

Beneficial Management Practices (WEBs)

Technical Summary #1

# **Biophysical Component**

Four-year review (2004/5-2007/8)





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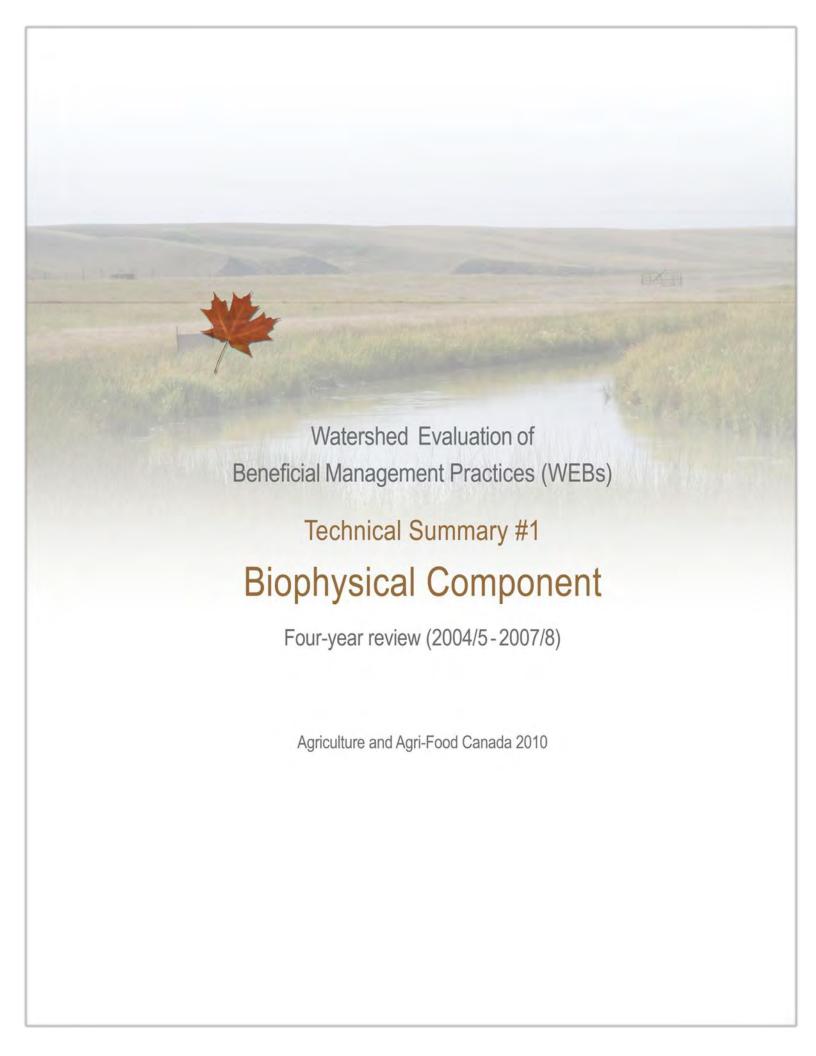
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#### Introduction

The Watershed Evaluation of Beneficial Management Practices (WEBs) is a national project led by Agriculture and Agri-Food Canada (AAFC), with Ducks Unlimited Canada as a major funding partner. WEBs was initiated in 2004 to measure the environmental and economic performance of selected agricultural beneficial management practices (BMPs) at a watershed scale. Research is carried out at seven micro-watershed sites across Canada (Figure 1).



Figure 1: Location of WEBs watersheds across Canada

For the purposes of this study, BMPs are science-based farming activities designed to help minimize potential environmental impacts, such as sediment and nutrient runoff into water bodies.

WEBs has applied a suite of BMPs at each site and has begun studying their environmental and economic impact at the small-watershed (300–2500 hectare) level. The selection of BMPs for testing in WEBs has been specifically tailored to the unique conditions of each watershed (Table 1). As a result, each site employs a suite of BMPs which may not directly correspond to practices in other WEBs watersheds.



Table 1: WEBs BMPs Applied by Watershed

	WEBs BMPs	Salmon River	Lower Little Bow River	South Tobacco Creek/ Steppler	South Nation	Bras d'Henri and Fourchette	Black Brook	Thomas Brook
Riparian	Cattle exclusion fencing (and offstream watering)	✓	✓		✓			✓
	Off-stream watering without fencing		✓					
	Grazed versus mechanical harvesting			✓				
	Manure management		✓			✓		✓
pJə	Zero versus conventional tillage			✓				
In-field	Crop rotation					✓		
	Perennial cover		✓	✓				
	Reduced herbicide use					✓		
	Diversion terraces and grassed waterways	WE	Bs is not de	effect	✓			
	Storm water diversion (farmyard runoff)	acr	oss differing			✓		
Runoff	Holding pond (cattle containment runoff)			✓				
	Small reservoirs			✓				
	Buffer strips		✓				✓	
	Suite of surface runoff control measures					✓		
Drainage	Controlled tile drainage				<b>✓</b>			

<sup>\*</sup> It is important to note that comparing the effect of individual BMP's across multiple watersheds and/or the assessment of any one BMP under a wide range of different watershed conditions is beyond the scope of WEBs.



Each of the seven WEBs watershed sites across Canada includes the following components:

- Biophysical evaluations measure the impact of individual BMPs or a suite of BMPs on water quality and other environmental factors at a watershed scale.
- On-farm economic assessments determine the costs and benefits of implementing BMPs.
- *Hydrologic modelling* contributes to a better understanding of background and watershed interactions and facilitates the extrapolation of findings to other locations.
- At two of the project sites, integrated modelling combines hydrologic, economic and producer behavioural aspects into a multi-faceted decision tool to facilitate long-term planning.

WEBs is focused on water quality, a likely predictor of other environmental impacts such as soil quality, air quality and biodiversity. In many cases, additional environmental parameters such as soil or riparian health are being examined.

The history of conditions and trends at each of the seven WEBs sites is generally well understood, due to past activities and data collection by local watershed associations or multi-agency teams. It is anticipated that these sites will continue as long-term benchmark locations for watershed health.

This technical summary compiles the biophysical findings of the project's first four years (2004/5 - 2007/8) from each of the seven WEBs project watersheds. These watershed summaries are presented from west to east across Canada. Please note that, owing to the brief period of data collection at most WEBs watersheds, the information in these summaries is based on initial study and locally-focused peer review. Hence, these findings should be considered preliminary and may change with further study and formal peer-review.

A compilation of findings from the economics research conducted under WEBs is available in a separate companion document entitled: -Watershed Evaluation of Beneficial Management Practices (WEBs) Technical Summary #2: Economics Component – Four-year review (2004/5 - 2007/8)". A compilation of findings from the hydrologic and integrated modelling research is available in a further companion document entitled -Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #3: Hydrologic and Integrated Modelling Components – Four-year review (2004/5 - 2007/8)". These documents are available in both print and PDF format in both official languages.

A condensed report -Watershed Evaluation of Beneficial Management Practices (WEBs): Towards Enhanced Agricultural Landscape Planning – Four-year review (2004/5 - 2007/8)", providing an overview of the WEBs project and summarizing the findings from all three of these Technical Summaries, is available in print and PDF format.

For further information on WEBs, please refer to our website at <a href="www.agr.gc.ca/webs">www.agr.gc.ca/webs</a> or email us at <a href="www.agr.gc.ca/webs">webs@agr.gc.ca/webs</a>



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#### Salmon River Watershed (BC)

Initiated in 2004, the Watershed Evaluation of Beneficial Management Practices (WEBs) project examines the environmental and economic impact of beneficial management practices (BMPs) at a small-watershed scale. Water quality is used as the primary indicator for the environmental impact of the BMPs. The project is being led by Agriculture and Agri-Food Canada (AAFC) with Ducks Unlimited Canada as a key funding partner.

After a proposal-based process, seven projects were selected across Canada. Each of the seven WEBs watershed sites includes the following components: biophysical evaluations (the subject of this Technical Summary), on-farm economic assessments, and hydrologic modelling. Integrated economic-hydrologic modelling is occurring at two of the project sites. The economics findings are the subject of a second technical summary -"Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #2: Economics Components - Four-year Review (2004/5 - 2007/8)"; and the modelling findings are the subject of a third technical summary "Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #3: Hydrologic and Integrated Modelling Components - Four-year Review (2004/5 - 2007/8)". All three Technical Summaries are companion documents to the Four-year Review report.

This executive summary is based on a review of the project's first four years (2004/5 - 2007/8) and presents the environmental (biophysical) evaluation of two BMPs in the Salmon River Watershed WEBs project, located in southern British Columbia.

#### **Background and Issues**

The 1,500-square-kilometre Salmon River Watershed (Figure 2), in south central British Columbia (BC), is an area with severe water deficits, especially during the summer and early fall. The river is about 145 km long and has mean monthly discharge of 5.0 m³ sec⁻¹ with an extreme high freshet flow of 41.0 m³ sec⁻¹ in May of 1997 and low flow of 0.3 m³ sec⁻¹. Agriculture, forestry and urban development have increasingly impacted the river over the last 100 years. Ranching and dairy (with the accompanying forage crop production) comprise the largest agricultural base within the watershed.

Most farms in the watershed use irrigation water from the Salmon River or its tributaries to produce forage for grazing and winter-feeding. Beef cattle normally graze in the forested upland range from late spring to early fall. They spend the winter adjacent to the river, where they are fed and where calving takes place, thus creating the potential to negatively affect riparian areas through trampling and fecal contamination.

Water quality concerns in the Salmon River Watershed include loading from sediment, fecal bacteria and nutrients such as nitrogen (N) and phosphorus (P). Contamination can occur through surface runoff, groundwater seepage, streambank erosion, in-stream sedimentation, and from direct cattle access to the river. Other concerns include water quantity, low summer flows, and high summer water temperatures.

Improving water yield and quality are necessary to protect aquatic life, wildlife, livestock watering, irrigation, drinking water supplies, and recreational water use in the watershed.

The WEBs study area comprises approximately 250 hectares within the Salmon River Watershed. The BMPs are implemented on three beef farms along sequential reaches of the river, with each reach ranging from 700 to 1,600 metres in length.

The Salmon River Watershed Roundtable (SRWR) has been working actively in the watershed for over 18 years, with the goal of improving watershed health. WEBs has built on this work to improve and protect water quality.

#### **BMP Effect**

The biophysical component of the study is focused on evaluating the environmental effect of the following two BMPs on water quality:

- 1) Restricted livestock access
- 2) Off-stream watering

Since these two BMPs work together, a separate evaluation of each BMP has not been conducted. Instead, they have been evaluated for their *collective* impact on water quality.

A summary of the background, methods, and results specific to the BMPs assessed as part of this project are described below.



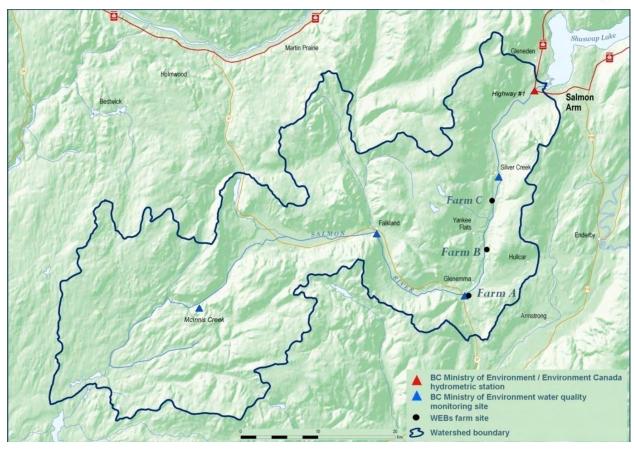


Figure 2: Location of the Salmon River Watershed WEBs project

### Restricted livestock access and off-stream watering

#### **Background**

The fencing BMP study was conducted over four years (September 2004 to September 2008) on three cow-calf cattle farms. The three replicate study sites (Farms A, B and C) are located within the lower third region of the Salmon River Watershed (Figure 3). Farms were selected on the basis of existing fencing structures and for being representative of the cow-calf cattle business in the interior of BC. In beef cattle production, feeding and calving occurs on the farm site from late fall to late spring. During the remainder of the year, the cattle are grazed in the upland forested summer ranges. The primary farm product is spring-born calves weaned and sold in the fall to Alberta feedlots.

The study focuses most intensely on the period where the cattle production cycle intersects with the fall *salmonid* spawning and low river flow. Cattle that enter the river channel to drink and graze the riparian area can physically disturb spawning redds (areas of gravel at the bottom of the streambed where salmon lay their eggs).

Fisheries and Oceans Canada regulates (*Fisheries Act, Sec 35 and 36*) concerning impact disturbances and release of deleterious substances into the waters of fish habitat. The use of BMPs such as exclusion fencing to mitigate or avoid impacts to fish and fish habitats is advised by both DFO and Environment Canada, and prescribed within the AAFC Environmental Farm Planning Initiative.

#### **Methods**

The study consisted of two experiments. In 2004 (Experiment I), fencing was installed/improved for the upper half of the river reach flowing through each farm to exclude cattle from the riparian zone. The lower half of each reach was left unfenced giving cattle access to the riparian area along the river. This experiment was a replicated design (three sites) conducted from September 2004 to September 2006.

In 2006 (Experiment II), the fencing was extended through the entire reach at each farm, and off-stream or controlled stream access watering was provided. The experiment was altered to include a variant of different fencing situations at each farm



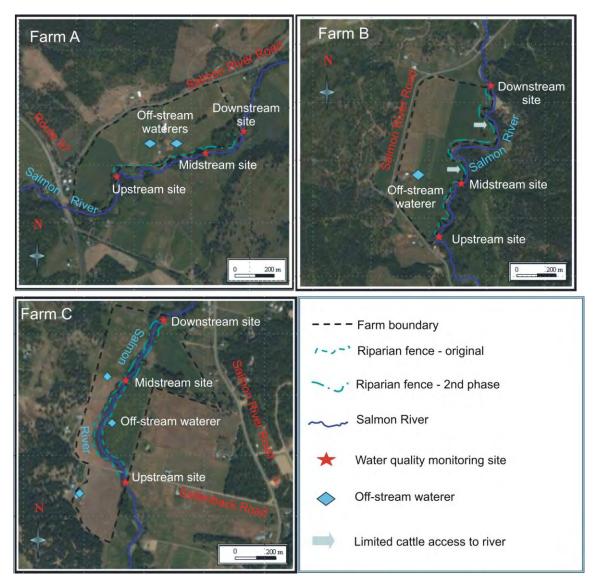


Figure 3: Location of riparian fencing and off-stream watering at each WEBs farm site

(un-replicated) as follows: Farm A had controlled stream access but permitted grazing throughout the riparian corridor through open gates. Farm B had two controlled stream access points that precluded riparian grazing. Farm C had full exclusion from the riparian zone. Experiment II results only apply from September 2007 to September 2008.

In both experiments, cattle were present on each farm for fall grazing, winter feeding and calving (September though May). During the summer grazing season (June through October), the cattle were moved to rangelands, with the exception of Farm A during Experiment II where cattle remained on the farm all year. Water quality, in terms of

water chemistry and suspended sediment, was measured throughout each year.

A specially-adapted sediment sampler was used to collect suspended sediments from a point in the stream cross-section, at two-week intervals throughout most of each year. Cattle impacts are episodic, and discrete (point-in-time), hence sampling methods can miss many water contamination events. The time integrated passive sediment sampler', designed specifically for the Salmon River WEBs project, has the advantage of being present and active during the entire sampling period.

A discrete open-mouth bottle grab-sampling method was used to collect water samples from a



point in the stream cross-section for water chemistry measurements. Water quality assessments of cattle impacts within this watershed were also considered in the context of the published B.C. Ministry of the Environment (BCMOE) -Water Quality Assessment and Recommended Objectives for the Salmon River Summary Report 1998".

#### Results

Experiment I – Bacteriology results determined that there were significantly lower numbers of *E. coli* recorded within the sediment samples (Pr>|t|=0.018) and water samples (Pr>|t|=0.023) collected from the fenced areas compared to the unfenced areas. On average, the *E. coli* number differences were measurable only during the September to May period. There were no measurable differences during the June to August period when cattle were not present on the farms. This finding confirms that the cattle grazing behaviour was controlled by the fencing treatments, and that the experimental structure and methods were sensitive enough to detect differences in bacterial contamination.

Total fecal coliform measurements from sediment samples collected during the September to May period were significantly (Pr>|t|=0.035) greater in the fenced areas, predominately at Farm A. This result could not be explained by the experiment and may have been due to some uncontrolled upstream influence. There was no significant fecal coliform count difference measured during the June to August period. Fecal coliform count differences were not found in the water samples during either of the two feeding periods.

The particle size analysis of sediment collections from the fenced areas had significantly greater per cent fine sand (Pr>|t|= 0.040) fractions and lower per cent silt and clay (Pr>|t|=0.028) fractions during the September to May period. Finer particle sized silt and clay can be re-suspended by cattle disturbances of the stream bed, and this was detected by the sediment collections. As the silt/clay component decreased, the fine sand component had greater representation within the collected sediment samples. There were no measurable differences during times of range grazing when cattle were not present at the farm sites. Other sediment variables measured by the sediment collectors, such as total weight, and per cent carbon were not statistically different between fencing treatments.

The Experiment I water chemistry results determined that there were measurably greater levels of total dissolved phosphorus (Pr>|t|=0.005) and soluble reactive phosphorus (Pr>|t|= 0.05)

recorded within the water samples collected from the fenced areas compared to the unfenced areas. On average, during both feeding periods of both study years, the soluble phosphorus readings were highest within the fenced reaches of Farm A and Farm B. Nitrite levels were significantly lower (Pr>|t|=0.004) in the fenced reaches when cattle were on the range. There are no explanations for these results that can be attributed to the study experimental design. When averaged over the three farms for the term of Experiment I, phosphorus and nitrite results could not be used as explanatory variables for the use of fencing. The watershed perspective shows that the natural range of these solutes far exceed any measurable differences between fencing treatments. Any significant differences therefore could be due to natural sources.

On a watershed scale, the calculated differences in water quality parameters between fencing treatments in Experiment I are small compared to the natural annual background variation. The total phosphorus and nitrite-nitrate variation was due to watershed nutrient cycles, discovered in the data collected from the sites along the mainstream from the headwaters to the mouth. The nitrite-nitrate measurements had a significant (p<0.006, r²=0.71) relationship to monthly temperature.

**Experiment II** – Bacteriology results determined that there were no significant *E. coli* count differences between the upstream and downstream reaches of the three farms during both years of the experiment. This result supports the effectiveness of the fencing BMP as indicated in Experiment I because *E. coli* differences were no longer evident after the entire farm riparian zone was fenced.

The water chemistry results were less definitive and were possibly dependant on localized contributions of phosphorus and nitrogen from stream bank erosion and groundwater sources. Results from the three farms were compared to measurements at the mouth of the Salmon River. A mean separation test (p<0.05) indicated that the soluble phosphorus and nitrite water values were higher at Farm A compared to Farm B, Farm C, and the Salmon River mouth during the term of both Experiments I and II. Thus, these water chemistry results appear to be more dependent on location than due to riparian fencing management.

Total phosphorus was significantly related to monthly hydrologic discharge (p<0.001, r²=0.85) and monthly suspended sediment concentration (p<0.001, r²=0.87). These findings indicate that the watershed water quality is not measurably impaired by cattle winter feeding/grazing impacts at studied locations within the watershed.



The Falkland BCMOE sampling site (upstream of the WEBs test area) appears to be an anomaly, because although the phosphorus and nitrogen cycles are evident, the levels of nitrite, nitrate and sediment readings are elevated above watershed background levels and did not correlate on a monthly basis with the other sampling sites. Falkland is a village with an abandoned open pit mine and a confluence with Bolean Creek, a major tributary. The water impacts might be due to urbanization, upstream land-use activities and/or mining along this tributary stream. Furthermore, the soluble reactive phosphorus levels at Falkland and the headwaters are elevated above the lower watershed reaches. Soluble forms of phosphorus are greatest at the headwater end of the watershed indicating a possible naturally rich geologic source of this dissolved mineral.

On a watershed scale, a comparison was made to the findings of the -Salmon River-Water Quality Assessment and Recommended Objectives-1998". The WEBs 2006 (Experiment I) average for all data for each of the three farms indicated that the water quality was better than the average values collected at the Salmon River mouth between 1988 and 1996. The three farms met the BCMOE water quality objectives for ammonia and total suspended solids. The turbidity and phosphorus objectives were only marginally exceeded, while the bacterial objectives were exceeded by a wide margin.

#### **Additional studies**

Additional studies to evaluate the effect of these two BMPs on biophysical aspects other than water quality were included and have substantially enhanced this study. They include:

- riparian vegetation study
- soil nutrient study
- bacterial source tracking study
- benthic invertebrate study

#### Vegetation study

The greenline method developed by Winward (2000) was used to assess vegetation along the edge of the stream over a three-year period, where cattle exclusion fencing of the riparian area had been incorporated at each of the three study farms. Monitoring was initiated in 2006 at the end of the exclusion fencing part of Experiment I, towards the end of summer when the vegetation was mature. Monitoring consisted of two 100-metre transects each, above and below the mid-point established in the riparian area between the cattle exclusion and the unfenced area (Figure 4). Permanent

photo points were established at 20-metre intervals along the riparian greenline, and vegetative cover was estimated for each step taken along the transect line.

Those sites that have had cattle exclusion fencing in place for longer periods of time had less bare soil and a greater amount of vegetative cover. Furthermore, improvements downstream of the mid-point (those sites fenced more recently) are evident at Farms B and C with decreases in the amount of bare soil. At Farm A, the opposite (south) side of the river was unexpectedly used as pasture during the summer of 2007. Because the pasture had no fence, cattle were able to access the riparian zone on both sides of the river. although they showed a tendency to stay closer to the south side. Damage to the riparian area vegetation was observable due to grazing and browsing as well as from the numerous cattle trails leading to and from the stream to pasture. More damage was evident on the pasture side of the stream compared to the fenced side and this was attributed to the cattle spending more time on that side.

The amount of bare soil for two of the transects at Farm A (transects 2 and 4) increased from less than 5 percent in 2006 to over 50 percent in 2007. This carried over into 2008 with these two transects having about 48 and 33 percent bare soil, respectively. For transect 2 this came at the expense of the shrub component, while for transect 4 it was at the expense of the grass component. The vegetation assessment transects have shown that riparian fencing has a positive effect on riparian health.

#### **Nutrient study**

The aim of the nutrient study was to determine the levels of various nutrients arising from different types of crops and farming operations in order to provide baseline data. This information can be used for modelling and to relate farming practices and nutrient levels to fertilizer and manure applications. Less than 5 percent of the farms in the watershed were thus sampled, totalling 32,000 hectares. The sample was fairly representative of the farms within the watershed, comprising mainly beef and dairy operations.

Surprisingly over three quarters of the fields tested were deficient in N. This degree of deficiency would amount to reduced production, with limited excess N leaching into the Salmon River. Phosphorus deficiencies were much lower, with 11 percent of the fields tested being deficient.



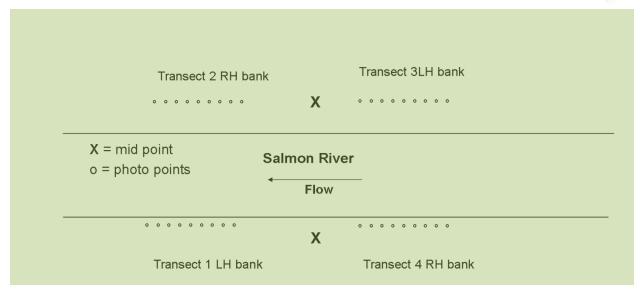


Figure 4: Layout of stream greenline transects and permanent photo points on left and right banks of the Salmon River upstream and downstream of mid-point

Nitrate ( $NO_3$ ), K and Sulphate ( $SO_4$ ) levels were the greatest for hobby farms, while dairy farms had the highest amount of phosphates ( $PO_4$ ). Not surprisingly, high-density livestock paddocks which are used to confine livestock had the highest nutrient levels for all four nutrients evaluated. As these nutrients levels are significantly higher than other fields it can be assumed that these fields contribute to nutrient loading within the river.

