by the realization that effective flood mitigation requires an integrated approach to natural and water resources management.

- Water quality and the eutrophication of water bodies has become another focus of basin-wide cooperation efforts. The Red River Basin delivers 60 per cent of the nutrient loads to Lake Winnipeg, which has become the most eutrophied large lake in the world.
- The ecosystem services approach has evolved into an effective way to communicate and assess the real economic benefits from ecosystem services, such as nutrient reduction and flood mitigation derived from natural environments.
- The ecosystem services approach to watershed-based natural resource management is potentially a more cost-effective alternative to conventional water resources investments.
- Assessing the ecosystem services approach requires careful analysis and scoping of pilot projects.

Objectives

- Build partnerships with relevant partners and stakeholders to develop a structure to facilitate the cost-benefit analysis of ecological infrastructure investments in the Red River Basin
- Compile comprehensive Red River Basin maps to create an online basin viewer that can be used for ecological infrastructure investment planning
- Develop a comprehensive decision support system to assess ecological infrastructure investment opportunities and support cost-effective infrastructure expenditure decision-making
- Investigate ecological infrastructure investment scenarios in the basin
- Build capacity for ecological infrastructure investment assessments through communication and education efforts within municipalities, counties and other institutions that deliver services

Outcomes

- Stakeholder engagement on ecosystem services concepts within the Red River Basin
- Development of a comprehensive decision support system for ecological infrastructure investments in the Red River Basin (at the basin and watershed scales)
- Three pilot projects initiated within Manitoba, North Dakota and Minnesota to investigate ecological infrastructure investment benefits
- Scenarios development and exploration of various ecological infrastructure investments strategies such as nutrient trading at the municipal and state/provincial levels by developing scenarios
- Dissemination of the DSS within municipalities and counties within the Red River Basin

1.1 Project Activities

This project consists of two phases (Phase I and II). Phase I is currently underway and consists of the following key project activities:

Phase I: October 2008–June 30, 2010

(1) *Building Partnerships* – Build partnerships with decision-makers and stakeholders throughout the basin, including government agencies (local, provincial/state, federal), land-use planners, natural resource organizations and community groups. Letters of support are being requested to fulfill Phase I grant obligations and to help leverage funding for Phase II.

    Current partners/supporting agencies include the Association of Manitoba Municipalities, Manitoba Conservation Districts, Agriculture and Agri-Food Canada, University of Manitoba, University of Minnesota, Minnesota Centre for Environmental Advocacy and the International Water Institute.

(2) *Data Gap Analysis* – This step will also consist of identifying data gaps, developing strategies to fill them, and preliminary analysis of the data collected including: biophysical, hydrological, infrastructure and socioeconomic.

(3) *Modelling Workshop* – A modelling workshop will be held in June 2010. Representative stakeholders from across the basin will be invited to provide insights for the development of the required decision support tools/models.

(4) *Selection of Case Studies* – Case study locations will be selected to help develop and apply the tools/models. These locations will be selected through stakeholder consultation and by conducting site visits.

Phase II: The duration will range from 2 to 4 years and the start and end dates will be based on the funding acquired. Phase II of this project will consist of development and implementation of the decision support tools/models and will include scenario investigation (i.e., case studies) and capacity building through hands-on instruction, communication and outreach activities.

1.2 Funding

The funder's objectives will be detailed in this section of the document once funding has been secured for this project.

The RRBC received a C$55,000 grant for Phase I of this project from Environment Canada through the Lake Winnipeg Basin Stewardship Fund.[136] In-kind contributions include C$25,000 from IISD and C$32,000 from the RRBC. Other agencies are also providing important resources and support.

Funding for Phase II is currently being sought through various grant organizations, including: Environment Canada (Lake Winnipeg Basin Stewardship Fund), International Joint Commission (International Watershed Initiative) and the National Science Foundation.

2.0 Project Advisory Committee (PAC) Terms of Reference

The purpose of the PAC is to provide guidance, input and quality control (i.e., review of progress and reports) for the project. A timeline has been developed detailing the roles and responsibility requirements for the PAC over Phase I and II of the project.

2.1 Membership

Each member of the PAC is to make provisions for an alternate and provide their name, position, organization and contact information to the Project Manager.

2.2 Meetings

The PAC will be notified 45–60 days in advance of planned meetings. Meeting materials will be provided one month prior to meetings for review and to solicit input/feedback.

- Conference calls – every 4 to 6 months
- Face-to-face – once/year (central location such as Grand Forks). Lunch and refreshments will be provided.

A tentative timeline has been compiled to provide an understanding of how the project may unfold.

[136] The LWBSF priorities can be accessed at: www.ec.gc.ca/paae-apcw/default.asp?lang=En&n=D7134110-1

General Tentative Timeline															
Guidance will be sought for each activity listed. The activities may be greatly accelerated depending on the funding acquired.															
Year 1				Year 2				Year 3				Year 4			
Design of the decision support system through expert and stakeholder consultations. PAC meetings to ensure that all expertise and stakeholders have been adequately consulted				Data acquisition and development of the DSS. PAC meetings to provide project updates and get advice on the design of the DSS.				Pilot implementation and fine tuning of the DSS. PAC meetings to provide project updates and get advice on the implementation of the DSS.				Dissemination and implementation of the DSS (outreach and training activities). PAC meetings to provide project updates and get advice on the dissemination of the DSS.			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Stakeholder consultations	Proposed designs	Design selection	Fine tune design with feedback from stakeholders	Select or develop DSS platform	Computer programming of the DSS architecture	Test computing efficiency	Acquire the data necessary and test the DSS (sensitivity analysis)	Choose pilot location	Calibration of the DSS	Application of the DSS within the pilot location	Fine tune the DSS design	Online distribution of the DSS (website development)	Educational and outreach activities	Obtain feedback from users	Fine tune the design

2.3 Information Sharing/Data Collection

In addition to conference call and face-to-face meetings, RRBC's Sharepoint data system will be used as an integral project management and communication tool. All project information (i.e., agendas, meeting minutes, reports, data, funding proposals, grants, etc.) will be posted on the Sharepoint site. Members of the PAC will be provided with a password that enables access to the project information.

It is anticipated that PAC members will allocate at least one hour per month to review project information and provide feedback/input using Sharepoint.

Letters of Support

Letters of Support have been received from the following organizations:

1. Seine-Rat River Conservation District (dated : July 6, 2010)
2. Assiniboine Hills Conservation District (dated: April 12, 2010)
3. Swan Lake Watershed Conservation District (dated: April 12, 2010)
4. East Interlake Conservation District (dated: February 11, 2010)
5. Turtle Mountain Conservation District (dated: March 16, 2010)
6. Association of Manitoba Municipalities (dated: May 28, 2009)
7. Little Saskatchewan River Conservation District (dated: May 11, 2010)
8. Red River Joint Water Resource Board (dated: April 22, 2010)
9. Red River Watershed Management Board (dated: June 30, 2010)
10. Roseau River Watershed District (dated: August 4, 2010)
11. Manitoba Conservation District Association (dated: August 13, 2010)
12. Manitoba Eco Network (dated: July 27, 2010)

Original letters can be supplied upon request.

The table below summarizes the partnership-building activities. (Note: this table shows key partnership-building activities and does not include the myriad of other face-to-face and teleconference meetings that have also taken place.)

Table 2: Partnership-building activities

Agency	Date(s)	Project Activities	Outcome
International Red River Board (IRRB)	August 2009	Met with IRRB representative to discuss project and solicit input, including potential data/technical resources and partnership possibilities	Acquired useful technical information and interest in upcoming project modelling workshop. IISD and RRBC were invited to attend the IRRB transboundary modelling workshop held in July 2010.
Agriculture and Agri-Food Canada (AAFC) (AESB and Geomatics Branch)	Sept 17, 2009	Presented project description via PowerPoint and discussed research activities throughout the RRB The Group on Earth Observations work was discussed. The RRB was proposed as a research site.	Received verbal confirmation that AAFC supports the project Secured an in-kind contribution of 4 to 5 days of AAFC staff time for data processing work

University of Minnesota, Minnesota Centre for Environmental Advocacy and International Water Institute	Sept 25, 2009	Discussed project components and work plan; partnership development; organizational activities; data gaps and needs; areas of potential collaboration	Agreed to collaborate on project and identified expertise, relevant organizations and funding sources for project development
Red River Basin Commission North Chapter Meeting 382 delegates in attendance	Oct. 24, 2009	PowerPoint presentation to local decision-makers from the Manitoba Interlake Region	Acquired numerous contacts and relevant research information
Association of Manitoba Municipalities Convention 900 delegates in attendance	Nov 23–25, 2009	Attended convention, set-up display booth; networked and discussed project with attendees; provided project information and contacts	Acquired numerous contacts and relevant data and research information
Manitoba Conservation Districts Association Convention 543 delegates in attendance	Dec 7–9, 2009	Attended convention, set-up display booth; networked and discussed project with attendees; provided project information and contacts	Received important feedback; acquired numerous contacts and relevant data and research information
Red River Basin Commission 27th Annual Conference	Jan. 21, 2010	PowerPoint Presentation at the annual conference	Informed basin-wide audience of the project. Received good feedback on the presentation and its contents
Manitoba Conservation District (CD) Managers meetings (Hecla Oasis Resort and Portage La Prairie)	Feb 5, 2010 and April 6, 2010	Developed and provided a comprehensive PowerPoint presentation; developed and disseminated a questionnaire to solicit input and feedback; compiled and disseminated meeting minutes for review and comment; corresponded with numerous CD managers	Received letters of support from four CDs; received several completed questionnaires; invited to present to the Seine-Rat River CD Board on May 17, 2010
United States Geological Survey (USGS)	Feb 18, 2010	Attended workshop at University of North Dakota to establish potential partnership with USGS	USGS will provide access to data, Ecoserv model.
Manitoba Eco-Network Water Caucus Meeting	March 18, 2010	PowerPoint presentation to group representing water organizations in Manitoba	Received important feedback; acquired numerous contacts The Network provided a letter of support

North Dakota Red River Joint Water Resource District Board (West Fargo)	April 14, 2010	Developed and provided a project summary paper for presentation to the Board	Board provided a letter of support
Minnesota Red River Watershed Management Board (Thief River Falls)	April 20, 2010	Developed and provided a project summary paper for presentation to the Board	Board provided a letter of support
Rural Municipalities (Manitoba) and Counties (Minnesota and North Dakota)	Sept 2009–present	RRBC Outreach Program—briefly presented project to local decision-makers to provide awareness, develop potential partnerships and solicit input	Education and information was provided to local decision-makers Valuable contacts were made and insights were received
Seine-Rat River Conservation District (SRRCD)	May 18, 2010	Presented PowerPoint on project	Received letter of support and confirmed a SRRCD project as a case study.
Pembina County Water Resource Board	June 1, 2010	Presented PowerPoint on project	Information was provided to local decision-makers

Appendix B – Data Gap Analysis

This appendix provides a summary of the information and their sources described in the data gap analysis. RRB maps that were generated using datasets collected during the data gap analysis are also included here.

Summary Table

Table AB1: Summary of information and their sources.

Type	Description	Agency/Source
Biophysical		
Elevation	ASTER – Global Elevation Dataset Maps with 20 m elevation with 95 per cent. SRTM – Global Elevation Dataset at 90 m, Available for the U.S. only at 30 m. LIDAR – Horizontal accuracy of 0.91 m and vertical accuracy of 0.15 m. Available in the U.S. portion of the basin and in parts of the Canadian portion	NASA (http://wist.echo.nasa.gov/wist-bin/api/ims.cgi/u421317#SCROLL) USGS (http://dds.cr.usgs.gov/srtm) *United States*: International Water Institute (www.internationalwaterinstitute.org/lidar_specs.htm) USGS (http://lidar.cr.usgs.gov/) *Canada*: Manitoba Land Inventory (http://mli2.gov.mb.ca/about_us/index.html)
Land Cover	LandSat imagery – Available at 30 m basin wide free of charge. Variety of Higher Resolution Satellite Imagery that are freely and commercially available (i.e. Quickbird – 0.5 to 0.6 m resolution).	*United States*: USGS (http://landcover.usgs.gov/landcoverdata.php#na) NASA (https://wist.echo.nasa.gov/api) *Canada*: Manitoba Land Inventory (http://mli2.gov.mb.ca/landuse/index.html) *Private Vendors*: Global Mapping Solutions (www.mapmart.com/Products.aspx) Satellite Imaging Corporation (www.satimagingcorp.com)
Soils	Soil Map Unit File is freely available for Manitoba at 1:20,000 to 1:40,000. SSURGO – Freely available in the United States at 1:12,000 and 1:63,360.	*Canada*: Manitoba Land Inventory (https://mli2.gov.mb.ca/soils/index.html) *United States*: NRCS Soil Data Mart (http://soildatamart.nrcs.usda.gov/)

Bedrock	Geological Information available in Manitoba at 1:1,000,000. Geological information available in the US at 1:1,000,000.	*Canada*: Manitoba Land Inventory (https://mli2.gov.mb.ca/geology/index_1million.html) *United States:* USGS (http://tin.er.usgs.gov/geology/state)
Water Quantity and Quality	A variety of water quantity and quality sources are available on both sides of the border.	*United States*: USGS - National Water Information Service (http://waterdata.usgs.gov/nwis), National Water Quality Assessment Program (http://water.usgs.gov/nawqa). USEPA – Watershed Assessment, Tracking and Environmental Results (www.epa.gov/waters). *Canada*: Environment Canada - Water Survey Program (http://scitech.pyr.ec.gc.ca/waterweb/formNav.asp) Manitoba Water Stewardship and the City of Winnipeg also monitor water flows. Water Quality information is collected by Environment Canada, Manitoba Water Stewardship and the City of Winnipeg as well as Conservation Districts and individual Regional Municipalities.
Climate	Extensive climate data is available on both sides of the border.	*Canada*: Environment Canada Meteorological Services Canada (http://climate.weatheroffice.gc.ca/Welcome_e.html) *United States* : Department of Commerce National Climatic Center (www.ncdc.noaa.gov/climate-monitoring/index.php#networks)
Water Consumption	Water consumption information is available from various levels of governments	*Canada*: Statistics Canada - Industrial and Agricultural Water Use (www.statcan.gc.ca/pub/16-401-x/2008001/5003964-eng.htm, www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5145&lang=en&db=imdb&adm=8&dis=2) Environment Canada – Municipal Pricing and Water Use (www.ec.gc.ca/eau-water/default.asp?lang=En&n=ED7C2D33-1) Manitoba Water Stewardship – Water Licensing (www.gov.mb.ca/waterstewardship/licensing/index.html) *United States*: USGS (http://water.usgs.gov/watuse/data/2005/index.html) Minnesota Department of Natural Resources (www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html) North Dakota State Water Commission (www.swc.state.nd.us/4dlink9/4dcgi/redirect/index.html) Minnesota Department of Natural Resources – Water Permitting (www.dnr.state.mn.us/waters/index.html) North Dakota State Water Commission – Water Permitting (www.swc.state.nd.us/4dlink7/4dcgi/permitsearchform/Map%20and%20Data%20Resources)

