Applying the Water Soft Path Concept for Agro-ecosystem Adaptation in Prairie Canada

Matt McCandless[1], Henry David Venema[1], David B. Brooks[2]

[1] International Institute for Sustainable Development, Winnipeg, Canada
[2] Friends of the Earth Canada, Ottawa, Canada

Abstract

A soft paths strategy for water involves shifting from managing the supply of water, to reducing existing water demand while increasing efficiency. Water soft paths study involves defining a state of future water sustainability and a charting path to achieve it. In order to apply the concept of water soft paths to a region such as the Canadian Prairie Province of Manitoba, which has a low population density, intensive agricultural production, and a highly variable and seasonal water regime; it is necessary to determine the present state of Manitoba's watersheds. The International Institute for Sustainable Development has been studying the potential of a water soft paths strategy for southern Manitoba. This study has involved constructing a watershed model to determine the present water budget. By entering climate change scenario predictions into the model, it has been possible to predict the response of Manitoba watersheds to climate change. This paper outlines the concept of water soft paths and how it applies in Manitoba's agro-ecosystem, and describes the modelling work done to determine baseline and future conditions. The paper concludes with the implications of the modelling results for a water soft paths study in Manitoba.

1. Water Soft Paths

Traditionally water management challenges have been met with hard infrastructure, such as treatment plants, irrigation works and dams. These hard engineering approaches are predicated on the assumption that technology must be employed in order to help us overcome challenges. The concept of taking a soft approach to a commodity was first championed by Amory Lovins of the Rocky Mountain Institute during the mid-1970s energy crisis. Lovins's soft path viewed energy as a means to an end, and not an end in itself. The strategy relies on renewable energy, decentralised infrastructure, simple technology, and matching scale and quality to end-use needs (Lovins 1976, 1977). Much of the conservation to be achieved with a soft path is through increased efficiency in the production, distribution and use of energy.

Lovins recognized that his soft path could be applied to other commodities as well. It was at the Pacific Institute in Oakland, California in the 1990s that the soft paths approach was first applied to water. Peter Gleick critically examined water use in California, primarily pertaining to municipal and irrigation uses (Gleick et al. 1995, Gleick at al. 2003). Gleick determined that water use could be reduced by two-thirds by applying a soft paths approach (one-third reduction could be achieved through readily available water conservation technologies and one-third by applying a soft paths approach). Water soft paths study in Canada has its roots with David Brooks of Friends of the Earth and his studies on water conservation (Brooks and Rose 2004, Brooks and Brandes 2007, Brooks 2005, Brandes et al. 2007, Brandes and Brooks 2005, Brandes and Kriwoken 2006). The POLIS Project on ecological governance at the University of Victoria has been examining municipal water use across Canada and identified opportunities for water conservation through increased efficiency (Brandes et al 2005, Brandes and Ferguson 2003).

Much of the demand for water is not for the substance itself, but for the services it provides. We use water for cleaning, disposing of wastes, watering lawns, and for agricultural production. Water soft paths suggests that by critically evaluating each of these services, we may determine that water is not essential for these activities to occur (Brooks and Rose 2004, Brandes et al. 2007, Brooks 2005, Brandes and Kriwoken 2006). For example, composting toilets would eliminate the need to use water to carry human waste to a central treatment facility. Changing the species composition of our lawns can eliminate the need for watering. Changing agricultural methods or selecting alternative crops can significantly reduce the amount of water required for crop production.

We rely on our ecosystems for services such as food production and water purification (Millennium Ecosystem Assessment 2005). Water soft paths recognises natural systems as purveyors and users of water (Brooks and Rose 2004, Brandes et al. 2007, Brooks 2005, Brandes and Kriwoken 2006). Any water management system founded on soft paths principles shall be founded on the concept of ecological sustainability; water use shall be within the limits of sustainability imposed by the ecosystem.

Water distributed by municipal utilities is typically of the highest quality. It is water fit for human consumption. This water is used for multiple purposes, such as bathing, washing and watering lawns and gardens. Only a fraction of the municipally-treated water is actually used for drinking (Brandes and Ferguson 2003). The remaining uses of water do not require such high quality. A water soft paths strategy would strive to match water quality to its intended use, thus reducing the need for energy and chemical inputs for treating to drinking water standards (Brooks and Rose 2004, Brandes et al. 2007, Brooks 2005, Brandes and Kriwoken 2006). The principles of matching water quality to intended use go beyond municipally treated water and apply also to agriculture, industry, livestock, and recreation.

In any water soft paths analysis, a future state of water sustainability should be defined (Brooks and Rose 2004, Brandes et al. 2007, Brooks 2005, Brandes and Kriwoken 2006). This future state should be formed according to the principles of ecological sustainability. Once this state is defined, a 'backcasting' exercise is carried out to link the present with the future. The path from present to future will be built on sound policy and water management decisions (Brooks and Rose 2004, Brandes et al. 2007, Brooks 2005, Brandes and Kriwoken 2006). The soft path will go beyond simple water policy and will have implications for sectors such as agriculture, industry and municipal planning.