The impact of various fertilizer and manure application methods could be observed in the soil testing results. Fields receiving both manure and chemical fertilizer had the highest levels of  $NO_3\text{-}N$ , K and  $PO_4\text{-}P$ . Higher soil  $PO_4\text{-}P$  levels were observed for those fields receiving only manure. Those fields receiving only chemical fertilizer resulted in having the lowest K and  $PO_4\text{-}P$  soil test levels. This is attributed to the use of a nitrogendominant fertilizer mix, of which these nutrients are generally not a part. Nutrient management planning as part of overall farming operations would be beneficial for the purpose of anticipating nutrient deficiencies and optimizing nutrient use.

#### **Bacterial source tracking study**

Bacteria levels were determined as part of the water quality monitoring process. Agricultural operations have often been said to be sources of bacterial water contamination, often without adequate proof. Bacterial source tracking identifies the fecal sources impacting a water system. Bacteria in general tend to be non pathogenic, but their presence can indicate the potential presence of pathogens as well. Where indicator organisms

such as fecal coliforms might signal the *presence* of pathogens, microbial source tracking indicators such as bacteroides (intestinal bacteria), can identify the actual *source* of fecal contamination. Recent bacterial source tracking studies within the Salmon River watershed and elsewhere have shown that farm animals are typically not the main contributors to bacteria in watercourses (Meays et al. 2006; Pearson 2006). Wildlife, including the *avian* component, often contributes more than 75 percent of the *E. coli* and indirectly all detected bacteria in that sample.

*E. coli* and fecal coliform bacteria were sampled monthly from August 2007 to February 2008 at five locations along the Salmon River from its headwaters to the mouth. For each sampling duplicate samples were collected for bacteroides and five samples were taken for bacteria in order to obtain a representative sample of each.

Average fecal coliforms during the sampling time were about 10 times greater than average *E. coli* (37 vs. 402 colonies 100 ml<sup>-1</sup>). Bacterial numbers were higher for the first four samplings at 70 and 590 compared to the last four months of 4.3 and 214 bacterial colonies 100 ml<sup>-1</sup> for *E. coli* and fecal coliform, respectively. The October bacterial numbers were the highest. The greatest *E. coli* numbers were observed at the mouth of the Salmon River, the only site that had readings above 100 colonies with 132, 217 and 712 colonies 100 ml<sup>-1</sup> for August, September and October, respectively. The two upper stream sites at Falkland (town and Bolean Creek tributary just



upstream) and McInnis Creek (close to headwaters) had the higher average fecal coliform numbers at 513 and 454 colonies 100 ml<sup>-1</sup> for the sampling period.

In this study, two techniques were used to determine the sources of fecal bacteria:

#### **Bacteroides method**

The bacteriodes method of analysis is useful for establishing the presence or absence of particular species or groups of species. Salmon River water samples were analyzed at Environment Canada, using bacteroides markers specific for humans, ruminants, pigs, horses, dogs and elk. Of the 88 samples analyzed for bacteroides, only one sample (at the Highway #1 Bridge) did not contain bacteroides and nine samples contained bacteroides that did not match a known marker. These occurrences were detected during the winter when bacterial numbers are generally lower.

Seventy-nine of the samples indicated the presence of ruminant-sourced bacteroides, with seventeen indicating pig and seven human. Surprisingly, no horse or dog sourcing was detected. As yet, this procedure is unable to distinguish between specific types of ruminants. Some of those numbers may account for deer and moose as well as cattle. Elk sources can be distinguished separately, but were neither expected nor detected in the Salmon River samples. No avian marker has yet been developed.

#### Rep-PCR method

Rep-PCR genomic fingerprinting, a DNA amplification-based technique was conducted at the University of Victoria, and performed on two to four selected colonies of *E. coli* from each of the above microbial samples collected and compared to a library consisting of known sources to determine source. The library includes a range of wild and domestic animals commonly found in the watershed being fingerprinted. A much broader range of animal sources could be detected compared to the bacteroides method. Animal sources included: goose, deer, songbirds, duck, raccoon, horse, cow, canine, human and unknown.

These samples are also able to give an indication of the percentage of contributors. Samples averaged over all five sites (in terms of increasing order of detection) had 5 percent canine, 7 percent unknown, 8 percent human, 8 percent large wildlife (i.e. moose, deer, cougar, bear etc.), 20 percent domestic and 52 percent avian as the source of the bacteria. In a separate study in the north Okanagan, it was shown that the wildlife

component was close to 80 percent and that the avian component was the largest within the wildlife component.

The human component for both bacteroides and Rep-PCR DNA fingerprinting are very similar. Results from the Rep-PCR technique in particular, tend to support those of other studies, suggesting that domestic livestock in the Salmon River Watershed contribute a relatively low degree of bacterial contamination, when compared to wild sources.

#### Benthic invertebrate study

A common method for measuring the impact of anthropogenic influence on aquatic ecosystem health is through the use of aquatic indicator species. By definition, benthic macroinvertebrates or benthos' are aquatic invertebrates larger than half a millimetre in size. As a diverse group containing a large number of species, they possess a wide range of responses to stressors such as organic pollutants, sediments, and toxicants. Biomonitoring of benthic macroinvertebrates was conducted in the Salmon River to determine the impact of agricultural stress and the mitigating effect of BMPs on aquatic ecosystem health. Sites were selected throughout the watershed in areas affected to varying degrees by agricultural practices and containing different riparian buffer zone characteristics. In addition, several reference sites were chosen for comparison. A variety of statistical analyses<sup>1</sup> were then used to determine the impact of the calculated environmental gradients on benthos community dynamics.

The relative abundance and composition of benthos found in agricultural sites was significantly different from the average reference community. Benthic macroinvertebrate communities affected by agricultural land-use intensification were characterized by high abundance and increased proportional abundance of Trichoptera and Elmidae, and a decrease in the proportional abundance of Plecoptera. This can be directly attributed to the health and physical condition of the stream and the riparian buffer zone. Difference in relative faunal abundance was also predicted by soil pH rating adjacent to the stream and agricultural nutrient enrichment. The structure of the benthic macroinvertebrate community was influenced by several calculated gradients associated with livestock access to the stream.

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<sup>&</sup>lt;sup>1</sup> Principal components analysis, stepwise multiple regression, and partial redundancy analysis.



Finally, benthic macroinvertebrate community function was predicted by stream organic carbon as well as a calculated gradient of stream substrate sensitive to agricultural land use intensification. In all measures of benthic macroinvertebrate community structure and function, calculated gradients sensitive to agricultural activities accounted for the largest proportion of explained variance.

This study demonstrates that agricultural land use intensification is having a significant impact on the benthic macroinvertebrate community dynamics, and the health of riparian buffer zones play a role in mitigating the negative impact of agricultural degradation in this watershed.

#### Conclusion

Overall, it can be concluded that *E. coli* and fine sediment contamination from the Salmon River Valley cow-calf industry can be controlled by a fencing BMP. Nitrogen, phosphorus and carbon levels are not measurably affected by the cow-calf

industry within the watershed, and therefore, can not be used to assess the effectiveness of a fencing BMP. It is recommended from the results of this study that a fencing BMP be employed as a remedy from cattle impacts on streams prone to conflicts with salmonid species. Furthermore, additional studies within the Salmon River watershed have shown that fencing has a positive impact on the overall health of riparian vegetation and benthic invertebrate populations.

#### **Project Partners**

The Salmon River WEBs project was led by AAFC and directed by a multi-agency/multi-disciplinary team. The team is comprised of specialists from Federal Agencies (Environment Canada and AAFC), Provincial Agencies (the BC Ministry of Agriculture and Lands, BC Ministry of Environment), University of Victoria, Okanagan College (Salmon Arm Campus), Ducks Unlimited Canada and Salmon River Watershed Roundtable and the cooperating producers.



# Lower Little Bow River Watershed (AB)

Initiated in 2004, the Watershed Evaluation of Beneficial Management Practices (WEBs) project examines the environmental and economic impact of beneficial management practices (BMPs) at a small-watershed scale. Water quality is used as the primary indicator for the environmental impact of the BMPs. The project is being led by Agriculture and Agri-Food Canada (AAFC) with Ducks Unlimited Canada as a key funding partner.

After a proposal-based process, seven projects were selected across Canada. Each of the seven WEBs watershed sites includes the following components: biophysical evaluations (the subject of this Technical Summary), on-farm economic assessments, and hydrologic modelling. Integrated economic-hydrologic modelling is occurring at two of the project sites. The economics findings are the subject of a second technical summary -"Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #2: Economics Components - Four-year review (2004/5 - 2007/8)"; and the modelling findings are the subject of a third technical summary "Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #3: Hydrologic and Integrated Modelling Components - Four-year review (2004/5 - 2007/8)". All three Technical Summaries are companion documents to the Four-year Review report.

This executive summary is based on a review of the project's first four years (2004/5 - 2007/8) and presents the environmental (biophysical) evaluation of five BMPs in the Lower Little Bow Watershed WEBs project, located in southern Alberta.

#### **Background and Issues**

Since 1999, the LLB River Watershed has been studied as part of the Oldman River Basin Water Quality Initiative. Results from this and other studies indicate that nutrients from manure and fertilizers, and bacteria from manure may be affecting water quality in the LLB River. Phosphorus (P), nitrogen (N), fecal coliforms, and *E. coli* have been quantified in surface runoff at 10 monitoring stations along the river. The major water quality problems in the river are bacteria, P and, to a lesser extent, N. Various beneficial management practices (BMPs) were implemented within the WEBs LLB River watershed as part of the Oldman River Basin Water Quality Initiative.

The 2,565-hectare Lower Little Bow (LLB) River Watershed (Figure 5) is located within the larger Oldman River Basin, about 35 km northeast of Lethbridge, in southern Alberta. The watershed is unique because flow in the LLB River is controlled by on-stream irrigation reservoirs and because the local climate is dominated by strong chinook winds. Land use in the watershed is a mixture of irrigated crops, dryland crops, and cattle grazing on native rangeland.

Annual precipitation during the WEBs study (2004-2007) ranged from 264 to 598 mm. Annual precipitation was lower than the long-term average in all years of the study except for 2005.

The LLB River is intensively managed for irrigation, and flows are controlled by releases from a dam at the Travers Reservoir. Mean daily flow rates in the LLB River during this study (2004-07) ranged from < 1 to 12.7 m<sup>3</sup> s<sup>-1</sup>. Surface runoff enters the LLB River mainly by gully flow in small ravines, and to a lesser extent by sheet or rill erosion from exposed and nonvegetated soil adjacent to the river. However, flows in the river are more variable during the summer, as they are affected by inputs of rainfall and irrigation return flows and withdrawal of irrigation water. Irrigation return flows enter the LLB River between early May and early October. The river bottom is coarse sediment consisting of mainly sand. The LLB River flows through mainly native rangeland, with some reaches flowing through cultivated land.

One existing BMP and four new BMPs were utilized for our WEBs study. The streambank fencing with a cattle crossing BMP was initiated in 2001 as part of the Oldman River Basin Water Quality Initiative. The other four new BMPs were initiated in 2004 as part of the WEBs study.

#### **BMP Effect**

The biophysical component of the WEBs study is focused on evaluating the environmental effect of the following five BMPs on water quality:

- 1) streambank fencing with a cattle crossing
- 2) off-stream watering without fencing
- 3) conversion to greencover
- 4) manure management
- 5) buffer strips

Additional studies conducted include spatial analyses of land use, topography, and hydrology and a nutrient budget of the WEBs LLB Watershed, and a study on the influence of cattle watering systems on soil nutrient distribution from cattle manure.



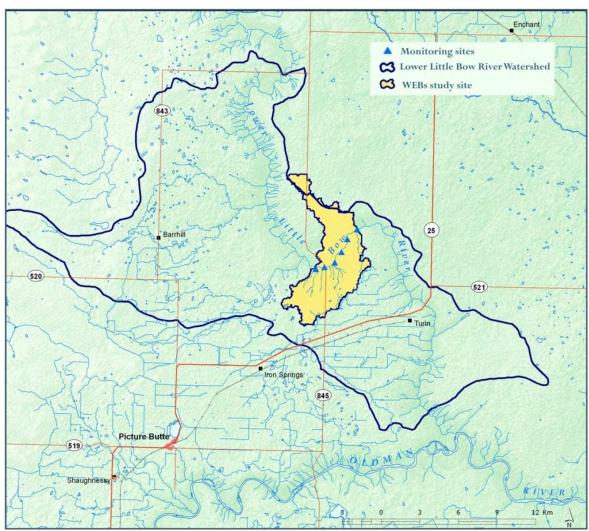


Figure 5: WEBs study location within the Lower Little Bow River Watershed

A summary of the background, methods, and results specific to each of the BMPs assessed as part of this project are described below. These BMPs are illustrated in figure 6.

#### Streambank fencing with a cattle crossing

#### **Background**

Streambank fencing has been proposed to minimize pollution of streams and rivers from livestock grazing on pastures and rangeland. However, limited research has been conducted to evaluate the actual influence of this BMP on water quality, as well as the riparian health of rivers. A four-year study was conducted on a fenced 800-metre reach of the LLB River (fenced in 2001) to determine the influence of streambank fencing with an open-access cattle crossing) on water quality and riparian health of the river.

#### Methods

Physical, chemical, and microbiological variables in the river were determined throughout the four years, and water quality variables at the upstream (control) and downstream (BMP-impact) sites were evaluated using a paired t-test. Interpretation of the BMP was based on the assumption that changes in downstream water quality were due to the BMP. A riparian health assessment was also conducted during the pre- and post-BMP phases.

In addition to monitoring upstream and downstream, rainfall simulations were conducted in a native pasture along the river, adjacent to where the streambank fencing had been installed in 2001. The primary objective of this study was to determine the effect of four to six years of cattle exclusion on runoff quantity and quality, soil chemistry, and rangeland health. Ten rainfall simulations were conducted annually in the grazed (control) and cattle excluded (BMP) native pastures



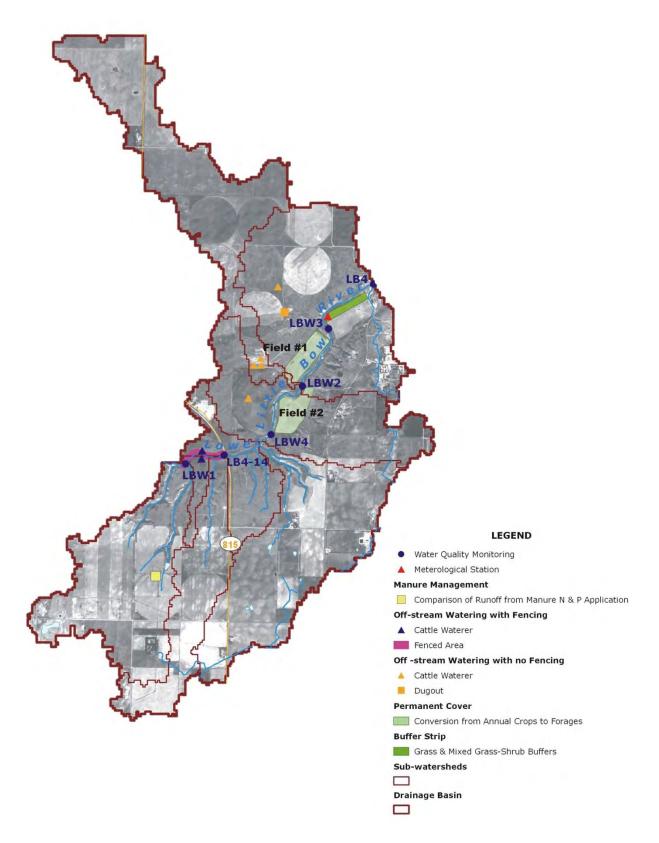


Figure 6: BMPs implemented in the Lower Little Bow River WEBs project



for three years (2005-07). Runoff quantity and quality of rainfall simulation runoff were measured after 30 minutes of runoff.

#### Results

River water quality – Streambank fencing with a cattle crossing did not improve the majority of the 31 water quality variables measured in the LLB River, indicating that overall, this BMP was not effective in the short term at improving river water quality. In some years certain water quality variables were significantly improved, whereas in other cases there was a degrading of water quality. Although the cattle crossing did not significantly degrade water quality variables downstream, it did allow cattle to inadvertently and occasionally wander into the upstream area and this may have contributed streamside contaminants by fecal deposition.

Other possible factors contributing to the apparent ineffectiveness of the BMP may include: the limited length of the fenced reach, contamination of the river by wildlife, the masking of BMP influence by potential loadings from irrigation return flow or other contaminants upstream, natural geochemical processes releasing contaminants within this reach, the natural variability in the water quality data, and the limited duration of the post-BMP period.

Riparian health – Although streambank fencing did not improve the majority of water quality variables, riparian health was visibly enhanced. The overall health of the riparian area was improved from a score of 65% (healthy but with problems) for the pre-BMP phase in 2001 to 81% (healthy) for a post-BMP phase in 2005. Riparian health may be a more sensitive, early indicator of BMP response than river water quality for evaluating the effects of streambank fencing and off-stream watering.

We propose to continue evaluating this streambank fencing BMP in the future. Continuous monitoring of river water quality will be conducted using water quality probes, to determine if this more intensive sampling method detects BMP effects with more sensitivity than weekly grab sampling. In addition, sampling of aquatic insects will also be determined at the upstream and downstream sites to determine if such biological indicators are responsive to the BMP. Riparian health assessments will also continue in the future as we have found this method to be a very sensitive indicator of BMP effectiveness.

**Rainfall simulation runoff** – Our hypothesis in this study was to determine if cattle-excluded

pastures were a potential BMP to improve vegetation, soil, rangeland health, runoff quantity, and runoff quality compared to grazed pastures. Although the majority of vegetation and soil properties were not significantly affected by cattle exclusion in 2005 and 2006, the majority were significantly improved in 2007. The rangeland health was also improved by cattle exclusion. The cattle exclusion BMP did not decrease the majority of runoff variables overall. However, there were some significant decreases in runoff variables during the latter two years of the study.

Specifically, runoff volume, and mass loads of total N (TN), total dissolved N (TDN), total particulate N (TPN) and dissolved reactive P (DRP) were all significantly reduced under cattle exclusion in 2006 and 2007; and TN and total P (TP) concentrations were significantly reduced in 2007. There were, nevertheless, significant increases in runoff turbidity in 2006 and increased concentration of total particulate P (TPP) in 2007.

Significant relationships were found to exist between runoff quantity and quality versus various vegetation and soil properties. Of the nine independent variables sampled, total basal area, live basal area, and slope had the most frequent influence on runoff variables in 2005, 2006, and 2007, respectively. We found no relationships between N and P in surface soil and concentrations and loads of N and P in runoff. Cattle exclusion had little or no influence on selected chemical properties of the surface soil. Mean pH values were higher for the cattleexcluded than grazed pasture. Mean ammonium nitrate (NH<sub>4</sub>-N) concentration in surface soil was higher for the cattle-excluded than grazed pasture on the south side of the river, but there was no difference between the pastures on the north side

Rangeland health – The rangeland health of the cattle-excluded pasture (72%) was better than the grazed pasture (55%) in 2007, indicating that this BMP had improved the overall health of the excluded pasture after six years of cattle exclusion.

Since cattle exclusion resulted in significant improvements in certain vegetation and soil properties, rangeland health, and certain runoff variables, we recommend further research be conducted to determine if more positive BMP effects can be determined over a longer period of time. In addition, we did not measure bacteria in runoff during this study, and this should be examined in the future as cattle fecal pats are a major source of bacterial contamination.



#### Off-stream watering without fencing

#### **Background**

Off-stream watering without fencing has been proposed as a way to minimize the pollution of streams and rivers from livestock grazing without the added expense and maintenance issues of exclusion fencing. A three-year study was conducted on a reach of the LLB River to determine the effect of this BMP on river quality, riparian health, and rainfall simulation runoff adjacent to the river.

#### Methods

The off-stream watering system consisted of an upslope dugout that supplied water to five water troughs located throughout the pasture area. The system was activated on August 24, 2005. Physical, chemical, and microbiological variables in the river were determined throughout the year at the upstream (control) and downstream (BMP impact) stations during the pre-BMP (Jan. 5, 2004 to May 25, 2005) and post-BMP (Oct. 5, 2005 to Dec. 10, 2007) periods. The influence of the BMP on water quality during the post-BMP period was analyzed by spatial analyses (upstreamdownstream) using a paired t-test. In addition, the riparian health of the most degraded reach was assessed during the pre- and post-BMP phases.

#### Results

River water quality – Off-stream watering without fencing did not improve the majority of water quality variables in the LLB River. During the pre-BMP phase, loading of sediment, nutrients and bacteria generally increased downstream. suggesting degradation by cattle at historic onstream watering sites. However, after BMP implementation, the majority of these and other water quality variables were either not affected or continued to be significantly increased. For example, electrical conductivity, chlorophyll-a, concentrations of total suspended solids (TSS) and TN, mass loads of TN, nitrate-nitrogen (NO<sub>3</sub>-N), NH<sub>4</sub>-N, DRP, as well as loads of fecal coliforms and E. coli were significantly increased. Dissolved oxygen was the only variable that showed a significant decrease or improvement during this study, but we are unsure as to why this occurred.

The most likely explanation for the low effectiveness of this BMP is that cattle were still coming to the river during the post-BMP period. There was no significant reduction in number of cattle observed on the streambank, cattle in the stream, or cattle drinking from the stream for the post-BMP phase. However, there was a non-significant trend for lower numbers of cattle in the stream and drinking from the stream after the BMP was installed. Other possible factors contributing to

BMP ineffectiveness include those already described above in association with the <a href="Streambank Fencing">Streambank Fencing</a> BMP.

Riparian health – Although the overall riparian health rating (healthy but with problems) of the upper reach was not improved by this BMP, the rating score was increased from 60% (pre-BMP) to 65% (post-BMP), indicating a slight benefit from the BMP. Again, riparian health may be a more sensitive indicator of BMP response than river water quality for evaluating streambank fencing and off-stream watering.

Rainfall simulation runoff – In addition to the upstream and downstream monitoring, we also conducted rainfall simulations in a tame pasture adjacent to the LLB River where an off-stream watering system (without fencing) was installed, to determine if this BMP reduced runoff quantity and improved runoff quality. Ten rainfall simulations were conducted during each year of the pre-BMP phase (2005) and post-BMP phases (2006, 2007) of the study. The quantity and quality of simulated runoff was measured 30 minutes after runoff initiation. The majority of runoff variables were either significantly increased or were unaffected by off-stream watering without fencing. The only improvement was a decrease in TPN concentrations in 2007.

We speculate that climate, soil or vegetation factors may have dominated runoff quantity and quality, masking any potential BMP effect. Multiple step-wise regression showed that bulk density, live basal area, and bare soil had the most frequent effects on the runoff variables in 2005, 2006, and 2007, respectively. In addition, monitoring two years of the post-BMP phase may not have provided sufficient time to elicit a BMP response in this experiment. Under these circumstances, off-stream watering without fencing did not improve runoff variables on tame pasture adjacent to the LLB River.

Future evaluation of this BMP will be discontinued as the tame pasture adjacent to the river (which was used for summer grazing) has been converted to annual cropping.

#### Conversion to greencover

#### **Background**

Conversion from annual crops to forages may reduce runoff quantity and contaminants in runoff.

#### **Methods**

Runoff quantity and quality in two agricultural fields incorporating a barley-alfalfa rotation were measured using a rainfall simulator, to determine if



conversion from barley to alfalfa reduced runoff quantity and contaminants in runoff. Field #1 (see figure 2) was in barley in 2004 and then in alfalfa from 2005 to 2007. Field #2 was in barley in 2005 and then in alfalfa in 2006 and 2007.

