FARM LEVEL POLICY ~

AGRICULTURAL POLICY RESEARCH NETWORK

Preliminary Results from the Farm Behaviour Component of the Integrated Economic-Hydrologic Model for the Watershed Evaluation of Beneficial Management Practices Program

Draft Progress Report

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March 31, 2008

PROJECT REPORT FLP 506

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Acknowledgements:

We extend thanks to Bill Turner, Jim Yarotski, Mohammad Khakzaban, Terrie Scott and Brook Harker of AAFC for assistance with this research. We also thank Shane Gabor (DU), Wanhong Yang, Yongbo Liu, Jing Yang (all at University of Guelph), John Tisdell (Griffith University), and John Ward (CSIRO) for helping us formulate research ideas and providing advice at various stages of this research. Finally we thank Les McEwen, Dale Steppler, Gordon Orchard and the other producers involved in the Deerwood Soil and Water Management Association for sharing their data with us and discussing various aspects of their farming decisions. Without them this research could never have been conducted.

Funding for this project was provided by the Watershed Evaluation of BMPs (WEBS) and the Farm Level Policy Agricultural Policy Research Network (APRN). WEBS and APRN are funded by Agriculture and Agrifood Canada.

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Introduction

Greencover and other conservation programs established under the environmental component of the Agricultural Policy Framework (APF), are currently being implemented on the agricultural landscapes of Canada. These programs have been introduced to mitigate the adverse environmental effects of agricultural production. Unlike the United States and the European Union, conservation programs in Canada typically do not provide financial incentives to farmers for implementing beneficial management practices or conserving land and ecosystem services. The approach currently being considered in Canada involves the development of beneficial management practices (BMPs) with an understanding that these BMPs will be adopted by farmers under various incentive schemes.

Under the Federal Provincial Farm Stewardship Programs, a BMP is defined as an agricultural management practice which ensures the long-term health and sustainability of land-related resources used for agricultural production; positively impacts the long-term economic and environmental viability of the agricultural industry; and minimizes negative impacts and risk to the environment.

The Watershed Evaluation of BMPs (WEBs) project is a partnership between Agriculture and Agri-Food Canada (AAFC) and Ducks Unlimited Canada (DUC) established to evaluate the economic and environmental performance of BMPs for water quality at the watershed scale. To date the effectiveness of BMPs has been tested primarily on plots or small fields, with results extrapolated to watersheds. But plot and field tests might not accurately predict watershed effects due to confounding spatial factors, and cumulative effects. The WEBs project selected seven representative sub-watersheds (i.e. micro-watersheds in the range of 300 ha) to implement BMPs, establish monitoring stations, and collect water quality and socioeconomic data associated with adoption of BMPs. We think that some of the specific questions that should be addressed under WEBS are as follows:

1. Does BMP adoption at a given farm significantly change the farm's output of point and non-point pollution?
2. Does BMP adoption at a given farm make the individual farm household better or worse off from an economic perspective?

3. In the regional watershed what is the current contribution of each farm to the total pollution load and ensuing level of water quality?
4. If each farm were to adopt targeted BMPs what would be the level of pollution abatement and overall impact on water quality in the regional watershed.
5. Given a policy what would be the adoption rate of targeted BMPs among the relevant set of farms at the regional scale and if adopted, what would be the overall levels of pollution abatement and water quality improvement?
6. Given a level of costs associated with the policy inducing producers to adopt BMPs, what are the associated social and economic benefits of the overall abatement of pollution in the region?

A multi-faceted research program was designed to address these questions. The overall framework for addressing these questions was proposed by Yang et al. (2007). The fundamental components of the program consist first of understanding field and farm level environmental benefits of adopting BMPs as well as farm level costs of BMP adoption. In two study sites, Bras d'Henri in Quebec (BdH) and South Tobacco Creek in Manitoba (STC), the economic and hydrological components were integrated and aggregated to a sub-watershed scale. Policies to encourage adoption of BMPs could be tested and the overall policy costs and benefits of BMP adoption can be evaluated.

The integrated project model is illustrated in Figure 1. The adoption of BMPs is determined by the on-farm costs of BMP adoption, as well as the type of policy incentives provided. The ultimate policy cost of BMP adoption depends on private benefits of BMPs that accrue to producers as well as the way in which the incentive payment is implemented. For example, producers might receive fixed payments for BMPs based on previously determined cost sharing rules. Or conservation contracts might be established with producers based on specific auction bid selection rules (e.g. lowest bid, maximum environmental benefit, etc.). The willingness of producers to accept payments for BMPs will depend on the design of the auction and contract, which in turn affect the costs of policy implementation.