2. Water Soft Paths in the Prairie Context

The study area of this research is the agricultural region of the province of Manitoba (see Figure 1). Manitoba is the easternmost of Canada's three Prairie Provinces. It has a population density of approximately two people per square kilometre; however this figure is skewed by the fact that two-thirds of Manitoba's million inhabitants live in the provincial capital of Winnipeg (Statistics Canada 2007). Southern Manitoba is under extensive agricultural production, primarily grains and oilseeds such as wheat, canola, barley and oats. Manitoba also has an expanding livestock industry. Hog production has grown extensively throughout much of the province over the past decade.

Manitoba's hydrology is characterised by five months of winter with average temperatures below freezing. Precipitation falling during the winter months is stored as snow until April when it melts, often causing flooding (see Figures 2 and 3 for temperature and precipitation graphs of the study area). Manitoba summers are hot and dry. While the summer is generally a time of water deficits, there is typically enough water stored in the root zone for crop growth, and irrigation is unnecessary for most crops.

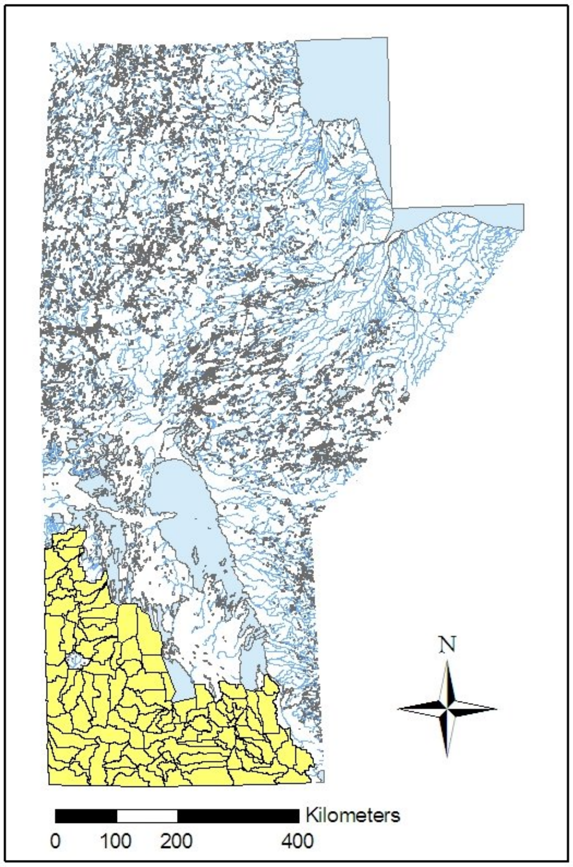

Fig. 1. Map of Manitoba showing case study sub-watersheds (source data: Manitoba Land Initiative 2007)

Manitoba receives runoff from its neighbouring states and provinces. Many major rivers pass through Manitoba on their way to Hudson's Bay, including the Saskatchewan, Nelson, Churchill and Winnipeg Rivers. These rivers drain a significant portion of North America all the way from the Rocky Mountains in the west to almost the Great Lakes in the East, and the Dakotas in the south. Manitoba has capitalised on this abundance of water by developing a hydroelectric industry. Manitoba Hydro, the hydroelectric utility owned by the Province of Manitoba, satisfies the province's power requirements and is able to export half its production to the United States.

While it is generally viewed that Manitoba has a wealth of water resources, all is not well with province's lakes and rivers. Lake Winnipeg, the 11th largest lake in the world, has been experiencing severe algae blooms in recent years. These blooms are caused by increased phosphorus loading from Manitoba and neighbouring jurisdictions. In addition, changing weather patterns have led to increased precipitation in early summer and unusual summer flooding and crop losses. In addition to the earlier summer flooding, late summers have been drier putting the crops that managed to survive the floods in danger of drying out (Schindler 2001, Venema 2006). This trend is predicted to increase as the global climate continues to change (see Figures 2 and 3 for graphs of predictions of future temperature and precipitation.

Water soft paths studies have been carried out in jurisdictions with high population densities. Our preliminary research revealed the situation in Manitoba is quite different. Direct human withdrawals of water amount to approximately 0.2% of total yearly precipitation. Most water that falls on the province (around 91%) returns to the atmosphere as evaporation and transpiration from the landscape. Around 8% of annual precipitation ends up as runoff, most of it in the spring after the freshet. The challenge for water management in Manitoba is to ensure that there is no flooding in the spring, yet enough water throughout the rest of the year to maintain the healthy functioning of our aquatic, terrestrial and agro-ecosystems.

We envision a state of future water sustainability that is built on healthy ecosystems, agriculture, and sustainable cities in a future changed climate.