#### Results

Conversion from barley to alfalfa for the two fields resulted in either no significant effect or a significant increase in the majority of runoff variables. However, some runoff variables were significantly decreased by alfalfa, dependent on the field and year of the study. We attributed the lack of a positive BMP response to the greater surface residue under barley than alfalfa. The unexpected seeding of winter triticale in the barley stubble in Field #2 (2005) may also have contributed to the absence of significant reductions in runoff variables for this particular field. Other environmental factors such as year, time of rainfall simulations, canopy cover, and bare soil exposure may have been contributing factors. We recommend that further evaluation of this BMP be discontinued as the current experimental results indicate little promise of BMP improvement.

#### Manure management

#### **Background**

Application of beef cattle manure based on nitrogen requirements of crops, has resulted in elevated levels of soil test phosphorus in surface soils; and runoff from soils with excess P may contribute to eutrophication of surface waters. Few studies have documented the effects of runoff under N versus P-based manure applications.

#### Methods

We conducted a small-plot field study on a fineloamy to fine-silty Lethbridge series soil, to evaluate the BMP of employing a P-based manure application system. The experimental treatments were founded on the current industry standard of beef cattle manure applied based on: nitrogen (N) to satisfy crop growth requirements for one year (N1); phosphorus (P) to satisfy crop growth requirements for one year (P1); and P to satisfy crop growth requirements for three years (P3). The N1 and P1 treatments were applied annually in the spring during each of the three years (2005-2007) of the study, and the P3 treatment was applied once in the spring only, during the first year of the study. There was also an unamended control or check plot. The three treatments and control were replicated five times in a randomized complete block design. A portable rainfall simulator was used to generate artificial runoff for 30 minutes. Runoff water was analyzed for flow-weighted mean

concentrations and loads of various N and P fractions, as well as other variables.

#### **Results**

The P-based manure application systems did not reduce total P (TP) and total particulate P (TPP) concentrations and loads in runoff compared to the N-based application. However, total dissolved P (TDP) concentrations and loads were significantly lower for the P1 treatment than the N1 treatment after the first year of application. The TDP concentration and loads were also lower for both the P1 and the P3 treatments versus the N-based treatment after the second year of application. In addition, dissolved reactive P (DRP) concentrations and loads for the P-based treatments were generally lower than the N-based treatment after the second and third years of application. Few significant differences were found between the P1 and P3 treatments for concentrations and loads of the different P fractions, indicating no water quality advantage of applying P based on one versus three years of crop growth. However, the practical advantage of a three-year application allows for manure to be applied at the higher rate.

The concentration of TP in runoff generally exceeded the Alberta provincial water quality guideline of 0.05 mg L<sup>-1</sup> for all treatments, including the unamended control. Soil test P of surface soil was similar among the three manured treatments after one and two years of manure application, but values were significantly lower for the P-based treatment than for the N-based treatment after the third N-based application.

Our findings indicated that one or three years of P-based manure application generally did not reduce TP and TPP in runoff, but did reduce TDP and DRP, and soil test P was lower after the third year of P-based manure application. Significant reductions in certain P fractions in runoff for the P-based treatment suggest that continued evaluation of this BMP is warranted.

#### **Buffer strips**

#### **Background**

Vegetative buffers are often recommended to reduce the impact of non-point source contaminants on water quality. However, little research has been conducted to examine agricultural buffers less than 10 m wide, or the effects of multi-species buffers. The purpose of this study was to evaluate how a planted buffer (using a combination of vegetation types and buffer lengths) at the base of a cultivated agricultural field



affects surface water quality from natural field runoff and rainfall simulations.

#### Methods

A vegetated buffer was established at the base of a 32.5 ha irrigated, cultivated field along the LLB River. Slope within the field ranged from 1% near the river to 7% further away. Soils were Rego Brown Chernozemic, with minor inclusions of Calcareous Brown Chernozemic. Soil textures ranged from sandy clay loam to sandy loam.

The buffer was a randomized block design with four treatments and three replicates in 60 by 30 m plots. The treatments consisted of: a native grass mix; a tame grass and alfalfa mix; a barley crop (control); and a mixed grass-shrub buffer, which consisted of native grass mix and three rows of shrubs. Four surface runoff collectors were placed in each treatment to collect natural surface runoff.

Two rainfall simulation experiments were conducted. The objective of the first experiment was to determine the effect of vegetation type and buffer width on water quality of surface runoff. The experimental design consisted of three types of vegetation (native grass, tame grass-alfalfa, barley) as described above and three buffer widths (3, 6, and 9 m) at randomized locations as split-plots within each buffer plot. The second rainfall simulation experiment was designed to compare the effect of adding a shelterbelt to a native grass buffer versus native grass alone. This experiment involved two treatments (native grass mix and mixed grass-shrub buffer) at a fixed width of 6 m with five replicates.

#### Results

The establishment year of 2005 was wetter than normal, averaging 120% of the normal growing season monthly precipitation. The majority of runoff in 2005 occurred during two rainfall events. The rainfall of September 10 set a new record for a 24-hour period (100 mm). Field runoff collectors showed that NO<sub>3</sub>-N loss was significantly higher in the barley crop than the other three treatments. There were no significant differences for NH<sub>4</sub>-N, TDN, total Kjeldahl nitrogen (TKN), DRP, TP, or TSS losses.

The subsequent two years were about 20% drier than normal and not enough natural surface runoff was generated for analysis. The rainfall simulations showed no significant differences for TP loads or for TN loads among vegetation types. However, loads of TN were significantly higher from the 3-metre plots than from the 6- and 9-metre plots. Loads of TSS were significantly affected by both buffer width and vegetation type. The 3-metre wide plots had significantly higher TSS load than the 9-metre plots and the native grass treatment had

significantly higher TSS load than the tame grassalfalfa treatment.

The second rainfall simulation experiment of adding a shelterbelt to a native grass buffer showed no significant differences in TP, TN, and TSS concentrations and loads between the native grass and mixed grass-shrub buffer treatments of TP, TN, and TSS concentrations and loads.

Additional data were collected on the buffer soil nutrient status, vegetation cover and yield, and the electrical conductivity of the subsurface soil. Analyses showed the initial nutrient status of the soils was well below agronomic levels. Comparisons of the soils in subsequent years showed minor changes. The soil nitrate-nitrogen increase was the result of fertilizer application to the barley. Yield measurements showed that the native grass and barley treatment had similar yield. The tame grass-alfalfa treatment had about 20 to 50% more yield than the native grass and barley treatments due to the inclusion of the broadleaf alfalfa with the grasses.

An EM-31 survey of the buffer field was conducted to categorize the bulk conductivity of soils to a depth of 6 m. Interpretation of the EM-31 survey with geomorphology suggests that the low conductivity values are due to coarse sediments. The subsurface hydrology is typical of alluvial floodplains and is complicated by old oxbow channels and shallow subsurface flow.

In conclusion, based on surface runoff alone, this study suggests that buffers are likely not required along the LLB River because little surface runoff occurs. In years of extreme rainfall events when channel flow is created, a buffer of 6 m or less may reduce the risk of TSS transport and possibly nitrate loss from a fertilized crop field. The best vegetative cover may be a tame grass mix with a deep-rooted alfalfa variety and shrubs. This type of cover will be the most productive from an economical perspective and may provide the best filtration for subsurface water movement. Future research may examine the effectiveness of shortwidth grass buffers to filter bacteria, or may examine the effectiveness of vegetated swales or channels to filter pollutants.

#### **Additional Studies**

In addition to the five BMPs evaluated in this study, other supplemental studies were also conducted. The spatial analyses study was used at the watershed scale to construct a GIS spatial database that would link with hydrologic modelling. The nutrient budget study was conducted on a



watershed scale to determine if this method has potential to target BMPs on those inputs causing a nutrient surplus in the watershed. The cattle watering systems and soil nutrient study was conducted to link the effects of the streambank fencing and off-stream watering BMPs.

#### Spatial analyses

Spatial analyses of land use, topography, and hydrology can aid in understanding watersheds. We conducted a spatial analysis of the WEBs LLB watershed using ArcGIS and LandMapR software. LandMapR software is an automatic method to classify landforms into different slope positions based using digital elevation maps (DEMs). We found such spatial analysis was a useful tool towards understanding this watershed.

Mapping of hydrological facets revealed that the major water shedding areas contributing to surface runoff were located in the river valley adjacent to the river, and areas associated with coulee ridges on the south side of the river valley. Most of the upland plateau areas were classified as a planar or a water neutral area with little potential to contribute to runoff. The areas of highest topographic wetness index (TWI) were associated with the bottom of the coulees in the southwest area of the watershed. Slope position had few or no significant effects on surface soil physical and chemical properties. Slope did have a significant influence on TWI values, where values were highest at the lower slope position. Mean soil NH<sub>4</sub>-N values under cereal were significantly greater for the mid and upper slope positions compared to the lower slope position. This information is useful in understanding the spatial distribution of hydrology and nutrient distribution within the landscape of a watershed, and may also be useful for hydrologic modeling.

#### **Nutrient balance**

Nutrient balances of watersheds can be a potential tool to identify possible inputs contributing to N or P surpluses. Beneficial management practices can then be targeted on those inputs allowing the nutrient surplus to be managed and protect water quality. An N and P budget was conducted on the LLB Watershed. Producers in the watershed were contacted to obtain information on typical crop rotation, fertilizer use, manure practice, crop yields and stocking rates for each quarter section of land. The N and P budget for the watershed was then estimated based on this information. Major inputs considered for N and P were fertilizer, manure, fixation (N only), and atmospheric deposition (N only). Major outputs considered for N and P were harvested crop and weight gain of livestock.

Inputs of N and P were greater than outputs for the WEBs LLB watershed, indicating a nutrient surplus. Surpluses were negligible for dryland pastures and roughly similar for dryland cropland, irrigated cropland, and irrigated pastures. Major inputs causing the N surplus within the watershed were manure, followed by fertilizer; and the major input causing the P surplus was manure. Therefore, BMPs to reduce N in the watershed could be targeted on fertilizer and manure, and BMPs to reduce P could be targeted on manure alone. We concluded that nutrient budgets may be a good technique to target BMPs on those inputs causing nutrient surpluses in watersheds.

#### Cattle watering systems and soil nutrients

Nutrient transport to surface water bodies is reduced in grazed rangelands by providing alternative water sources, due to reductions in direct defecation and streambank erosion. However, surface soil adjacent to watering systems may eventually become enriched in N and P and may become nutrient —hespots". The objective of this study was to evaluate nutrient enrichment of surface soil adjacent to both a natural water body and alternative water sources.

Surface soil samples were obtained at three recently-installed watering troughs and six locations adjacent to the LLB River. At each location, surface soil samples were obtained along four transects of 100 m in length. Surface soil immediately adjacent to cattle watering sites on the LLB River was not enriched in available P or N. These nutrients were likely removed during high flow events that would have flushed the nutrients away in the river. Surface soil at distances less than 10 metres from the alternative water sources was approximately three times higher in available P and seven times higher in NO3-N than surface soil obtained at greater distances. Overall, surface soil was enriched in available P and N adjacent to the cattle watering systems, but not adjacent to the river. Although off-stream watering systems may reduce nutrient inputs into rivers by cattle, these nutrients may just be redistributed and concentrated adjacent to the off-stream watering systems.

#### **Project Partners**

The Lower Little Bow River WEBs project was lead by AAFC and directed by a multi-agency/multi-disciplinary team. The team is comprised of specialists from Federal Agencies (Department of Fisheries and Oceans, and AAFC), Provincial Agencies (Alberta Agriculture and Rural Development), the University of Alberta, Ducks Unlimited Canada, the County of Lethbridge and the cooperating producers.



#### South Tobacco Creek/ Steppler Watershed (MB)

Initiated in 2004, the Watershed Evaluation of Beneficial Management Practices (WEBs) project examines the environmental and economic impact of beneficial management practices (BMPs) at a small-watershed scale. Water quality is used as the primary indicator for the environmental impact of the BMPs. The project is being led by Agriculture and Agri-Food Canada (AAFC) with Ducks Unlimited Canada as a key funding partner.

After a proposal-based process, seven projects were selected across Canada. Each of the seven WEBs watershed sites includes the following components: biophysical evaluations (the subject of this Technical Summary), on-farm economic assessments, and hydrologic modelling. Integrated economic-hydrologic modelling is occurring at two of the project sites. The economics findings are the subject of a second technical summary -"Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #2: Economics Components - Four-year review (2004/5 - 2007/8)"; and the modelling findings are the subject of a third technical summary "Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #3: Hydrologic and Integrated Modelling Components - Four-year review (2004/5 - 2007/8)". All three Technical Summaries are companion documents to the Four-year Review report.

This executive summary is based on a review of the project's first four years (2004/5 - 2007/8) and presents the environmental (biophysical) evaluation of five BMPs in the Steppler – South Tobacco Creek WEBs project, located in south-central Manitoba.

#### **Background and Issues**

The 210-hectare Steppler sub-watershed is located within the 7500-ha South Tobacco Creek (STC) watershed, approximately 150 kilometres southwest of Winnipeg, Manitoba (Figure 7). The creek originates on the Manitoba escarpment and flows eastward, flowing into the Red River and eventually into Lake Winnipeg. The STC watershed is located at the base of the escarpment and has a drainage area of 74.2 km². The area has had a history of BMP assessments and monitoring of runoff, nutrient and sediment, which made it a good fit for the WEBs project.

The Steppler farm is comprised of a cattle and grain/oilseed operation. The producer resides in the sub-watershed and maintains a typical farm yard, whereby cattle are wintered in a small feedlot and then pastured in, and outside of, the farm watershed area. The farm-watershed landscape consists of several small intermittent watercourses, which makes it well suited for sub-dividing into smaller sub- watersheds, where individual BMPs could be established and assessed.

To facilitate the assessment of BMPs, either on an individual or collective basis, a network of runoff monitoring and water sampling stations was established throughout the farm. In total, 15 runoff monitoring and 19 water sampling sites were maintained (refer to Figure 8 for the location of the runoff and water sampling sites, designated as -Ms" on the map). The collected water samples were sent to a laboratory and analyzed for total suspended sediments and dissolved and particulate forms of nitrogen and phosphorus

To improve current understanding of the nutrient sources and cycling within the watershed (and Canadian Prairies), a number of sampling and monitoring regimes were also initiated. For example, examination of the residue on the fields before fall freeze-up and aqueous extraction of nutrients from the residue; measurements of soil fertility; snow sampling with determination of water content, nutrient and sediment composition; and soil moisture. The locations of the various sampling initiatives are shown in Figure 8. In addition a limited amount of climate data was collected, which included rainfall at a 5-minute resolution and air temperature.

The seasonal precipitation during the 2004-2008 WEBs study period, varied from average to slightly above average. The snow-water equivalent, for the November to March period, varied from a 1:1.5 year event (106 mm in 2005) to a 1:4 year event (147 mm in 2007). The rainfall depths for the April to October period, varied from a 1:2.4 year event (423 mm in 2004) to a 1:5 year event (490 mm in 2005). The return periods for snow-water equivalent and rainfall data, were based on the 43 vear period, 1965-2007, of recorded data at the Miami-Orchard Environment climate station. The climate data recorded at the WEBs project site was not used directly for the frequency analysis, because the period of record was short (1993-2007), however the rainfall data recorded at the project site compared reasonably well with the Environment Canada climate data.



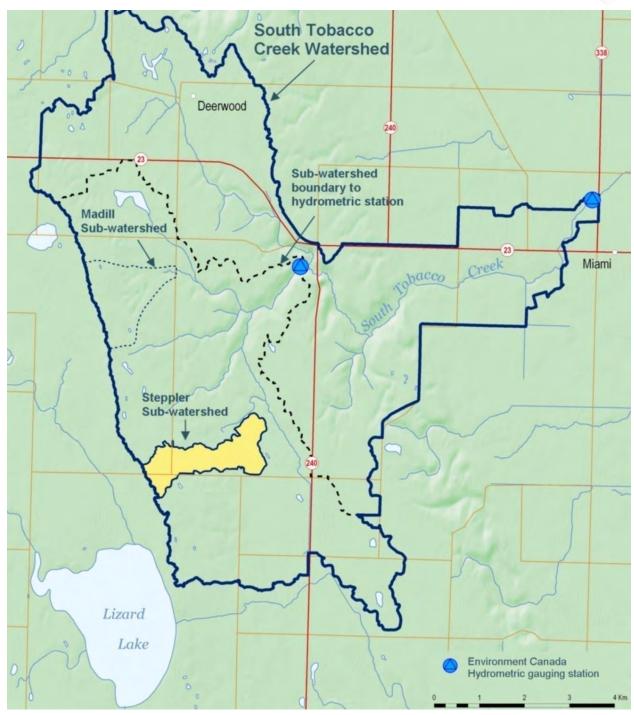


Figure 7: Location of the Steppler Sub-watershed within the South Tobacco Creek Watershed



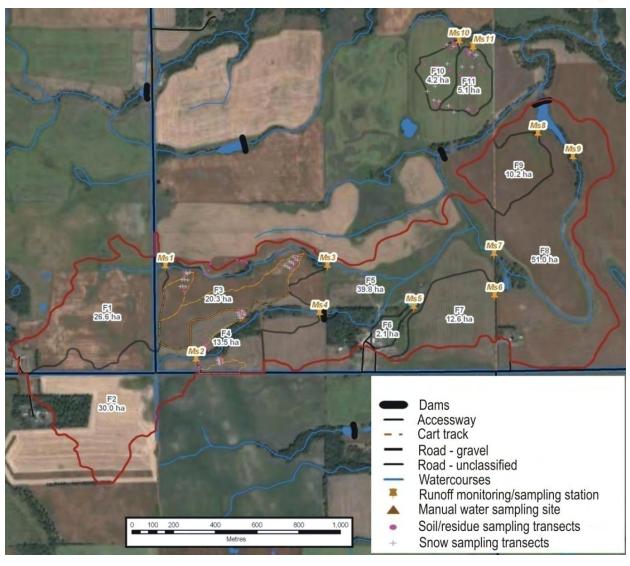


Figure 8: Location of monitoring sites and sampling locations within the Steppler Sub-watershed

Runoff information was collected for numerous sub-watersheds throughout the WEBs- Steppler sub-watershed. The majority of runoff monitoring sites were established in the fall of 2004 and runoff data has been collected for the 2005-2007 period. In each of the monitored years a spring runoff event occurred; runoff depths of 53 mm in 2005, 87 mm in 2006 and 38 mm in 2007. Multiple rainfall runoff events (7 to 8) occurred in 2005 and 2007, however, in 2006 no rainfall runoff events occurred. The total rainfall runoff depth in 2005 was 111 mm and in 2007 was 25 mm.

The spring snow-melt runoff depth for the 2004-2008 period, varied from a 1:1.5 year event to 1:8 year event. The maximum annual runoff event due to rainfall runoff varied from a 1:1.4 year event to a 1:45 year event. Due to the short

duration of runoff monitoring in the sub-watershed, the Environment Canada hydrometric station located downstream of the WEBs project site near the town of Miami (05OF017 - which has runoff data for the 44 year period, 1964-2007), was used as a proxy to identify the hydrologic return periods for the WEBs study period.

#### BMP assessment

The five BMPs being assessed in the Steppler - STC watershed are as follows:

### Conservation tillage versus conventional tillage

A paired watershed study was used to compare snowmelt and rainfall-induced runoff, sediment and



nutrient losses under a conventional and a conservation tillage system (zero tillage), typical to western Canada. A typical annual conventional tillage practice would have included a fall and spring tillage (cultivator and harrowing) and then spring seeding. The conservation tilled field was direct seeded in the spring with no other cultivation.

This study was initiated in 1993 and carried over into the WEBs project in 2004. During the calibration period (1993 to 1996), the two watersheds were tilled and cropped identically and paired water quality data (i.e., flow, sediment, particulate and dissolved forms of nitrogen (N) and phosphorus (P)) was collected. During the treatment period (post 1996), one of the two watersheds was converted to a conservation tillage system, while the control watershed remained under the same management.

#### **Small reservoirs**

The impact of small reservoirs on nutrient, sediment and runoff peaks was investigated (i.e. water quality of the outflow relative to the inflow). Between 1985 and 1995, local landowners in the South Tobacco Creek watershed constructed 26 small dams/reservoirs for erosion and flood control. Runoff monitoring into and from two of these reservoirs, the Steppler and Madill Reservoirs, was initiated in 1990. However, it was not until 1999 that water samples were taken and analyzed for nutrients and sediment. In 2004 the monitoring of the two reservoirs became part of the WEBs project. Inflow and outflow were monitored on a continuous basis and water samples were collected during runoff events for water quality analysis.

As the outlet for the Steppler farm watershed, Steppler Reservoir provided a downstream point for monitoring farm runoff and nutrient output, as well as for monitoring the cumulative impact of four of the BMPs implemented on the Steppler farm. The Madill reservoir served as a coarse benchmark against which to compare relative changes within the Steppler reservoir. Nevertheless, the land use upstream of each of the reservoirs was clearly different: much of the land in the Madill watershed was under conservation tillage and the riparian areas were wide, treed and the streams are incised in the landscape; while the Steppler watershed was under conventional tillage, contained pasture. riparian areas were narrower and the streams shallow (not incised in the landscape). Also the Madill reservoir retained very little of the runoff (largely a flow through reservoir for peak flow attenuation) while the Steppler reservoir retained approximately 10% of watershed runoff in storage.

#### **Holding pond**

The impact of capturing the runoff from an overwintering cattle feeding area, rather than having the runoff enter the stream system, was investigated. A small holding pond was constructed downstream of a 2.1 ha cattle overwintering/feeding area during the summer of 2005. Runoff monitoring and water sampling into the pond was carried out in 2006 and 2007. In 2004 and 2005 water samples were taken, but runoff was not monitored (the holding pond was not yet constructed). Water samples were evaluated for nutrients, sediment and E. coli. The pond was designed to store 130 mm of runoff from the cattle containment area. The runoff collected in the pond was applied to a nearby forage field through irrigation.

### Conversion of annual cropped lands to forage

The impact on water quality of converting annual cropped lands to forage was assessed for two pairs of sub-watersheds. All four fields were all under annual crop, after two years of baseline monitoring two of the fields were converted (fields in forage in 2006 and 2007) to forage. Runoff and water samples are taken from each of the sub-watersheds to define the runoff characteristics.

#### Comparison of riparian area management

The management practices of two riparian/buffer areas were assessed based on their impact on water quality. The riparian area of one subwatershed was widened and seeded to forage and the forage was mechanically harvested. The riparian area in another watershed had been historically overgrazed with the cattle pastured in the sub-watershed most of the summer period. This sub-watershed was made part of rotational grazing plan and the cattle were kept out of the sub-watershed after mid-August. Prior to implementing the plan in either sub-watershed, the runoff was monitored and sampled.

#### **BMP Results**

Results of the environmental assessment of the BMPs are as follows:

### Conservation tillage versus conventional tillage

A paired watershed approach was used to compare the annual and seasonal runoff and nutrient loading under two different tillage systems; conservation tillage and conventional tillage. The



paired watershed approach is recommended for use when assessing and comparing the effects that different management systems have on runoff and associated nutrient losses from a watershed – especially when replication is not practical. The main benefit of the paired watershed approach is that it statistically controls seasonal and yearly climatic and hydrological variability between the two watersheds, and any differences between the two can be attributed directly to the treatment effect.

Two statistical methods were used to determine if there was an effect on water quality due to the conversion to conservational tillage: (i) An ANCOVA method was used to statistically compare log-transformed annual flow-weighted mean concentrations and total loads from within each of the two watersheds—i.e., regression lines from both the calibration and treatment periods were compared for slope and intercept; (ii) A non-parametric Kruskal-Wallis test was used to compare median snowmelt and rainfall-induced runoff, sediment and nutrient flow-weighted concentrations and export between the two watersheds for both the calibration and treatment periods.