Infrastructure		
Water-Related	Water-related infrastructure (water supply, water treatment, wastewater, stormwater, drainage, flood prevention) information is available from various levels of government	*United States*: USEPA – water treatment facilities (www.epa.gov/owm/index.htm) Minnesota Health Department – drinking water supply (www.health.state.mn.us/people.html) Minnesota Pollution Control Agency wastewater treatment facilities, septic field and stormwater (www.pca.state.mn.us) Minnesota Watershed Districts – water treatment infrastructure (www.mnwatershed.org/index.asp?Type=NONE&SEC={EC4561E7-5A37-4381-A983-E192911452C6}) North Dakota State Water Commission – water supply distribution, wastewater treatment facilities (www.swc.state.nd.us/4dlink9/4dcgi/redirect/index.html, www.ndhealth.gov/WQ/WasteWater/WasteWaterProgram.htm) North Dakota Water Resource Districts (Red River Joint Water District) – water supply, drainage and retention structures (www.swc.state.nd.us/4dlink9/4dcgi/GetCategoryRecord/Map%20and%20Data%20Resources) South Dakota Department of Environment and Natural Resources – water related infrastructure (http://denr.sd.gov/tech.aspx, www.sdgs.usd.edu) *Canada*: Environment Canada Water Survey – water treatment, water pricing and finance, sewer systems, wastewater treatment facilities, wastewater pricing and finance (www.ec.gc.ca/Water-apps/MWWS/en/export_tables.cfm). Existence of municipal water and sewage systems (www.communityprofiles.mb.ca) Cities and Regional Municipalities provide information regarding their water and wastewater treatment systems (i.e., City of Winnipeg - www.winnipeg.ca/WaterandWaste/water/default.stm) Manitoba Floodway Authority – City of Winnipeg Floodway (www.gov.mb.ca/waterstewardship/reports/index.html#floods, www.floodwayauthority.mb.ca/home.html) Some Conservation Districts provide drainage information (i.e., Lasalle Redboine CD - www.lasalleredboine.com/drainage_information.htm).
Other	Facilities that could have direct or indirect environmental impacts on watersheds (industrial and manufacturing facilities such as mines, petroleum storage facilities and existing	*United States*: USEPA – manufacturing , food processing, hospitals, landfills, paving materials, pulp and paper, power generation and waste combustors (www.epa.gov/waterscience/guide/industry.html#exist) USEPA - "Envirofacts Warehouse," water, waste, land, toxics, facilities and compliance (www.epa.gov/enviro/index.html). USEPA contaminated sites and Toxmap Environmental Health Maps - landfills, drum sites, abandoned barrels, metal finishing

	contaminated sites as well as large agricultural operations such as feedlots and hog barns). This information is available from various levels of government.	sites and various manufacturing sites (http://cfpub.epa.gov/supercpad/cursites/srchsites.cfm, http://toxmap.nlm.nih.gov/toxmap/facilities/navigate.do) Minnesota Pollution Control Agency – contaminated sites, feedlots, hazardous waste locations, water facilities, tanks and leaks, solid waste locations, investigation and cleanup, and sites with multiple activities. (www.pca.state.mn.us/programs/lust_pSearch.cfm, www.pca.state.mn.us/wimn/index.cfm) North Dakota State Water Commission and the Department of Health – similar information as above (www.swc.state.nd.us/4dlink9/4dcgi/redirect/index.html, www.ndhealth.gov/ehs) South Dakota Department of Environment and Natural Resources – similar information as above (http://denr.sd.gov/documents.aspx) *Canada*: National Pollutant Release Inventory – large industrial sites (www.npri.ca) Conversation Districts - of livestock operations, storage facilities, mining activities, mining claims and quarries (i.e., LaSalle Redboine Conservation District - www.lasalleredboine.com/SLWMP_15.htm). Individual Regional Municipalities may also have information on infrastructure and operations that could have an impact on water resources.
Socioeconomic		
Demographics	Information related to describing specific populations (education, culture, employment, income, household size, gender, languages, etc.).	*United States*: United States Census Bureau – pop (http://factfinder.census.gov/home/saff/main.html?_lang=en) *Canada*: Statistics Canada (www12.statcan.gc.ca/census-recensement/2006/dp-pd/prof/92-591/index.cfm?Lang=E)
Agriculture	Information related to all aspects of the agricultural operations (Census of Agriculture and all related reports).	*United States:* USDA National Agricultural Statistics Services (www.nass.usda.gov/About_NASS/index.asp) Additional information can also be accessed through Minnesota Department of Agriculture and the North Dakota Department of Agriculture and the South Dakota Department of Agriculture. State Universities can also provide important agricultural data. *Canada:* Statistics Canada – Census of Agriculture (www.statcan.gc.ca/ca-ra2006/about-apropos/new-nouveau-eng.htm, www.statcan.gc.ca/ca-ra2006/index-eng.htm, http://cansim2.statcan.gc.ca/cgi-win/CNSMCGI.EXE?LANG=Eng&Dir-Rep=CII/&CNSM-Fi=CII/CII_1-eng.htm)

Red River Basin Maps

ASTER Data (30 m resolution) Elevation Map

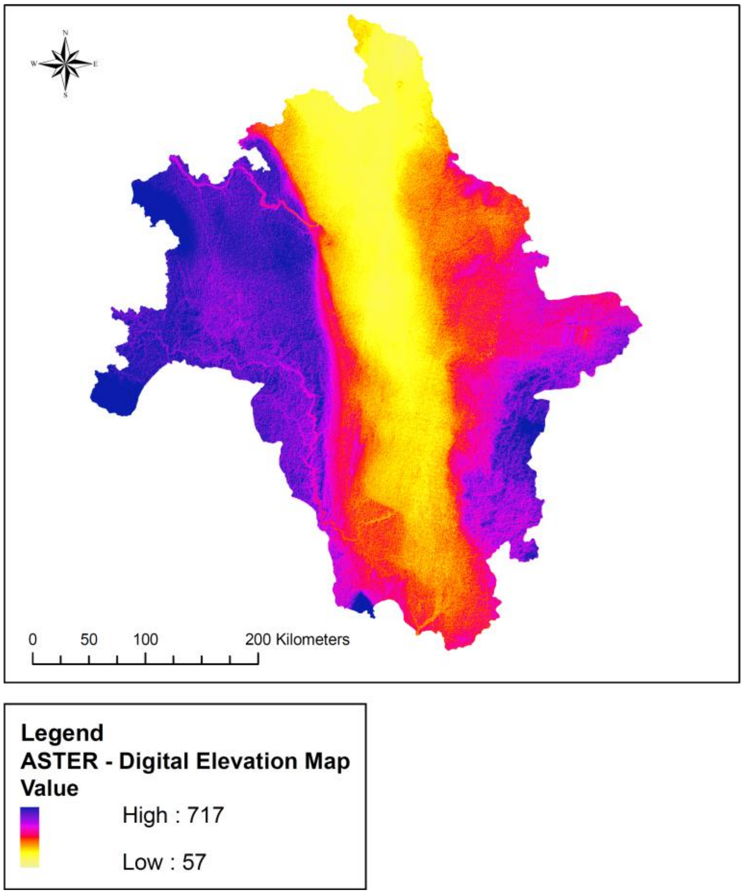


Figure AB1 Red River Basin Digital Elevation Map.

The map above was compiled using ASTER elevation data at 30 m horizontal and 7 to 14 m vertical resolution. The map indicates that the highest elevation in the basin is 717 m (2,352 ft) and that the lowest elevation is 57 m (187 ft). These values are known to be inaccurate as the highest elevation in the basin is 1,200 ft and the lowest elevation at Lake Winnipeg is 750 ft. Although the map is inaccurate in absolute terms, it provides relative information with respect to higher and lower elevations across the basin.

LandSat (30 m resolution) Land Cover Map

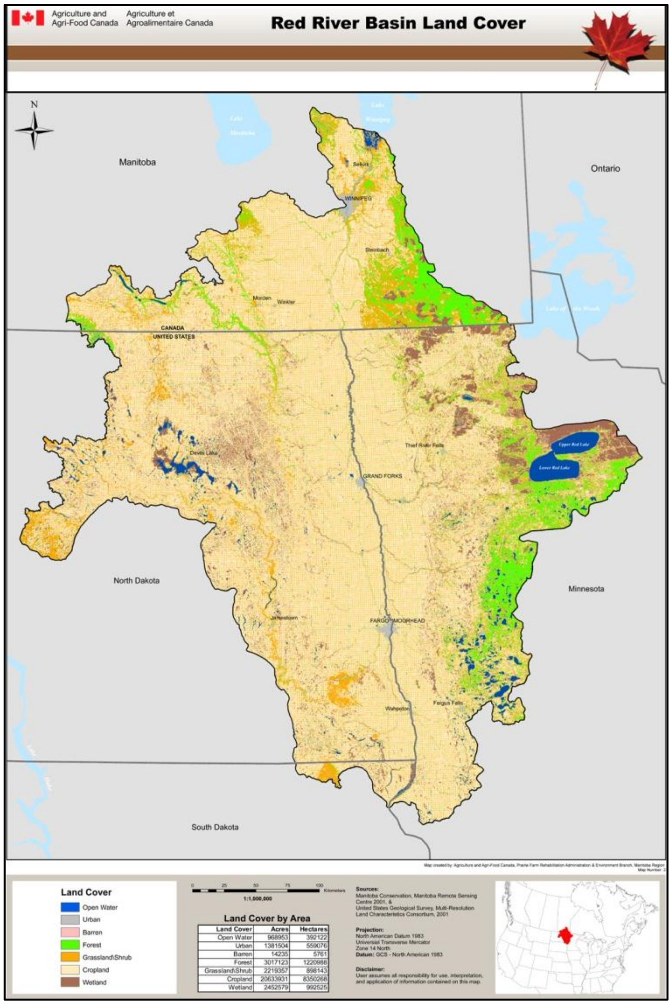


Figure AB2 Red River Basin Land Cover Map

SSURGO and SoilMUF Soil Map

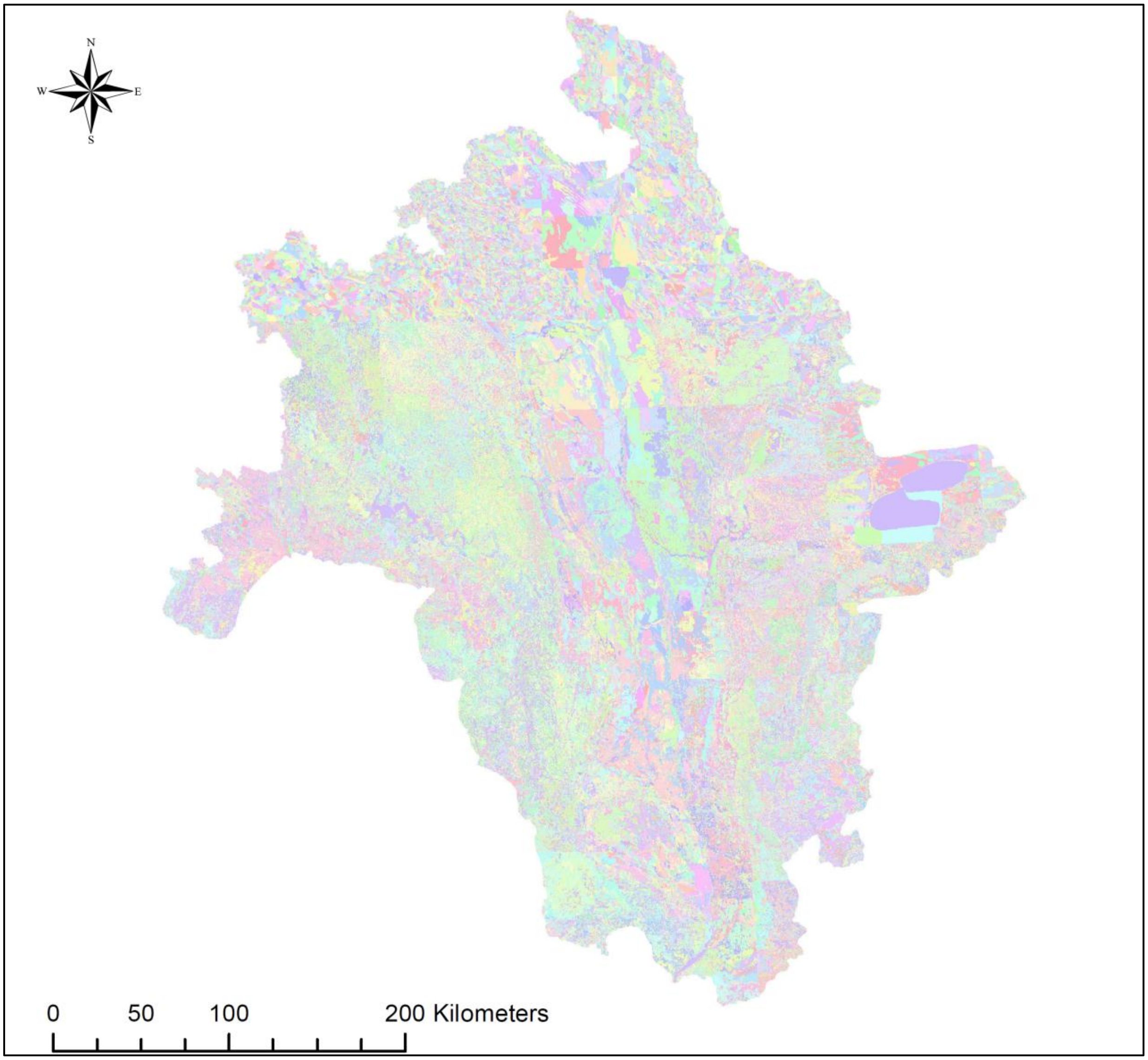


Figure AB3 Red River Basin Soil Map

The soil map was compiled using County soil SSURGO dataset (with a resolution of 1:12,000 to 1:63,360) and the Regional Municipality soil SoilMUF data set (with a resolution of 1:20,000 to 1:40,000). There are over 38 different soil types on the Canadian side and over 300 soil types on the American side of the Red River Basin (please see the next page). For this reason, a legend could not be included with this map but the soil names are listed on the next page. It must be noted that the soil data of Koochiching County will not be quality controlled by NRCS till September 2010.