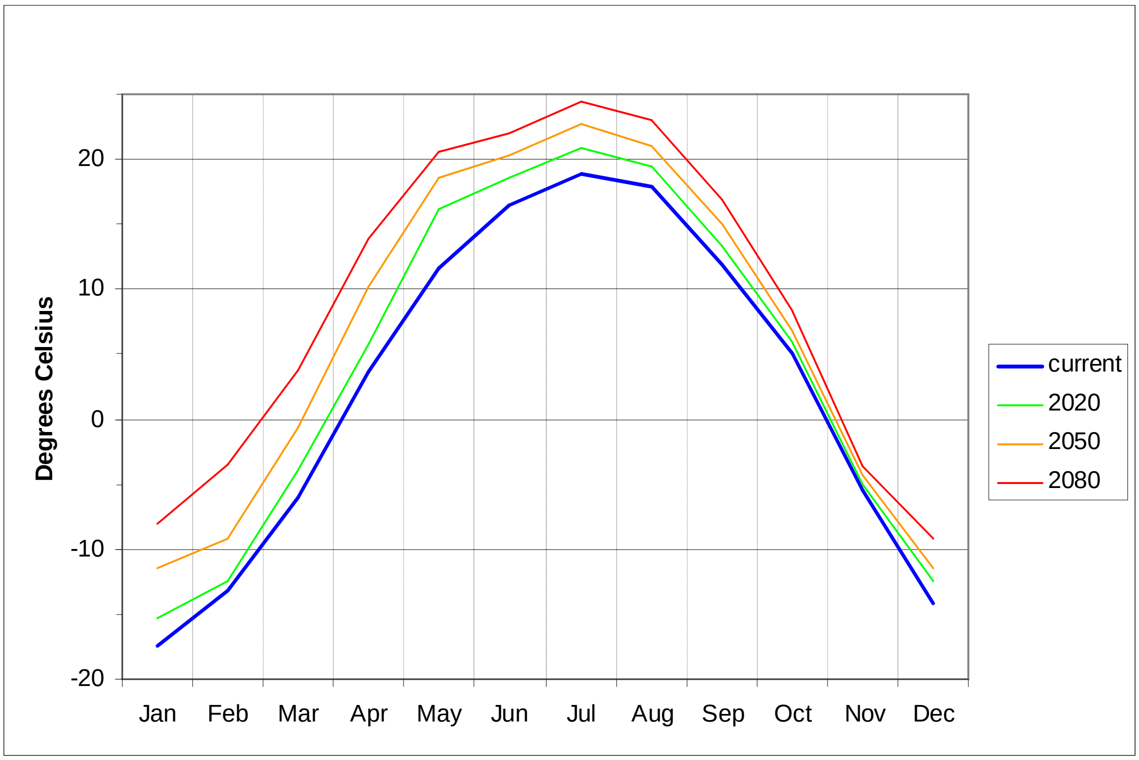

Fig. 2. Average current temperature and future temperature predicted by CGCM2 A21 scenario over the case study area (source data: Environment Canada 2002, Canadian Climate Impacts and Scenarios 2004)