The results show that snowmelt runoff can be an extremely important source of both N and P entering surface freshwater in western Canada. In general, dissolved nutrient concentrations were greater during the spring snowmelt period, while sediment and particulate concentrations were controlled by rainfall events. However, in both of the paired watersheds, total runoff was dominated by snowmelt and total export of sediment and nutrients was much greater during the spring snowmelt period than over the summer. In addition, nutrient export was primarily in the dissolved form, in both the spring and summer.

#### Runoff

During the treatment period (1997-2004), there were very few significant differences in runoff between the two tillage systems (Figure 9a).

#### Sediment

Although conservation tillage did significantly reduce annual and seasonal concentrations and loads of sediment export (Figure 9b), the total sediment export from both watersheds was extremely low (< 0.1 Mg ha<sup>-1</sup> yr<sup>-1</sup>). After comparing the predicted values (using the calibration regression equation) and values observed during the treatment period, the overall annual reduction in sediment concentration and export due to conservation tillage was 44 and 65%, respectively. In addition, the conservation tillage watershed had

significantly lower concentrations of sediment in snowmelt runoff waters, compared to the conventional tillage watershed. Also, conservation tillage significantly reduced total sediment export in both snowmelt- and rainfall-induced runoff.

#### Nitrogen

Conservation tillage also reduced mean annual concentrations and total loading (Figure 9c) of nitrogen (TN). Both were approximately 3x greater for the conventional tillage watershed then the conservation tilled watershed (conventional: 6.5 mg L<sup>-1</sup> and 6.5 kg ha<sup>-1</sup>, respectively; conservation: 2.3 mg L<sup>-1</sup> and 1.8 kg ha<sup>-1</sup>, respectively). In addition, conservation tillage also reduced total concentrations and export of particulate N (PN), dissolved N (TDN) and nitrate/nitrite-N (NOx). For all four significant nitrogen parameters, there was a shift toward lower nitrogen concentrations and losses after conversion to conservation tillage.

Conservation tillage resulted in a slight increase in ammonia (NH<sub>3</sub>) losses—there was a slight shift in both concentration and export regression equations towards greater losses from the treatment watershed, compared to the conventionally tilled control watershed, but these differences were not significant. Using the calibration regression equations to predict treatment nitrogen losses and comparing those values to the observed data indicated that annual concentrations of TN, PN, TDN and NOx were, overall, decreased by 50, 47, 45, and 82%, respectively after implementation of conservation tillage. Similarly, total export of TN, PN, TDN and NOx were reduced by 68, 63, 48, and 80%, respectively.

In terms of seasonal precipitation effect (snowmelt vs. rainfall), during snowmelt, the conservation tillage watershed had significantly lower FWMCs (flow weighted mean concentration) and export of TN, TDN and NOx in snowmelt runoff waters, compared to the conventional tillage watershed: but there were no significant differences in PN and NH<sub>3</sub> between the two watersheds. During the summer, there were fewer significant differences between the watersheds than in the spring snowmelt period. For FWMC, only NOx was significantly different between watersheds, with the conservation tillage watershed having lower concentrations than the conventional tillage watershed. However, conservation tillage significantly reduced total export of TN, TDN, NH<sub>3</sub> and NOx during these same rainfall-induced events.



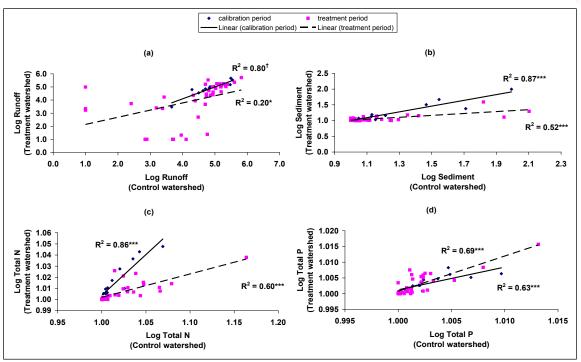


Figure 9: Example of the ANCOVA analysis used in this study, including the calibration and treatment period regressions for the treatment (conservation tillage) and control (conventional tillage) watersheds for annual (a) runoff, (b) sediment, (c) total N, and (d) total P. Statistical differences between calibration and treatment period slopes: (a) NS; (b)  $p < 0.0001^{***}$ ; (c)  $p < 0.0001^{***}$ ; (d)  $p = 0.076^{\dagger}$ . Note: NS,  $\uparrow$ ,  $\uparrow$ ,  $\uparrow$ , and  $\uparrow$  indicate non-significance and significance at the 0.10, 0.05, 0.001, and 0.0001 probability levels, respectively

#### **Phosphorus**

Contrary to expected results, the data suggests that in cold semi-arid climates such as western Canada, reduced tillage systems are actually more susceptible to losses of total P (TP), in particular, soluble P. Mean annual concentrations and export of total TP were approximately two times greater from the conservation tillage watershed relative to the conventionally tilled watershed (conventional: 0.42 mg L<sup>-1</sup> and 0.38 kg ha<sup>-1</sup>, respectively; conservation: 0.82 mg L<sup>-1</sup> and 0.59 kg ha<sup>-1</sup> respectively). In addition, based on the ANCOVA analysis, for both concentration and export (Figure 9d) there was a significant shift toward greater annual losses of TP after conversion to conservation tillage. Overall, converting to conservation tillage increased the annual concentration and export of TP by 14 and 12%, respectively.

For particulate phosphorus (PP), the ANCOVA analyses show that converting to conservation tillage reduced annual concentrations of PP by 11%, but there were no significant differences for total annual PP export. For total dissolved phosphorus (TDP), there were no significant differences between the conventional and

conservation tilled watersheds for concentration. However, for total annual export there was a significant shift in the regression equation toward larger TDP losses from the conservation tillage watershed during the treatment period. On an annual basis, converting to conservation tillage increased TDP export by 36%.

In terms of seasonal precipitation effect (snowmelt vs. rainfall), the conservation tillage watershed had significantly higher concentrations and export of both TP and TDP in snowmelt-induced runoff, but there were no differences between tillage systems for PP. During rainfall-induced runoff events, the conservation tillage watershed also had significantly greater concentrations of TDP than the conventional tillage watershed, but no differences were evident for TP or PP. However, for total export during rainfall-induced runoff events, the conventional watershed had significantly greater loads of PP, while there were no significant differences between watersheds for TP and TDP exported over the summer. We suspect that differences between the two tillage treatments in concentrations and losses of P after conversion were likely due to the stratification of P at the soil surface and the leaching of P from crop residues



#### Water quality guidelines

Overall, the average concentrations of N and P exceeded the guidelines recommended for freshwater in Manitoba (i.e., 1.0 mg N L<sup>-1</sup> and 0.05 mg P L<sup>-1</sup>) within both of the paired watersheds, in all years of the study. In fact, total N and P guidelines were exceeded within every single sample taken over the course of the study, before and after conversion. However, while concentrations of N and P in both snowmelt and rainfall-induced runoff were high, the total export of N and P from either the conventional or conservation-tilled watershed averaged less than 6.5 kg N ha<sup>-1</sup> yr<sup>-1</sup> and 0.6 kg P ha<sup>-1</sup> yr<sup>-1</sup>; which is much lower to that reported previously for conventional and conservation tillage in the U.S. mid-west.

#### **Small reservoirs**

#### **Peak flow**

The impact that the Steppler and Madill reservoirs have had on peak flows from their respective upstream sub-watersheds (i.e., inflow to the reservoir relative to the outflow) was guite variable between 2004 and 2007. However, overall, the Steppler and Madill reservoirs reduced peak flow during the spring snowmelt period by approximately 55%, while peak flow during summer rainfall-generated runoff was reduced by 19% for Steppler and 26% for Madill. On the other hand, during the total time period since runoff monitoring for the two watersheds was initiated in 1990, the average reduction by the Steppler reservoir has been 50% for spring peaks (29% for Madill) and 42% for summer peaks (Steppler and Madill). However, the actual reduction in the summer peak flow events can be fairly significant. For example, in 1990 a summer inflow peak at the Steppler Reservoir of 4.1 m<sup>3</sup> s<sup>-1</sup> resulted in an outflow of 0.45 m<sup>3</sup> s<sup>-1</sup>, a reduction of 89%.

While the reservoirs successfully attenuated the peak flow, very little of the overall runoff volume was retained for a significant length of time. Overall, the Steppler reservoir reduced the annual runoff volume by an average of 6%, whereas the Madill reservoir reduced annual runoff volume by only 0.2%. This is because the Steppler reservoir was constructed as a multi-purpose dam (whereby  $\approx 15\%$  of storage capacity is retained for summer water use), while the Madill reservoir is a dry/flood control dam (which fills and then slowly releases most of the water in a controlled manner).

<u>Concentration</u> – (sediment and nutrient)

Despite these hydrological differences, both reservoirs reduced annual concentrations of sediment, TN and TP to downstream receiving

waters (Steppler, average of 69.7, 0.4, and 0.03 mg  $L^{-1}$  yr<sup>-1</sup>, respectively; Madill, average of 33.4, 0.7, and 0.06 mg  $L^{-1}$  yr<sup>-1</sup>, respectively).

#### Loading - (sediment and nutrient)

There was considerable inter-year variation in the effectiveness of the dams in reducing annual sediment and nutrient loads (Figure 10). Nonetheless, both reservoirs significantly reduced annual loads of sediment, total nitrogen and total phosphorus. This resulted in an average annual retention from the Steppler watershed of 25 T yr<sup>-1</sup> of sediment, 166 kg yr<sup>-1</sup> of N and 17 kg yr<sup>-1</sup> of P and about a third that amount of sediment retention (6 T yr<sup>-1</sup>) from the Madill watershed, with similar amounts of N and P retained. On a per ha watershed basis, this is equivalent to an annual retention of 0.12 T ha<sup>-1</sup> yr<sup>-1</sup> of sediment, 0.81 kg ha<sup>-1</sup> yr<sup>-1</sup> of N and 0.08 ha<sup>-1</sup> yr<sup>-1</sup> of P from the Steppler watershed.

In addition, both reservoirs were effective in reducing average annual loads of dissolved N and P (Steppler, 14% N and 10% P yr<sup>-1</sup>; Madill, 23% N and 15% P yr<sup>-1</sup>). The Steppler and Madill reservoirs were also effective in removing dissolved N and P during both snowmelt and rainfall-generated runoff. but the retention of dissolved nutrients was slightly higher during the summer than the spring. Surprisingly, both reservoirs were much less effective in reducing suspended nutrients than dissolved nutrients to downstream water bodies. While the reservoirs were effective in removing particulates during snowmelt-generated runoff. they were often sources (rather than sinks) of suspended nutrients during rainfall-generated events. We suspect that this was a combination of very little particulates actually entering the reservoirs (especially in comparison to total dissolved nutrients) and algal growth during the summer. However, since dissolved nutrients were the dominant form of both N and P (> 70% in both snowmelt and rainfall-induced runoff events), both reservoirs were successful in reducing overall nutrient loads to downstream water bodies, annually and seasonally.

#### Holding pond

#### Runoff

Runoff from the cattle overwinter/feeding area has been monitored since the holding pond was constructed in the late summer of 2005. The average spring runoff coefficient has been 49% and average summer runoff coefficient has been 72%. The high runoff coefficients are typical of active feedlots where chemicals in the urine and manure change the soil chemical and physical



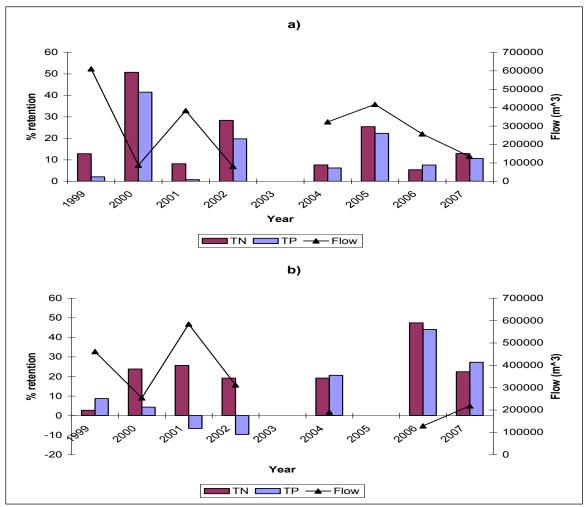


Figure 10: Example of the annual percent retention of total N (TN) and total P (TP) at the (a) Steppler reservoir, and (b) Madill reservoir

properties to create an impermeable layer. Once the manure layer is saturated, after a sequence ofstorms or a long duration storm the hardpan directs all the precipitation to runoff.

Concentration (sediment and nutrient)
Since flow measurements at the holding pond only began in 2006, the concentration data were used to summarize the results from 2004 to 2007.
Nutrient and sediment concentrations in the runoff from the overwinter/feeding area were compared to concentrations in runoff from the nearest field and concentrations measured at the final runoff sampling site, just upstream of the Steppler dam.
Concentrations of NH<sub>3</sub>, TDN, TN, TDP and TP were significantly greater in the yard runoff than at the other sampling sites in all years. The mean concentrations of NH<sub>3</sub>, TN and TP in the yard effluent from 2004 to 2007 were 7.4, 21.9 and

2.6 mg L<sup>-1</sup>, respectively, while the corresponding

maximum concentrations were 247, 543 and 40 mg  $L^{-1}$ .

Nutrient concentrations in the yard drainage were significantly greater in 2005 than in the other years. The high concentrations likely reflect activities in the yard in the winter of 2004/05 since the greatest difference was observed during snowmelt rather than during the summer period when excess nutrients could have been attributed to the construction of the holding pond. At the MS9 site, concentrations in 2005 were not significantly different from the other years.

#### **Nutrient loading**

In 2006 and 2007, the nutrient load contained by the holding pond is the amount of nutrients that were removed from the stream by the holding pond BMP. Although the area drained by the holding pond represents only 1% of the basin, flow to the



holding pond was 4% of total flow in the basin in both 2006 and 2007. If we assume that in the absence of the holding pond all captured nutrients would have been directly transported to MS9, we can calculate% nutrient reduction due to the holding pond BMP (Table 2). These values overestimate the effectiveness of the holding pond as some of the nutrients in the yard site runoff would have been lost due to in-stream processing during transport to MS9. Nonetheless they given a useful indication of the proportion of nutrients removed from the stream system by the holding pond BMP.

Table 2: Percent nutrient reduction due to the holding pond BMP, assuming all captured nutrients would have reached MS9

Year	NH <sub>3</sub>	TDN	TN	TDP	TP
2006	51%	14%	16%	17%	19%
2007	86%	35%	37%	27%	30%

Ammonia was the nutrient whose entry to the stream system was most affected by the holding pond. The load of NH<sub>3</sub> in the drainage to the holding pond was the same as that at MS9 in 2006 and more than 6 times greater than the load at MS9 in 2007. Reductions in transport of total and dissolved N and P were between 20 and 40%. The holding pond appeared to be more effective in reducing nutrient load in summer runoff than in snowmelt but that may not reflect greater anticipated in-stream processing during the summer months. In 2006 the percent reduction calculated for the summer period was roughly double that during snowmelt and in 2007 the summer reduction was 2 to 4 times greater than in snowmelt. The overall impact of the holding pond was greater in 2007 when almost double the percentages of nutrients were retained compared to 2006.

#### E. coli loading

Mean *E. coli* counts from most sites within the Steppler Watershed were usually less than the water quality guideline limit for primary recreational activities in Manitoba; maximum of 200 *E. coli* 100 mL-1. Mean *E. coli* counts in runoff from the farmyard-cattle-corral (2004 to 2007) were significantly greater than the guideline and were usually significantly greater than at other water quality sampling sites in the watershed. Annual maximum counts also came from the farmyard-cattle-corral and were as high as 2,300,000 *E. coli* 100 mL-1 during 2007. The lowest mean *E. coli* counts were generally 10 *E. coli* 100 mL-1 or less and came from a small, natural wooded watershed

that was not sampled as extensively as the Steppler Watershed.

The holding pond was generally effective at intercepting and keeping overwinter/feeding area runoff (highly contaminated with E. coli) from being transported to further downstream areas. But its effectiveness to significantly reduce counts any more than natural attenuation prior to use of the holding pond was inconclusive. There was no significant difference in mean E. coli counts between sites upstream and downstream of the overwinter/feeding area from 2004 to 2007 despite operation of the holding pond in 2006 and 2007. Between-year, mean E. coli counts for each individual site were also not significantly different. It appeared that distances between sampling sites of 500 m or more in the Steppler Watershed provided the opportunity for substantial count reductions through additional dilution and/or increased die-off due to exposure to the sunlight's ultraviolet radiation.

*E. coli* counts entering the holding pond were often in the range of 104 to 205 *E. coli* 100 mL-1 while counts were one or more orders of magnitude lower when the pond was being emptied. Counts generally declined to less than 200 *E. coli* 100 mL-1 before the pond was empty. It took approximately 27 to 37 days from the time spring runoff started filling the holding pond to when *E. coli* counts there had dropped to 200 *E. coli* 100 mL-1 or less during 2006 and 2007, respectively.

This study showed that frequency and magnitude of runoff events could be major factors on effectiveness to operate the holding pond. Significant increases in *E. coli* counts entering the holding pond from the overwinter/feeding site generally coincided with runoff of 2 L s-1 or more. High runoff volumes over a short period of time could quickly fill the pond and cause some overflow of effluent that had a minimal amount of treatment out an emergency spillway.

Occasional, very high *E. coli* counts occurred in the Steppler Watershed at some sampling sites other than from the overwinter/feeding site. These incidences appeared to often coincide with the presence of livestock nearby these sites during runoff events.

#### **Summary**

The holding pond was a highly effective BMP for reducing nutrient and pathogen inputs to the stream system. It intercepted runoff from the yard site with high nutrient concentrations and *E-coli* counts and prevented this from draining into the stream. The pond potentially reduced the nutrient



loading in the stream by between 14 and 86% depending on the year and the nutrient of interest.

### Conversion of annual cropped fields to forage

Of the two pairs of fields used to assess the forage conversion BMP, one pair, F7 (forage) and F9 (annual crop), were separately drained (that is, all surface drainage waters there originate from within the fields themselves). But the other pair, F4 (forage) and F3 (annual crop), were flow-through fields (other drainage waters already flow through the fields from outside locations), where the stream water was sampled as it flowed into and out of each of field. Upstream-downstream sampling works well in years when the upstream water quality is similar for both the forage and the annual crop fields, however if there are large differences in the upstream water quality between the two fields, the treatment effect may be obscured by differences in in-stream processes between the upstream and downstream sites.

Since snowmelt flow monitoring only began in 2005, there is but one year of pre-conversion transport data (2005) and two years of post-conversion data (2006 and 2007). Given the variability in hydrology between years and the complexity of influences on stream water quality, this sampling period is deemed insufficient to draw any firm conclusions about the effectiveness of the forage BMP. The information presented hereafter should be regarded as preliminary observations rather than as an assessment of the practice.

#### Flow

Flow characteristics varied between years and sites with no clear pattern emerging from the preliminary data. The annual rainfall runoff depths from the four fields (F3, F4, F7 and F9) prior to conversion (2005), were 122 mm, 59 mm, 83 mm and 29 mm, respectively. In 2007 the annual rainfall runoff depths for these same four fields, were 0 mm, 0.1 mm, 4 mm and 2 mm, respectively.

#### Soil and residue sampling

Samples of soil and plant residue collected in the fall of 2004, 2005 and 2006 on F4 (forage) and F3 (annual crop) were analyzed for available N and P. Standard soil test methods were used for the soil samples (Olsen P and  $NO_3$ -N) whereas residue samples were frozen, thawed and extracted with water which was subsequently analyzed for TDN and TDP. Findings indicate that in the preconversion samples (2004) there were no differences in the N and P content of the soil or residues between the two fields. In both sets of

post-conversion soil samples (2005 and 2006), Olsen P was significantly greater in the 0-6" and 6-24" depths of the forage field than in the annual crop field. There were no significant differences in NO<sub>3</sub>-N between fields in 2005 but in 2006, NO<sub>3</sub>-N was greater in the surface soil of the annual crop field than in the forage field. The post-conversion residue extracts from the forage field had significantly more TDN and TDP than residue extracts from the annual crop field.

#### **Nutrient transport**

In general, the water quality data did not reflect clear differences in available nutrients between the forage and annual crop. Differences in nutrient transport between years were greater than any differences between the fields. Transport of TN and TP was greatest in 2005 and decreased in 2006 and again in 2007. Dissolved N and P transport was greater in both 2005 and 2006 than in 2007. The only trend in nutrient transport that is consistent between field pairs and years, is for TDN loading which appears to be greater from the annual cropped fields than the post-conversion forage fields. This is in keeping with the greater NO<sub>3</sub>-N in the surface soil of the annual crop field than in the forage field in 2006.

#### Concentration

On the flow-through fields, nutrient concentrations were consistent through the sampling period, but on the independently draining fields, concentrations of TN and TP were higher in both fields (F7 and F9) in 2004 and 2005 than in 2006 and 2007 The average concentrations of TN and TP in all 4 fields in all years exceeded the currently recommended guidelines for freshwater in Manitoba (1.0 mg N L<sup>-1</sup> and 0.05 mg P L<sup>-1</sup>). Indeed, of the 425 water samples collected from the 4 fields during the 4-year period, only 11 samples met the guideline for TN and 1 sample for TP.

Further monitoring of the forage conversion BMP is required before we can adequately assess its effectiveness for protecting water quality.

#### Comparison of riparian area management

The riparian area management BMP has been the most difficult in which to quantify net effect. The experimental design is such that the riparian practices contribute to overall management in the watershed, but are difficult to assess individually. As the length of sampling record increases, we should be able to see improved water quality at the outflow of the watershed due to the combination of BMPs that have been implemented but a reliable assessment of the individual riparian practices will not be obtained.



The riparian management practices were implemented lower in the watershed in flow-through fields where concentration data do not give a clear indication of the effect of the treatment. Improved riparian management began in 2005 when only one year of pre-treatment loading data had been collected. Therefore, it is difficult to assess the impact of the BMP implementation. We can however, assess the nutrient loading from the fields where the practices were implemented relative to the other fields.

The riparian area in F8 was widened and seeded to forage which was thereafter mechanically harvested. Nutrient loadings in F8 were greater in the pre-implementation year (2005) than in the subsequent years (2006 and 2007). Loading of TN and TDN were about 40% of 2005 loadings in 2006 and only 20% in 2007. Total P and TDP loadings were between 10 and 16% of 2005 loadings in both 2006 and 2007 while the drop in sediment load was even greater. The lower loadings in 2006 and 2007 occurred even though field runoff to the stream in F8 was greater in 2006 and 2007 than it had been in 2005. If these results were considered in isolation, the BMP would appear to be performing well. However, the overall trend in the loading data indicated that there was a large reduction in loadings at all sites from 2005 to 2006 and 2007. The ranking of the load per unit area of F8 relative to the other fields was relatively constant throughout the period. Sediment and TN load rank on F8 increased somewhat relative to the other fields in 2006 and 2007 while TDN, TP and

TDP loadings showed a relative improvement in 2006 but returned to their 2005 rank in 2007.

We are unable to make a quantitative assessment of the performance of the individual riparian BMPs at this time but they will be assessed as part of the overall management plan for the Steppler subwatershed. There is presently no evidence that the implementation of these BMPs has affected water quality.

## Cumulative Impact of BMPs in the Steppler Sub-watershed

Flow, sediments and nutrients have been monitored at the downstream site (outflow from the Steppler Dam) of the Stepper sub-watershed since 1999 (excluding 2003), giving a 6-year pre-BMP record against which to begin assessing the post-BMP years (2006 and 2007). The combined effects of the holding pond, forage conversion, and riparian management BMPs can be assessed by this comparison, but the tillage BMP (conservation and conventional tillage) is outside of the watershed and the small dam BMP has been in place throughout the period of record.