The adoption response of producers to various incentives is identified in the Farm Behavior component of the integrated modeling project. Auctions and other mechanisms for establishing contracts vary in a number of important characteristics including perceived fairness, cost effectiveness, and environmental benefits. BMP adoption scenarios for alternative BMP programs provide the following data to the integrated model:

- Farm participation rates in BMP programs
- Adoption levels (acres under adoption)
- Delivery costs of BMPs.

Once the adoption rate under different incentives is established it is possible to evaluate the program costs and environmental benefits of various policy incentives for BMP adoption. Finally, non-market valuation of the benefits would facilitate a full cost-benefit analysis of BMP programs. However, non-market valuation is outside the scope of the current WEBS program. In sum, the results of the integration framework will hopefully suggest cost effective policy measures for governments to achieve watershed scale pollution abatement targets.

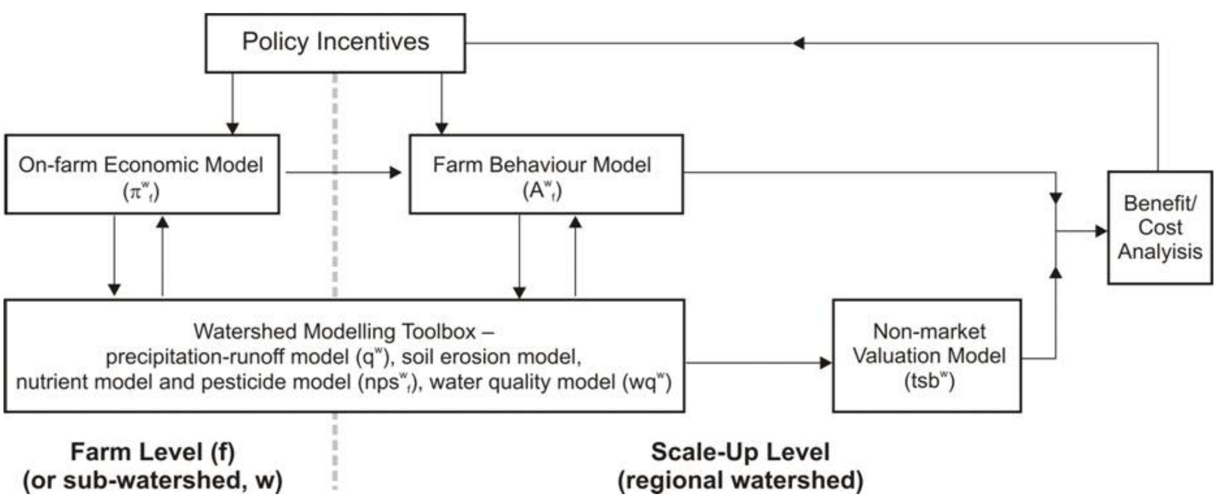

Figure 1. An integrated economic hydrologic modeling framework from Yang et al (2007).

This report summarizes some preliminary results of the Farm Behavior component of the integrated modeling project that was implemented in the South Tobacco Creek watershed in Manitoba. In order to develop the producer response functions it was necessary to develop field and farm-level costs of BMP adoption based on knowledge of producer activity levels. This is facilitated by the existence of an extensive dataset of production information for the producers in the watershed from 1991 to 2006 collected by the Deerwood Soil ad Water Conservation Association. The first part of this report develops the on-farm cost models that were used to parameterize the farm behavior model. The second part of this report develops the farm behavior model. Producer adoption responses were tested using policy experiments with student subjects and limited trials with producers. The results of the farm behavior research are used to draw preliminary observations on BMP policy design, and form the basis for recommendations for further research.

A Review of BMP Costs of Adoption for Some STC BMPs

The BMPs currently under examination in the South Tobacco Creek watershed are summarized in Table 1 below. We examine the first four of these in this research project.

Table 1. The beneficial management practices (BMPs) being evaluated in South Tobacco Creek, Manitoba in the Watershed Evaluation of Beneficial Management Practices Program.

BMPs	Definition
Riparian area management	Cattle are given limited access to riparian areas by fences to prevent grazing.
Converting cropland to forage (Green Cover)	The cropland under cultivation is converted to perennial forage production providing continuous vegetative cover.
Reduced or zero tillage	Reduced or zero tillage refers to practices that minimize soil disturbance and maintain crop residual cover by using alternative tillage equipment and applying herbicide for weed control.
Runoff holding pond	Holding pond is constructed to temporarily store runoff from a cattle containment area, especially from a winter feeding area.
Small reservoir retention	Small reservoir is constructed to monitor inflow and outflow and to assess downstream nutrient loading.
Crop rotation	A rotation based on the oilseed-cereal-legume-cereal model will ensure a good mix of high and low crop residues and a better defense against weeds and diseases. In addition, legume crops can biologically fix nitrogen in the soil.