Soil Types in the Canadian Portion of the Red River Basin
Loamy Till (Black Chernozem)
Loamy Lacustrine
Clayey Lacustrine (Black Chernozem)
Clayey Lacustrine (Gleysols)
Sandy Lacustrine
Sand and Gravel
Eroded Slopes
Loamy Till (Dark Gray Chernozem)
Variable Textured Alluvium (Regosols)
Loamy Till (Luvisols)
Extremely Calcareous Loamy Till (Black Chernozem)
Sandy Lacustrine (Gleysols)
Sandy Eolian
Sandy Loam Lacustrine
Loamy Till with water worked surfaces
Sand and Gravel with Overlays
Loam Lacustrine (Gleysols)
Water
Extremely Calcareous Loamy Till (Brunisols and Dark Gray Chernozem)
Loamy Till (Gleysols)
Clayey Lacustrine (Luvisols and Dark Gray Chernozems)
Shallow Organic Fen Peat
Highly Calcareous Loamy Till (Brunisols and Dark Grey Chernozem)
Urban, Modified or Unclassified
Deep Organic Forest or Sphagnum Peat
Shallow Organic Forest Peat
Deep Organic Fen Peat
Sand and Gravel (Gleysols)
Highly Calcareous Loamy Till (Gleysols)
Variable Textured Alluvium (Gleysols)
Sand and Gravel with Overlays (Gleysols)
Marsh
Sandy Loam Lacustrine (Gleysols)
Limestone Bedrock
Clay over Shale Bedrock
Highly Calcareous Loamy Till (Black Chernozem)
Weakly Calcareous Sandy Loamy Till
Clayey Lacustrine (Gleysols)

Soil Types in the United States Portion of the Red River Basin							
ANTLER	COE	FOLDAHL	HILAIRE	MARYSLAND	POPPLETON	SPOTTSWOOD	WILLIAMS
ARVESON	COLVIN	FORADA	HIWOOD	MAUVAIS	QUAM	STIRUM	WILLOSIPPI
ARVILLA	CORLISS	FORDVILLE	HUOT	MAVIE	RADIUM	STRANDQUIST	WINGER
AUGANAUSH	CORMANT	FORMAN	INKSTER	MAX	RANSLO	STRATHCONA	WINTERFIELD
AUGSBURG	CRESBARD	FORMDALE	KARLSRUHE	MCDONALDSVILLE	RAUVILLE	SUGARBUSH	WOODSLAKE
AYLMER	CROKE	FOSSUM	KARLSTAD	MCINTOSH	REDBY	SUOMI	WURTSMITH
BALATON	DALBO	FOXHOME	KELVIN	MEEHAN	REINER	SVEA	WYANDOTTE
BANTRY	DARNEN	FOXLAKE	KENSAL	MEKINOCK	REIS	SVERDRUP	WYARD
BARNES	DEBS	FRAM	KINDRED	METIGOSHE	RENSHAW	SWENODA	WYKEHAM
BAUDETTE	DEERWOOD	FRIENDSHIP	KITTSON	MINNEWAUKAN	RENTILL	SYRENE	WYNDMERE
BEARDEN	DELAMERE	FULDA	KLOTEN	MOOSECREEK	RIFLE	TACOOSH	WYRENE
BELTRAMI	DICKEY	GALCHUTT	KNUTE	MOOSELAKE	ROCKWELL	TALMOON	ZAHL
BEMIDJI	DIVIDE	GARBORG	KRANZBURG	MORANVILLE	ROLETTE	TAWAS	ZELL
BENOIT	DONALDSON	GARDENA	KRATKA	MORITZ	ROLISS	THIEFRIVER	ZERKEL
BEOTIA	DORA	GARNES	LA PRAIRIE	MUSTINKA	ROLLA	TIFFANY	ZIMMERMAN
BERNER	DORAN	GILBY	LADELLE	NAHON	RONDEAU	TONKA	ZIPPEL
BIGSTONE	DOVRAY	GLYNDON	LALLIE	NARY	ROSCOMMON	TOTTEN	
BINFORD	EAGLEPOINT	GONVICK	LAMOURE	NAYTAHWAUSH	ROSEGLEN	TOWNER	
BOASH	EASBY	GRANO	LANGHEI	NEBISH	ROSEWOOD	TWO INLETS	
BOHNSACK	ECKMAN	GRAYCALM	LANKIN	NECHE	ROTHSAY	ULEN	
BORUP	ECKVOLL	GREAT BEND	LANONA	NERESON	RUSHLAKE	URANDA	
BOTTINEAU	EDGELEY	GRIMSTAD	LARSON	NEWFOLDEN	RUSO	URNESS	
BOWSTRING	EGELAND	GRYGLA	LEAFRIVER	NIELSVILLE	RYAN	VALLERS	
BRAHAM	EGGLAKE	GUNCLUB	LEHR	NORTHCOTE	SAGO	VANG	
BRANDSVOLD	ELMVILLE	GWINNER	LEMERT	NORTHWOOD	SAHKAHTAY	VELVA	
BRANTFORD	EMBDEN	HALVERSON	LENGBY	NOYES	SANDBERG	VENLO	
BULLWINKLE	EMRICK	HAMAR	LETCHER	NUTLEY	SAX	VERENDRYE	
BUSE	ENSTROM	HAMERLY	LINDAAS	OJATA	SEELYEVILLE	VIKING	
BYGLAND	EPOUFETTE	HAMLET	LINVELDT	OLDHAM	SERDEN	WABANICA	
CAMTOWN	ERAMOSH	HAMRE	LISMORE	OLGA	SIECHE	WABEK	
CASHEL	ESMOND	HANGAARD	LIZZIE	ONSTAD	SINAI	WAHPETON	
CASTLEWOOD	ESPELIE	HANTHO	LOHNES	OSAKIS	SIOUX	WALSH	
CATHAY	ESTELLINE	HARMONY	LOWE	OVERLY	SISSETON	WALUM	
CATHRO	EXLINE	HARRIET	LUDDEN	PARNELL	SKAGEN	WAMDUSKA	
CAVOUR	FAIRDALE	HASLIE	LUPTON	PEEVER	SKIME	WARROAD	
CHAPETT	FALSEN	HATTIE	MADDOCK	PELAN	SMILEY	WARSING	

CHILGREN	FARGO	HAUG	MAHKONCE	PENGILLY	SNELLMAN	WAUBAY	
CLAIRE	FAUNCE	HECLA	MANFRED	PERCY	SOL	WAUKON	
CLEARRIVER	FERNEY	HEDMAN	MANTADOR	PERELLA	SOUTHAM	WHEATVILLE	
CLEARWATER	FLAMING	HEGNE	MARKEY	PLAYMOOR	SPOONER	WILDWOOD	
CLONTARF	FLOM	HEIMDAL	MARQUETTE	POINSETT			

Appendix C – Modelling Workshop Supporting Information

Workshop Participants

Fargo, ND node

Chad Engels	Moore Engineering
Kyle Glazewski	EERC Grand Forks
Greg Thielman	Houston Engineering
Peter Mead	USDA-NRCS
Dave Jones	NRCA - Thief River Falls
Scott Jutila	U.S. Army Corps of Engineers
Bethany Kurz	EERC
Randy Gjestvang	ND State Water Commission
Mike Sauer	ND Department of Health
Michael J. Ell	ND Department of Health
Rick St. Germain	Houston Engineering, Inc.
Dan Thul	MN Dept of Natural Resources
Henry Van Offelen	MN Center for Env. Advocacy
Leah Thvedt	Red River Basin Commission
Janeen Stenso	Red River Basin Commission

Winnipeg, MB Node

Haitham Ghamry	Fisheries and Oceans Canada
Karl-Erich Lindenschmidt	Manitoba Water Stewardship
Sharon Gurney	Manitoba Water Stewardship
Conrad Stang	Greenland Consulting Engineers
Neil Marsden	Greenland Consulting Engineers
Jarrett Powers	Agriculture and Agri-Food Canada
Gordon W. Bell	Agriculture and Agri-Food Canada
Dave Morgan	Tetres
Jason Vanrobaeys	Agriculture and Agri-Food Canada
Greg McCullough	University of Manitoba
Vivek Voora	International Institute for Sustainable Development
Robin Gislason	Red River Basin Commission
Hank Venema	International Institute for Sustainable Development

Workshop Agenda

9:00 to 9:15

1. **Introductions**: The Winnipeg and Moorehead participants will have an opportunity to introduce themselves to each other.

9:15 to 9:45

2. **Presentation of Workshop Objective and Agenda and Project Overview**: The workshop roadmap and the general objective, plan and progress associated with the multi-purpose land and water investments project will be presented.

9:45 to 10:15

3. **Discuss needs and tools to facilitate integrated watershed management across the basin**: Provide examples where integrated watershed management was and could be facilitated by well-designed models and tools (Mississippi River Basin, Chesapeake Bay Watershed and Willamette River Basin). The discussion will centre on the themes of incorporating good science and utilizing state of the art communication methods to improve policy-making.

10:15 to 11:00

4. **Presentation on existing models and tools currently being used for integrative watershed management**: Models being used in the basin and elsewhere for integrative watershed modelling will be presented and discussed (SPARROW, INVEST, EcoServ, SWAT, HEC-RAS, Mike-11, HSPF). Discuss how existing models and tools can be built upon to facilitate integrative watershed management.

11:00 to 11:15 – Coffee break

11:15 to 12:00

5. **Discuss pre-workshop structured questions (1 to 3) and brainstorm decision support system elements (break-out groups)**: Reflections on the first three strategic questions will be shared and discussed within each break out group.

12:00 to 12:45 – Lunch break

12:45 to 13:45

6. **Debrief structured questions and brainstorm**: The reflections discussed will be reported back to the participants. An open conversation on the required elements to be incorporated into the decision support system will follow.

13:45 to 14:15

7. **Presentation of a potential architecture for integrated watershed management**: The general framework for a Red River Basin multi-purpose land and water investments decision support system architecture will be presented. The Open MI concept, which ensures compatibility with various modelling and data management structures, as well as the logic for land and water management that optimizes for economic and ecological well-being, will be presented.

14:15 to 15:15

8. **Discussion and critique of the architecture presented (break-out groups)**: How can the architecture be improved? What was overlooked? The discussion points will be reported back to the participants.

15:00 to 15:15– Coffee break

15:15 to 17:00

9. **Discuss a plan for moving forward on developing the decision support system (Question 4) (break-out groups)**: A strategy will be developed with input from the participants for developing the sophisticated decision support system for multi-purpose land and water investments. The discussion points will be reported back to the participants.

17:00 to 17:30

10. **Conclusion and wrap-up**: A summary of the workshop insights will be briefly presented. Opportunities to provide some final thoughts and comments will be provided.

Pre-Workshop Materials

Note: The background information was assembled using direct passages from documents and research compiled by the Red River Basin Commission, the International Water Institute and the International Institute for Sustainable Development.

Setting the Context

The Red River Valley is a 44,029.89 square kilometres (17,000- mi^2) piece of incredibly flat real estate occupying substantial portions of eastern North Dakota, northwestern Minnesota, northeastern South Dakota and southern Manitoba. One of the most productive agricultural areas in the world, the quality of the valley's cereal and feed grains, sugar beets, sunflowers, potatoes, and a host of other row crops is world-renowned (Krenz & Leitch, 1993).

The Red River Valley is the centrepiece for a larger Red River Basin (RRB). The RRB includes not only the old lake bed (Red River Valley) but also about an additional 72,519.67 square kilometres (28,000 mi^2) for a total of about 116,549.46 square kilometres (45,000 mi^2). Of the total, nearly 103,599.52 square kilometres (40,000 km^2) are located in the United States. The total drainage area of the RRB is shared by Manitoba (11 per cent), North Dakota (47 per cent), Minnesota (41 per cent) and South Dakota (1 per cent) (Krenz & Leitch, 1993).

The RRB slopes at about 15 cm per 1.61 km (0.5 foot/mile) average (39 to 6 cm/1.3 to 0.2 feet mile range) south to north along Red River in the valley portion and about 61 to 91 cms/1.61 km (2–3 feet/mile) east and west. At the edge of the basin, which is shaped like an oblong bowl that is very steep at the edges and very flat in the valley, the elevation raises sharply from 91 to 213 m (300 to 700 feet) above the valley floor as flows from south to north. This rise in elevation occurs in some parts of the basin in less than 8 km (5 mi).

The Building Capacity for Multi-Purpose Land and Water Investments in the Red River Basin project is a research initiative being developed by the International Institute for Sustainable Development (IISD) in partnership with the Red River Basin Commission (RRBC). The project can be described and examined by casting a spatial and political lens at the macro (Red River Basin), meso (state and provincial portions of the basin) and micro (municipalities) scales. Examining the RRB using these lenses provides a way to better understand the environmental and socio-political dynamics unfolding in the basin.

At the macro scale, the RRB is a complex multi-jurisdictional international basin that lacks a coherent and integrated basin-wide management plan. This need was accentuated by the 1997 flood, which devastated parts of North Dakota and Manitoba. Subsequent to the flood, a number of agencies worked towards developing tools and approaches to minimize flooding impacts of the Red River. The International Joint Commission Red River Task Force created the Red River Basin Decision Information Network, which provides useful data sets through an online map interface tool for local decision-makers. In addition, the RRBC developed and published a natural resources management framework in 2005, which lays out a vision and general method to implement a more integrative approach to managing the natural resources within the basin.

This basin-wide plan is often overlooked and superseded by government policies and economic activity carried out at the meso scale. Manitoba, North Dakota, South Dakota and Minnesota have varying policies for dealing with development and environmental protection. Agriculture is an important part of their economies and it has had a marked impact on the landscape and the water resources across the basin. Excessive nutrient loading primarily attributed to water and wind erosion from agricultural lands has greatly impacted surface water quality.[137] It is estimated that the RRB contributes 60 per cent of the phosphorus load that flows into Lake Winnipeg, which has become the most eutrophic large lake in the world. Once again the need to implement a more cooperative and integrated watershed resource management approach has been heightened.

At the micro scale, municipalities responsible for upholding their citizens' quality of life by delivering services face a number of fiscal, political and environmental context specific challenges. Municipalities are on the front lines of having to implement cost-effective solutions to deal with flooding and water quality issues. The services provided by natural environments offer municipalities opportunities to provide cost-effective services that can be evaluated using an ecosystem services approach. Mary Trudeau of Engineers Canada states, "To solve our infrastructure and affordability problems, we need to think in terms of the services offered and the needs to be addressed instead of business-as-usual pipes and pavement" (Mastromatteo, 2008, p. 47). Implementing an integrated watershed management plan across the basin could be achieved by striking the right balance between human-altered and natural landscapes, which may require investments in the preservation and restoration of natural environments on the landscape.