Total flow, sediment and nutrient losses from the Steppler watershed are shown in Table 3 for the snowmelt and summer periods between 1999 and 2007. Nutrient and sediment losses in the summer of 2006 and 2007 and during snowmelt in 2007 were lower than previously measured in the watershed.

Table 3: Total flow, sediment and nutrient losses measured at the downstream site (Steppler Dam outlet) between 1999 and 2007

	Snowmelt				Summer					
	NH <sub>3</sub>	TN	TP	TSS	Flow	NH <sub>3</sub>	TN	TP	TSS	Flow
	kg		Т	dam <sup>3</sup>	kg			Т	dam <sup>3</sup>	
1999	35	1132	133	-	245	15	601	108	-	347
2000	0	0	0	-	0	10	194	31	-	64
2001	70	883	86	-	169	22	484	62	-	210
2002	0	0	0	-	0	13	228	45	-	66
2004	76	875	131	11.1	155	14	435	60	2.8	128
2005	81	637	88	1.5	101	26	721	155	8.9	299
2006	44	654	78	2.6	166	5	128	18	0.8	83
2007	15	245	39	0.8	70	4	76	13	0.3	49
2006	44	654	78	2.6	166	5	128	18	0.8	8

Note: "-" indicates that data is not available.



#### Summer effect

The small losses during the summer period in 2006 and 2007 were measured in runoff volumes that were comparable to those in 2000 and 2002 and appear to show that the combined BMPs had a positive influence on summer runoff water quality. Losses of NH<sub>3</sub> and TP in the summers of 2006 and 2007 were only about 40% of those measured in 2000 and 2002 while losses of TN were approximately halved. There were no measurements of sediment losses in 2000 or 2002 so the apparent reduction in sediment loading can't be verified but the reduction in PP, which was highly correlated with sediment, was similar to that for NH<sub>3</sub> and TP.

#### **Snowmelt effect**

Although nutrient and sediment losses in snowmelt runoff in 2007 were generally lower than previously measured, the runoff volumes in 2007 were also lower than in previous years and it is not clear to what extent the small losses reflect the BMP implementation. However, despite an increase in runoff volume between the snowmelt periods in 2005 and 2006, NH<sub>3</sub> losses in 2006 were almost half those in 2005. Losses of TP also decreased slightly between snowmelt 2005 and 2006 while TN losses were relatively constant. This provides some evidence the BMPs may have had a positive impact on NH<sub>3</sub> and TP transport in snowmelt. Sediment losses were higher during snowmelt in 2006 than in 2005 and may reflect the soil disturbance that occurred in fall 2005 during installation of the holding pond and riparian BMPs.

Although there are only 2 years of post-BMP data, implementation of the forage, riparian and holding pond BMPs may correspond with reduced nutrient losses during the summer period. If this trend continues, we may be able to recommend this BMP mix as a means of reducing summer nutrient losses. The post-BMP data are currently insufficient to detect a clear trend in snowmelt water quality.

# Continuation of the Steppler WEBs Project

Continuation of the Steppler WEBs project would be very beneficial to improve our understanding of the impacts and processes of the implemented BMPs on runoff, nutrient and sediment output. Several of the BMPs have been in place for only the last couple of years and as a result, it is difficult (almost impossible) to assess trends and develop conclusions on the environmental impact of these BMPs.

#### Whole farm testing

It is also desirable to move the entire BMP assessment process towards a -whelfarm" approach, whereby the entire farm management system will be examined, moving to a more realistic management rather than an —exerimental management" assessment. For example, on the fields which were converted from annual crop to forage, cattle were not allowed to fall graze for fear of tainting the outcome of the forage conversion assessment. Also manure has been applied on fields outside the watershed, which is not a realistic farm operation and the hope is to move the application of manure within the watershed. However, it is only after several years of monitoring in order to understand associated runoff-nutrient processes that these kinds of farm management changes can be made.

#### Specific BMPs

In general, the assessment of the five existing BMPs will continue, except for a few alterations to some of the BMPs, and a new BMP will be added to the assessment.

- Conservation tillage compared to conventional tillage – adjust the BMP to try and reduce dissolved phosphorous runoff from the conservation tilled field. This will involve fall tilling the conservation tilled field every other year.
- 2) Forage conversion the existing forage and annual crop fields will be swapped (i.e. forage fields switched to annual crop and visa versa) in order to neutralize factors (noise in the system, like the riparian areas) affecting nutrient or sediment runoff, so that impact of conversion can be better isolated.
- Holding pond BMP continue, except a second holding pond will be constructed elsewhere (involving a second producer) to replicate the test results.
- 4) Small reservoir and riparian management BMPs continue as they have been.
- Cattle winter feeding/bedding BMP the practise of feeding and bedding cattle in the field (outside the feedlot area) will be examined.
  - The recognized benefits of this practice (based on other studies and reports by producers), are that there is less or no accumulation of manure in the feedlot pens and as a result, less cost associated with manure management. The other benefit is that the animals tend to stay healthier.



 The unknown aspect of this management practise is its impact on the environment (i.e. water quality). A paired watershed approach will be used, whereby one field will serve as a control and the other will be used as a treatment area. The surface runoff will be tracked along with other parameters to assess nutrient and sediment runoff.

#### Sampling/monitoring

The effect of the various BMPs on the nutrient status within the study watershed and subwatersheds was evaluated based on a detailed sampling and monitoring program. The runoff monitoring and water sampling program included 23 monitoring sites. A majority of these sites are automated, however, several sites are based on grab samples. To compliment the current nutrient and runoff sampling, the existing surface materials (snow, vegetation and soil) testing strategy will continue. The surface material testing will be used to aid in understanding the sources and pathways of nutrients and sediments that are measured at the water sampling locations.

Some of the monitoring that has been carried was for the benefit of the integrated modeling and economic assessment and will continue. For example, the sampling and monitoring of flows at the downstream end of the larger watershed and at an intermediate location, and collection of agronomics data, has severed these two functions. To compliment and aid in the integrated modeling, an —ni stream processes" assessment will be initiated, with the objective of assessing the origin of sediment—whether it be due to in-stream erosion or from off the field landscape.

## **Project Partners**

The Manitoba WEBs project was lead by AAFC and directed by a multi-agency/multi-disciplinary team. The team is comprised of specialists from Federal Agencies (Environment Canada, Department of Fisheries and Oceans, and AAFC), Provincial Agencies (Manitoba Water Stewardship, and Manitoba Agriculture, Food and Rural initiatives), the University of Manitoba, Ducks Unlimited Canada, Deerwood Soil and Water Management Association; and the cooperating producers.



## **South Nation Watershed (ON)**

Initiated in 2004, the Watershed Evaluation of Beneficial Management Practices (WEBs) project examines the environmental and economic impact of beneficial management practices (BMPs) at a small-watershed scale. Water quality is used as the primary indicator for the environmental impact of the BMPs. The project is being led by Agriculture and Agri-Food Canada (AAFC) with Ducks Unlimited Canada as a key funding partner.

After a proposal-based process, seven projects were selected across Canada. Each of the seven WEBs watershed sites includes the following components: biophysical evaluations (the subject of this Technical Summary), on-farm economic assessments, and hydrologic modelling. Integrated economic-hydrologic modelling is occurring at two of the project sites. The economics findings are the subject of a second technical summary -"Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #2: Economics Components - Four-year review (2004/5 - 2007/8)"; and the modelling findings are the subject of a third technical summary "Watershed Evaluation of Beneficial Management Practices (WEBs). Technical Summary #3: Hydrologic and Integrated Modelling Components - Four-year review (2004/5 - 2007/8)". All three Technical Summaries are companion documents to the Four-year Review report.

This executive summary is based on a review of the project's first four years (2004/5 - 2007/8) and presents the environmental (biophysical) evaluation of two BMPs in the South Nation Watershed WEBs project, located in eastern Ontario.

## **Background and Issues**

Eastern Ontario's South Nation River drains approximately 3,900-square-kilometres of land from its headwaters just north of the St. Lawrence River near the city of Brockville, northward to its confluence with the Ottawa River near the community of Plantagenet. The South Nation Watershed is a highly productive agricultural region. Approximately 60 per cent of the watershed is farmed – with a mix of livestock and cash crop production, mostly on flat, tile-drained fields. Nutrient and bacterial contamination of the South Nation River and its tributaries has been linked to agricultural activities.

Over the last 40 years, concern over declining water quality trends in the river basin has grown.

Key identified problems include fecal and nutrient contamination of surface water, resulting in part from livestock interaction with watercourses; off field transport of land applied manures; and tile drainage systems acting as efficient conduits for field-based contaminants to move into adjacent drainage networks.

Two adjacent paired micro-watersheds (the Philippe Blanchard and the Roland Bisaillon municipal drains) within the South Nation Watershed (Figure 11) have been chosen to evaluate the effectiveness of two BMPs—restricted cattle access (RCA) and controlled tile drainage (CTD) which are designed to alleviate pollutant loads to surface drainage systems. The two microwatersheds of this study feature the kind of agricultural-based activities found throughout Eastern Ontario.

The efficacy of both the RCA and CTD BMPs has been referenced in terms of surface and soil/ground water quality improvements. Water quality endpoints included, but were not limited to, forms of nitrogen, phosphorus, sediment, indicator and pathogenic bacteria, and parasites.

## **Biophysical Component**

The biophysical component of the study is focused on evaluating the environmental effect of the following two BMPs on water quality:

- 1) Restricted cattle access
- 2) Controlled tile drainage

A summary of the background, methods, and results specific to each of the BMPs assessed as part of this project are described below.

#### Restricted cattle access

#### **Background and methods**

Towards evaluation of the impact of restricting cattle from water courses on water quality, a portion of the Blanchard watershed that has been historically used to pasture livestock, was subdivided into an above-and-below' watershed design. For the above' treatment, pastured livestock were physically restricted from the stream using fencing (RCA), whereas for the downstream or below' treatment, livestock were free to pasture in an unrestricted fashion (UCA). Fencing was installed to ensure a minimum three-metre buffer strip between the stream and adjacent pasture areas. Pasturing density for UCA and RCA was 2.5 head hectare (a density common in the region).



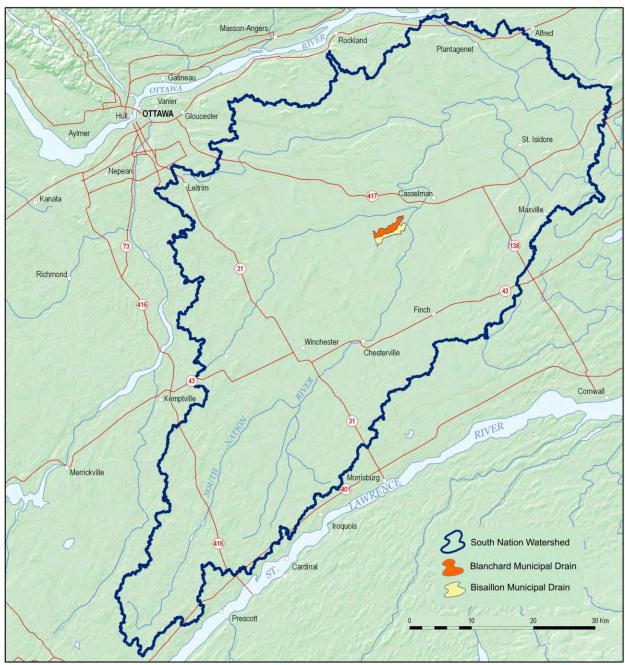


Figure 11: Locations of the Philippe Blanchard and Roland Bisaillon Municipal Drains within the South Nation Watershed

Measurements include stream input and output water quality, and other microbiological and nutrient indicators for each site. Additional methods are used to verify fecal sources.

#### Results

Statistical analyses indicated that there were no significant differences (p>0.1) in stream contaminant mass loads among the two pasturing treatments, although median mass loads of

nutrients, bacteria, and parasites were higher (not statistically) in the UCA relative to the RCA (N = 4 years). All stream contaminant mass loads were significantly greater (p<0.1) in both the RCA and UCA systems after yearly livestock introduction, relative to spring pre-pasturing. Restricted access also augmented riparian vegetation growth and reduced degradation of stream morphology. Nevertheless, *E. coli* in the stream was sourced primarily as livestock (80%), but parasites such as *Cryptosporidium* spp. were



often associated with wildlife, perhaps a result of improving upstream riparian habitat through restricted cattle access. On average, the highest nutrient and bacteria loads were upstream of both pasturing treatments, suggesting that fecal loading in the watershed due to upstream manure application may be more important than loadings induced by light pasturing operations.

#### Controlled tile drainage

#### **Background and methods**

Following a paired-watershed design', a test' (480 ha Blanchard) and control (230 ha Bisaillon) micro-watershed were instrumented to evaluate potential water quality improvements associated with CTD intervention, relative to conventional tile drainage (UTD). In 2008, >75% of the test' watershed was under CTD while the control' watershed was entirely under UTD (see figure 12). The CTD practice consisted of installing in-line water level control structures at header drain outlets to seasonally restrict the water in these

drains (often elevating water tables) from discharging into watercourses – thereby retaining soil water and nutrients in the field for crop growth. Studies have shown that such drainage management can improve crop yields.

In early spring, control structures on the tile headers remain open to permit free drainage and allow for improved soil aeration until after field operations or, in some cases, until after crops are adequately established. The structures within the test watershed are then closed to restrict drainage. The effects of controlled drainage are studied primarily through assessment of N balances, crop performance, and soil/groundwater hydrology. Nitrogen is used as a mass balance endpoint within this study.

#### Results

Relative to UTD, growing season N mass loads for corn fields under CTD were reduced by ~75 to ~100%. Nitrogen uptake by corn under CTD

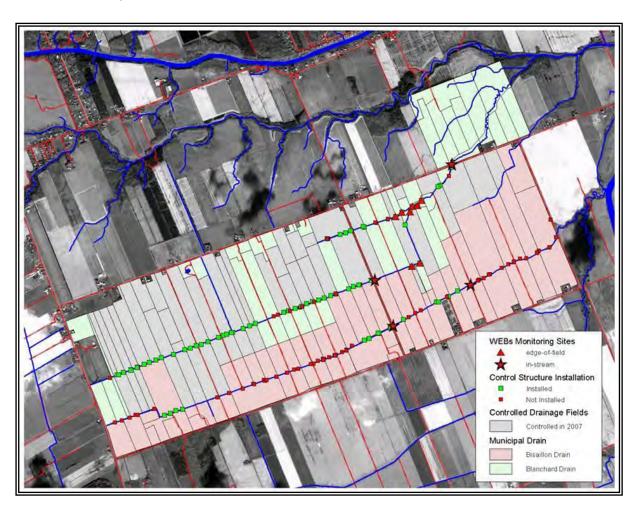


Figure 12: Fields under controlled tile drain management at South Nation



consequently increased ~7 to ~21%, relative to UTD corn, and ultimately, yields were estimated on average to improve by ~4 to ~30%. Groundwater nitrate and ammonium mass loads from field to adjacent stream were approximately 2% greater for CTD (relative to UTD fields) as a result of: i) heightened groundwater nitrate and ammonium concentrations in groundwater resulting from reduced N loss via tile, and ii) elevated water tables imposed by CTD slightly increasing groundwater flow to stream -- albeit total growing season groundwater nitrate and ammonium mass loss from CTD fields were only around 10% of those from UTD fields (~1 kg N exported as groundwater per ha<sup>-1</sup>). Emissions of nitrous oxide from CTD corn fields was approximately 40-52% less than those from UTD fields, perhaps as a result of more efficient nitrogen and water use by crops, reducing denitrification potential.

Nitrogen isotopic signatures ( $\delta^{15}N$ ) were examined to evaluate nitrogen recycling in CTD and UTD fields. Findings indicate that there is a longer residency time of nitrogen in the groundwater in CTD fields which resulted in higher fractionation and higher  $\delta^{15}N$  signals. Hence, the CTD practice induced more nitrogen recycling and reduced nitrate export to surface waters. For years when

there was greatest CTD intervention on the test watershed, reductions of ~84% ammonium, ~35% nitrate, and ~6% total phosphorus mass loads were observed from the test' watershed (Blanchard), relative to the control watershed (Bisaillon) streams. Although the reporting time frame is short in terms of being able to confidently identify the watershed-scale impact of CTD, the current short-term results are indicative of a substantial water quality improvement. In an attempt to more fully understand the impact of CTD on water quality at watershed scales of investigation, future work on this project will, at a minimum, involve the continuation of stream monitoring for flow and mass loads of agriculturally-derived contaminants.

#### **Project Partners**

The Ontario WEBs project was led by AAFC and directed by a multi-agency/multi-disciplinary team. The team is comprised of specialists from Federal Agencies (Environment Canada, Health Canada and AAFC), Provincial Agencies (the Ontario Ministry of Agriculture, Food and Rural Affairs), the University of Ottawa, Ducks Unlimited Canada, South Nation Conservation and the cooperating producers.



# Bras d'Henri and Fourchette Watersheds (QC)

Initiated in 2004, the Watershed Evaluation of Beneficial Management Practices (WEBs) project examines the environmental and economic impact of beneficial management practices (BMPs) at a small-watershed scale. Water quality is used as the primary indicator for the environmental impact of the BMPs. The project is being led by Agriculture and Agri-Food Canada (AAFC) with Ducks Unlimited Canada as a key funding partner.

After a proposal-based process, seven projects were selected across Canada. Each of the seven WEBs watershed sites includes the following components: biophysical evaluations (the subject of this Technical Summary), on-farm economic assessments, and hydrologic modelling. Integrated economic-hydrologic modelling is occurring at two of the project sites. The economics findings are the subject of a second technical summary -"Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #2: Economics Components - Four-year review (2004/5 - 2007/8)"; and the modelling findings are the subject of a third technical summary "Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #3: Hydrologic and Integrated Modelling Components Four-year review (2004/5 - 2007/8)". All three Technical Summaries are companion documents to the Four-year Review report.

This executive summary is based on a review of the project's first four years (2004/5 - 2007/8) and presents the environmental (biophysical) evaluation of four BMPs in the Bras d'Henri and Fourchette Watersheds WEBs project, located in southeastern Quebec.

#### **Background and Issues**

Hogs and dairy cattle are the predominant animal production south of Quebec City with a marked intensification of hog production in recent years. Significant amounts of fertilizers of animal origin have long been produced in the Chaudière and Etchemin Watersheds. The increasingly high level of soil phosphorus (P) saturation of this region (Simard et al., 1995) and soil erosion have contributed significantly to the non-point source pollution of streams. Excess runoff and the presence of shallow aquifers could also contribute to well contamination by nitrates and possibly enteric pathogens. Since 1999, the Québec government has attempted to improve manure management by implementing agro-environmental fertilization plans based on the level of phosphorus in the soil and crop uptake. This policy ultimately

promoted the use of annual crops that require high amounts of P, such as grain corn and soybean—as well as the cultivation of marginal and forested lands in order to use up manure. In the study area, grain corn area has increased appreciably in recent years, creating a more homogeneous agroecosystem where non-point sources of pollution by phosphorus, nitrogen, herbicides and enteric pathogens are more abundant.

In the study area, solutions for diminishing the environmental burden of agricultural production include the adoption of beneficial management practices (BMPs) to reduce or control the transport of pollutants from agricultural land to streams (Novotny and Olem, 1994). Water management BMPs at the field level can also improve crop yields by more efficient use of nutrients. Other BMPs are aimed at either reducing the amount of potential pollutants used, such as herbicides, or optimizing the management of nutrients and pathogens with more appropriate slurry spreading systems. Although the impacts of BMPs on water quality are better understood at the plot level, they still need to be thoroughly evaluated at the watershed scale (Ice and Whittemore, 1998).

The project took place on critical tributaries of the Chaudière and Etchemin Rivers, respectively the Bras d'Henri River, a sub-basin of the Beauriyage River, and the Fourchette Brook, a sub-basin of the Le Bras River. The Chaudière and Etchemin Watersheds are located within the agro-climatic region of Chaudière-Appalaches in southern Québec. They are among the province's thirtythree main watersheds where integrated watershed management aimed at improving water governance was put in place (Quebec Water Policy, 2002). In this agro-climatic region where most non-point source exports of phosphorus occur during snowmelt runoff and spring and fall precipitation, soil and water conservation practices are essential for draining off the water gradually while minimizing soil erosion and washout due to inrushes of water (Cluis et al., 1995).

#### The Bras d'Henri Watershed

The watershed covers 150 km² with forage, corn, soybean and grain production accounting for 41% of its surface area. Animal production has one of the highest livestock densities in Quebec with 4.7 animal units per hectare under cultivation. Hog production represents 59% of animal units in the watershed, versus 23% for cattle and 6% for poultry. Two watersheds were selected near the city of Saint-Bernard where producers interested in collaborating in the WEBs project were all members of an agri-environmental club. The installation phase began in 2004 and was completed in 2006 with the development of surface



runoff control structures in the intervention microwatershed. The other micro-watershed was set as a control monitoring site with producers operating business-as-usual agricultural practices. The calibration phase took place from 2004 to 2007 and the evaluation phase started in 2008. The BMPs implemented and evaluated in the Bras d'Henri River intervention micro-watershed consisted of soil and water conservation practices, reduced herbicide use, an improved slurry spreading system and adapted crop rotations.

#### The Fourchette Watershed

The watershed covers 120 km<sup>2</sup> with 60% under agricultural use. The environmental pressure from agriculture is high given that 75% of the streams are bordered by farmlands that have a livestock density of 2.1 animal units per hectare. In 2001, the Institut de Recherche et de Développement en Agroenvironnement (IRDA), in partnership with regional and provincial organizations, set up an agreement to study two micro-watersheds located near Saint-Isidore. Between 2001 and 2003, the installation and calibration phases received funding from the Fonds d'action québécois pour le développement durable and the Centre de développement de l'agriculture du Québec. From 2004 to 2008, the evaluation phase was supported by the WEBs project. Soil and water conservation practices along with crop rotations were the BMPs implemented and evaluated in the Fourchette Brook intervention micro-watershed.

## The Project

The WEBs study occurred within two sets of intervention and control micro-watersheds of approximately 300 ha each (Figure 13). Four BMPs were globally assessed in the Bras d'Henri and Fourchette intervention micro-watersheds. Water quality trends were analyzed between the intervention micro-watersheds and the control micro-watersheds where no BMPs have been implemented for the WEBs project. Two of the four BMPs were implemented exclusively in the Bras d'Henri intervention micro-watershed and assessed with an edge-of-field experimental setup (Figure 14).

#### Site characterization

This project was set up using existing soil surveys to target twin micro-watersheds in the Bras d'Henri and Fourchette drainage basins, and to implement BMPs in the intervention micro-watersheds in order to get temporal and measurable water quality improvements. It soon appeared after a detailed soil mapping that the identified Bras d'Henri and

Fourchette twin micro-watersheds had more contrasted soil characteristics than deemed initially. This new-found piece of information was subsequently exploited to better quantify and interpret soil effects on BMP performance. In order to compare the initial soil conditions of the twin micro-watersheds of the Bras d'Henri and Fourchette basins, a detailed soil survey (1:20 000 scale) was conducted using the stratified random transect method applied, as described by Nolin et al. (1994). A total of 688 soil profiles (1 m deep) were described in the four microwatersheds using the Canadian System of Soil Classification.

Moreover, in the Bras d'Henri micro-watersheds, the agricultural soil surface layer (0 to 0.2 m) was sampled and analyzed to determine soil texture, organic matter content, soil reaction (pH), Mehlich-3 extractable elements (P, K, Ca, Mg, Fe and Al), ammonium oxalate extractable Fe, Al and P, water soluble P and P sorption index. The degree of soil P saturation was estimated using both P/Al Mehlich-3 and P/Al+Fe ammonium oxalate ratios.

Historical and actual agronomic data were provided by producers and classified by animal production, crop area, amount of mineral and organic fertilizer use, time of application of fertilizers, soil nutrient analyses, and soil management. Landscape, pedology and agronomy data were geo-referenced and compiled into a GIS atlas.