Source: "Assessing the Water Quality Benefit of BMPs: At Watershed Scale across Canada", AAFC. "Steppler WEBs Project: South Tobacco Creek", AAFC.

The net costs of adopting BMPs consist of both direct costs due to changes in required management applications (e.g. purchase of new equipment for conservation till; changes in fertilizer applications), as well as indirect or opportunity costs related to foregone yields and net revenues from business as usual practices. BMPs can provide other indirect benefits. Some BMPs improve soil condition resulting in future yield improvements for example; BMPs may also reduce risk. In this section we review the existing literature on BMP costs and benefits to highlight potential cost drivers in STC.

Beneficial Crop Rotations

A number of on-farm private benefits of beneficial crop rotations have been identified (Wicks and Howitt, 2005; Yiridoe and Weersink, 1998; Gebramedhim and Schwab, 1998):

- Legumes fix nitrogen and reduce inorganic fertilizer needs;
- The alternation between cereal and non-cereal crops breaks pest and disease cycles and reduces herbicide and chemical use;
- Residues from legumes that contain N may also be utilized by the subsequent crop;
- Including winter cover crops in the rotation may increase soil quality by building up soil organic matter and increasing subsequent yields.
-

A number of studies find that production costs increase for beneficial crop rotations. For example, crops such as canola that are planted alternately with cereals have been shown to require more N fertilizer and more herbicide than cereal crops (Lafond et. al., 1993, Zentner et. al., 1999, Sonntag et. al., 1997; Hope et al., 2002). Lafond et al. (1993), and Zentner et al. (1999) find that input costs were greater for a beneficial crop rotation (such as cereal-oilseed-cereal-legume) compared with a conventional crop rotation (cereal-cereal-cereal-fallow). Nonetheless, the improvements in crop yields and gross revenues from beneficial crop rotations outweigh these costs on average for the Black soil zone of the prairies. Zentner et al. (1999) find net benefits in the range of \$23/ac to \$27/ac. Net returns were highest for cereal-oilseed-pulse rotations followed by cereal-oilseed rotations. Both of these rotations provide higher benefits than monoculture cereal cropping systems that include fallow every four years (Lafond et. al., 1993).

Beneficial crop rotations do not seem to have a significant effect on business risk. Reducing business risk requires a crop combination to have negative price and yield co-variances among the crops in the rotation. This would ensure that if the yield (or price) of one crop were to decline, the yields (or price) of another crop would offset the loss. Evidence suggests that there is little price covariance among spring wheat, barley, canola and field peas and hence beneficial crop rotations have little effect on reducing price risk (Bradshaw et al., 2004). Furthermore yield covariance is also small for some of the crop combinations (Bradshaw et al., 2004).

BMPs can result in unintended environmental consequences which should be considered prior to implementing a BMP program. For example, beneficial crop rotations that include canola could require more inorganic N fertilizer use and herbicide use than cereals or other oilseeds. Further, because the stubble left over from harvesting canola is shorter than that from cereals, it does not provide as much a cover against erosion (Hope et al, 2002).

Conservation Tillage

With the exception of Ontario, where 31% of seeded land uses zero tillage, zero tillage is predominantly a prairie practice (Fig. 2). Among the prairies, Saskatchewan has about 60% of its seeded area in zero tillage, followed by Alberta at 48%, and Manitoba at 21%. The seeded acreage in Manitoba is lower than the National average at 34%.

A number of studies have examined the on-farm benefits and costs of conservation tillage across Canada. Table 2 shows changes in the costs of inputs for zero tillage for wheat and canola crops for farms of similar size and for agro-ecological zones similar to STC (Nagy, 2001; SAF 2001). Both studies show an increased expenditure on herbicides, but savings in other inputs resulting in net savings. Neither of these two studies considers changes in fertilizer costs. While zero tillage is widely adopted in Canada, the benefits depend on several factors including soil zone, age of existing capital equipment, and type of crop rotation.

Major factors influencing the economic viability of conservation tillage appear to be weather, types of equipment employed, and the amounts and price of other inputs including fertilizer, pesticides and energy (Gray et al., 1996; Nagy, 2001; Weersink, 2001).