Beyond the micro scale, private landowners pay property taxes, enabling municipalities to deliver important services to their residents. Restoring natural environments through ecological infrastructure investments may impact a local government's (municipality or county) tax base by lowering living space and agricultural land. The cost-benefit analysis for multi-purpose land and water investments within a given local government will have to take this important aspect into consideration to determine whether or not it will provide a net benefit. Overall, this project aims to

[137] As one example of erosion and sedimentation in the RRB, the Sand Hill Watershed experienced heavy rains in June 2002 that produced the highest turbidity levels recorded over eight years of data collection. Based on a sampling run following these rains, it was estimated that the water flowing down the Sand Hill River was transporting the equivalent of nearly one ton of soil per minute, or the equivalent of 153 12-cubic-yard dump trucks per day, equating to a dollar value of $16,565 per day in lost topsoil based on the going price of $9 per cubic yard for black dirt. They ran the numbers for the sediment level they found on the Red River in the Climax area on that day as well, and came up with the equivalent of over 27 tons a minute going down the Red, which equalled 4,364 dump trucks a day at an estimated dollar value of $471,000 per day. Water quality variables are impacted by the volume of water and sediment load being carried; as with turbidity, total phosphorus and nitrate nitrogen levels were highest on those sample dates that coincided with significant rainfall events. This one example is repeated time and time again in the basin during spring runoff and during heavy summer rain falls.

enable investments that are more cost-effective and sustainable to uphold and improve the quality of life of the residents within the RRB.

Foundational Initiatives in the Red River Basin

The Red River Basin Decision Information Network (RRBDIN) and the work being done to enhance it (the Next Generation RRBDIN) provide foundational work for the development and establishment of a basin-wide Decision Support System (DSS) that provides for the implementation of IWM principles at the basin, as well as the local, scale.

The proposed DSS will provide additional insights for geographically prioritizing programs such as the Agricultural Water Enhancement Program (AWEP) being coordinated by the Red River Basin Commission. The lessons learned from the AWEP program will also provide insights on how best to design the DSS so that it can be complementary to the implementation of similar government programming efforts.

International Water Institute: Next Generation RRBDIN

The goal of the Next Generation RRBDIN effort is to meet the needs of local land and water managers in the U.S. portion of the RRB by developing an innovative suite of interactive and publicly available web-based DSS tools using the best available information. Overall, the next generation RRBDIN will provide tools to:

- Make more informed and defendable decisions,
- Take prudent corrective action to effectively manage the basin's natural resources,
- Minimize future losses due to flood and drought events,
- Ultimately improve the quality of life in the RRB, and
- Become an open framework where other organizations can contribute and maintain information.

Specifically, the next generation RRBDIN will enhance and provide functionality in the following areas:

1. **Develop and deploy the Next Generation RRBDIN**: Conceptual designs will be generated for the next generation RRBDIN with the help of stakeholders, the BasinViewer application will be modernized and Content Management System will be implemented with software and hardware upgrades. The Next Generation RRBDIN will be redeployed and stakeholders will be notified to solicit feedback.

2. **Geospatial coordination and planning for emergency management**: An emergency response viewer will be developed through geospatial workshops with Emergency Managers for improving coordinated responses to emergencies in the basin.
3. **Develop crowd sourcing and social networking applications**: Computer-based networking disseminates information immediately and reaches a broad and varied audience who can provide a positive feedback loop in the decision-making and support process. A number of crowd sourcing and network tools will be developed: Flood Assessment and Forecast Collaborative Community Network, River Watch Education Network, Emergency Responder Collaborative Practitioner Network, Natural Resources and Water Quality Project Practitioner Network.
4. **Expand the Flood Forecast Display Tool (FFDT) to the entire Red River mainstem:** The current FFDT will be enhanced by expanding it to the remaining portions of the RRB and improving existing and developing new functionalities (inundation mapping of additional tributaries and the mainstem, levee risk tool, road inundation and closure tool, flood static map tool and tributary and boundary condition flood hydrograph scenario manager and library).
5. **Water quality forecast tools**: A water quality impairment analysis tool will be developed to provide water quality estimates for low and high flow conditions and the existing riverine emergency management model for responding to spills will be updated.
6. **Project development and permitting evaluation tool**: Watershed Districts and Water Resources Districts implement and construct a variety of projects to reduce flood damages and enhance water quality and natural resources within the RRB. The purpose of this phase is to develop a watershed-scale geospatial tool that will identify and rank areas on the landscape to apply established flood damage reduction strategies and to assess the likelihood that a project proposed for an area will meet permit requirements.
7. **Maintenance plan, public outreach, project management and administration**: The overall project will include a five-year maintenance plan to keep the software and hardware up to date. Public outreach activities will also ensure that the Next Generation RRBDIN functionalities are communicated to various stakeholders in the basin. The project will be administered by the International Water Institute.

The Red River Basin Commission: Agricultural Water Enhancement Program

The strategies of this project are geared specifically to address the scope and intent to the AWEP provisions of the U.S. Farm Bill while at the same time addressing key land and water problems unique to the RRB. They include slowing the beach runoff, which causes erosion and poor water quality from sediments and nutrients. The entire project will target the following strategies:

1. **Sugar Beet Cover Crop Strategy**: The sugar beet cover crop strategy will pay producers to plant cover crops to protect sugar beet and other appropriate row crop land in the spring from wind erosion. This is critical as this erosion not only can destroy seeds and newly growing plants, which increases costs and reduces profits, but it also adds soil to drainage and waterway systems at the time of spring runoff and spring rains, thereby having an enormous impact on water quality in the surface water system.
2. **Beach Ridge Erosion Reduction Strategy**: The focus of this strategy is to reduce the speed and force of runoff, which is the cause of the erosion from the old beach ridge areas. This strategy will identify areas where there are ravines and similar runoff locations to implement total sediment containment by a holding section at the top, a tile line to the bottom and a grassed waterway if needed.
3. **Restricted Flow Sediment Pool Strategy**: The size and location of landowner culverts can have a significant impact on slowing and holding water on a short-term temporary basis. This will allow the sediment and nutrients impacting water quality the time to settle out and remain on the producers' land where they can be recaptured. By controlling flows to match downstream channel capacity, breakout flows across adjacent cultivated fields, which often cause severe erosion, will be minimized.
4. **Water Flow Retardation Strategy**: Many land-use practices such as buffer strips, wetland restoration and cover crops have provided positive benefits. This strategy, however, involves holding water in larger amounts and for longer periods of time. This will slow and hold water, improve water quality, hold water for supply and other uses, assist in flood damage reduction, provide habitat and impact conservation by reducing soil erosion.
5. **Other Activities Strategy**: Other activities that normally apply under EQIP will be utilized as appropriate, especially the buffer strip concept and agricultural erosion reduction strategies.
6. **Basin Coordination Strategy**: The basin coordination by RRBC will assist in development of criteria for funding, prioritization for funding, and basin-wide targeted strategies related to the top priority basin projects balanced with sub-watershed priorities.

Slowing water down and holding it for as long as possible where it falls will greatly enhance water quality and reduce erosion. Coupled with land-use changes related to cropping, cover crops, buffer strips and similar activities, this provides positive impacts on wind erosion and sediment-filled waterways. Stream bank erosion also adds large amounts of sediment impacting water quality throughout the basin. Holding and slowing water will also have a positive impact on water supply by allowing more groundwater recharge (that will impact rural wells and irrigation endeavours) and a longer flow of surface water, which is so critical to people and livestock for drinking water supplies.

Integrated Water Resource Management

Implementing integrated watershed management (IWM) can be facilitated by the use of models that examine the interactions among various social and environmental components within a watershed or basin. The models can be brought together within a DSS to provide valuable information for policy and decision-makers to implement IWM.

Three basins are briefly examined to determine how modelling was utilized to facilitate the implementation of IWM. The primary focus of these models was to help assess the condition of the basin to target resources for remediation and to develop and assess the advantages and disadvantages of future land-use change scenarios. The applicability of these various tools and how they can be used to implement IWM within the RRB (with a total surface area of approximately 127,000 km^2) is briefly discussed.

Willamette River Basin

Located in the State of Oregon the Willamette River Basin (WRB) has a total surface area of 29,728 km^2 and is bordered by the Coast Range and the Pacific Ocean to the east and the Cascades Range to the west. Settlement began in the basin in 1850, which brought agricultural cultivation and livestock rearing to the Willamette River valley. The area has since developed substantially, with logging operations and agriculture being the main land-use change drivers in the area.

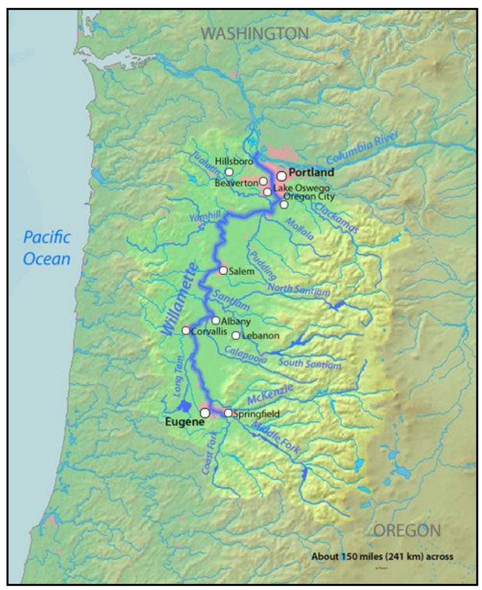


Figure AC1 – WIllamette river basin.

Two thirds of the basin is forested, mostly within its mountainous areas. Its population of approximately 2 million people in 2000 is projected to reach 4 million by 2050 and is concentrated primarily in its three largest cities, Portland, Eugene and Salem. Agricultural operations and urban environments cover 45 per cent and 11 per cent respectively of the valley area. With increasing demands for land and water resources, adequate land-use planning has become eminent to meet future requirements. Building on the first state-wide land use planning and growth management program based on a report entitled *The Willamette Valley: Choices for the future* commissioned in 1972, efforts are underway to investigate the advantages and disadvantages of various future land use scenarios.

The Pacific Northwest Ecosystem Research Consortium, consisting of 34 scientists from 10 different institutions, undertook an alternative futures analysis for the WRB. With the help of stakeholder groups, a current landscape based on 1990 LandSat imagery and three plausible scenarios for 2050 were established (see Figure 1).

Plan Trend: The Plan Trend 2050 scenario assumes current policies and trends continue. Due to Oregon's current conservation policies, landscape changes and projected environmental effects were relatively minor compared to the baseline.

Development: The Development 2050 scenario features a market-oriented approach facilitated by a loosening of current policies. This scenario results in a loss of 24 per cent of farmland and 39 per cent of wildlife lose habitat relative to the 1990 landscape.

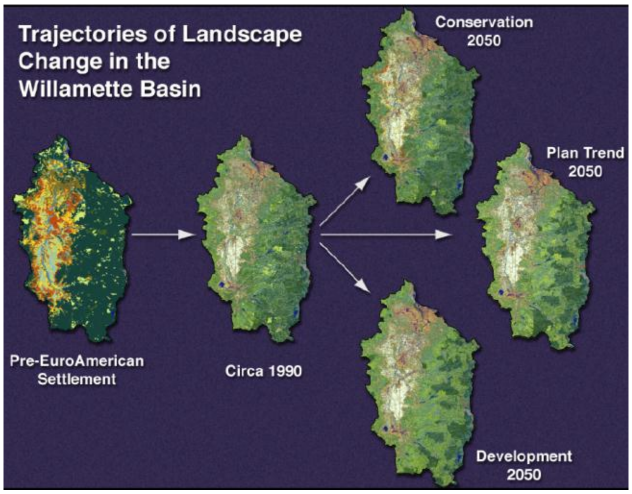


Figure AC2 – Willamette river basin land use scenarios (Bolte, Undated).

Conservation: In the Conservation 2050 scenario, ecosystem protection and restoration are prioritized. Most ecological terrestrial and aquatic indicators recovered 20–70 per cent of the losses sustained since Euro-American settlement

The land-use change scenarios were assessed using a variety of computer models. For example, water availability among competing uses was assessed using Watermaster; a wildlife population model entitled PATCH simulated wildlife abundance and distribution; regression models based on surveys estimated biotic changes in streams and the river. A total of six indicators (market value of commodity production, biodiversity conservation, storm peak management, soil management, water quality and carbon sequestration) were assessed to determine the desirability of each scenario. The results were discussed with stakeholders charged with developing a vision and restoration strategy.

Building on the scenarios work, an extensive agent-based modelling effort was undertaken within a sub-watershed of the WRB. EvoLand (Evolving Landscapes) is a modelling tool that supports the development of spatially explicit, actor-based approaches to landscape change and alternative futures analysis. EvoLand provides a framework for representing (Bizikova, 2009):

1. A landscape consisting of a set of spatial containers, or integrated decision units (IDUs), modelled as a set of polygon-based geographic information system (GIS) coverages containing spatially-explicit depictions of landscape attributes and patterns;
2. A set of actors operating on a landscape, defined in terms of a value system that couples actor behaviour to global and local production metrics and in part determine policies the actor will select for decision-making;
3. A set of policies that constrain actor behaviour and whose selection and application results in a set of outcomes modifying landscape attributes;
4. A set of autonomous process descriptions that model non-policy driven landscape change;
5. A set of landscape evaluators modelling responses of various landscape production metrics to landscape attribute changes resulting from actor decision-making.

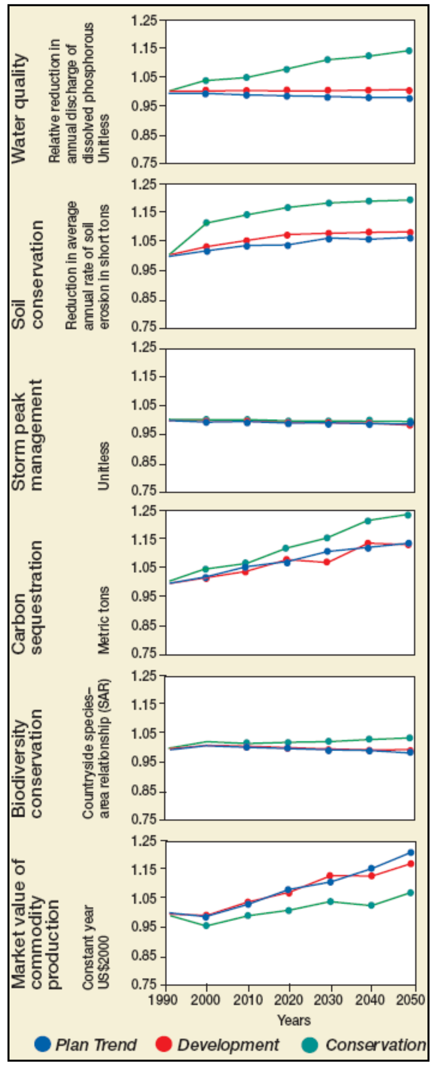


Figure Ac3 Land-use scenario assessment.