#### **BMP Effect**

The surface runoff control and crop rotation BMPs were implemented in both intervention microwatersheds, while the hog slurry application and the reduced herbicide use BMPs were implemented only in the Bras d'Henri intervention micro-watershed. The surface runoff control BMP implementation is a long-term multi-phase process and has been recently completed in the Bras d'Henri micro-watershed. Consequently, it will need time to equilibrate before it can be effectively evaluated.

The <u>surface runoff control BMP</u> targeted areas at risk for soil water erosion, sediment and contaminant transport to ditches and streams. This BMP consisted of developing riparian buffer strips with trees and shrubs, windscreens, streambank stabilization, re-grading the ditch bank, stream course rehabilitation, infiltration ditches, grassed waterways, area drains, and tile drain outlet stabilization. This BMP aims to control soil water erosion; to intercept sediments, nutrients, pathogens and pesticides; and to prevent streambank failure.



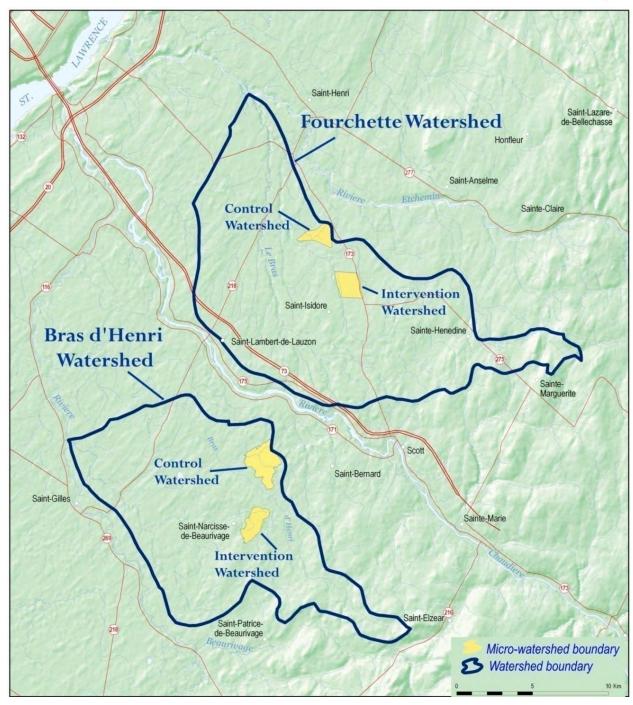


Figure 13: Location of the Bras d'Henri and Fourchette control and intervention micro-watersheds



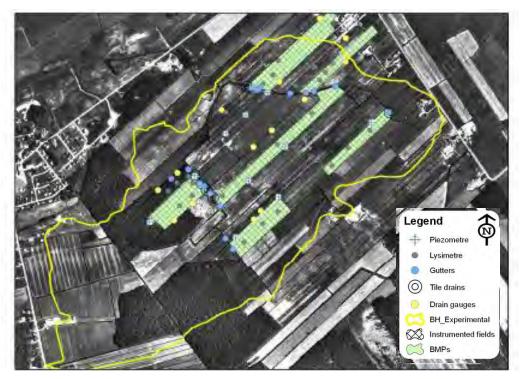


Figure 14: Edge-of-Field experimental setup in the Bras d'Henri intervention micro-watershed

(Table 4). A survey of sites presenting soil water erosion and streambank failure was conducted in 2002 in Fourchette and in 2005 in Bras d'Henri. Thereafter, survey results were presented to the producers to agree on solutions, investments and funding necessary to correct the problematic situations. The third phase consisted of implementing the corrections in Fourchette in 2003 (Figure 15a) and Bras d'Henri in 2006-2007 (Figure 15b).

- 2) The <u>hog slurry application BMP</u> aimed to use nitrogen more efficiently in order to reduce the amount of nitrogen loss through volatilization and leaching during manure spreading. The slurry was applied using an improved spreader designed with trailing hoses spaced in rows. Post-emergence and shallow incorporation of the slurry shortly after the surface application was intended to optimize phosphorus and nitrogen uptake by the crop to further reduce the risk of nutrient and pathogen losses.
- The <u>crop rotation BMP</u> was implemented in addition to crop rotations already included in

- farm plans by the agri-environmental counsellors and the producers. The target of this BMP within the WEBs project was to find alternative crops to minimize the negative environmental impacts of long corn rotations, such as soil water erosion and soil phosphorus enrichment.
- 4) The reduced herbicide use BMP targeted corn and soybean crops. Weed control in these wide-spaced row crops is intensive and herbicide use is widespread. Several approaches were investigated in the Bras d'Henri intervention micro-watershed. The first one consisted of testing an AAFC-developed herbicide reduction decision-support system based on an intervention threshold (weed cover from digital images) and estimated yield reduction risks. Other measures included sprayer calibration and reduced herbicide rates of selected herbicides on specific fields. Finally, weed surveys coupled with a new web tool developed by the provincial government (http://beta.sagepesticides.gc.ca/) allowed for the recommendation of herbicides having a lower environmental impact



Table 4: Runoff and Erosion Control Structures in Bras d'Henri and Fourchette intervention micro-watersheds

Description of Structure		s d'Henri	Fourchette		
		Length (m)	n	Length (m)	
Stream bank restoration/protection     Reduction of the bank slope gradient     Bank stabilization by seeding with herbaceous plants	-	400	-	1275	
Riparian buffer strip delineation	-	6684	-	-	
Bank stabilization with shrubs (bioengeering)				400	
Riparian buffer strip with shrubs and trees  • Planting a mixed row of trees and shrubs on the bank  • Species used: Shrubs: Thuja occidentalis, Viburnum trilobum, Spiraea latifolia, Physocarpus opulifolius, Aronia melanocarpa Trees: Quercus macrocarpa, Fraxinus americana, Picea abies	-	3480	-	6690	
Riprap at the outlet of drain or depression	56	-	24	-	
Tile outlet stabilization  Stabilizing outlet with riprap	42	-	8	-	
Culvert protection  Riprap protection at entry and outlet of culvert	6	-	-	-	
Grassed waterway	2	115	3	225	
Filtering trench	1	25	3	n/s	
Catch basin with tile inlet			6	-	



Figure 15a: Runoff and erosion control structures in the Fourchette intervention micro-watershed



Figure 15b: Runoff and erosion control structures in the Bras d'Henri intervention micro-watershed



#### Water quality assessment

Water quality was assessed at the microwatershed scale (~300 ha) in both the Fourchette and Bras d'Henri sites. Water quality was also evaluated at the edge-of-field (3 to 7 ha) scale in the Bras d'Henri where surface runoff and drainage waters were collected using gutters, drain gauges, suction cup lysimeters and secondary tile drain collectors. Stream water was sampled at the microwatershed outlets using auto-samplers, and groundwater was collected from piezometers in the Bras d'Henri intervention micro-watershed. Samples were analyzed for various forms of nitrogen, phosphorus and other major and minor nutrients, herbicides, E. coli and Salmonella. Automated multi-probes were also used to monitor physico-chemical water quality parameters (pH. electrical conductivity, temperature, turbidity and oxidation-reduction potential).

## **Results and Interpretation**

#### **Biophysical component**

Pedology of micro-watersheds – The detailed pedology study of the four micro-watersheds showed significant differences between the twin micro-watersheds but also high variation within watersheds (Figure 16). These conditions significantly influence the soil P enrichment and soil P desorption risk by storm events under intensive livestock production and the potential surplus of nutrients within these watersheds. Contrasting soil characteristics also influence leaching and surface runoff potentials of nitrogen and phosphorus forms, as well as those of other contaminants (pathogens, herbicides, trace elements).

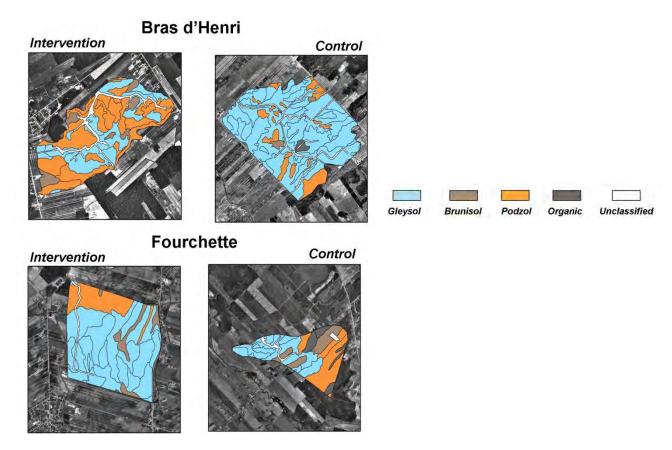


Figure 16: Pedology of micro-watersheds: Dominant soil order



#### Bras d'Henri twin micro-watersheds -

comparison of initial soil conditions. The intervention micro-watershed showed a higher pedodiversity than the control micro-watershed. The soils of the intervention micro-watershed are mainly podzols (50%) and gleysols (30%), imperfectly (40%) to poorly drained (40%), with a sandy loam surface texture and sandy to coarse loamy family particle-size (50%). They were mostly developed over fluvial deposits. In the control micro-watershed, dominant soils (80%) are poorly drained, with a loam surface texture and a loamy family particle-size. These soils belong to the gleysolic order and are developed over fluvio-lacustrine deposits.

Having a coarser texture and being more permeable, the intervention micro-watershed soils have a higher potential of N leaching (medium) than the control micro-watershed soils (weak). The two micro-watersheds have similar surface runoff potentials (weak to medium). However, being mainly podzolic, the soils of the intervention microwatershed showed a higher average P sorption capacity than the dominant gleysolic soils of the control micro-watershed (Table 5). Soils of these two micro-watersheds have similar P content, but the intervention micro-watershed soils have lower soil phosphorus saturation than the soils of the control micro-watershed. Therefore, the risk of soil P loss to the stream by surface runoff is significantly higher in the control micro-watershed than in the intervention micro-watershed.

Fourchette twin micro-watersheds – comparison of initial soil conditions. According to their initial soil conditions, the Fourchette twin micro-watersheds were also quite different, with the intervention watershed having lower pedodiversity than the control. Soils in the intervention micro-watershed are predominantly (70%) poorly drained and gleysolic, with a loam to sandy loam surface texture and sandy to coarse-loamy family particle-size. They were mainly developed over fluvial and till deposits. The dominant (90%) slope class is 0-3%.

In the control micro-watershed, soil conditions vary from podzolic (40%) to gleysolic (30%) and are poorly drained (40%) to well drained (25%). Soil textures are sandy loam to clay loam at the surface, sandy-skeletal to fine-silty family particlesize. Slopes vary from 0-3% (50%) to 3-8% (40%). Soils were developed over fluvial, fluvio-lacustrine, lacustrine, marine and organic deposits.

Accordingly, the control micro-watershed soils are deemed more permeable and sensitive to N leaching than intervention micro-watershed soils.

The intervention and control micro-watersheds have similar potential to surface runoff (weak to medium).

#### Agriculture in micro-watersheds

Despite being located in the same area, noteworthy agronomic differences were found between intervention and control micro-watersheds in both Bras d'Henri and Fourchette basins (Table 5).

Within the Bras d'Henri intervention microwatershed, the average annual crop area (2004-2007) covered 53%, while it was only 26% of the control micro-watershed. This difference is explained by the specific animal production found in each micro-watershed, with 85% of all animal units being swine in the intervention microwatershed which required more cropland to produce grain for pigs. Manure was significantly applied in excess to crop uptake in the intervention micro-watershed leading to an annual phosphorus excess of 22 to 39 kg P<sub>2</sub>O<sub>5</sub>/ha. The entire annual crop area was under conventional tillage in both micro-watersheds, with 50% of the annual crop in the intervention micro-watershed being ploughed under before winter every year.

In the Fourchette basin (2002-2006), the annual crop and forest areas covered respectively 37% and 8% of the intervention micro-watershed. The annual crop area was only 11% in the control micro-watershed while the forest still constituted 38% of total area. Both micro-watersheds showed a phosphorus surplus of 15 kg  $P_2O_5/ha$  and 20 to 31 kg  $P_2O_5/ha$  in the intervention and control micro-watersheds, respectively. Conservation tillage occupied up to 50% of the annual cropped area in the intervention micro-watershed, while these crops were largely conventionally ploughed in the control micro-watershed before winter.

## Impact of pedology, hydrology, climate, etc. on water quality at micro-watershed outlets

Although the main objective of this project was to evaluate environmental impacts of a range of BMPs at the watershed scale, this required quantifying the reduction of contaminant loadings at the watershed outlet, in order to identify sources of contaminants in stream water, and to understand the timing of contaminant transport. Therefore, an initial characterization and calibration phase was required before assessing the efficiency of the BMPs. Results of the detailed soil and site characterization showed important soil and agronomy variations between micro-watersheds, as reported above—diverse sources of



Table 5: Pedology and land use characteristics of micro-watersheds

	Bras d'I	Henri	Fourchette		
	Intervention	Control	Intervention	Control	
Total Watershed Area (ha)	236	423	250	192	
Dominant soil order	Podzol (55%) Gleysol (25%)	Gleysol (25%)	Gleysol (75%)	Gleysol (40%) Podzol (55%)	
Dominant slope	3-8%	0-3%	0-3%	0-3% (60%) 3-8% (35%)	
Soil surface textural class	Sandy loam	Loam	Loam to sandy loam	Sandy loam to clay loam	
Soil P saturation (P/Al Mehlich3)	6.97	8.14	-	-	
Annual Crop Area	53%	26%	37%	11%	
Hay/Pasture Area	30%	46%	42%	37%	
Forest Cover Area	13%	17%	8%	38%	
Other	4%	11%	13%	14%	

contaminant production and transport seasonality all interacting significantly with potential BMP performance. These factors need to be considered in future plans to develop and implement appropriate BMPs. The major findings of the project in this regard are reported as follows.

Bras d'Henri - intervention and control microwatersheds – Water quality was monitored from 2004 to 2007 and water flow was measured from 2005 to 2007. In-stream four-year median concentrations of N and P forms showed contrasted values and opposite trends between the two micro-watersheds (Table 6). This can be clearly explained by their pedology differences. The intervention micro-watershed has soils of coarser texture with greatest N leaching potential that favoured respectively 3, 2 and 5 times higher total N, nitrate and nitrite concentrations than those measured at the control watershed outlet. On the contrary, total P, dissolved P and particulate P concentrations were respectively 2, 4 and 1.6 times lower at the intervention outlet due to the presence of more podzols with higher P sorption capacity than in the control watershed. Total N and P loading ratios estimated between the intervention and control micro-watersheds during three crop seasons (2005 to 2007) generally confirmed the concentration trends except for particulate P loadings that are equal. Although the intervention watershed has dominant podzols with higher P

sorption capacity than the gleysols of the control watershed, the control is also characterized by significant slopes, coarse soil texture and large row crops, increasing the risk of soil water erosion and particulate P transport by surface runoff. Significant dissolved P concentrations and loadings at the control watershed outlet were also increased by macropore flow transfer from pasture on gleysols to tile drains.

In the intervention micro-watershed, a detailed N source tracking study in groundwater showed that soil N mineralization and nitrification occurred during winter, producing new nitrate, nitrate leaching and aquifer contamination throughout the winter. Most of the nitrate measured in soil leachates, piezometer and stream waters had an expected dominant manure fingerprint. PhD thesis research discovered peak nitrite concentrations at acute and chronic toxic levels for aquatic life. These nitrite peaks did not occur at the same time as high nitrate in-stream levels, leading to the need to elucidate specific sources at the water sediment interface.

In both watersheds, the winters of 2006 and 2007 were also studied to characterize the snow cover interactions with frozen soils and areas at risk for soil erosion at snowmelt. These high risk areas have significant slopes, bare soils and proximity to ditches and streams. Proportions of frozen and



Table 6: Contaminant median concentrations and loadings estimated for the Bras d'Henri intervention and control micro-watersheds during the calibration period (2004-2007)

	Intervention watershed				Control watershed					
		Loading		Median	n conc. Loading				Median conc.	
	(kg ha <sup>-1</sup> )		mg L <sup>-1</sup> CV (%)		(kg ha <sup>-1</sup> )			mg L <sup>-1</sup> CV (%)		
	Growing season	Runoff	Baseflow	Grow seas	•	Growing season	Runoff	Baseflow	Growing	season
Total suspended solids	363	109	254	15.65	263	169	108	61	13.95	563
Total nitrogen	48.12	19.68	28.44	6.21	27	20.28	9.10	11.18	2.56	49
Nitrate-N	38.97	11.94	27.03	5.26	36	12.81	5.38	7.43	1.43	87
Nitrite-N	0.24	0.06	0.18	0.03	85	0.16	0.07	0.09	0.02	330
Ammonium-N	0.87	0.23	0.63	0.09	208	0.80	0.35	0.45	0.09	182
Total phosphorus	1.24	0.63	0.61	0.08	132	1.47	0.84	0.64	0.15	118
Dissolved phosphorous	0.47	0.26	0.21	0.02	116	0.80	0.46	0.34	0.06	98
Particulate phosphorous	0.78	0.37	0.41	0.05	160	0.68	0.38	0.30	0.08	172
Orthophosphates	0.35	0.20	0.15	0.01	134	0.65	0.37	0.28	0.04	117
Atrazine	1.2x10 <sup>-3</sup>	1.7x10 <sup>-4</sup>	1.1x10 <sup>-3</sup>	3x10 <sup>-5</sup>	419	3.9x10 <sup>-4</sup>	1.2x10 <sup>-4</sup>	2.6x10 <sup>-4</sup>	1.7x10 <sup>-5</sup>	209
Nicosulfuron	7.5x10 <sup>-5</sup>	2.4x10 <sup>-5</sup>	5.2x10 <sup>-5</sup>	9x10 <sup>-6</sup>	91	4.4x10 <sup>-5</sup>	1.4x10 <sup>-5</sup>	2.8x10 <sup>-5</sup>	1.5x10 <sup>-5</sup>	128
Water yield (mm)	925					689				
Loadings duration (day)	573	148	425	208		566	146	420	205	
Herbicides monitoring (day)	449	108	341			452	110	342		
Monitoring period (year)	2005-2007			2004-2007		2005-2007			2004-2007	

unfrozen soils varied significantly from year to year, leading to variable P losses at snowmelt but higher particulate P with snowmelt erosion on frozen soils. P losses are of the same concentration magnitude at spring melt as during the crop season months.

Fourchette - intervention and control microwatersheds - Continuous hydrometric and geochemical monitoring, together with discrete water sampling, allowed a description of the temporal and spatial patterns of sediment and nutrient exports from the Fourchette twin watersheds (Table 7). Hydrograph separation derived from the electrical conductivity of the stream waters, highlighted that flashy peak flow events in late winter and early spring periods provided most of the annual load in sediment and nutrient when saturation-excess overland runoff was dominant. Statistical analysis (ANCOVA) of suspended solids and nutrients showed contrasting signatures between watersheds. These can be related to various mechanisms of sediment and

nutrient transport which integrate flow regime, season, land use and landscape gradients. Water quality analysis also allowed detection of a response to riparian buffers and structural runoff controls on suspended solid concentrations.

From an operational perspective, this research demonstrated that planning and implementation of measures to prevent agricultural non-point sediment and nutrient exports must document landscape drivers of hydrological activity and address both nutrient mass balance and runoff control. Long-term control of topsoil P enrichment and timing of manure issues are currently governed by mandatory fertilization management plans and extension services in Quebec. The agrienvironmental agenda now calls for adoption of conservation cropping techniques, riparian buffers and structural runoff controls in order to significantly reduce non-point source sediment and nutrient loadings to surface water in rural watersheds.



Table 7: Contaminant flow-weighted concentrations and loadings estimated for the Fourchette intervention and control micro-watersheds during the calibration (2001-2003) and evaluation periods (2004-2006)

Intervention watershed							
	Calibration period			Evaluation Period			
Water quality parameter	Loading kg	Concentration ug L <sup>-1</sup>	CV <sup>1</sup>	Loading kg	Concentration ug L <sup>-1</sup>	CV <sup>1</sup>	
Total suspended solids	120 900	47 300	0.130	236 400	57 200	0.124	
Total phosphorus	577	226	0.063	1 063	257	0.064	
Bioavailable phosphorus	371	145	0.062	668	167	0.065	
Dissolved phosphorus	309	121	0.071	549	133	0.073	
Orthophosphates	279	109	0.077	496	120	0.078	
Ammonium-N	966	378	0.127	831	201	0.104	
Nitrate-N	13 141	5 149	0.038	14 293	3 458	0.069	
Calcium	130 336	51 066	0.047	187 700	45 414	0.030	
Water yield (mm)	1020			1652			
Monitoring duration (day)	567			822			

Control watershed								
	Calibration period			Evaluation Period				
Water quality parameter	Loading kg	Concentration ug L <sup>-1</sup>	CV <sup>1</sup>	Loading kg	Concentration ug L <sup>-1</sup>	CV <sup>1</sup>		
Total suspended solids	267 700	139 200	0.131	456 700	125 000	0.095		
Total phosphorus	699	364	0.108	1 217	333	0.089		
Bioavailable phosphorus	345	180	0.115	606	166	0.097		
Dissolved phosphorus	186	97	0.154	358	98	0.143		
Orthophosphates	156	81	0.196	308	84	0.155		
Ammonium-N	1 633	849	0.153	1 981	542	0.480		
Nitrate-N	6 742	3 505	0.040	9 550	2 614	0.037		
Calcium	43 069	22 389	0.031	60 700	16 630	0.023		
Water yield (mm)	1011			1922				
Monitoring duration (day)	567			822				

43

<sup>&</sup>lt;sup>1</sup> CV estimated with the <u>-ja</u>ck-knife" method



### **BMP** impacts

#### Surface runoff control

The environmental impact of this BMP was globally evaluated at the micro-watershed outlets. In the Fourchette, despite an important inter-annual variability in hydrological conditions, statistical analysis highlighted a significant decrease in sediment concentration in stream water at the intervention outlet. This significant reduction applied only to the crop season (May to November) because the winter sediment concentrations did not differ significantly between the calibration (2001-2003) and evaluation (2004-2008) periods. In contrast, the statistical analysis of total phosphorus (TP) concentration did not show any significant treatment effect. These contrasting trends between sediment and TP concentration responses to the surface runoff BMP may be interpreted by the fact that the BMP effectively reduced sediment loadings from eroding streambanks, but had marginal effects on sediment transport from landscape sources. Moreover, sediment loadings from eroding streambanks have typically lower P contents than sediments exported from the landscape.

In the Bras d'Henri micro-watershed, because BMP implementation was not completed until summer 2007, the temporal trend analysis of surface runoff BMP impacts on sediment, N and P forms, pathogen and herbicide transport did not begin until 2008. These results will be reported after a three to four-year evaluation period.

#### Slurry application

This BMP has been developed to control N losses from hog slurry applications on corn and forage fields.

Within the Bras d'Henri intervention watershed, edge-of-field results showed that this BMP significantly decreased nitrate concentrations in surface runoff during the 2005 and 2006 crop seasons, and in leaching during 2006 and 2007. Concentration of phosphorus forms also decreased in surface runoff in 2005 and 2006. However, N and P concentrations in runoff water indicated reverse trends between the BMP and conventional practice in 2007. It was estimated from previous studies that ammonia volatilization was reduced by half, following incorporation of slurry shortly after application. Moreover, slurry incorporation considerably decreased fecal coliform surface transport. Some BMP disadvantages were observed such as the increasing application time

using the new spreader and difficulties operating machinery on high slopes.

This BMP produced positive results on edge-of-field water quality and allowed producers to dispose of their slurry locally while saving on N chemical fertilizers. However, it did raise some concerns in this watershed regarding a tendency of decreasing crop yields. In fact, solely using slurry to fertilize crops on a nitrogen basis will repeatedly contribute to soil enrichment in P beyond recommended levels. Whenever the slurry BMP is used to mitigate nutrient losses (P and N) in a watershed having a nutrient surplus, P in excess of crop demand and high soil P saturation levels will remain problematic.