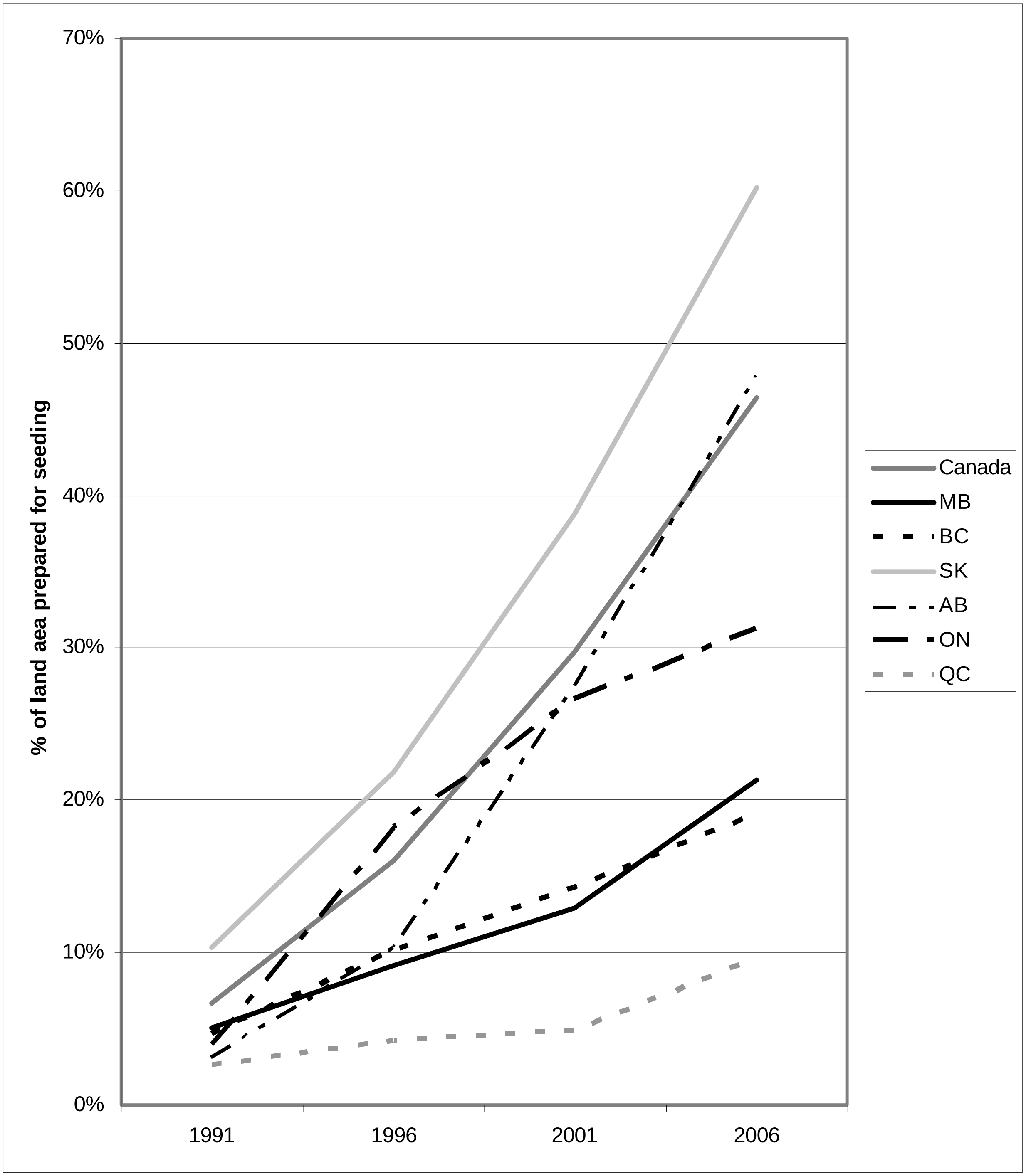

Figure 2. Estimates of areas seeded to zero tillage by province over time.

Table 2. Some financial impacts of adopting zero tillage on input costs (2001 $/acre).

Cost component	Wheat		Canola	
	Nagy (2001$/ac)	SAF (2004$/ac) Cost differences	Nagy (2001$/ac) Cost differences	SAF (2004/$ac) Cost differences
Herbicides	6.54	3.5	2.7	6.81
Fuel and oil	-6.49	-2.7	-5.58	-2.7
Machinery repair	-3.4	-1.15	-3.09	-1.15
Operating interest	0	-0.1	-0.19	+0.8
Hired Labour	-1.72	0	-1.54	0
Machinery Depreciation and Interest	-5.45	-3.52	-0.07	-3.52
Unpaid Labour	-2.93	0	-2.93	0
Inorganic fertilizer	0	0	0	0
Total difference	-13.45	-3.87	-10.7	-0.56