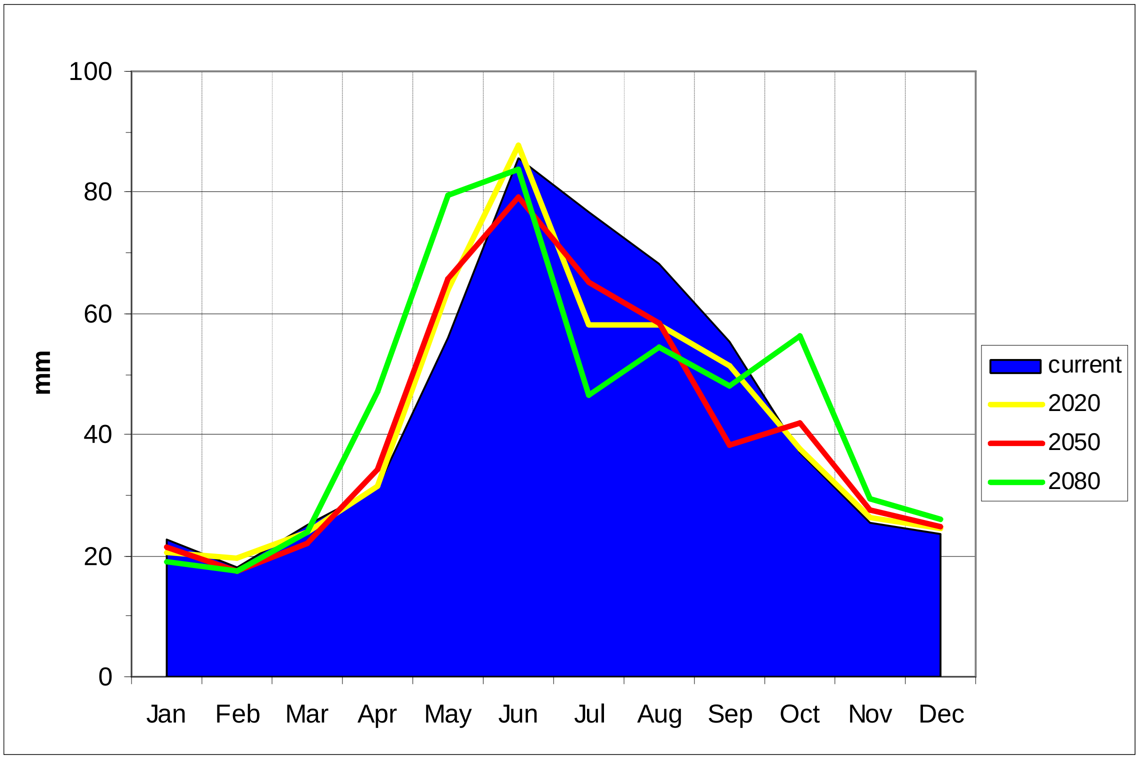

Fig. 3. Average current precipitation and future precipitation predicted by CGCM2 A21 scenario averaged over the case study area source data: Environment Canada 2002, Canadian Climate Impacts and Scenarios 2004)

3. The Manitoba Watershed Model

In order to conduct a soft paths analysis for Manitoba, it is essential to understand the current state of water resources in Manitoba's watersheds. The range of future possibilities that climate change will present must also be examined. Water balance modelling is common and similar watershed-based modelling work has taken place throughout the world (Jones et al. 2007, Perangi-nangin et al. 2004, Renault et al. 2001, Roost et al. 2003, Molden et al 2001). A study has recently been published of modelling work to determine watershed responses to climate change in Greece (Baltas 2007).

The study area is the agricultural region of southern Manitoba. As the basic unit of water resources, the watershed is the geographic unit of this study. The study area was divided into 94 sub-watersheds based on drainage zones defined on provincial water resources maps (Manitoba Land Inventory 2007). The total surface area of the study region is 90,914 km^2. A model was constructed to simulate watershed processes for all 94 sub-watersheds on a monthly time step. The model estimates average monthly evaporation, runoff, soil water storage, evapotranspiration, water surplus and water deficit.

The model uses the modified Penman-Monteith method of estimating potential evapotranspiration as described in FAO Irrigation and Drainage Paper No. 56 (Allen et al. 1998). The modified Penman-Monteith model functions by establishing a reference evapotranspiration (ET_O). Inputs required for the reference evapotranspiration are precipitation, temperature, solar radiation, wind speed and relative humidity. This reference evapotranspiration is then multiplied by a crop coefficient (K_C) to obtain the potential evapotranspiration of the land under crop cover (ET_C):

$$ET_C = K_C\, ET_O \tag{3-1}$$

For each of the 94 case-study sub-watersheds, a reference evapotranspiration was calculated using average 1971-2000 data from the nearest World Meteorological Organization approved weather station (Environment Canada 2002). Proximity of each watershed to the weather stations was determined by the Thiessen method (Thiessen 1911). Average crop coefficients for each of the 94 sub-basins were calculated using land use and crop data from the Manitoba Land Inventory and the 2006 Agricultural Census of Canada (Manitoba Land Inventory 2007b 2007c, Statistics Canada 2007). Interpolation of Census data was carried out as the data is complied according to census division units rather than by watershed.

Soil water storage was calculated according the Thornthwaite-Mather Water Balance Model (Thornthwaite and Mather 1955, 1957). Data required for calculating soil water storage includes soil texture and rooting depth. Average rooting depths were calculated for each sub-watershed which, along with soil texture, established the water holding capacity for each sub-watershed. Soil water content (W_S) relates to the accumulated potential water loss (WL_{POT}) and water holding capacity (HC) as follows (adapted from Thornthwaite and Mather 1957):

$$W_S = WL_{POT} \exp(-WL_{POT}/HC) \tag{3-2}$$

The water holding capacity of soil (HC) is determined by multiplying the maximum holding capacity of a particular soil texture (AW_{SOIL}) by the plant root zone depth (RZ):

$$HC = AW_{SOIL}\, RZ \tag{3-3}$$

The information required for the modified Penman-Monteith and Thornthwaite-Mather models was compiled in Microsoft Excel and a model was constructed using STELLA dynamic modelling software to calculate average monthly soil water storage, actual evapotranspiration, water deficit, water surplus, domestic water use, irrigation withdrawals, and livestock water use (see Figure 4 for a STELLA watershed model). The STELLA model calculated these parameters for each of the 94 sub-watersheds simultaneously, and calculated the monthly discharge of the watersheds to rivers and streams. The STELLA model was calibrated by comparing the runoff generated with measured streamflow data averaged over the years 1971 to 2000, by adjusting average monthly surface water retention and K_C values.

Once it was determined that the model was accurately representing watershed responses to precipitation events, the model was run using climate change scenarios. Precipitation, temperature and potential evapotranspiration were scaled using adjustments from the Canadian Climate Impacts and Scenarios (2004) CGCM2 A21 scenario (see Figures 2 and 3 for predicted future temperature and precipitation). Several runs of the Manitoba watershed model under this scenario have been conducted. Additional runs are planned to study the effect of changing seeding and harvest times, and crop composition.