#### Herbicide reduction

Herbicide application is a very efficient management option for controlling recurrent weed pests that have a significant impact on yields. However, herbicide inputs may need to be reduced to limit unintended effects on human health and the environment.

In the Bras d'Henri micro-watershed, the first approach to reduce the use of herbicides consisted of testing an AAFC-developed herbicide reduction decision-support system (DSS). After two years of testing, it became evident that this approach was not appropriate to the study area because of high weed pressure. Based on the model, only one field had a weed pressure low enough to allow reduced rates. Moreover, the recommendation of a reduced rate was not followed by the producer. This approach was therefore not retained for subsequent testing.

A second approach consisted of introducing a series of practices such as sprayer calibration, mechanical weeding, reduced rates of broadspectrum herbicides on low weed pressure fields (based on a study from Laval University), and the use of less toxic herbicides. The application of mechanical weeding necessitated major changes in the producers' day-to-day operations and could not be implemented in such a short time. The producers are considering implementing this practice in the future. Sprayer calibration, reduced rates of selected herbicides on selected fields, and the use of less toxic herbicides were implemented in 2007.

#### **Crop rotations**

Within the Bras d'Henri watershed at the beginning of the WEBs project, one of the three producers



involved was already conducting three crop rotations:

- Soybean grain corn (3-4 years)
   soybean
- Oats perennial/forage establishment
   perennial/forage (4 years) oats
- Oats perennial/forage establishment – perennial/forage (4 years) – grain corn (4 years) – soybean

The cropland of this farm covers approximately 300 ha of which only 25% were within the Bras d'Henri micro-watershed. The other two producers did not have an effective crop rotation plan. One farm (135 ha) is essentially cropping grain corn (88%) and soybean (12%) and 34% of its total cropland is within the Bras d'Henri micro-watershed, while the other farm (37 ha), essentially in forages and pasture, is entirely within the micro-watershed. The major constraint for these two farms in implementing crop rotations is their need to grow crops specifically for animal feed production.

The crop rotation at the farm scale had 9 out of 11 fields in grain corn and only two fields in forage within the micro-watershed in 2007, contrasting with 2004 when six fields were cropped in grain corn and four fields in perennials/forage.

In the Fourchette Watershed, a major shift from hay crop to annual crop was observed in the control micro-watershed. During 2001-2003 (calibration period), hay and annual crop areas counted respectively for 24% and 23% of the control micro-watershed area. For the evaluation period (2004-2008), the proportions were 37% and 11% for hay and annual crops, respectively.

# Conclusions, recommendations and way forward

This four-year project on BMP environmental evaluation at the watershed scale showed that pedology, hydrology and climate were highly variable and significantly influenced in-stream water quality parameters in both Bras d'Henri and Fourchette basins. The twin micro-watershed experimental setup allowed analysis of temporal trends of a suite of BMPs implemented with producers in intervention micro-watersheds compared to control micro-watersheds where no WEBs BMPs were implemented. In fact, the BMP evaluation phase (2004-2007) showed significant improvements of water quality parameters in the already underway Fourchette Watershed, which improvements should likely be observed in the Bras d'Henri Watershed during its evaluation phase of 2008-2013. The success of the

Fourchette approach can be attributed to an initial expert diagnosis of areas prone to erosion, sediment and contaminant transport. Thereafter, huge land improvements have been made by the producers in both intervention micro-watersheds to significantly reduce soil water erosion and runoff water speed on cultivated fields and also along streambanks to decrease bank failure, as well as erosion around tile drain outlets.

#### Site characterization vs. BMP performance

A detailed site characterization showed more contrast in pedology among the twin microwatersheds and higher variability within microwatersheds than initial information available from existing soil surveys indicated. Despite the proximity of the micro-watersheds, their agriculture parameters and land use were different. Nevertheless, instead of impairing interpretation of results, this additional information has contributed to the understanding that site soil conditions need to be carefully considered when implementing BMPs and evaluating their performance. Soil conditions are significant in determining potentials of nitrogen and phosphorus transport to streams. For example, higher leaching potential and nitrogen concentrations in the Bras d'Henri intervention micro-watershed call for the implementation of BMPs specifically adapted to control nitrogen balance and drainage. Lower soil P sorption capacity and higher soil phosphorus saturation should call for BMPs that mitigate P loss in surface runoff and drainage waters.

#### Cropping season vs. snowmelt runoff effects

Results also demonstrated that the timing of nutrient transport was related to climate and hydrology. In fact, nitrate was produced from nitrogen mineralization and nitrification in snow covered soils and leached to shallow groundwater during winter aguifer recharges due to rain on snow or partial snowmelt events. Significant amounts of sediments and particulate and dissolved phosphorus were also transported during snowmelt on bare frozen soils in watersheds characterized by factors of high soil erosion risk. Currently, site BMPs mainly target nutrient losses during the crop season, but the BMP mix should also be structured to be effective during the most critical hydrological periods (snowmelt runoff) of the year.

#### **Preliminary BMP effects**

The slurry application BMP has effectively reduced the nitrogen losses to surface waters and fecal coliform transport but at the same time has



amplified the soil phosphorus saturation. These mixed results have demonstrated that excess phosphorus and nitrogen in the watershed requires nutrient reduction at the source by using such techniques as precision animal feeding or slurry treatment BMPs. Incorporation of slurry in the soil surface shortly after application showed dramatic reductions of fecal coliforms in runoff water. The occurrence of different waterborne pathogens in local livestock populations and pathogen survival factors are not sufficiently documented. However, the results showed that the timing between manure application and storm events is critical for pathogen transport to streams. The further reduction of pathogen transport across and along riparian buffer strips, infiltration ditches, grassed waterways and area drains should be quantified in the future.

The herbicide reduction BMP presented a major challenge for the producers facing weed control and crop yield sustainability. In the Bras d'Henri watershed, herbicide reduction was shown to be difficult and mostly questionable. Consequently, it was concluded that better environmental practices could be implemented by using less toxic herbicides.

In this study, the crop rotation BMP happened to be inconclusive. In fact, the inter-annual rotations in crops planted within the micro-watershed under investigation have clearly demonstrated the challenges of working at the micro- watershed scale with BMPs that are usually established at the farm scale. Therefore, the methodology to evaluate the impact of crop rotation as a BMP has to be designed differently to account for this scaling effect.

Surface runoff control BMP preliminary results have demonstrated two important facets related to surface runoff and stream peak flow; that is soil surface water erosion and streambank water erosion. In the Fourchette micro-watershed, the surface runoff control BMP has impacted primarily on the latter as shown by a significant reduction in sediment load and no significant change in total P. In the Bras d'Henri micro-watershed, the first results should be available in the next coming years.

#### Collaborators

AAFC: Nadia Goussard, Martin H. Chantigny,
Farida Dechmi, Jamila Zaakar, Julie Corriveau,
Roger Lalande, Jian Zhou, Luc Lamontagne,
Isabelle Perron, Marie-Line Leclerc,
Geneviève Bégin, Hubert Perrodin,
Muriel Badina, Toshiro Yamada,
Stéphane Martel, Julie Côté, Alexandre Asselin,

Aurélie Munger, Caroline Dufour-L'arrivée, André Martin, Catherine Bossé, Karine Belzile, Karine Labrecque, Mario Deschênes, Oumar Ka, Athyna Cambouris, Johanne Tremblay, Brigitte Patry, Marie Bipfubusa.

MAPAQ: Donald Lemelin, Armand Gagnon.

**IRDA:** Richard Hogue, Julie Deslandes, Jacques Desjardins, Michèle Grenier.

NRCan-GSC: Martine M. Savard, Daniel Paradis.

EC: Allan Cessna, Jonathan Bailey.

INRS-ETE: Alain N. Rousseau, Daniel Cluis.

<u>CFB</u>: Marielle Laferrière, Mathieu Gourde-Vachon, Véronique Samson, Annie Beaumier.

#### Producers of Bras d'Henri Watershed:

Jean-Pierre Fortin, Sylvain Fortin, Daniel Fortin, Mario Roberge.

#### **Producers of Fourchette Watershed:**

Gaëtanne Dallaire, Jean-Paul Turcotte, Hélène Pelchat, Daniel Pelchat.

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## **Black Brook Watershed (NB)**

Initiated in 2004, the Watershed Evaluation of Beneficial Management Practices (WEBs) project examines the environmental and economic impact of beneficial management practices (BMPs) at a small-watershed scale. Water quality is used as the primary indicator for the environmental impact of the BMPs. The project is being led by Agriculture and Agri-Food Canada (AAFC) with Ducks Unlimited Canada as a key funding partner.

After a proposal-based process, seven projects were selected across Canada. Each of the seven WEBs watershed sites includes the following components: biophysical evaluations (the subject of this Technical Summary), on-farm economic assessments, and hydrologic modelling. Integrated economic-hydrologic modelling is occurring at two of the project sites. The economics findings are the subject of a second technical summary -"Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #2: Economics Components - Four-year review (2004/5 - 2007/8)"; and the modelling findings are the subject of a third technical summary "Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #3: Hydrologic and Integrated Modelling Components - Four-year review (2004/5 - 2007/8)". All three Technical Summaries are companion documents to the Four-year Review report.

This executive summary is based on a review of the project's first four years (2004/5 – 2007/8) and presents the environmental (biophysical) evaluation of two BMPs in the Black Brook Watershed WEBs project, located in north western New Brunswick.

## **Background and Issues**

The 1,450-hectare Black Brook Watershed (BBW) is located north of Grand Falls, New Brunswick, in the province's potato belt (figure 17). It is part of the 380-square-kilometre Little River Watershed (LRW). Topography is rolling with slopes generally ranging from two to nine per cent, but with some slope segments in excess of 15 per cent.

Agricultural land constitutes approximately 921 hectares (64 per cent of the land base) with the remainder either forested or under urban and residential development. The major crop is potato in rotation with grain, peas and hay for forage. Half of the agricultural land is annually under potato production.

There are concerns about the environmental impacts of the area's intensive agricultural practices, particularly in areas of rolling topography and high precipitation. Soil erosion from these areas may contribute excessive amounts of sediments and nutrients to surface waters, if appropriate soil and water conservation practices are not applied.

Since 1988, the area in the watershed under variable grade diversions and grassed waterways has increased from 56 hectares to 500 hectares in 2005. Much of the land brought under these conservation systems has been identified as being excessively erosion prone. The land use survey conducted throughout the 1988 to 2005 period indicated that, with the exception of terraces/grassed waterway systems other conservation practices were relatively unchanged since 1988.

The Black Brook watershed contains a climate monitoring network (established in 1992), which consists of five weather stations strategically located within the watershed. Parameters collected at each station consist of air temperature and relative humidity, rainfall amount and intensity. Snowfall was monitored at the permanent runofferosion plots located approximately 10 km away. Based on topographic features, soil conditions, and most importantly cropping and management practices, nine sub-watersheds in the Black Brook Watershed were identified and selected for monitoring the impact of agriculture on water yield and quality. Annual land use surveys are conducted to identify crops grown, nutrient and pesticide inputs and land management practices.

The Eastern Canada Soil and Water Conservation Centre (ECSWCC), an organization that promotes sustainable natural resource management, works closely with producers and other stakeholders in the watershed, helping to implement the BMPs. The ECSWCC has had a good working relationship with many of the area farmers over the years, many of whom are actively cooperating in this project.

## Monitoring regime and uncertainties

A major WEBs-related activity occurring in 2005 involved refurbishing and upgrading infrastructure, (i.e. water gauging and sampling stations), and monitoring and data acquisition systems. This included the installation of a cellular phone communication system along with the data loggers in major gauging stations for real-time monitoring. Campbell CR10 data loggers were replaced with CR10X, and the mechanical sampling setup at



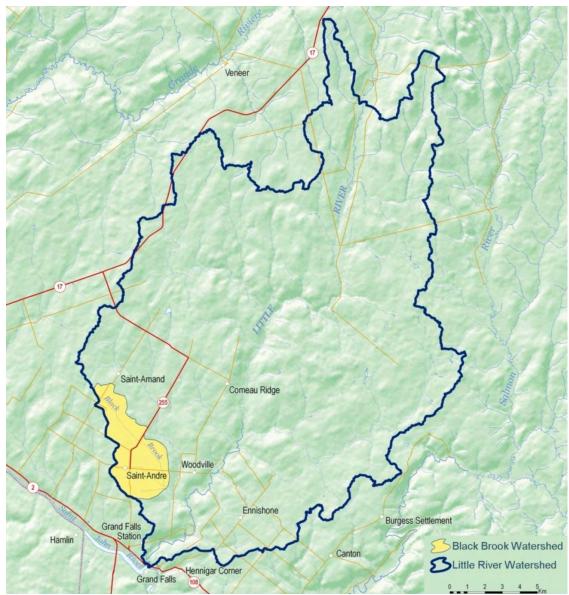


Figure 17: Location of the Black Brook Watershed within the greater Little River Watershed

sub-watershed #6 and #9 was replaced with ISCO automatic water samplers.

Although only sub-watersheds #6,#8, #9 and #1 (outlet of the entire watershed) were used for the WEBs study, the operation of the other sub-watersheds (a total of 11 including 2 gauging stations outside of the Black Brook watershed) were maintained from 2004 to 2008 (Figure 18).

Enabled by the installation of a composite weir, discharge at individual gauging stations was monitored continuously and water samples were collected with an ISCO automated sampler at 72-hr intervals if the stage height was within 5 cm of the previous interval. Additional samples were

collected if the stage height increased by more than 5 cm. This sampling scheme was found to be essential for capturing water quality information during major rainfall events. Stage height data with sampling information were downloaded automatically using a remote computer located in Fredericton.

Historical water quality data sets (1992-94) for subwatershed #8 were collected using an automated ISCO sampler which is the same method used during the 2004-07 period. However, prior to 2005, water quality data for sub-watershed #6 and #9 were based on samples collected using a mechanical sampling setup in such a way that one sample was collected at 12.5, 25.0, 37.5, 50.0 and



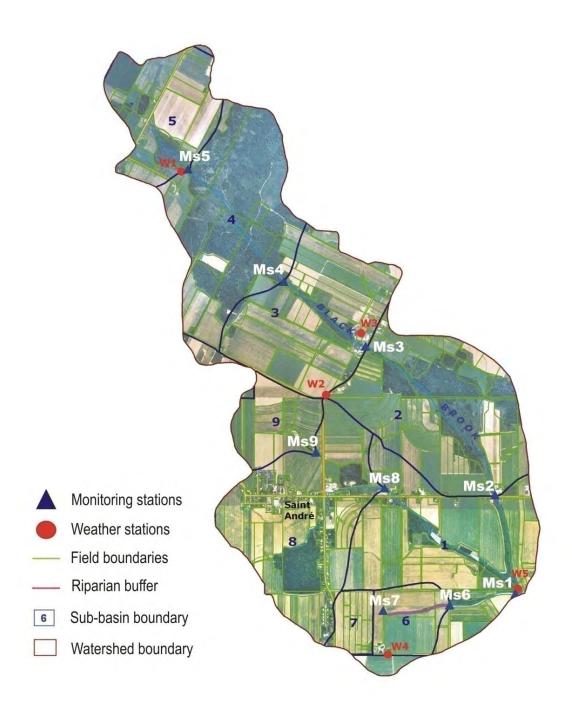


Figure 18: Map of Black Brook Watershed showing sub-basin boundaries and monitoring stations



62.5 cm above the base of the V-notch weir during the raising limb of a hydrograph. These stage height activated samples, along with an additional sample taken at the sample removal time were sent to a laboratory after each major rainfall event.

Water quality calculated from these samples may not be exactly comparable to the automated sampling because the automated ISCO sampler collected a sample at every 5 cm increase in stage height, comparing to the height of the previous sample, whereas the mechanical sampling setup took only one sample when the stage height increased at a fixed height increase of 12.5 cm.

Since only one sample was collected at a specific stage height per rainfall event, storms with multiple discharge peaks may further introduce uncertainty in the computed water quality. In spite of the slightly different sampling techniques, loading and flow weighted concentration computed from samples collected from both methods are scientifically valid.

Climatic data including air and soil temperature, relative humidity, rainfall amount and intensity were monitored at nine automated weather stations. Five of these stations were in the Black Brook watershed. Snowfall, wind and radiation data were collected in one station located adjacent to a permanent erosion plot which is approximately 10 km from the outlet of the Black Brook watershed. The discharge, associated water quality data and weather information are available for the 1992-94 and 2004-07 periods, inclusive.

#### **BMP Effect**

The biophysical component of the study is focused on evaluating the environmental effect of the following two BMPs on water quality:

- Diversion terraces and grassed waterway systems
- 2) Vegetated riparian buffer zones

A summary of the background, methods, and results specific to each of the BMPs assessed is presented below.

## Diversion terraces and grassed waterway systems

#### **Background**

The costs associated with the construction of diversion terraces are high and additionally, substantial negotiations with land owners are needed for the implementation of this type of BMP. As a result, no new terraces were installed as part

of the WEBs project. Alternatively, two subwatersheds (#8 and #9 – combined total 301 ha) already having a large number of terraces and grassed waterway soil conservation systems installed over the years (1996-2002 period, immediately preceding WEBs), were selected for the study. These sub-watersheds had a large percentage of land base under potato production

#### Methods

The effectiveness of variable grade diversion terraces and grassed waterway systems for upland erosion control in agriculture-dominant watersheds is being evaluated. These systems were established prior to WEBs but upgraded as required under WEBs. The major benefit of this upgrade and monitoring of existing structures approach, is that the WEBs monitoring and evaluation period followed the typical lag time required for BMPs to take effect. To improve the efficiency of the existing systems, considerable work on land forming, reshaping of grassed waterways and installation of a rock-lined waterway (815 m) were completed.

#### Results

Sub-watershed #9 is 77 ha with 72 ha in agriculture (93% of farmland) whereas sub-watershed #8 which receives surface runoff from #9 is 294 ha with 202 ha in agriculture (69% of farmland). Average percentages of farmland protected by terraces and/or grassed waterways system during 1992-1994 were 21% (43 ha) and 27% (19 ha) for sub-watershed #8 and #9, respectively. Due to the increased subsidy levels for soil conservation structure implementation and farmer awareness, by 2005, the acreages of farmland protected by terraces and/or grassed waterways increased to 156 (77%) and 56 ha (78%) for #8 and #9, respectively.

In response to the increases in conservation systems between the 1992-94 and the 2004-07 monitoring periods, mean annual discharge was reduced by about the same amount (12.4% and 11.5%) for sub-watersheds #8 and #9, respectively. In terms of loading effect, sediment loading was reduced by 51% for sub-watershed #8, yet remained relatively unchanged for sub-watershed #9. Both sub-watersheds showed an increase in Ortho-phosphorus (P) loadings with the reduction in discharge. Nitrate (NO<sub>3</sub>) loading also shows an increase in sub-watershed #8 whereas a reduction was found in sub-watershed #9. Reductions of 46% and 26% were found in potassium (K) loading for #8 and #9, respectively.

In terms of discharge concentration effect, with the exception of decreased flow weighted



concentration of suspended sediment and K, both sub-watersheds show a considerable increase in nitrate and Ortho-P concentrations. The increase in nitrate and Ortho-P concentrations may be attributed to a higher proportion of base flow discharges which normally contain higher nutrient levels. The increase in such base flow discharges can be attributed to diversion terraces and grassed waterways, which intercept surface runoff and provide greater time for this water to infiltrate into the soil, resulting in increased base flow discharges, and decreased peak flow discharges.

Research conducted prior to WEBs in Grand Falls, using paired drainage basins under potato production, indicated that terraces and grassed waterway systems resulted in an average reduction of runoff by a factor of 7 and of soil loss by a factor of 20 times. These figures are several orders of magnitude greater than that measured using the sub-watersheds approaches because the paired drainage basins were only 6.5 and 3.5 ha in size for the basin with and without the terraces and grassed waterway systems respectively, and were 100% under potato cultivation. Unlike the larger sub-watersheds, only percentage of the land was protected by conservation systems and was under potato production. Greater variations in topographic feature in larger watersheds also enhance re-infiltration of runoff and re-deposition of detected sediment. The terraces and grassed waterways conservation practices also delayed the time of runoff concentration, increased lag time and reduced peak discharge rate, which reduced the likelihood of potential ditch and stream floods resulting from major storms. Contour planting of potatoes associated with terraces were found to reduce annual runoff by as much as 150 mm of rainfall equivalence, and thereby increased available moisture for plant growth (Chow et al. 1999. J Soil and Water Conservation 54:577-583).

In general, diversion terraces and/or grassed waterway conservation systems reduced surface runoff and sediment load, but often increased nutrient (N and P) loading and the associated flow weighted concentration.

#### Vegetated riparian buffer zones

#### **Background**

Vegetated (grassed) riparian interceptor buffer strips (15 m wide) were established on both sides of a grassed waterway in 2004-05. Vegetated (grassed) riparian interceptor buffer zones are strips of vegetation established along water courses such as streams or grassed waterways. They are designed to slow and filter nutrients and sediment out of surface runoff before entering the

waterway, whereas grassed waterways are channels that intercept terraces or are constructed within buffer zones for safe disposal of concentrated surface runoff. Grassed waterways are normally used in conjunction with terraces, whereas buffer zones are placed anywhere in a field where excess runoff is a problem. Buffer zones were established in sub-watersheds #6 and #7 (combined total 80 ha), an area of the Black Brook Watershed where limited conservation work had previously occurred. Their effectiveness in reducing sediments and nutrients from entering surface waters is being evaluated at the edge-of-field and sub-basin level.

#### **Methods**

Edge-of-field measurements were initiated in 2006-07 to evaluate the effectiveness of vegetated riparian buffer zones to filter sediment and nutrients. Two potato cropping practices, namely up-and-down slope cultivation and contour planting, were evaluated on each side of the grassed waterway. The lengths of the fields above the buffer zones were 198 m and 153 m, respectively. The slopes of these fields were approximately 9%. To eliminate the problem of uneven runoff within the buffer zone and to ensure a representative sample, runoff from 18.6 m-long buffer zones at the edge of the buffer zone and at a 15 m distance inside the buffer zone were monitored by channelling the runoff from them to a trapezoidal flume/pressure transducer flow meter. A Campbell CR10X data logger was used to monitor the flow and to activate an ISCO water sampler to collect water samples at pre-determined changes in stage height. Full BMP installation in these sub-watersheds (#6 and #7) consisted of constructing or reshaping a total of 1,385 m of grassed waterway, 700 m of riparian buffer, 260 m of drain outlet, 148 m of diversion terrace, and replacing 198 m of drain tile used as an outlet for a stand pipe drainage inlet.

#### **Results**

Edge-of-field data collected in 2006-07 indicated that total reduction in surface discharge, sediment load, nitrate and Ortho-P resulting from 15 m of buffer width varied considerably between 2006 and 2007, with mean values of 57, 48, 75 and 61%, respectively. Compared to the reduction in flow weighted concentration of nitrate and Ortho-P (38% and 5% respectively), both sediment and K concentration show an increase of 24% and 128% respectively. Further monitoring is needed to resolve this issue. In addition to the specific width of the buffer zone, buffer effectiveness was dependent upon the intensity and amount of rainfall along with the effect of other conservation practices (contour cultivation) used in the field.



In general, the effectiveness of buffer zones to protect water quality decreased with increasing amounts and intensity of rain storms. Under traditional up-and-down slope cultivation (150 m slope length at 9%), 15 m buffer zones may be effective for rainfall not greater than 10 mm with a 30-minute intensity of less than 10 mm/hr. The results also indicate that the buffer zones increased the lag time and time of peak flow concentration. However, under heavy storms, the runoff, sediment and agro-chemical concentrations remained similar or higher than that before the buffer zones. It is important to note that there was very little or no runoff measured under contour planting of potatoes because the potato hills act as an embankment to intercept surface runoff and provide additional time for runoff infiltration. These results emphasize the need for integrated BMPs to control soil erosion under intensive potato production.