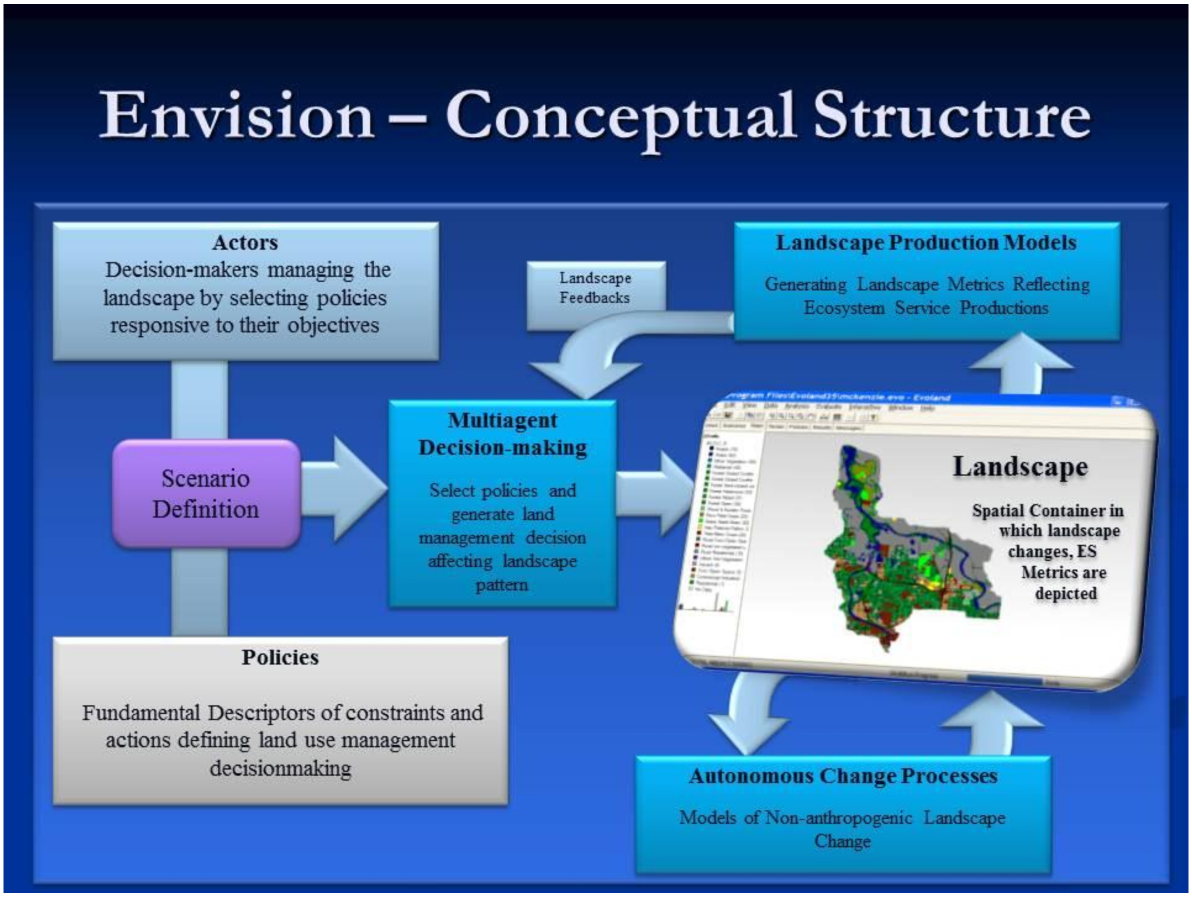


Figure Ac4 Evoland Model Architecture

The model has since been implemented in Puget Sound - Bainbridge Island 2025, Oregon, Southern Willamette (temperature credits), Portland (watershed planning) and the Okanagan Valley (biodiversity planning).

Mississippi River Basin

The Mississippi River Basin (MRB) is located in the heart of the United States and covers a surface area of approximately 3 million square kilometres, encompassing parts of 31 states. The basin drains extensive agricultural lands entraining high levels of nutrients from primarily agricultural nonpoint sources into the Gulf of Mexico. As a result, the northern shore of the Gulf of Mexico is afflicted with a hypoxic zone averaging 15,000 square kilometres in recent years. A number of programs have been initiated to reduce the nutrient loads flowing off agricultural lands within the basin and decrease the hypoxic zone in the Gulf.

Figure AC5 Mississippi River Basin and Gulf of Mexico hypoxic zone

A number of studies and modelling efforts have been undertaken within the basin to provide valuable insights for improving water quality within the basin and the state of the Gulf of Mexico. One particular effort entitled *From the Corn Belt to the Gulf* examined the societal and environmental implications of alternative agricultural futures. The project provided an innovative, integrated assessment of the agricultural and ecological systems in the Mississippi River Basin along with studies of local Iowa agricultural watersheds. Contributors from multiple disciplines discussed how agricultural policies have contributed to current environmental conditions, and developed alternative futures for agricultural landscapes that can generate more benefits (Bizikova, 2009).

The study, initiated in 1995, focused on two small Iowa watersheds (Walnut Creek, 5,600 hectares and Buck Creek, 8,800 hectares) within the most intensively farmed region of the basin (the Corn Belt within Minnesota, Wisconsin, Missouri and Iowa) to address the following question: Could plausible future agricultural landscape patterns and management practices deliver more environmental and societal benefits by 2025?

Policy scenarios were used to develop landscape futures for the watersheds. The landscape futures or scenarios emphasized commodity production, improved water quality and enhanced biodiversity. The cultural, ecological and economic performances for each landscape future were then assessed using a variety of techniques (Soil and Water Assessment Tool to determine water quality responses, Erosion Productivity Index Calculator to calculate return to crop yield, public perception spatially explicit method for landscape preferences, statistical estimate of change in habitat area and spatially explicit species population models). The study supported the need for and potential benefits associated with conservation efforts in the basin.

Table 11 – Summary of Results for Corn Belt to the Gulf Study[a]

Parameter	Present	Scenario 1	Scenario 2	Scenario 3
Policy emphasis	Produce commodities	Produce commodities and comprehensively apply BMPs[b]	Improve water quality and hydrologic regimes while producing commodities	Improve biodiversity while improving water quality and producing commodities
Water quality and effect	Baseline	Some improvement, but increased nitrate export	Substantial improvement	Substantial improvement
Return to land[c] or profitability	Baseline	Increase	Decrease	Increase
Farmer preference	Baseline	Decrease	Substantial increase	Substantial increase
Biodiversity	Baseline	Decrease	Substantial increase	Substantial increase
Overall effect	Baseline	Environmental and societal effects worsen overall, but return to land increases somewhat in some watersheds	Environmental and societal effects improve, but return to land decreases	Environmental and societal effects improve, and return to land increases somewhat in some watersheds

[a]This table was reproduced from Nassauer, Santelmann & Scavia (2007) p. 173.
[b]BMP stands for Best Management Practices and refers to environmentally friendly agricultural practices.
[c]"Return to land" refers to total watershed profits generated from agriculture.

Stemming from the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, established by the USEPA in 1997 to determine the causes of eutrophication and coordinate basin nutrient management, a number of initiatives have since been undertaken to provide resources and direction for remediation. The first action plan, released in 2001 by the National Science and Technology Council Committee on Environment and Natural Resources assessed the causes of hypoxia and identified nutrient loading in the basin as the main cause. This action plan spurred the development of programs that are being implemented at present. A second action plan was developed in 2008, and allows for a more adaptive strategy by requiring specific annual plans to be established for each year.

The Mississippi Basin Healthy Basin Initiative established in 2009, administered by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) consists of a 12-state (Arkansas, Kentucky, Illinois, Indiana, Iowa, Louisiana, Minnesota, Missouri, Mississippi, Ohio, Tennessee, and Wisconsin) effort to address the ecological issues in the Gulf of Mexico through voluntary implementation of agricultural conservation practices that will minimize nitrogen and phosphorous runoff in targeted watersheds. The initiative will channel USDA funding under the Farm Bill to the areas in the Mississippi basin where they can have the greatest impact on addressing basin priorities, while balancing state and local priorities at the same time. This initiative coordinates funds presently available from existing Farm Bill programs as well as dedicating US$80 million per year from 2010 to 2013 in targeted watersheds selected by each state, balancing both local and Mississippi basin priorities.

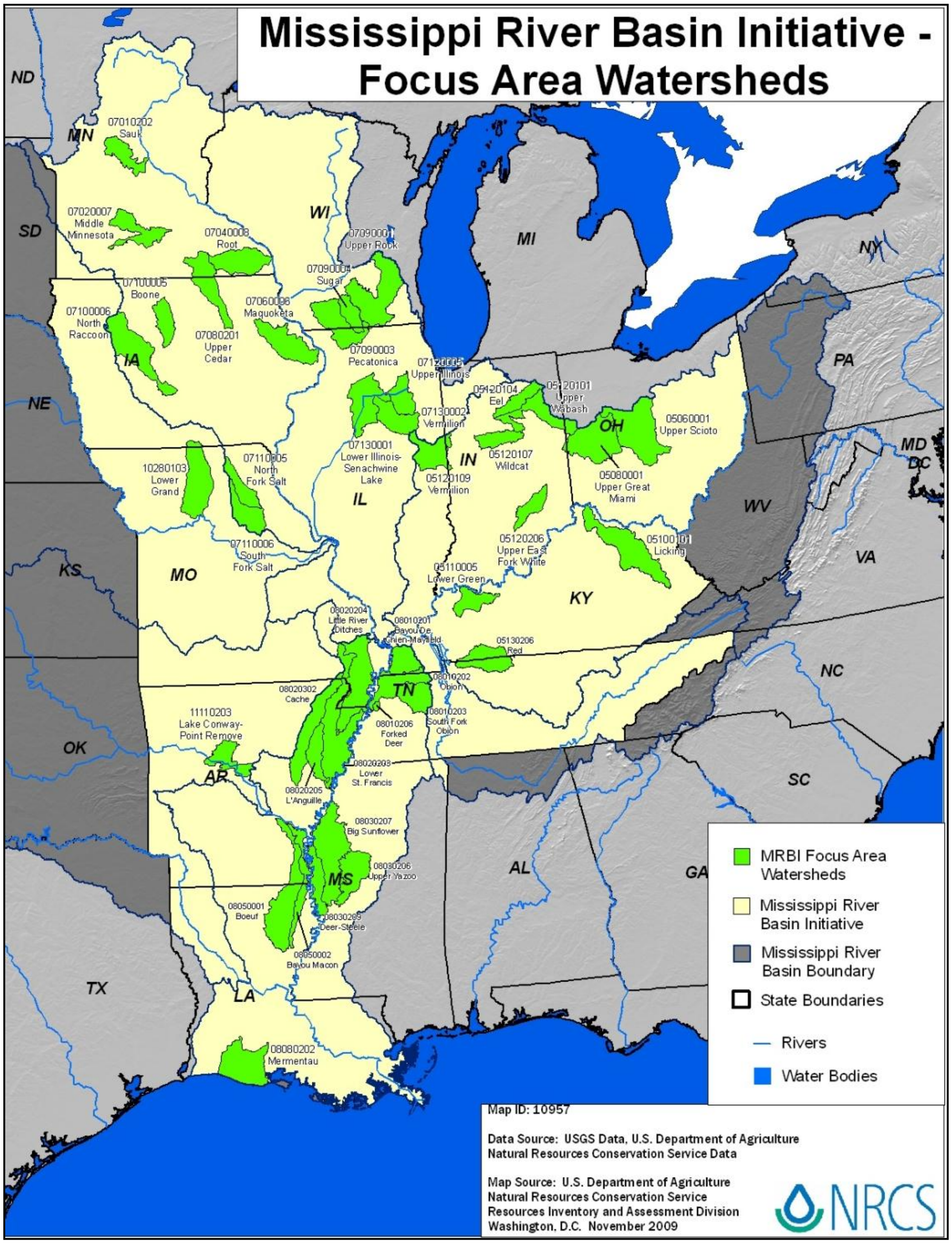


Figure Ac6 Mississippi River Basin Initiative: Participating states

The Chesapeake Bay

The Chesapeake Bay is the largest estuary in the United States and its multi-jurisdictional watershed comprises seven states (Pennsylvania, Virginia, West Virginia, District of Columbia, Maryland, Delaware, New York), covering an area of approximately 166,534 square kilometres (Breetz et al., 2004). The Bay has a long history of suffering from eutrophication due to increased population, agricultural runoff and industrial development. The states that make up the Bay have been working cooperatively to improve its water quality since 1983 under the Chesapeake Bay program (Breetz, et al., 2004).

Nearly one-quarter of the Bay watershed's land area is devoted to agricultural production, which contributes a relatively large percent of the nitrogen, phosphorous and sediments that contribute to the low oxygen levels in Chesapeake Bay.

A number of initiatives that aimed to characterize the severity of the problem and set nutrient reduction goals led up to the Chesapeake 2000 agreement. The agreement set a course for the Bay's restoration and protection. A watershed-based TMDL is being formalized and state-based targets will be determined to potentially enable inter-state nutrient trading. A USEPA-chaired committee with reps from USDA, Department of the Interior and others are focusing efforts on restoring clean water, conserving habitats and adapting to climate change. The World Resources Institute is supporting the development of the nutrient trading system for the bay.

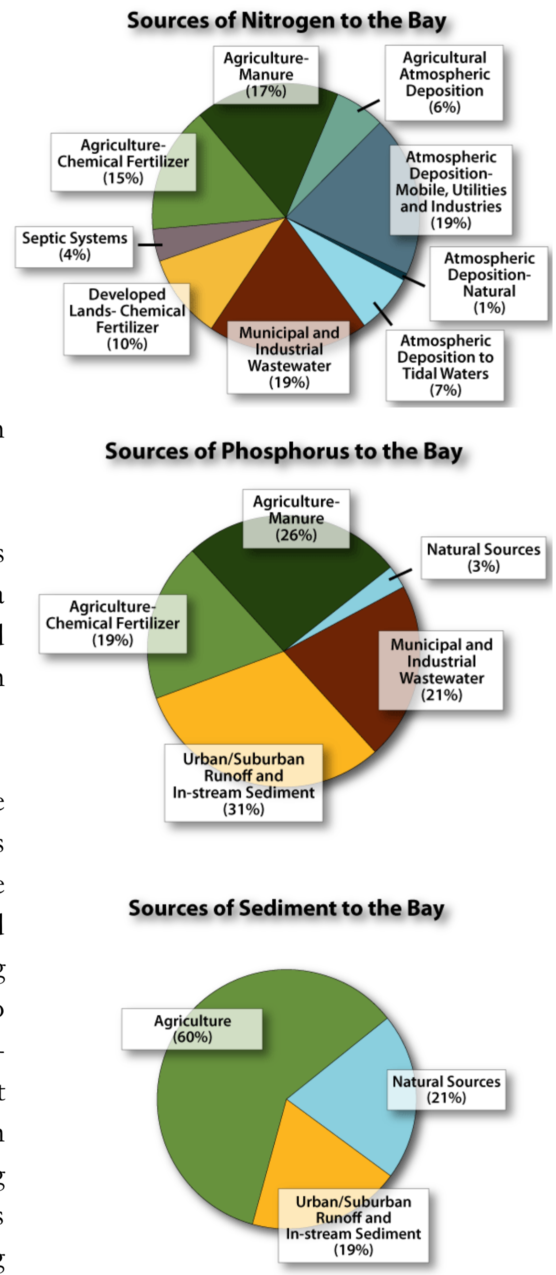


Figure Ac7 Sources of nitrogen, phosphorus and sediment to the Bay (Chesapeake Bay Program, 2009).