(Sources: Nagy, 2001; SAF, 2004)

Impacts of zero tillage on yields and net farm income from a number of studies are summarized in Table . The first three studies summarize results from multi-decade crop trials conducted at the AAFC research station in Melfort, Saskatchewan which is in the same soil-climatic zone as STC (Zentner et al. 2002; Zentner et al. 1999; and Agriculture and Agri-Food Canada, 2003). Zentner (1999) found that zero tillage had greater net returns than conventional tillage when combined with a beneficial crop rotation (cereal-oilseed-cereal-legume). However, net returns decreased with a cereal-cereal-cereal-fallow rotation. A comparison of crop yields by AAFC (2003) shows that zero tillage performed better than conventional tillage under both a cereal-oilseed rotation, and a cereal-legume rotation.

Zero tillage appears to have negative impacts on farm income in moist conditions. For example, Zentner et al. 2002 find that producers in moist environments or those in dry climates during wet weather cycles get higher yields from conventional tillage than from conservation tillage. Gray et al. (1996) find that zero till does not generate much of a yield advantage over conventional till in the (relatively drier) Dark Brown soil zone, as it does on the Black soil zone. Gray et al. (1996) also note that the investment in zero tillage related machinery (particularly expensive seeding equipment) is more cost-effective if done at the end of the life cycle of the older machinery.

Sparling and Brethour (2007) use data from a Canada wide survey, to calibrate a farm BMP simulation model to test the profitability of a suite of BMPs across Canada. They find that zero tillage improves yields for about half of the producers, and reduces costs among the majority. On average zero tillage increased farm net income in Manitoba by 12%. On the other hand, Samarawickrema and Belcher (2005) calibrated a farm model in Saskatchewan based on survey responses of producers who had adopted zero tillage. In their study, increases in input costs were greater than gains in revenue due to yield increases and net farm income was reduced by 8% after adoption of zero tillage.

Table 3. Some impacts of adopting zero tillage on farm revenues and income.

Study	**Location**	**Costs and benefits of adopting zero tillage**
(Zentner et al., 2002)	Melfort, SK	Conservation tillage practices reduce input costs between $3 to $6 per acre for most crops, except Canola
Zentner et al., (1999)	Melfort, SK	Zero tillage with beneficial crop rotation increases income by $3 per acre; with continuous cereal rotation reduces income by $1 per acre.
Agriculture and Agri-Food Canada (2003)	Melfort, SK (1986-9)	Zero tillage provided a yield advantage between 5% and 26%, for a cereal-pulse rotation. For a cereal-oilseed rotation, the yield advantage was between 7% and 13%
Gray, et al. (1996)	SK various soil zones	Zero tillage provided the following yield advantages and disadvantages compared with conventional tillage: Black soil zone: yields increased, 0% to 18% Dark Brown soil zone: yields increased 6% for wheat, but declined for canola
Sparling and Brethour (2007)	Canada and Provinces	Half the producers practicing zero till *perceived* yield increases, in cereals and canola. A majority perceived a decrease in costs. Model results showed increases in expected net income by 12% for Manitoba
Samarawickrema and Belcher (2005)	Black Soil Zone, SK	Net farm income for zero tillage declined by $8/ac, but yields for zero tillage were higher by 6% to 20%

Some studies have examined the impact that zero tillage has on farm business risk. Zentner et. al., (1999) indicated that producers at Indian Head, Saskatchewan with low risk aversion would choose the most diversified crop rotation with minimum tillage or zero tillage. Producers with medium or high risk aversion would also chose a diversified rotation (depending on grain prices), but only with zero till.

Non agro-environmental factors that influence the likelihood of adopting zero tillage in Canada include (Sparling and Brethour, 2007; Boame, 2005) are:

- Producer Age - likelihood of adopting zero tillage peaks between ages 36 and 55, and then declines. This is likely because this group of farmers is the most likely to benefit from long term yield benefits.
- Size of Farm - operators of large farms are more likely to adopt, possibly due to economies of scale required to make large machinery cost outlays cost effective.
- Custom Harvesting - farm operations that have customized harvester operations are more likely to see zero tillage adoption, possibly to reduce labour costs.
- Off-Farm Income - Producers with off-farm income were more likely to adopt zero tillage because they had higher opportunity costs of labour.
- Producers who have poultry and cattle are less likely to adopt, while those having 'other livestock' such as elk, goat, bison and llamas, are more likely to adopt. Although the reasons for this pattern are not clear, it is speculated that they may be related to attitudinal factors that are correlated with size of farm, and preferences for adopting experimental practices.