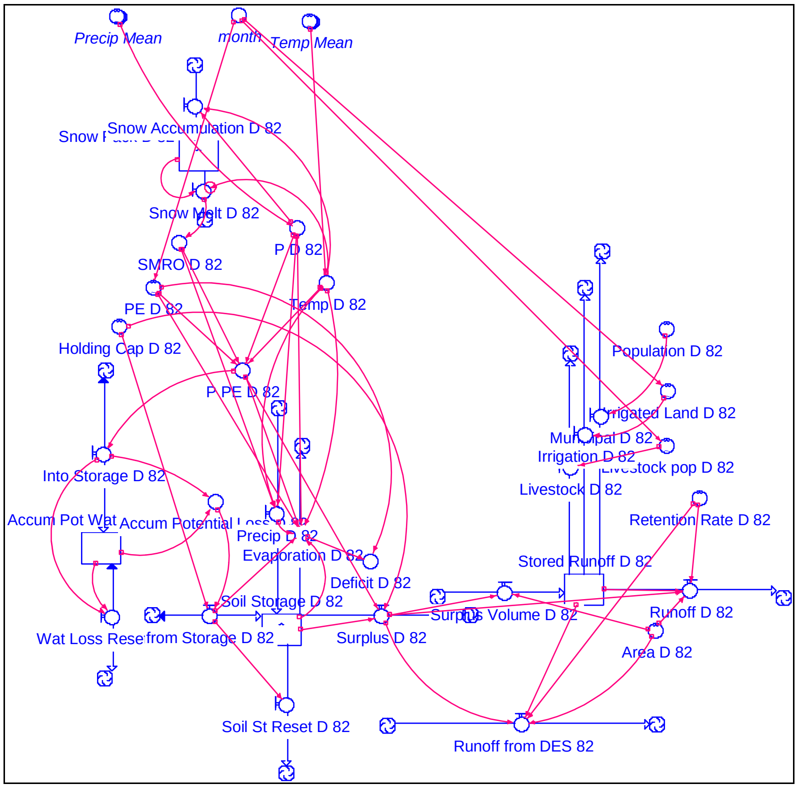

Fig. 4. STELLA model for one of 94 sub-basins in the study area

4. Model Results

The Manitoba watershed model has produced estimates on the current state of each of the 94 sub-watersheds in the study region. Overall, it was determined that an average of approximately 47,000 gigaliters (Gl) of precipitation fell on the study area annually for the years 1971 to 2000. Of this precipitation, around 43,000 Gl returns to the atmosphere as evapotranspiration and 4000 Gl leaves the watershed as runoff (Figure 5). Withdrawals for irrigation, livestock and municipal purposes amount to less than 0.2% of the precipitation falling on the watershed.

Runoff (Figure 6) is highly seasonal. Water surpluses tend to occur in the spring months as winter snow accumulations melt and fill rivers, streams and drains. While precipitation continues to fall throughout the year, in general this precipitation is absorbed into the soil and does not produce runoff. Evapotranspiration (Figure 7) peaks in July, and decreases significantly in the autumn months after plant growth slows and crops are harvested. Precipitation that falls in the months of September and October generally infiltrates into the soil where it remains until the following growing season (Figure 8). Precipitation in the autumn is important for agriculture as autumn soil moisture rates contribute to the success of the following year's planting.

Water deficits (Figure 9) occur in the summer months when actual evapotranspiration rates are below their potential. In Manitoba most crops are able to weather these deficits by relying on soil moisture. Irrigation is generally not required, and is typically used only on potatoes (Gaia Consulting 2004).