The Chesapeake Bay Watershed Initiative administered by the USDA Natural Resources Conservation Service (NRCS) was initiated in 2008 to assist agricultural producers with minimizing excess nutrients and sediments to restore, preserve and protect the Chesapeake Bay. The initiative offers financial and technical assistance to eligible agricultural producers to install practices to help control erosion and nutrient loading before they reach the Bay. Priority watersheds for BMP implementation have been identified by determining the nitrogen, phosphorus and sediment loading distribution across the basin using SPARROW modelling. This modelling work enables the USDA and NRCS to optimize their resources for water quality improvements.

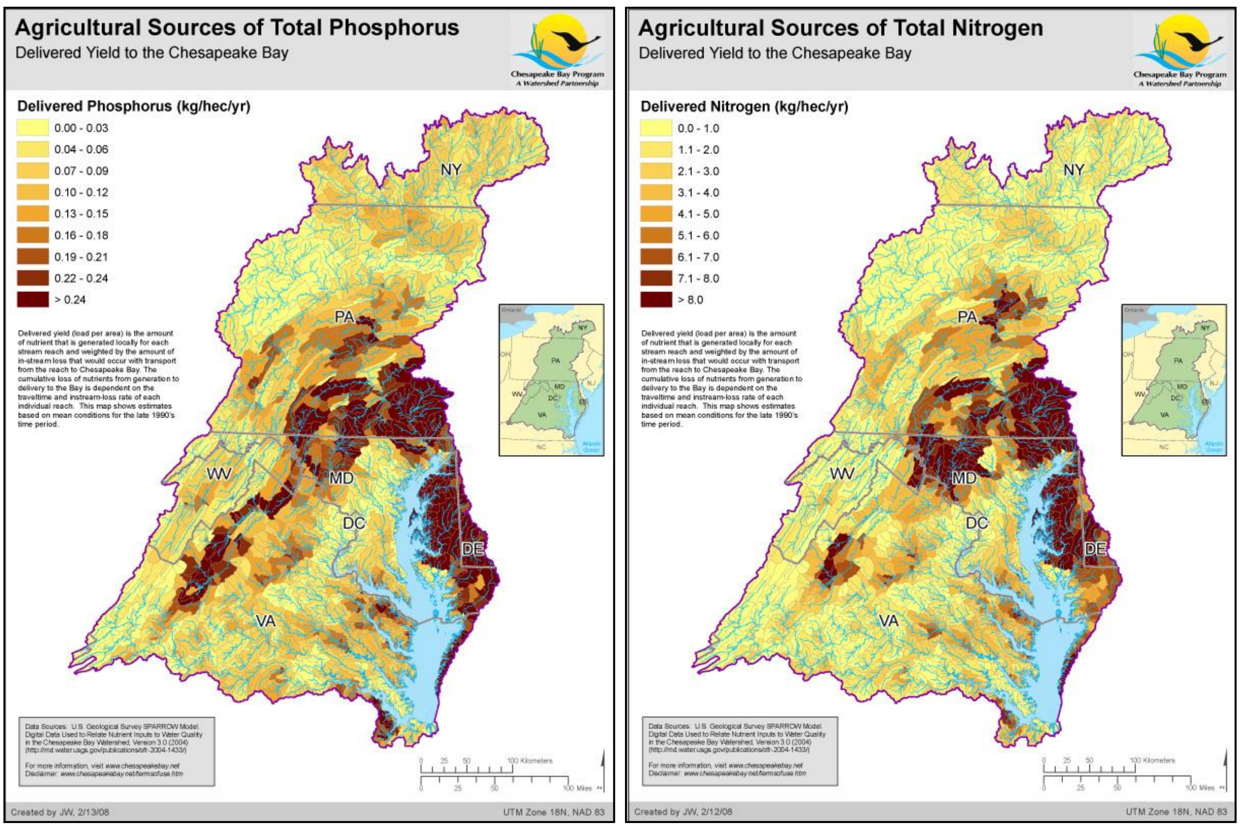


Figure AC8 SPARROW Nutrient Modelling (Natural Resources Conservation Service, 2009).

Applicability to the Red River Basin

The development of an agent-based model for representative sub-watersheds of the RRB may provide valuable policy development insights for the implementation of IWM. The ability to investigate how the decision-making parameters of stakeholders change the landscape over time can be invaluable for moving towards a preferred future.

Implementing a similar study to *From the Corn Belt to the Gulf* could potentially help mobilize various efforts within the basin to comprehensively fund multi-purpose land and water investments. For instance, a study entitled *From the Wheat Belt to the Lake* could examine how the landscape could be modified to improve agricultural productivity, flood mitigation, water quality and wildlife habitat.

The AWEP provides a precedent to move towards multi-purpose land and water investments by undertaking projects that achieve multiple goals namely, water and nutrient retention and groundwater recharge. A comprehensive DSS that builds on the AWEP and RRBDIN may provide a means to optimize government programming efforts to maximize their benefits.

Developing a DSS that can be used to identify and target priority areas to address specific issues, or a combination of issues, would be beneficial for implementing IWM within the RRB. SPARROW modelling, which can handle large sets of data and provide basin-wide insights for identifying the origins of nutrient loads, could be invaluable to address water quality problems within the basin. Providing the flexibility to map and overlay priority areas for other issues such as flooding and degraded wildlife habitats may assist in optimizing available remediation resources to address multiple issues and reap multiple benefits.

Models for Watershed Management

A number of tools and models are currently being used in the Red River basin to help with improving flood protection and water quality. These include SWAT, HEC-RAS, MIKE-11 and TELEMAC-2D. The SPARROW, Ecoserv and INVEST models, which are either used seldom or have yet to be utilized and implemented in the basin, are also described. These models provide building blocks along with other DSSs such as the next generation RRBDIN to develop a DSS for IWM and multi-purpose land and water investments.

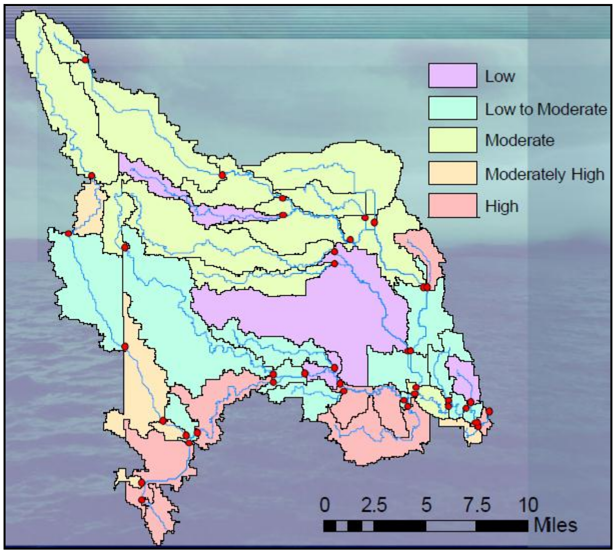


Figure AC9 Relative dissolved phosphorus contributions (Kurz, 2007)

SWAT: The Soil and Water Assessment Tool was developed by the United States Department of Agriculture to examine the impacts of land management practices in large complex watersheds. Specifically, the model provides insights into the effects of management decisions related to water, sediment, nutrient, pesticide yields. The influence that agricultural BMPs (such as buffer strips, no-till or reduced-till farming, fertilizer application rates and wetland restoration) can have on sediment, nutrient and pesticide loading can be examined using SWAT. The model components include: weather, surface runoff, return, flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, water transfer (Grassland Soil and Water Research Laboratory, 2010).

The model is currently being applied in the Red River Basin to examine sediment transport within a number of watersheds. For instance, the *Forest River Phosphorus Study* being conducting by the EERC's Red River Water Management Consortium is using SWAT to evaluate the phosphorus loading within sub-regions of the watershed. The model can be linked to other modelling efforts such as the MIKE-11 mainstem modelling and HEC-RAS modelling efforts (Kurz, 2007).

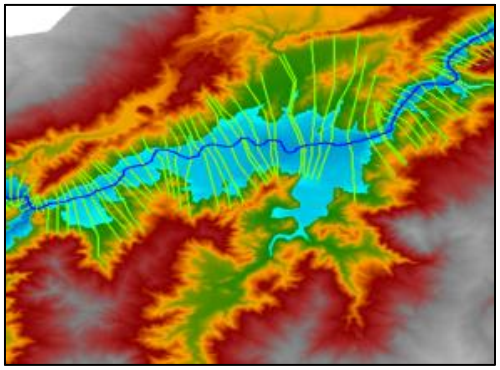


Figure AC10 Spatial Display of HEC-RAS Model Inundation Mapping Results (US Army Corps of Engineers, n.d.).

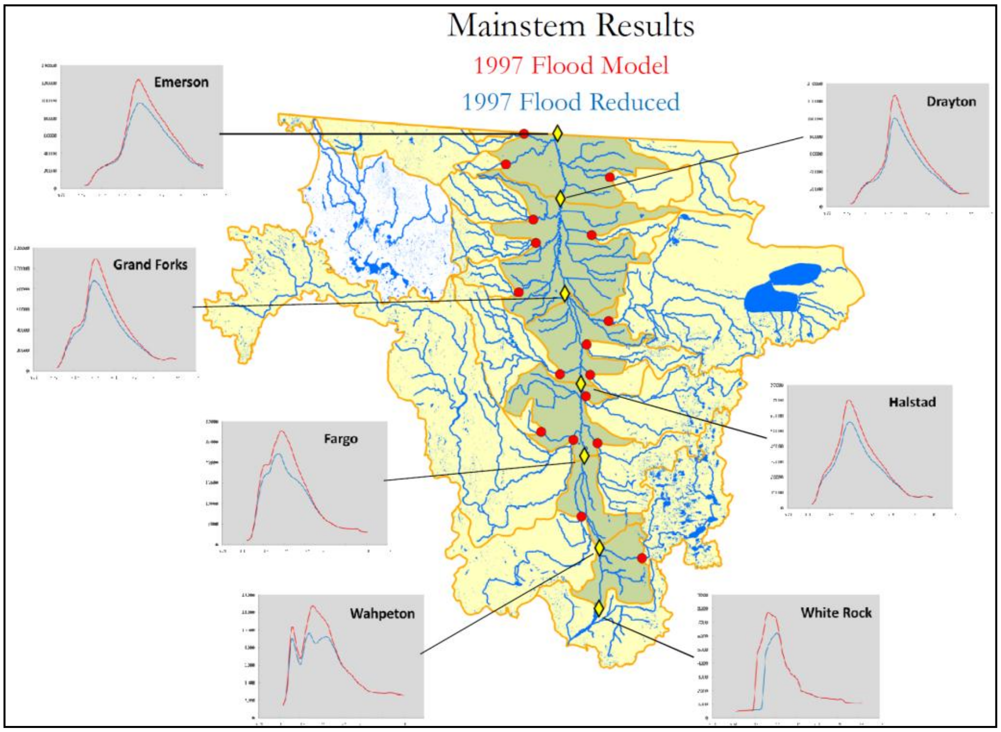
HEC-RAS: The Hydrologic Engineering Centers River Analysis System (HEC-RAS) is a hydrological simulation platform that allows for the modelling of one-dimensional steady flow, unsteady flow sediment transport/mobile bed computations and water quality modeling (US Army Corps of Engineers, n.d.). The model provides insights related to water flows and transport and fate of various water pollutants. The model displays result graphically and spatially. It is currently being used in various parts of the basin to provide hydrologic insights (flooding, water quality and ice flow behaviour). For instance, the model was used to examine potential flooding effects between the City of Winnipeg Floodway and Lake Winnipeg.

MIKE-11: Developed by the Denmark Hydrology Institute, the MIKE 11 model can be used generate a variety of hydrological information including (DHI, 2010):

- Flood analysis and flood alleviation design studies
- Real time flood forecasting
- Dam break analysis
- Optimization of reservoir and canal gate/structure operations
- Ecological and water quality assessments in rivers and wetlands
- Sediment transport and river morphology studies

- Salinity intrusion in rivers and estuaries
- Wetland restoration studies

The model is currently being used by the Red River Basin Commission to examine flood flow reduction strategies in the RRB. A mainstem model was developed and calibrated to simulate the 1997 spring flood. The peak and volume flow reductions required within each tributary was calculated to meet an overall 20 per cent flow reduction on the mainstem. It was determined that a combined flow reduction of 1,093 square kilometres (885,000 acre-feet) of water upstream of Emerson, MB would be required. Achieving this flow reduction could take many forms and will be dependent on local constraints. The Red River MIKE-11 model provides a starting point to develop flood flow reduction allocation process.



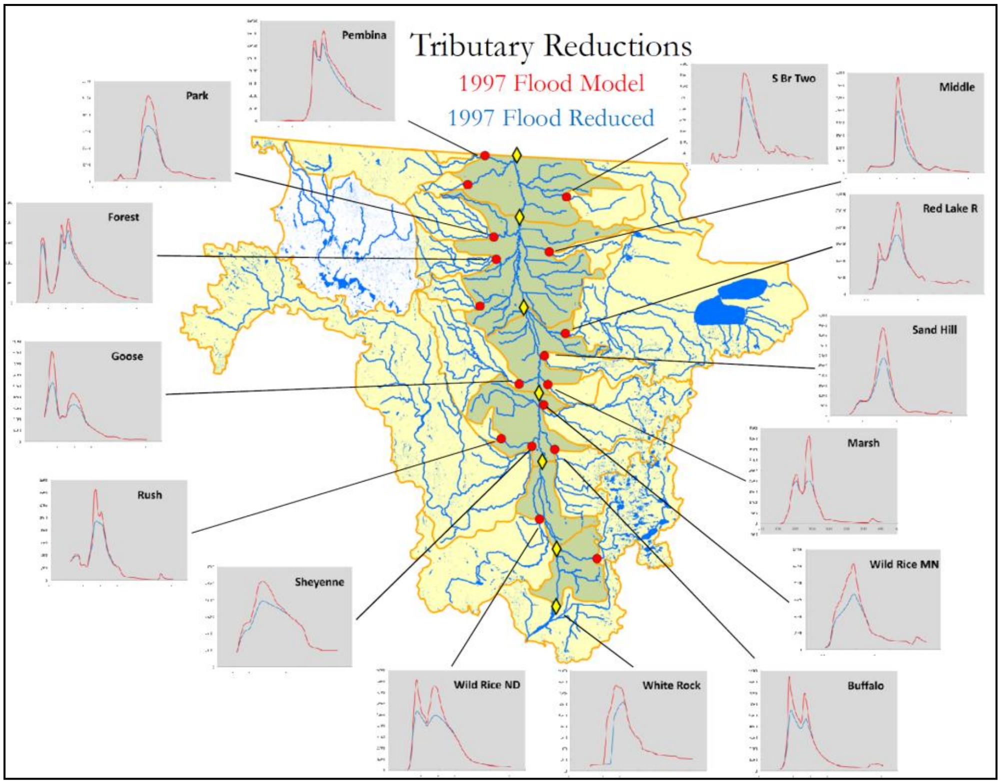


Figure AC11 MIKe-11 modelling flood flow reduction strategy (Anderson, 2010).