Sub-watershed #6, used for the riparian buffer study, is 80 ha in size with 74 ha under agricultural production (98%) and contains a very limited number of terraces and/or grassed waterways conservation systems. When comparing the pre (1992-94) and post (2005-07) BMP results for this watershed, indications are that the discharge and sediment loading reduced from 97,425 to 37, 708 m<sup>3</sup> (61%) and from 1,001 to 179 tons (82%), respectively. Nitrate and K loadings reduced by 45% and 62%, respectively, whereas the Ortho-P increased by 31%. In contrast to the edge-of-field results, considerable increases were found in the flow weighted concentration of nutrients, including nitrate and Ortho-P. Due to the late completion of this BMP (2005) and temporal variations in climatic patterns, two years of evaluation is insufficient and additional years of monitoring are essential.

Preliminary conclusions from the buffer zone study show reduced runoff, sediment, N and K loads, but increased Ortho-P loading. Flow weighed concentration of nutrients including suspended sediment were considerably higher with the buffer zones. The increased concentrations may be partially attributed to the newly constructed system which requires more time to recover from the excessive disturbance during implementation. Additional monitoring is necessary.

#### Suite of BMPs

Although this analysis is the result of conservation practices throughout the entire Black Brook Watershed, farm survey results indicate that only diversion terrace/grassed waterway systems have increased significantly in extent (i.e. from 18% of the cultivated land base in 1992 to 54% in 2005).

Therefore, observed changes in water quantity and quality can be mainly attributed to the increase in terrace/grassed waterway systems.

Mean cumulative precipitation for the 1992-94 and 2004-07 monitoring periods were 1,152 and 1,034 mm, respectively. The later is slightly lower than the 30-yr normal precipitation of 1,134 mm. However, computed rainfall erosivity for these two monitoring periods were 1,640 and 1,726 MJ mm/ha hr—considerably higher than the value (1,276 MJ mm/ha hr) suggested as required for effective conservation structure designs in northern Maine, USA. (Erosivity of a given rain storm is calculated from the total storm energy times the maximum 30-min intensity and is an indicator of rainfall erosive potential).

In response to the increase in diversion terrace/grassed waterway BMP implementation, along with resident climatic conditions, watershed discharge decreased from 10.9 million m³ (1992-94) to 8.3 million m³ in 2004-07, a reduction of 24%. Similarly, sediment load reduced from 6,543 tons to 2,976 tons, a 54.5% reduction; and flow weighted suspended sediment concentration reduced from 0.60 g/l to 0.39 g/l, a 35% reduction.

Although erosivity was high in 2005 and 2006, the sediment load remained at 3,454 metric tons and 3,051 metric tons, respectively. Erosivity in 2005 was 90% higher and in 2006 63% higher than the average erosivity from 1992 to 2007. In contast, NO<sub>3</sub>-N loading increased by only 12% whereas flow-weighted concentrations increased by 54% during these same periods. Increased NO<sub>3</sub>-N concentration may be related to deep percolation of nitrate to ground water which reappears as base flow during the dry season. Although the Ortho-P loading was reduced by 23%, the flow-weighted P concentration increased by 6.5%. Total K loading was 14.3 tons compared to 20 tons in 1992-94, a reduction of 29%. The K concentration varied greatly from year to year with an average reduction of 10.5%.

#### Conclusions

Both diversion terraces/grassed waterway systems and vegetated riparian buffer zones show positive reduction in discharge and sediment loading. The degree of improvement varies considerably from year to year depending upon precipitation amount, intensity and temporal distribution.

Loadings of K, Mg and Ca are reduced compared to values obtained before BMP implementation. On the other hand, the Ortho-P loadings always showed higher values than those prior to BMP



implementation, whereas mixed results were found for nitrate. Due to the substantial reduction in discharge, the flow weighted concentration of nitrate, Ortho-P, K, Mg and Ca were consistently higher after implementing the BMPs. Based on these preliminary findings, one may conclude that both terraces/grassed waterway systems and riparian buffer zones are positive in reducing discharge and sediment, whereas inconclusive results were found for nutrients.

Great effort has been devoted to building infrastructure, purchasing scientific equipment and building expertise and linkages between universities, NGO's and industry during the initial phase of WEBs. Continuation of WEBs is needed for effective use of these resources, which are essential to provide a better understanding of the full scope of agri-environmental and non-point source pollutant challenges. These challenges include such things as linkages and pathways between soil erosion, pesticide and nutrient losses and the effectiveness and functionality of selected BMPs. The results indicate temporal, climatic variations and high fluctuations in loading and concentration from year to year, suggesting that longer term monitoring and evaluation is necessary.

#### **Additional Studies**

In addition to the main BMPs evaluated, several associated studies related to watershed relationships in general and their potential for clarifying BMP effectiveness are also taking place and are briefly highlighted below.

## Impacts of forest and agricultural operations on surface water quality

Forested lands often constitute a large percentage of the area within Atlantic region agricultural watersheds. It is not uncommon for forest operations to be one of the major activities within such watersheds. Understanding the relative contribution of forest and agricultural operations on water quality should be a prerequisite when considering strategic BMPs for improving water quality.

The BBW (15 km²) is 65% agriculture land, the LRW (390 km²) is 16% agriculture land, with 77% forest and 7% residential, water and swamps), and the Upper Little River Watershed (ULRW) (197 km²) is almost entirely forest (4% forest nursery, 91% forest and 5% water and swamps). Average water yields per unit area from these three watersheds were 0.53, 0.76 and 0.82 million m³/km²/yr, respectively. On the other hand,

suspended sediment load appeared to decrease with decreasing agricultural intensity, with values of 173, 120 and 44 ton/km²/yr. Similar trends were found for agrochemicals, with the magnitudes of loading being 2.58, 1.05 and 0.40 ton/km²/yr for NO<sub>3</sub>-N, 0.032, 0.019 and 0.017 ton/km²/yr for Ortho-P and 1.03, 0.52 and 0.30 for K.

#### Pesticide residues

Jointly with Environment Canada, a pesticide residues component of the project was conducted using funding from the Pesticide Science Fund and WEBs. ISCO samplers were modified to collect the 12-2I samples needed for pesticide analysis, and data loggers were reprogrammed to sample under high flow situations during runoff-inducing events. Selected pesticides were monitored from 2005-2007 at the mouth of the Little River, the outlet of the Black Brook watershed and at BBW sub-watershed #9. In 2006, there were a total of 378 detections of 8 different pesticide products in samples collected from the outlet of BBW, LRW and sub-watershed #9. Of the 378 detections, 141 of these (for 5 different pesticide products). exceeded water quality guidelines for aquatic life. No pesticides were found during base flow periods within the growing season, whereas pesticide levels found during peak flow present a significant concern. BMPs might be developed to reduce these amounts.

## National Agri-Environmental Standards Initiative (NAESI)

Environment Canada, in partnership with AAFC, included Black Brook Watershed as the cornerstone watershed for the development of ideal and achievable environmental performance standards for in-stream flow, suspended and deposited sediments and nutrients. Stream assessments across an agricultural stressor gradient in north western New Brunswick showed that watersheds with high rates of potato production were significantly impaired compared to forested watersheds. The NAESI standards or targets may enable WEBs and producer groups to track improvements in water quality and ecological condition as a result of BMP implementation over time.

#### Microbial source tracking

Jointly with Health Canada, and other AAFC researchers across Canada, a number of sites in the Black Brook watershed were selected for the national Microbial Source Tracking (MST) study. High counts of coliforms, *E. coli* and other bacteria were found in many samples. These high counts



may be attributed to a sewage lagoon and/or wildlife activity.

#### Performance of multiprobes

Mutiprobes (sondes) from three different manufactures (YSI, Hydrolab and Horiba) were evaluated for their suitability for continuous monitoring of water quality in the Black Brook watershed. Preliminary results indicate that for general parameters such as temperature and pH, all sondes performed satisfactorily. However, under the high suspended sediment conditions typical for Black Brook, none of the sondes performed satisfactorily for continuous monitoring of turbidity, NO<sub>3</sub>, and NH<sub>4</sub>.

#### **Future Directions**

In addition to identifying the need to extend the monitoring period, WEBs results have also identified a number of issues requiring further attention. Some of these related to BMP and modelling effect are listed below:

- 1) Terraces/grassed waterway systems have been found to reduce discharge and sediment effectively. However, increased nitrate and Ortho-P concentration and enhanced percolation of previous runoff may cause a potential for ground water contamination. Nitrate and Ortho-P concentration from a number of domestic and research wells were monitored during the 08/09 WEBs continuity year, and this type of monitoring should be continued in the future.
- Pesticides found in surface water during peak flow periods raise the need for the development and validation of BMPs to mitigate pesticide contamination.
- 3) <u>Tile drainage effect</u> Potato is a moisture sensitive crop and over the years systematic

tile drains have been installed in many fields within the BBW. For effective modelling of surface and ground water hydrology, knowledge on efficiency of these drains in removing excess water is an important input parameter. Research has been initiated during the 08/09 Continuity year to monitor the quantity and quality of drainage from 4 drainage systems with different spacing between tiles, soil types and years in operation.

- 4) The <u>SWAT model</u> needs to be modified to reflect unique maritime climate conditions such as the fact that the local, thick snow cover can leave the soils beneath unfrozen, which can result in continued infiltration during the winter months.
- The <u>sub-model</u> developed for the vegetated riparian buffer zone, requires further improvement and integration into SWAT.
- 6) <u>REMM</u> or similar models might be applied to the Black Brook Watershed in order to improve model predictions on the impacts of forested riparian buffers located within depression areas.

#### **Project Partners**

The Black Brook WEBs project was lead by AAFC and directed by a multi-agency/multi-disciplinary team. The team is comprised of specialists from Federal Agencies (Environment Canada, Department of Fisheries and Oceans, Health Canada and AAFC), Provincial Agencies (New Brunswick Department of Agriculture and Aquaculture, and New Brunswick Department of Environment), the University of New Brunswick, Ducks Unlimited Canada, Eastern Canada Soil and Water Conservation Centre, Potatoes New Brunswick and the cooperating producers.



## Thomas Brook Watershed (NS)

Initiated in 2004, the Watershed Evaluation of Beneficial Management Practices (WEBs) project examines the environmental and economic impact of beneficial management practices (BMPs) at a small-watershed scale. Water quality is used as the primary indicator for the environmental impact of the BMPs. The project is being led by Agriculture and Agri-Food Canada (AAFC) with Ducks Unlimited Canada as a key funding partner.

After a proposal-based process, seven projects were selected across Canada. Each of the seven WEBs watershed sites includes the following components: biophysical evaluations (the subject of this Technical Summary), on-farm economic assessments, and hydrologic modelling. Integrated economic-hydrologic modelling is occurring at two of the project sites. The economics findings are the subject of a second technical summary – "Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #2:

Economics Components – Four-year Review (2004/5 – 2007/8)"; and the modelling findings are the subject of a third technical summary "Watershed Evaluation of Beneficial Management Practices (WEBs), Technical Summary #3: Hydrologic and Integrated Modelling Components – Four-year Review (2004/5 – 2007/8)". All three Technical Summaries are companion documents to the Four-year Review report.

This executive summary is based on a review of the project's first four years (2004/5 – 2007/8) and presents the environmental (biophysical) evaluation of two BMPs in the Thomas Brook Watershed WEBs project, located in eastern Nova Scotia.

### **Background and Issues**

The Thomas Brook Watershed (Figure 19) is typical of the Annapolis Valley of Nova Scotia. Agriculture accounts for 50 per cent of the land use within the watershed, 30 per cent is forested and rural residential land use is present throughout. Although the Annapolis Valley is perhaps best-

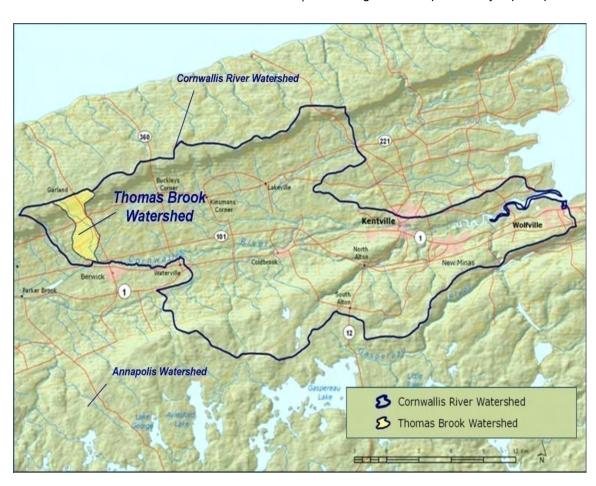


Figure 19: Thomas Brook Watershed location



known for its apple orchards, agriculture within the watershed is diverse, and includes high-value fruit and vegetable cropping, as well as beef, dairy, and poultry operations.

Water quality monitoring within the watershed began in 2001 with background growing-season stream monitoring. Considerable efforts have been made to improve data collection capabilities within the watershed as a result of the WEBs project. Complete water quality and flow data are now collected year round, so important off-season' impacts can now be included in observations. In addition, data related to field-level activities and cropping information is now part of the regular data collection. This information base is used for several related projects such as groundwater/surface water interactions in the Annapolis Valley, greenhouse gas monitoring in corn production, sediment E. coli survival studies, novel GIS application testing, and in the assessment of groundwater nitrate movement. These studies will be reported on at a later date.

# Watershed observations and complexity

Although relatively small at 760 hectares, there are a number of features which make the Thomas Brook Watershed complex. Soil types and topography consist of an interlocking mix of lighttextured soils with low slope, and heavier clay soils with over 9 per cent slopes. The watershed is influenced by three geological formations, which include a mountain ridge, and provides groundwater for a continuous flowing stream with baseflow levels of 0.05 cubic metres per second (m<sup>3</sup>/s). This baseflow is supplemented by surface runoff which is fed by an average of 1200 millimetres of annual precipitation, yielding flows in excess of 1 m<sup>3</sup>/s. The complex land matrix has evolved with small mixed land-use parcels including agriculture, forestry and rural residential spread throughout the watershed. As well, varied soil types support a mixed agriculture base. The watershed has 128 individual fields, which range from marginal pasture to intensive horticultural fruit and vegetable crops. Figure 20 illustrates the complexity of the land use in Thomas Brook.

Levels of several water quality parameters in the Thomas Brook routinely exceed guidelines for various uses (e.g. drinking water, irrigation). Mean concentrations for several key parameters (from 2001 to 2007) observed at the watershed outlet were: 1.8 mg/L nitrate-nitrogen, 0.16 mg/L total phosphorus, 60 mg/L total suspended solids, and 700 CFU<sup>1</sup> /100mL *E. coli*. Established national

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guidelines for drinking water are 10mg/L nitratenitrogen and 0 CFU *E. coli*, with irrigation limits set at 100 CFU *E. coli*. The trigger for eutrophic conditions in Canadian water >.035mg/L TP. Considering the level of water-quality impairment and the significant agricultural land use within the watershed, the use of BMPs is considered crucial for water quality improvements.

An assessment of the riparian areas within the Thomas Brook Watershed indicated that about a tenth of the watershed is classified as riparian area. Topography has left much of the stream buffered from the agricultural fields by natural riparian areas. Only 10 per cent of the riparian area is considered unhealthy, typically where used as pasture. Time of travel studies conducted within the watershed have illustrated extended nutrient retention times within these riparian zones. As a result, field-based BMP impacts are often muted by mature riparian areas which minimize stream water impacts.

The watershed's mixed land-use characteristics present challenges for identifying contaminant sources and the impacts of specific BMPs. Water samples collected from headwater sources upstream of intensive land-use activities possess background levels of contamination that are, at times, above recommended levels. For example source water concentrations of total phosphorus exceeded 0.03mg/L for 25 per cent of the samples collected while the average *E. coli* count was 32 CFU/100mL. This means that it will be challenging to meet certain water quality guidelines through the use of general agricultural BMPs.

As a result of WEBs, stream water sampling is now conducted at eight stations in the Thomas Brook, and at two additional stations in the Cornwallis River downstream of the Thomas Brook Watershed. The intensive monitoring in Thomas Brook targets BMP activities, while the Cornwallis River sites facilitate the scaling-up of modelling work. The robustness of the watershed requires that long term observations are needed to see stream water impacts from BMPs. Long-term datasets are also critical to the calibration and verification of modelling efforts.

### **Biophysical Component**

The biophysical component of the study is focused on evaluating the environmental effect of the following three BMPs on water quality:

- 1) Nutrient management plans
- 2) Off-stream watering
- 3) Storm water diversion

<sup>&</sup>lt;sup>1</sup> Colony-Forming Units



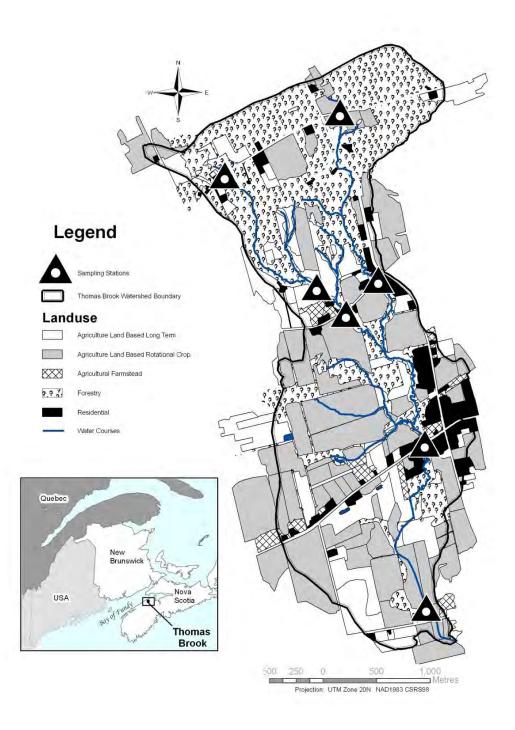


Figure 20: Thomas Brook land-use map, showing sampling site locations



A summary of the background, methods, and results specific to each of the BMPs assessed as part of this project are described below.

#### **Nutrient management plans**

#### **Background**

Nutrient management plans (NMPs) were prepared for commercial farms in the watershed with the goal of managing nutrient applications of nitrogen and phosphorus. Both nitrate and phosphorus were identified as concerns during previous monitoring.

#### Methods

Local nutrient management plan consultants developed three-year fertilization plans, following provincial recommendations. Original plans called for NMPs to be applied primarily to sub watershed zones for comparison. However, due to diverse land ownership and cropping practices, NMPs were eventually implemented in over 80 per cent of the cropland in the valley. Without the comparison at the sub-watershed level, water quality observations have been limited to the watershed outlet. Water was monitored for flow, total nitrogen, total phosphorus, ammonia, nitrate, suspended solids and *E. coli* bacteria.

#### Results

The current Nova Scotia NMP program operates on a three-year cycle. It is based on soil tests for phosphorus, potassium, and soil quality indices along with a standard N recommendation. With seasonal variations and changes in annual farm cropping plans, the three-year NMP program is not calibrated for specific cropping and nutrient requirements. Thomas Brook farmers have not reported major changes in production practices as a result of nutrient management planning. Combined with the complexity of the watershed, nutrient management planning as currently practiced has not demonstrated an observable impact on stream water quality.

A detailed database on water quality and land cropping practices has been developed that can lead to the fine tuning of nutrient management plans for Thomas Brook in the future. As nutrient management planning is considered key in controlling long-term nutrient loading for many water systems, future work will focus on developing nutrient management plans on an annual cycle, with annual benchmark soil sampling and cropping/fertilization recommendations. Annual soil sampling will facilitate tracking of soil nutrient trends, which may be a better indicator of the effectiveness of nutrient management planning. Future BMP work for Thomas Brook will involve

nutrient management planning with annual cropping and nutrient reviews, with the objective of reducing excess nutrient leaching. More accurate annual fertility estimates may also improve on-farm economics.

#### Off-stream watering

#### **Background**

Off-stream watering with cattle exclusion fencing was tested in some dairy farm rotational pastures in the watershed. A small section of stream (75 metres) previously left unfenced for water access, was fenced off and portable watering troughs were installed.

#### Methods

Monitoring for this BMP consists of an upstream-downstream approach whereby water quality analysis upstream of this BMP is being compared to results from a monitoring station downstream. Stream water was analyzed for nutrients (total nitrogen, total phosphorus, ammonia and nitrate), sediments and *E. coli*. In addition flow measurements were taken to enable loading estimations.

#### Results

Farm management changes during the implementation of this BMP resulted in reduced pasture usage. Due to this factor, combined with the short stream reach, the observable water quality impact of this BMP and its on-farm benefits were considered minimal, considering the costs for on-going maintenance and loss of pasture.

#### Storm water diversion

#### **Background**

A storm water diversion was installed at a dairy farmstead to transport runoff from buildings and to bypass a manure handling zone in order to reduce contaminated runoff. This was a targeted BMP as part of a waste handling improvement program for the farmstead. The diversion of rainwater away from the traffic area, where manure is loaded, also provided improved working yard conditions.

#### **Methods**

A system of French drains and surface inlets diverts the rainwater into a subsurface tile drain system which bypasses the manure storage and handling areas and discharges into a nearby riparian area. The impacts of this BMP are monitored at a water quality monitoring station immediately downstream. Flow measurements are taken and the water is analysed for nutrients (total nitrogen, total phosphorus, ammonia and nitrate), sediments and *E. coli*.



#### Results

Observed water quality improvement is attributed to the diversion, with peak concentrations of phosphorus and *E. coli* bacteria significantly reduced at the monitoring station just below the farm. High flow or event-driven total phosphorus levels declined by over half to near regular flow total phosphorus levels. While still excessive values for phosphorus and *E. coli*, the reduction in loading impact of this BMP was positive. This BMP is an example of how a targeted BMP can have a significant impact on specific water quality concerns.

#### Suite of BMPs

In general, the overall impact of the BMPs on water quality at the watershed outlet is not readily observed at this point in the monitoring program. High flow events and background contamination levels appear to have a large influence on water quality levels. A specific BMP, such as storm water diversion, had a significant immediate impact on water quality at times of high flow but showed no significant difference in water quality by the time the stream reached the outlet area. The BMPs tested were likely not aggressive enough to rapidly change water quality in this ecosystem adapted to functioning under diverse conditions.

#### Conclusion

Improved understanding of the larger-scale impact of agriculture in a mixed ecosystem has become an underlying goal of the Thomas Brook project. While targeted BMPs, such as storm water diversion, had significant impact on nearby water quality, there was no significant impact to the overall system in this time frame. The complexities of this watershed have limited our ability to report clear BMP impacts to date. However, the reality of this mixed ecosystem is its resiliency to be

productive for agriculture while still supporting its varied uses.

The establishment of Thomas Brook as a multidisciplinary study watershed under WEBs has been a catalyst for water and environmental research in the region. The heightened awareness has encouraged other research and demonstration as well as the formation of a local watershed association. While water issues have not been at the forefront of regional concerns, the local WEBs project has led to capacity building in the region for watershed-level studies. Dalhousie University, Acadia University, the Nova Scotia Agricultural College, the Nova Scotia Community College, and the Nova Scotia Department of Natural Resources have all increased their watershed research and demonstration efforts as a result of WEBs activities. Local awareness has also been raised with the formation of a watershed organization which includes Thomas Brook landowners. This group - The Cornwallis Headwaters Society provides a communication vehicle for watershed research initiatives, including WEBs. The underpinning value of a monitored watershed such as Thomas Brook is extensive, especially as water quality becomes more of a concern in this region.

## **Project Partners**

The Nova Scotia WEBs project was led by AAFC and directed by a multi-agency/multi-disciplinary team. The team is comprised of specialists from Federal Agencies (Geological Survey of Canada of Natural Resources Canada and AAFC), Provincial Agencies (Nova Scotia Federation of Agriculture and Nova Scotia Department of Agriculture), Dalhousie University, Nova Scotia Agricultural College, the Applied Geomatics Research Group of the Centre of Geographic Sciences, Ducks Unlimited Canada and the cooperating producers.



## Notes



## Notes



## Notes