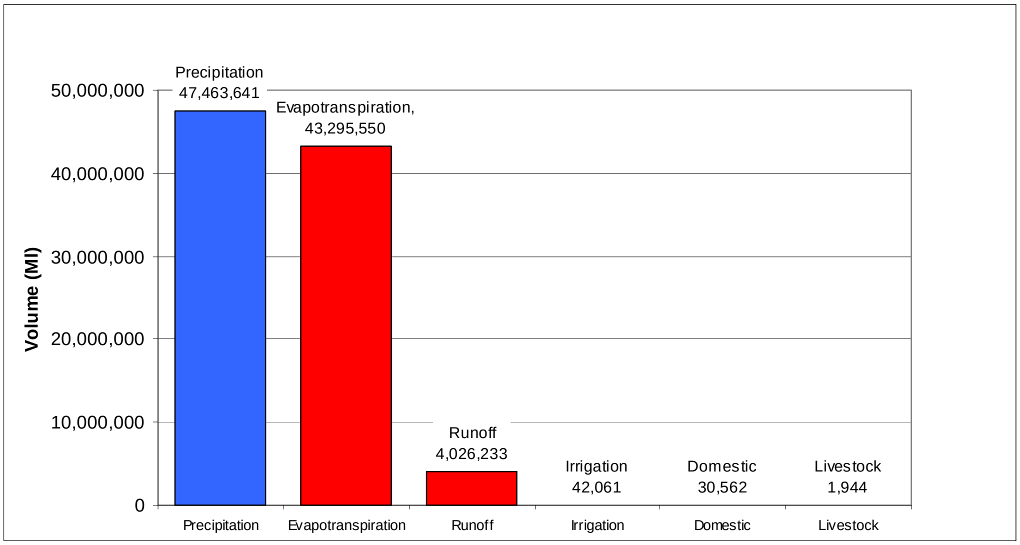

Fig. 5. Annual water budget of 90 914 km^2 Manitoba case study region

To date the model has been run twice using the CGCM2 A21 climate change scenario (Canadian Climate Impacts and Scenarios 2004). Run 1 assumed that agricultural crop composition, time of seeding and time of harvest would remain the same in the future. Run 2 assumed that agricultural species composition would remain the same as in 2006, but the time of seeding would advance earlier in the year, as conditions allow. By interpolating the monthly temperature predictions to determine the date at which average temperatures would rise above freezing, it was determined that in 2020 seeding could take place five days sooner on average. In 2050 seeding could take place approximately two weeks earlier, and in 2080 seeding could advance by a month. The predicted hydrological conditions plotted in Figures 6 to 9 are for Run 2 and reflect the adjusted time of seeding and harvest.

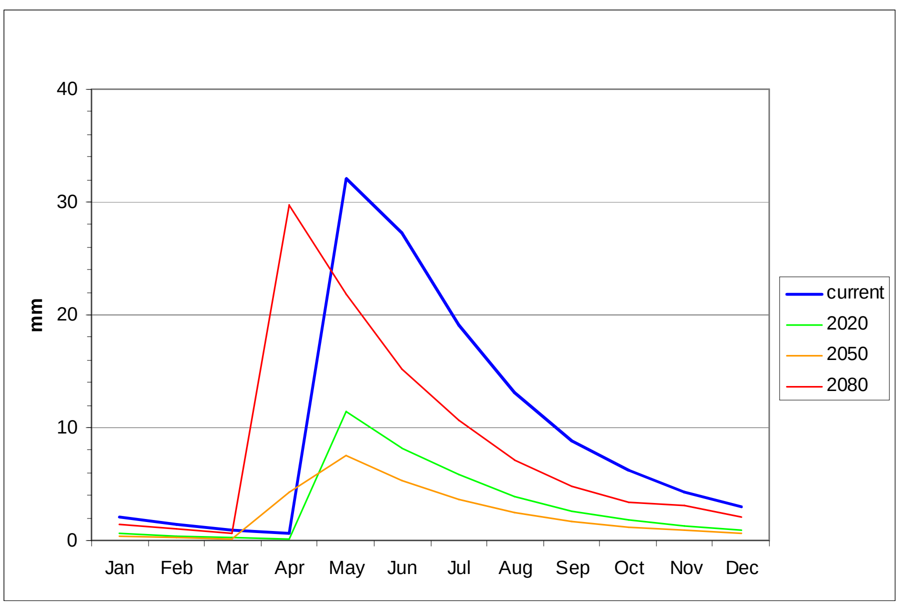

Fig. 6. Average total runoff from the study for the years 1971 to 2000, and predictions for future runoff under climate change scenarios

The results of Run 2 indicate that runoff and soil water storage will decrease as water deficits and actual evapotranspiration increase. The situation appears to be worse in the years 2020 and 2050 than in 2080. This is likely due to the changed precipitation patterns predicted in the CGCM2 A21 scenario. The scenario shows that precipitation will be similar to, or lower than the present situation in the autumn months in 2020 and 2050, however precipitation in the autumn months will increase beyond present levels in 2080. This increased autumn precipitation restores soil moisture in advance of the coming winter. The spring freshet rapidly allows soils to reach their maximum storage the following spring. This is an encouraging sign for the future of agriculture in Manitoba. Overall, the moisture patterns in 2080 are very similar to present conditions, except that they occur one month earlier in the year than they do at present.

Further analysis is ongoing to determine the ramifications of these results for crop growth. Future runs of the model will use altered crop species composition in order to determine a range of future possible scenarios under climate change. While the water budget model for our study area continues to be run under different scenarios, the results presented to date do offer insight into how Manitoba's water regime may look in the future. This allows us to begin envisioning how a future state of water sustainability may look.