TELEMAC: The Telemac system is a package of numerical models that aim to provide hydrology insights for free surface water flows (Telemac-2D, Telemac-3D), sedimentology (Sisyphe, Telemac-3D), wave mechanics (Artemis, Tomawac), water quality (Telemac-2D) and underground flows (Estel-2D, Estel-3D). The Telemac-2D system is currently being used to model the hydrology of modifying the road dike in the Pembina River watershed. The model, which is built on modifiable FORTRAN sub-routines, simulates free-surface flows in two dimensions of horizontal space providing at each point of the mesh the depth of water and two velocity components (Telemacsystem, 2009). The Telemac-2D model can take into account the following variables (Telemacsystem, 2009):

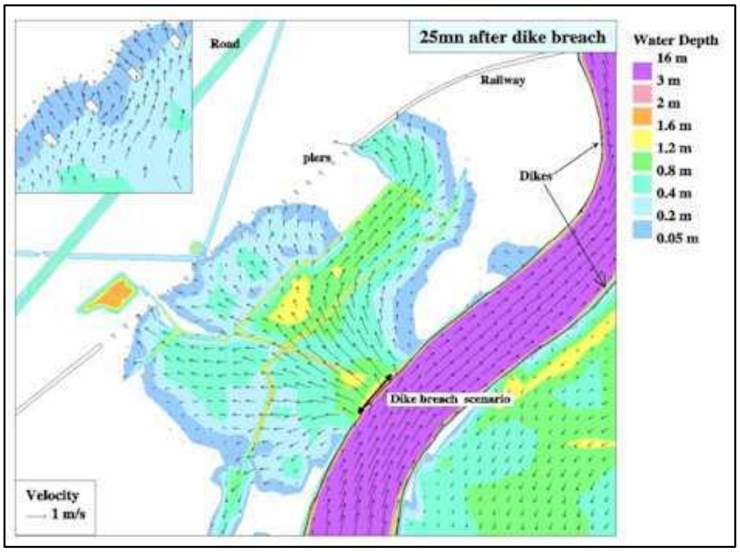


Figure AC12 TELEMAC-2D computational result (SOGREAH 1997): Hydrological simulation of a dike breach (Telemacsystem, 2009)

- Propagation of long waves, taking into account non-linear effects
- Bed friction
- Influence of Coriolis force
- Influence of meteorological factors: atmospheric pressure and wind
- Turbulence
- Torrent and river flows
- Influence of horizontal temperature or salinity gradients on density
- Cartesian or spherical coordinates for large domains
- Dry areas in the computational domain: intertidal flats and flood plains
- Current entrainment and diffusion of a tracer, with source and sink terms
- Monitoring of floats and Lagrangian drifts
- Treatment of singular points: sills, dikes, pipes.

A few examples of Telemac-2D implementation include examining the impacts of various types of construction projects, dam breaks, flooding studies, pollutant transport mechanisms. Stochastic events such as reservoir failures and natural disasters can also be investigated using the model.

SPARROW: Developed by the USGS, the SPatially-Referenced Regression On Watershed attributes (SPARROW) model integrates monitored data with landscape information to predict long-term average values of water characteristics at various spatial scales ranging small watersheds to large basins. Specifically, the model uses statistical methods to spatially measure water quality based on upstream discharge sources and watershed properties (soils, precipitation and land cover, steam channel and velocity). The SPARROW model can generate water characteristic estimates for areas with little-to-no monitoring information. The results can be mapped showing constituent loadings at multiple scales (from single streams to large basins).

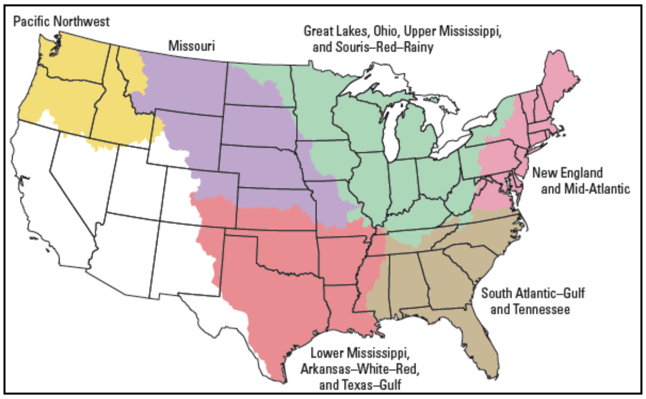


Figure AC13 SPARROW modelling for five major regions (Preston, Alexander, Woodside, & Hamilton, 2009).

Large SPARROW models have been completed to examine the nutrient transport within the Mississippi River Basin and the Chesapeake Bay Basin. The USGS is currently in the process of improving the accuracy and interoperability of the SPARROW model so that it can be applied to six major regions of the United States, including the RRB.

ECOSERV: Developed by a multi-disciplinary scientific team within the USGS, Ecoserv provides information on the change of ecosystem services under climate and land-use change. The model has been applied in South Dakota and has yet to be implemented in North Dakota and Minnesota.

INVEST: The Integrated Valuation of Ecosystem Services and Tradeoffs model was developed by the Natural Capital Project to provide information on the potential benefits of land uses by mapping the delivery and distribution and economic value of ecosystem services. The model helps users visualize how land-use changes will influence the ecosystem services provided by the landscape

Various landscape configurations can be fed into the model to examine their ability to supply a suite of ecosystem services, which can be measured in biophysical and economic terms. The results are presenting using maps, tradeoff curves and balance sheets. The model illustrates how resource management choices will impact the economy, the environment and human well-being (The Natural Capital Project, 2006). The model provides three tiers which provide differing levels of information based on the data available (Natural Capital Project, 2006):

- **Tier 1** is fundamentally simple, provides a relative sense of the level of services provided across the landscape and requires few input data.
- **Tier 2** provides a level of certainty needed to model economic terms realistically, but it needs more input data.
- **Tier 3** is capable of including land-cover and use dynamics, plant community succession, nutrient balances, and similar complex processes when the input data are available. Tier 3 usually includes existing models like the CENTURY model for carbon cycling or Ecosim for biodiversity modelling.

CRHM: The Cold Regions Hydrological Model (CHRM) platform is a flexible object-oriented modelling system that incorporates a number of physically based algorithms of hydrological processes of considerable uncertainty. These algorithms were generated based on integrated field and modelling research to characterize cold-climate hydrological behaviours such as snow redistribution by wind, snow interception, sublimation, snowmelt, infiltration into frozen soils and hillslope water movement over permafrost. The model was developed by the University of Saskatchewan and has been applied in the semi-arid Prairie and the Boreal Forest regions of Canada. The CHRM cold climate hydrology algorithms may be well suited to the cold regions of the RRB, thus providing more hydrological modelling accuracy.

Proposed Decision Support System Architecture

Lake Winnipeg Ecosystem Service Platform (LES-P) will provide a solutions platform for policy-makers and watershed managers to maximize the economic co-benefits of investing in ecosystem services for nutrient management. Key contributions of the LES-P of primary value to the LWBI will be:

- An Ecosystem Service Valuation (ESV) analytical module to quantify economic co-benefits of nutrient management activities, as well as carbon sequestration and biodiversity benefits
- A high-resolution parallel architecture for large basin analysis, demonstrated with the *CanWet* watershed model and OPEN-MI protocols
- A watershed design suite for use by local watershed planners for designing cost-effective, robust nutrient management strategies

Project Architecture

Our goal is to develop a state-of-the-art architecture for policy and programming decisions in large, heterogeneous basins such as the LWB. The key architectural concept is the separation of the watershed analysis engine from the underlying hydrologic and geographic data—here we leverage the large investment that Environment Canada has made in developing the Lake Winnipeg Information Portal, and we leverage the Greenland Technology Group's investment separating the *CanWet* watershed analysis engine from the underlying data model. This modular approach allows analysts to model the entire basin system as a set of parallel watersheds and allows implementation on high-performance computational clusters[138] and thus leverage IBM Canada's experience with large computational systems integration.[139] The parallel implementation provides three critical benefits for policy analysis and management:

- The use of high resolution input data (such as LIDAR elevation data) necessary for the accurate representation of ecosystem service features such as wetlands and drainage networks[140]
- The behaviour of the entire basin system can be analyzed under different policy scenarios—including policy benefit-cost ratio estimation; for example, the ESV benefits of a basin-scale policy of riparian corridor and wetlands restoration compared to BMP implementation costs using different economic instruments.
- Stochastic analysis is practical and allows analysts to convey to policy-makers key uncertainties. Essentially, system performance can be analyzed with varied inputs and varied parameters, for example the robustness of a nutrient management policy under different plausible climate change scenarios can be readily tested.

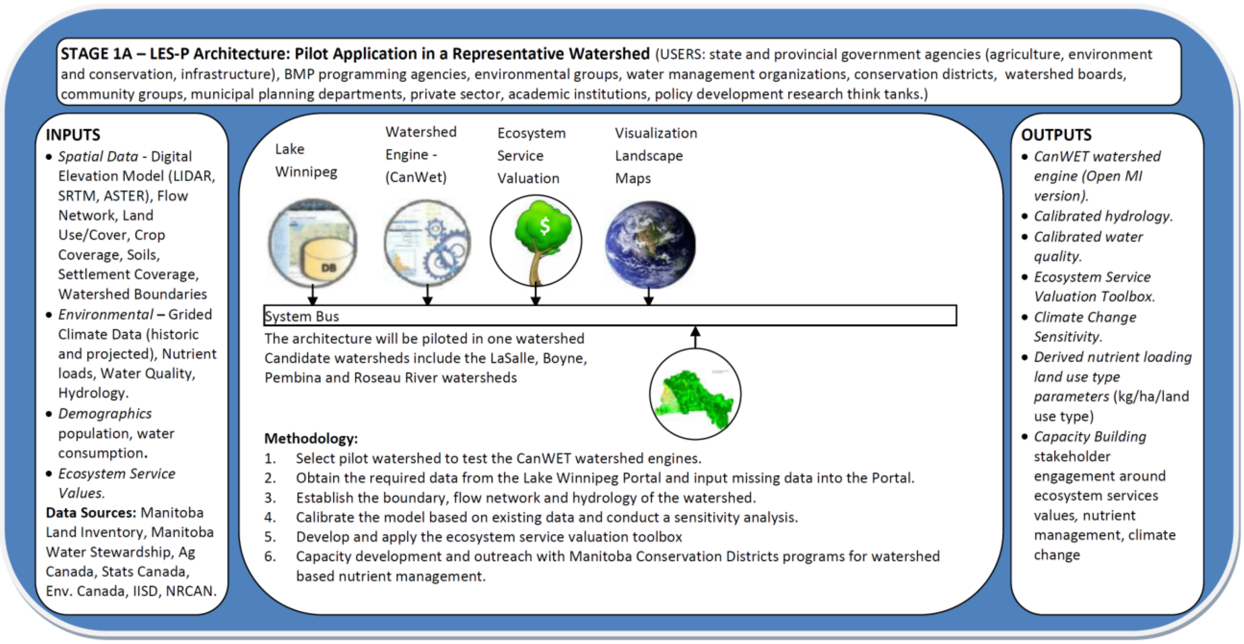
A fundamental design feature of LES-P will be access to the full suite of analytical tools at the watershed and sub-watershed planning levels. For example, a watershed planner in Manitoba will have full access to the stochastic and ecosystem valuation tools and will be able to analyze the performance of a portfolio of field-scale beneficial management practices under different assumptions of BMP efficiency and/or under different climate scenarios. Key design principles for the LES-P project will be conformance with Open-MI,[141] OGC and CGDI[142] design and data protocols.

[138] Representative Canadian high performance cluster capacity described here: http://www.hpcvl.org/
[139] See for example: http://www.hpcwire.com/offthewire/17869154.html
[140] IISD and Ducks Unlimited Canada (DUC) have both quantified the significant loss of ecosystem services in the LWB through the clearing of forests, conversion of prairie grasses and drainage of permanent and seasonal wetlands—analysis requiring high resolution LIDAR data: "Geospatial Data in the Lake Winnipeg Basin", B. Tedford, Canada LWBI Information Portal and Modelling Workshop, November 18, 2009.
[141] An international standard for land and water physical model interoperability used by Environment Canada: http://www.openmi.org/.
[142] The Open Geospatial Consortium http://www.opengeospatial.org/ develops standards for geospatial services that have been adopted by the Canadian Geospatial Data Infrastructure and applied by EC in LWB Portal development.

Development Strategy

The full development of LES-P will occur in three discrete stages with extensive user and stakeholder consultation at each stage.