A number of studies report unintended consequences as a result of adopting tillage. Zero tillage increases stubble and level of organic matter on the soil surface which reduces the speed of water run-off and increases water infiltration. Zero tillage also slows the process of nitrification of inorganic N fertilizer. These two effects may lead to an increase of inorganic N in the leachate to ground water (Weersink, 2001). Zero tillage also was found to increase the use of fertilizer (Samarawickrema, 2005); changes in N fertilizer use after adoption ranged between minus 20 to plus 80% and changes in inorganic P fertilizer were between 0 and 50%. Adoption of zero tillage may also negatively impact waterfowl because the multiple passes of machinery under conventional tillage created an impermeable layer in the sub-soil which helped maintain sloughs and pot-holes in the fields (Samarawickrema, 2005).

Converting Cropland to Forage

There are relatively few studies discussing the farm economic benefits of converting cropland to forage. Forage and pasture are encouraged in non-arable marginal lands. However, when forage (particularly forage legumes) are cultivated in arable lands as part of a rotation they help enhance subsequent crop production yields due to improvements in soil quality, particularly through improvements in soil structure and texture which improve water holding capacity, aeration, and organic matter (Cambell et al., 1990; Entz, 2006). Improvements to soil quality have improved grain yields between 9% and 82% compared with continuously seeding grain in Iowa and Minnesota (Scheaffer et al., 2001). The largest increases took place in loamy sand while the smaller increases took place in silt loam soils. However, in some soil conditions additional N fertilizer had to be applied in order for the subsequent yield improvements to be realized (Scheaffer, 2001). If pasture is grazed by livestock, there are added advantages to soil quality as grazing cattle are able to return N to the soil in form of their excreta (Barclay, 2006). This benefit is lost when forage is mechanically harvested and fed to cattle off-site.

A host of private benefits of converting cropland to perennial grass in western Canada could be discussed in relation to the Permanent Cover Program (PCP) (I and II). A joint federal-provincial program was created between years 1989-1992 to address the problem of increasing soil quality degradation from unsustainable cropping practices on marginal lands. This program encouraged the conversion of marginal lands (classes 4, 5, and 6) from crops to permanent grass cover. Eligible participants were provided a seeding payment of $50/ha and a subsequent one-time payment between $20/ac and $65/ac, depending on the length of the contract and province. A total of 522,000 ha of marginal lands were signed up for a total cost of $74 million in payments. A sample of 500 producers was interviewed in 1994 regarding their perceptions of the program (Vaisey, Weins and Wetlaufer, 1996). Among those who participated in the survey, 70 % perceived decreased operating costs. There were fewer costs on annual cropland resulting from reduced need for gully repair and rock picking, and reduced fertilizer costs. About 60%

said it decreased the need to purchase livestock feed. On the other hand, there were extra costs related to fencing, moving livestock or forage, water supply development, labour, wildlife damage, and travel time. Fifty-six percent perceived an increase in net farm income[1]. The participants indicated that they were using their PCP lands for the following purposes. A large proportion (79%) indicated that they used their PCP lands for haying. Of these, 85% fed their hay to their own herd, while 12% sold it to a neighbor. Approximately 65% percent also used the lands to graze their own cattle (Vaisey et al., 1996).

The PCP program resulted in a wide variety of public benefits including reduced federal government payments under former acreage based programs targeted at annual crop production (1993 payments were estimated at $11 million). The estimated benefit of reduced wind erosion on crop productivity was $2 - $5 million. The program reduced sedimentation and chemical residues as well as government expenditures from removing wind and water borne sediments from ditches (Vaisey et al., 1996).

Tables 4 and 5 below examine some influences of forage production on crops and soils as well as producer factors affecting forage adoption.

Table 4. The influence of growing alfalfa on some agronomic and environmental parameters.

Parameter	Nature of Alfalfa Influence	References
Soil N	Five year alfalfa stand provides significant N for two following crops. N benefit can last up to 7 years Release of N from legume residue slower when legume stand terminated using no-till.	Ferguson and Gorby (1971), Bowren and Cooke (1975), Bailey (1987). Hoyt and Leitch (1983), Mohr, Entz and Janzen (unpublished data)
	Annual alfalfa crops can contribute an average 50 kg ha^{-1} N to the soil. As high as 120 kg ha^{-1}.	Bruuslema and Christie (1987), Kelner (1994).

[1] It should be emphasized that the net farm income increase was perceived and not actual. As well, the sample of PCP participants cannot be generalized to the farm population because they were farmers who are likely to have a greater percentage of marginal land.