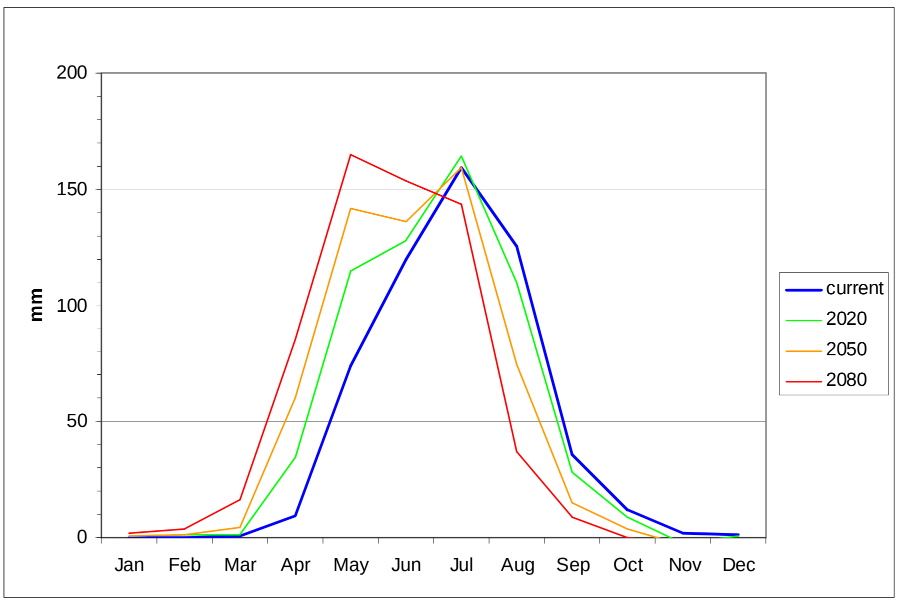

Fig. 7. Average evapotranspiration for the years 1971 to 2000, and predicted evapotranspiration for the years 2020, 2050 and 2080

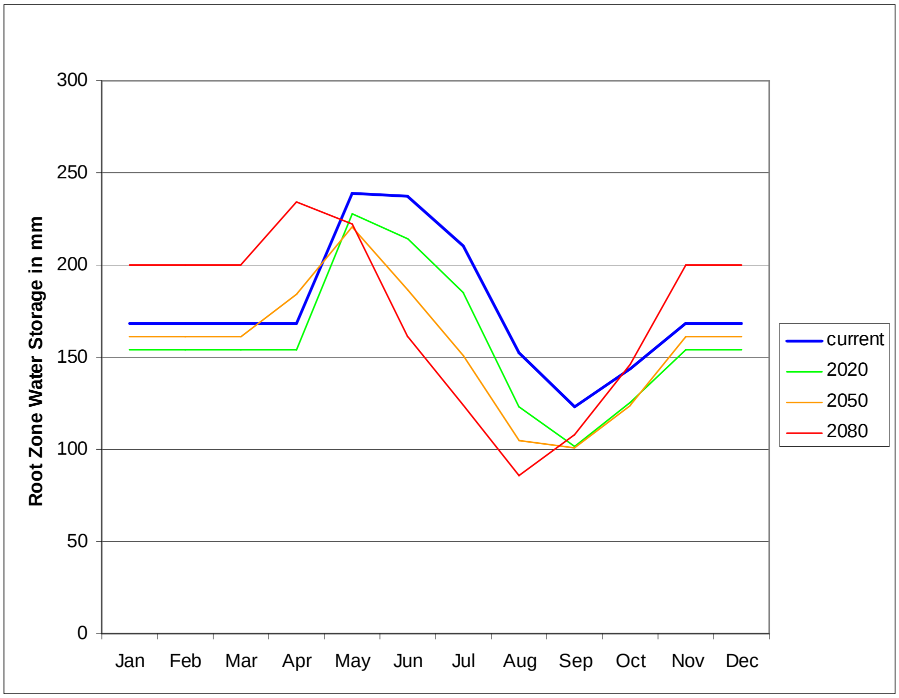

Fig. 8. Average soil water storage from 1971 to 2000 and predicted soil moisture for the years 2020, 2050 and 2080.

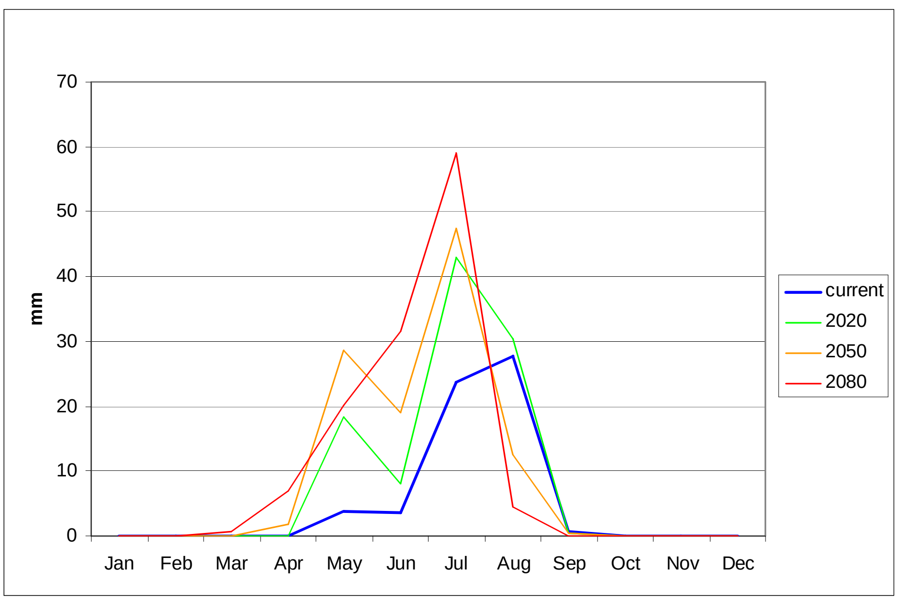

Fig. 9. Average annual water deficit for the years 1971 to 2000 and predicted average future water deficits