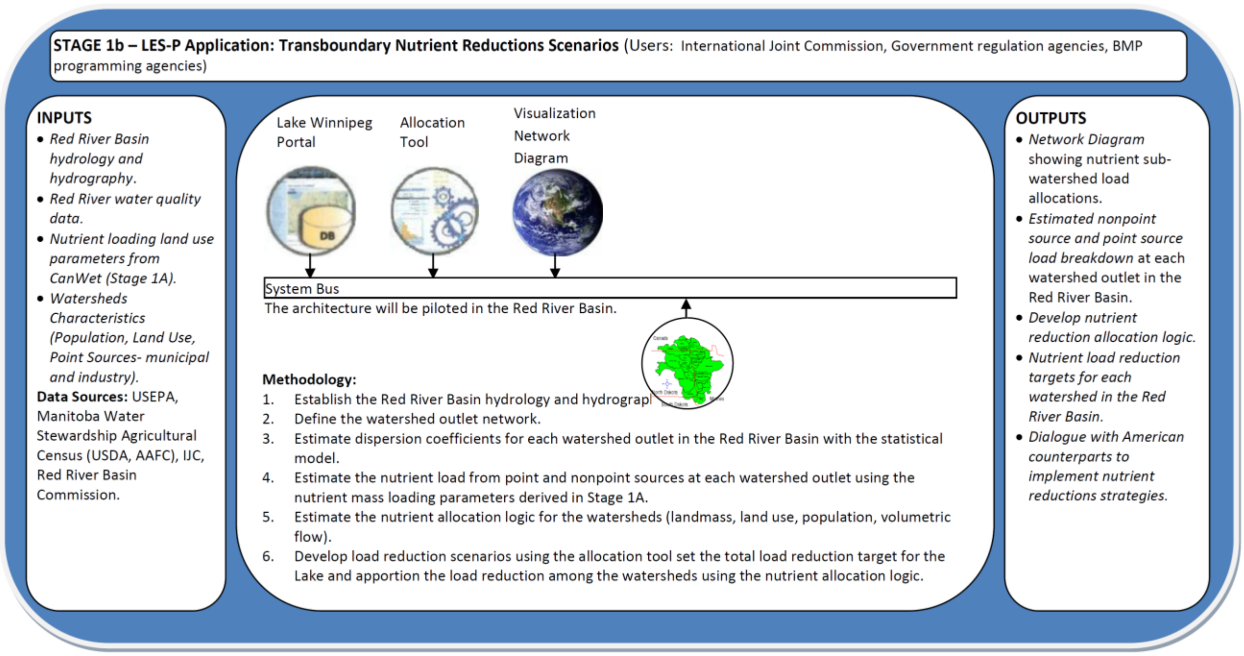
Stage 1A LES-P Architecture Pilot: Application in a single representative watershed



Key issues addressed: At this stage, we demonstrate the architectural proof-of-concept integrating portal data with modular implementation of the CanWet watershed engine based on OPEN-MI standards in a representative watershed. We also demonstrate the Ecosystem Service Valuation Toolbox (ESVT). The ESVT facilitates a comprehensive cost/benefit analysis of alternative ecosystem management strategies for policy development and planning purposes.[143] Our demonstration watershed will also be used as the context for initial outreach with the Manitoba Conservation Districts Program on the principles of watershed-based nutrient management strategies.

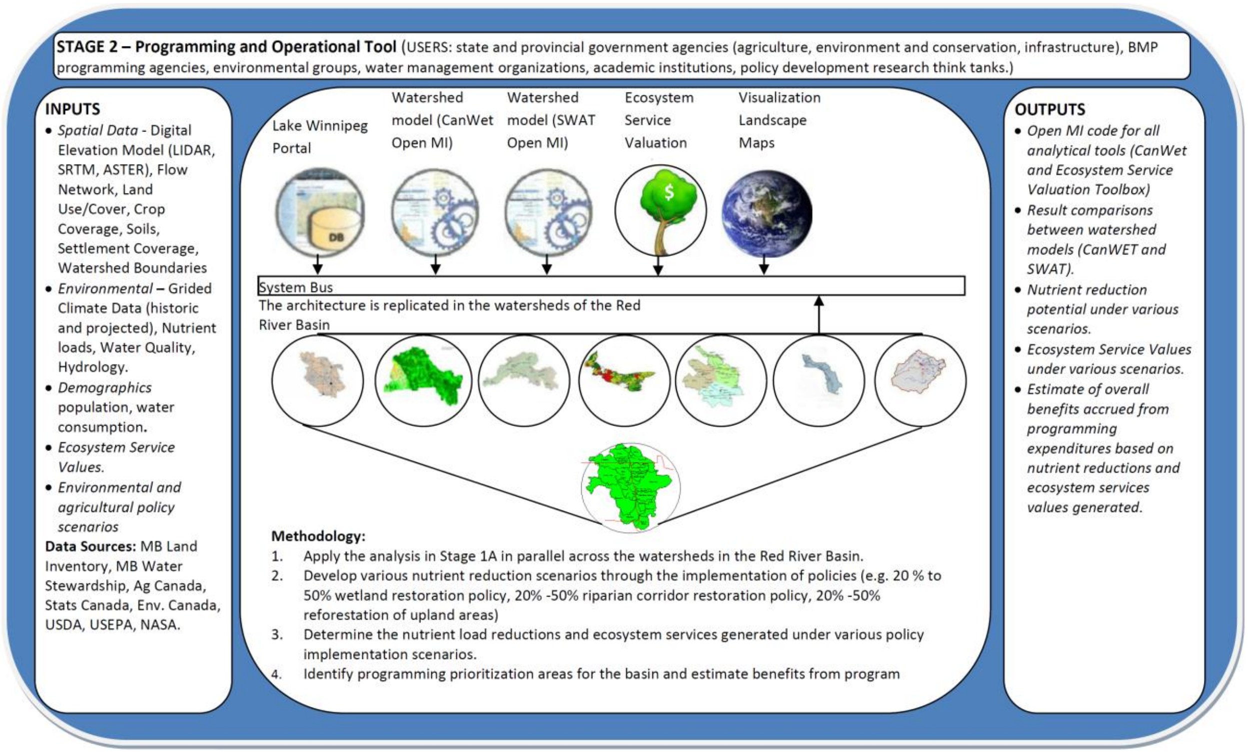
[143] The ESVT will provide a similar function to the *InVest* model developed for analyzing alternative development scenarios in the Willamette Basin in Oregon (Nelson et al., 2009)

Stage 1B: LES-P Application: Transboundary nutrient reduction scenarios



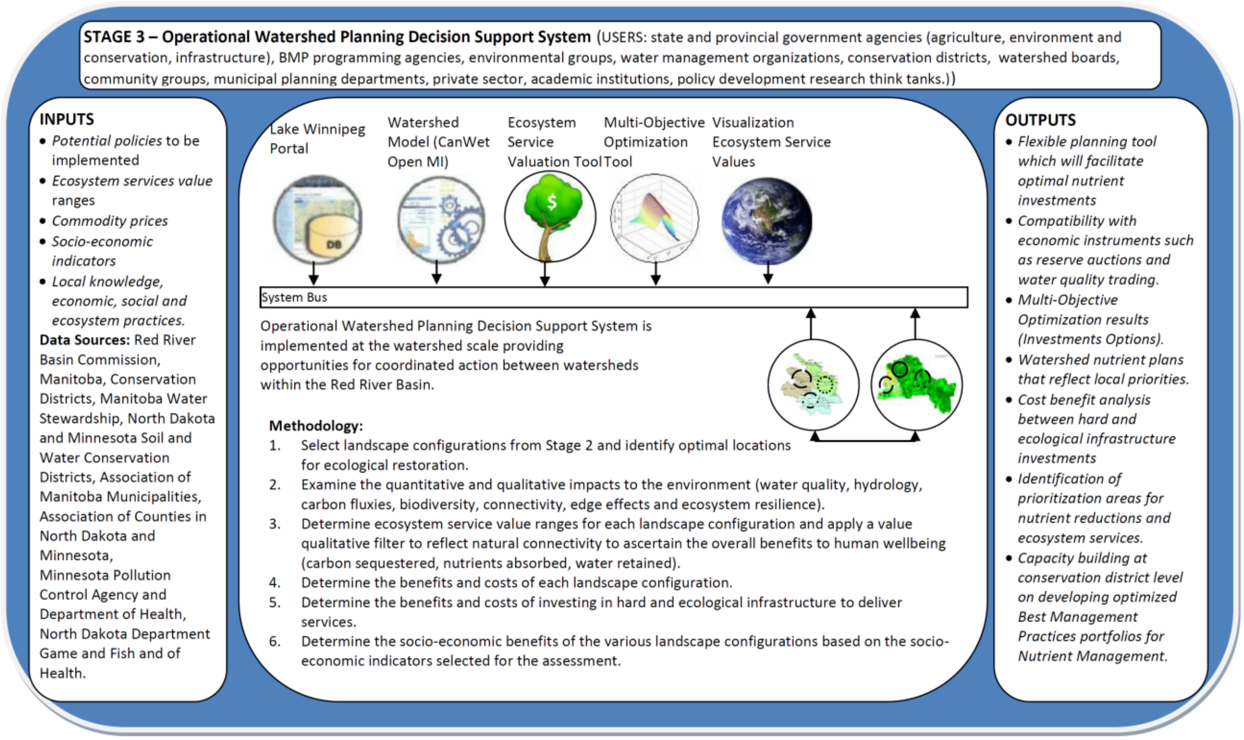
Key Issues Addressed: LES-P will facilitate an informed transboundary dialogue on the implications of Lake Winnipeg nutrient loading targets. We will answer fundamental questions such as, if the target P reduction on Lake Winnipeg is x tonnes of P, or the target average P concentration of the Red River at Emerson is y mg/l, what are the implied nutrient load reductions in the constituent sub-watershed of the basin? We will use a hybrid statistical model for the Red River Basin and simplified watershed nutrient loading parameters estimated in Stage 1. Sub-watershed nutrient reductions targets will consider area, population and the local structure of nutrient sources. Our analysis will be illustrative rather than prescriptive, but has nonetheless been identified as a high priority by the Aquatic Ecosystems Committee of the International Joint Commission. Initiating this dialogue is a very important element of a renewed IWRM vision for the RRB, with major implications for Lake Winnipeg management.

Stage 2: LES-P Architecture applied at basin scale



Key Issues Addressed: By applying LES-P using a parallel architecture, we make possible basin-scale policy analysis, with high-resolution identification of ecosystem services. We can conduct benefit-cost analysis of alternative nutrient management scenarios at basin scale; for example, the nutrient reductions associated with a basin-scale policy of riparian corridor protection, and the robustness of the policy evaluated against alternative climate scenarios. We also demonstrate that LES-P can accommodate alternative watershed analysis engines, by integrating an Open-MI version of SWAT, which is widely used in the U.S. portion of the basin. This stage of analysis will inform government policy development at federal, provincial and state levels for efficient nutrient management and we anticipate conducting policy workshops in the U.S. and Canada.

Stage 3: Operational watershed planning DSS using the LES-P architecture



Key Issues Addressed: At this stage, we exploit the major investment the Natural Resources Council and Greenland Technologies have made linking the CanWet watershed analysis engine with *NutrientNet,*[144] a tool developed for estimating the nutrient -reduction benefits associated with BMPs at field scale. Stage 3 is essentially a watershed nutrient investment decision support tool, which allows the planner to evaluate benefits and cost of alternative investment strategies. The watershed planner can evaluate the tradeoffs between technology investments and ecosystem service investments. The planner also has access to planning tools to construct cost-efficient BMP portfolios.

[144] NutrientNet enables nutrient and ecosystem service trading between point and nonpoint nutrient sources. It was developed by the World Resources Institute to address eutrophication of Chesapeake Bay by estimating the influence of agricultural BMPs and ecosystem management at field-scale on downstream nutrient loads.

Appendix D – Agriculture and Water Enhancement Program Expenditures

The following tables provide information related to the expenditures planned for the Agricultural Water Enhancement Program for the Red River Basin. The data is broken down into jurisdiction and project type.

Table AD1 2010 Red River AWEP Selected Project Summary – Minnesota, North Dakota, South Dakota

73 contracts obligated for$ 2,443,667
166,333 (reserve for cost overruns and technical assistance)
$2,610,000

Funding by Enhancement Activity	$ Obligated	No of contracts*
Sugar Beet Cover Crop	$343,074	24
Beach Ridge Erosion Reduction	**$586,251**	18
Restricted Flow Sediment Pool	$869,091	21
Water Flow Retardation	$234,268	6
Stream Bank Erosion	$314,207	5
Other	$96,776	6
Total	**$2,443,667**	
*Some contracts addressed more than one enhancement activity		
Funding by Selected Practices:	**Units**	**$ Obligated**
Cover Crop	20037 Ac.	$331,121 (3 years of Ac.)
Dam	4 No.	$180,000
Grade Stabilization Structure	17 No.	$162,646
Stream bank and Shoreline Protection	2,300 Ft.	$267,900
Water and Sediment Control Basin	16 No.	$33,000
Dike	25691 Ft.	$533,726
Pasture and Hayland Planting	553 Ac.	$13,685
Structure for Water Control	1 No.	$1,116
Residue Management - No Till, Strip Till	3,506 Ac.	$82,442
Grassed Waterway	59 Ac.	$175,284

Table AD2 2010 Red River AWEP Selected Project Summary – North Dakota

42 contracts obligated for $1,156,126.80

Funding by Enhancement Activity	$ Obligated	No of contracts*
Sugar Beet Cover Crop	$161,514	14
Beach Ridge Erosion Reduction	$0	0
Restricted Flow Sediment Pool	$851,019	20
Water Flow Retardation	$94,065	4
Stream Bank Erosion	$0	0
Other	$49528	4
*Some contracts addressed more than one enhancement activity		
Funding by Selected Practices:	**Units**	**$ Obligated**
Cover Crop (16 contracts)	14,000 Ac.	$190,000 (3 years of acres)
Grade Stabilization Structure (4 contracts)	4 No.	$67,331
Streambank and Shoreline Protection (1contract)	400 Ft.	$12,254
Dike (14 contracts)	24,091 Ft.	$511,342
Grassed Waterway (6 contracts)	57.8 Ac.	$167,054

Table AD3 2010 Red River AWEP Selected Project Summary - Minnesota

28 contracts obligated for $1,201,738

Funding by Enhancement Activity	$ Obligated	No of contracts*
Sugar Beet Cover Crop	$181,560	10
Beach Ridge Erosion Reduction	$586,251	18
Restricted Flow Sediment Pool	$18,072	1
Water Flow Retardation	$140,203	2
Stream Bank Erosion	$236,634	3
Other	$39,018	1
*Some contracts addressed more than one enhancement activity		
Funding by Selected Practices	**Units**	**$ Obligated**
Cover Crop	6037 Ac.	$141,121
Dam	4 No.	$180,000
Grade Stabilization Structure	13 No.	$95,315
Streambank and Shoreline Protection	1,225 Ft.	$178,073
Water and Sediment Control Basin	16 No.	$33,000
Dike	1600 Ft.	$22,384
Pasture and Hayland Planting	553 Ac.	$13,685
Structure for Water Control	1 No.	$1,116
Residue Management - No Till, Strip Till	3,506 Ac.	$82,442

Table AD4 2010 Red River AWEP Selected Project Summary – South Dakota

3 contracts obligated for $85,803.00

Funding by Enhancement Activity	**$ Obligated**	**No of contracts***
Sugar Beet Cover Crop	$0	0
Beach Ridge Erosion Reduction	$0	0
Restricted Flow Sediment Pool	$0	0
Water Flow Retardation	$0	0
Stream Bank Erosion	$77,573	2
Other – Grassed Waterway	$8,230	1
*Some contracts addressed more than one enhancement activity		
Funding by Selected Practices	**Units**	**$ Obligated**
Cover Crop	0	$0
Grade Stabilization Structure	0	$0
Stream bank and Shoreline Protection(2contracts)	675 Ft.	$77,573
Dike	0	$0
Grassed Waterway (1 contract)	1.2 Ac.	$8,230