Soil structure	Alfalfa roots perform " biological tillage", thereby improving soil environment for root growth of subsequent crops.	Blackwell et al. (1990), Entz (1994)
	On heavy clay soils, inclusion of alfalfa in rotation increases soil water infiltration. No-till alfalfa removal keeps pores intact.	Meek et al. (1990), Cavers and Eilers, Dept. of Soil Sci, U of MB (1994)
Subsoil N	A four year alfalfa stand effectively extracted N to a depth of 260 cm on an Osbourne clay soil in Manitoba.	Entz and Vessey (unpublished)
	Fallowing the year after forage breaking increases subsoil N, thereby increasing the risk of groundwater contamination.	Campbell et al. (1994)
Weeds	Two or three years of forage in a six year rotation virtually eliminated wild oat in cereal crops.	Siemens (1963)
	A survey of commercial fields in Manitoba indicated significantly fewer wild oat, green foxtail and Canada thistle plants in wheat following forage crops vs. wheat following annual crops.	Ominski et al. (1994)
	Eighty percent of producers in a MB/SK survey indicated fewer weeds in annual crops after forage-breaking compared with annual crops in an annual crop rotation. Good control of wild oat, green foxtail and Canada thistle was observed for a period of one (11% of respondents), two (50% of respondents), or more (33% of respondents) years.	Entz et al. (1995)
Soil water status after alfalfa	Black and Gray soil zones: Soil water in 0 to 60 cm usually recharged in alfalfa rotation, but subsoil drier. Fallow not required for water recharge after forage-breaking. Removing alfalfa stands using no-till increases soil water recharge by up to 3 cm.	Hoyt and Leitch (1983), Entz (1994), Bullied and Entz (unpublished data)
	Dark Brown soil zone: Including alfalfa in rotation results in moisture shortages in following year. Fallow required for water recharge after forage-breaking.	Brandt and Keys (1982)
Grain yield of following crops	Recent survey indicated that 71% of producers in MB and SK observe a yield benefit from including forages in their crop rotations. Yield benefit greatest in wetter areas and lowest in Brown soil zone. Yield benefits decrease sharply as alfalfa stand length increases beyond four years.	Entz et al. (1995)
	Cumulative yield benefit occurs when legumes repeatedly included in cereal-based crop rotation.	Poyser et al. (1957).
	In dry years, grain yields greater when alfalfa removed using no-till vs. tilled system.	Entz and Gulden (unpublished data)

(Source: Entz et al., 2008)

Table 5. Some factors influencing adoption of forage by prairie producers.

Questions on forage crop management	Percent response by producers	Comments
Main farm enterprise	Mixed (grain and livestock) - 62.8%; Dairy, Livestock only, Grain and forage seed - (10% each).	Mixed farms evenly distributed across survey area; forage seed concentrated in eastern MB and northeastern SK. Percent of tillable acres on survey farms dedicated to forages - 30%.
Rotational benefits: Grain yield following forages.	Higher yield after forages - 67.4%; Lower yields after forages - 9.3%; No change - 23.3%	Yield benefits of forages greatest in wetter areas and lowest in southern SK. In dry areas, as frequency of summerfallow after forage breaking increased, rotational yield benefits increased. Yield benefits lower when forage stands longer than 5 years.
Rotational benefits: Weed suppression by forages.	Fewer weeds after forage-breaking - 83.3% More weeds after forage-breaking - 7.9% No difference in weed populations - 8.8%	Producers noted weed suppression for one (11% of respondents), 2 (50% of respondents), or more (33% respondents) years after forage-breaking. Suppression noted for annual grasses, annual broadleaf weeds and Canada thistle.
Forage stand length	Average forage stand length 6.5 years. Forage stands longest in southern SK (>8 years), and shortest in south-central MB (4 to 5 years).	Current forage stand length much longer than required for rotational yield and weed control benefits, and slightly longer than economic optimum (which is 4 or 5 years, Jeffrey et al. 1993).
Why do farmers terminate forage stands?	Reduced yields - 58.1%; gophers - 18.7%; rotational considerations - 11.6%.	The strategy of most producers is to maximize forage stand life, and rotate forages only when necessary due to declining productivity.
How do producers terminate forage stands?	Tillage alone - 76.6%; tillage and herbicides - 22.1%; herbicides alone - 1.3%.	Over 20% of producers indicated fallowing land for one full year after forage stand termination. Producers who used both tillage and herbicides relied less heavily on fallow the year after forage stand termination (19 vs. 27% for those who used tillage alone).