5. Development of a Soft Path for Manitoba

All water used by Manitobans comes from lakes, rivers and aquifers fed by runoff. In addition to humans; ecosystems rely on regular infusions of fresh water to function healthily. The predictions for Manitoba under climate change presented in Section 4 of this paper indicate a significant decrease in runoff for the years 2020 and 2050, and an altered runoff pattern for 2080. These changes will present challenges for water management. Greater effort will have to be taken to ensure that enough spring runoff is retained for use throughout the year.

Since landscape processes largely determine the hydrologic balance of watersheds, altering these processes offers the best means of influencing runoff volumes. Factors that can influence the amount of runoff leaving land include best management practices (BMPs), farming methods, as well as crop selection. Crops with lower K_C coefficients transpire less throughout the year and will maintain higher soil moisture content, and promote runoff. Crops with lower K_C values include forages, berry plants, sunflowers and beans (Allen et al. 1998). Crops that have higher K_C coefficients include treed fruit, grains and potatoes (Allen et al. 1998). In addition to a crop's ability to promote soil moisture and runoff, tolerance to drought should also be an important consideration as water deficits are predicted to increase throughout the growing season (as shown in Figure 9). Agricultural BMPs often have erosion and nutrient loss reductions as their objective. Reducing erosion and nutrient loss will have direct implications for runoff as more water could be retained on the land to help maintain soil moisture.

In addition to carrying out activities to promote runoff from the landscape, retention of water is also an important consideration. Local approaches to water retention consistent with the soft paths philosophy may include small dams and wetlands. Spring runoff can be stored in wetlands or behind dams, and be drawn upon throughout the year as required. Besides the benefit of water retention, wetlands would also increase biodiversity.

Under a water soft paths system, the amount of water available for withdrawal should be determined by the natural environment. Water withdrawals should not impair the healthy functioning of ecosystems and their ability to perform beneficial services. As the amount of runoff decreases in the future, the volume of water that can be withdrawn may also decrease. The proportion of water presently being withdrawn in the study region amounts to less than 0.2% of all runoff. The total volume of human abstractions in all likelihood will increase as populations and development increase in the study area. As water is increasingly drawn from a decreasing runoff pool, the value of 0.2% will rise considerably. For this reason it is important to revisit the urban conservation concepts of water soft paths (Gleick et al. 1995, Gleick at al. 2003, Brooks and Rose 2004, Brooks and Brandes 2007, Brooks 2005, Brandes et al. 2007, Brandes and Brooks 2005, Brandes and Kriwoken 2006, Brandes et al 2005, Brandes and Ferguson 2003). Reducing human water withdrawals will increase the amount of water available for natural ecosystems.

Since one of the foundations of soft paths is a shift away from centrally planned management and hard infrastructure, water management decisions should be made locally. Manitoba has a number of Conservation Districts which are charged with varying degrees of authority over watershed planning. Increasing focus is being placed on Conservation Districts as watershed management institutions. This shift is entirely consistent with a soft paths strategy, Conservation Districts should be an integral part of a Manitoba soft path.

Work in defining the water soft path for Manitoba is ongoing. Landscape scenarios continue to be tested in the watershed model described in Sections 3 and 4, and adjustments are being made as necessary. Study is also ongoing to determine future ecological water requirements consistent with a soft paths philosophy, and work is also ongoing to determine how Manitoba's human water withdrawals can be optimised. Work to determine the best uses of water in Manitoba will be carried out using a method derived by Molden and Sakthivadivel (1999) for assessing water use in order to determine how the maximum return can be obtained for water. Gleick (2003) carried out a study of irrigation of agricultural crops in California and the returns that they generate using similar principles.

Charting a water soft path is an involved process. It requires significant understanding of a region's water resources, and a thorough understanding of the local watershed processes. Since water soft paths aims to define water use decades in the future, the impact of impending global climate change on local water resources will be a significant factor as well. Many jurisdictions have detailed knowledge of water resources, and climate change may be well documented. Manitoba has historically had few issues with water scarcity since European settlement and detailed studies have not been conducted. For this reason it was necessary to construct the watershed model described in Sections 3 and 4. Work with this model is ongoing, as the results generated lead to the development of new scenarios to be explored. Thus, establishing a future state of sustainable water management is an iterative process, but it will eventually lead to the development of a feasible scenario to be achieved by following a soft path.

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