(Source: Entz et al., 2008)

A Swedish study examining factors influencing willingness to convert land to forage during the Swedish Agricultural Reform of 1990 found likely adopters included farmers in the middle of their farming career, and producers with larger farms (Anderson, 2005). When crop production is no longer required to receive payments, farmers in the middle of their farming career are more likely to reconsider their choice of the vocation and opt for an alternative occupation than farmers in the beginning or end of their career. Larger farms were more likely to convert their land. They could afford to reduce their part of their operations compared to smaller farms. Higher economic potential in the region reduced the likelihood of conversion. This could indicate that farmers in more prosperous regions had off-farm employment already. This fact could imply that the production would remain in areas with a high economic potential, where the farmer is less dependant on off-farm income. Adoption was more likely in less fertile land, as would be expected, because the opportunity cost is lower. Highly specialized (value added) farms and those involved in labour intensive livestock operations reduced the chances of adopting, possibly because of greater opportunity cost of converting (Anderson, 2005).

Riparian Area Management

Riparian restoration provides a large number of public benefits including reduced off-site sediment and nutrient loadings, and increased waterfowl and native fish populations. Other off-site benefits include reductions in bacteria and pathogens from livestock farm runoff and cattle drinking water from creeks, improved recreation, ease of navigation, flood control and reduced water treatment costs (see Lynch and Tjaden, 2000;Yang et al., 2004; Watson et al., 2006). Lynch and Tjaden (2000) estimate that establishing buffers in Maryland to remove 40% of nutrients could cost about $617,000 annually. A comparable structural engineering approach involving major design and installation of storm water retention ponds would cost $3.7 billion annually.

Several studies have discussed the factors influencing the private costs of implementing a buffer strip for riparian area protection on a farm (Sohngen et al., 1999; Watson et al., 2006; Rein, 1999). The initial capital outlay includes fencing costs, off-site watering troughs for the cattle, and costs of seeding perennial grass or planting shrubs or trees as buffers. There are also annual maintenance costs for repairing fences, maintaining water troughs, and trimming the hedges or pruning the trees, if applicable. Finally, there are opportunity costs from not undertaking crop production on the site, as well as extra nuisance costs from maneuvering farm equipment around the buffer. There could also be opportunity costs to cattle grazers or ranchers from controlled grazing (Watson et al., 2006). The private benefits of riparian area management include top soil retention which improves crop production, benefits in scenic appearance to the farm, as well as benefits from increased sales of fishing and hunting rights.[2] The landowner could also benefit from the aesthetic appearance and harvest of trees, grass or orchard crops (e.g. Lynch and Tjaden, 2000).

Sparling and Brethour (2007) found that across all provinces installing buffer strips resulted in a negative private net benefit because of the lost productivity of land and initial capital outlay. The net loss after installing a buffer strip on an average Manitoba farm was 1% t (Sparling and Brethour 2007). Sohngen et al (1999) suggest that buffer strips may be more cost effective on larger fields as the cost of riparian area protection could decrease if producers manage and harvest timber or other marketable products from the buffer strip.

A number of studies evaluated factors that affect the water quality impacts of buffer strips. Buffer size was identified as an important factor by Uusi-Kampa et al. (2003). Buffer strip effectiveness can also be increased by enrolling land parcels that are located closer to the source of the pollutants (Uusi-Kampa et al. 2003). This suggests that on a watershed scale buffer zones need to be spatially targeted and that adjacency to other buffer strips will increase the productivity of the buffer. With use of integrated hydrologic-GIS and economic models, it was found that the benefits of reduced sediment erosion can be increased by enrolling land parcels that are closer to water bodies, and have higher erodible soils and slopes (Yang et al., 2003; Yang and Weersink, 2005). Furthermore, cost-effectiveness could be further increased if the buffer width is allowed to vary by location, rather than assuming a uniform width (giving preference to slope, soil erodibility and proximity to water bodies).

Summary

This literature review suggests that there are private benefits for some of the BMPs examined in STC. In some cases the benefits from beneficial crop rotations, conservation tillage and perennial cover exceed the private costs of implementation for some producers. However, heterogeneity in soils, climate, and producer characteristics are all shown to have an impact on BMP costs and benefits. Thus, adoption of these practices would likely not be advantageous

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[2] In the US, on certain preserved lands, landowners are allowed to sell fishing licenses and hunting leases (which, for the latter have been between $5 and $20 per acre).

across all farms in most watersheds. Some BMPs, like riparian area management, generally have greater public benefits than private benefits, and may require incentives for adoption. The review confirms that programs that encourage adoption of BMPs should consider variation in producer characteristics that influence costs and benefits of BMPs.

Estimating On-Farm Costs of Adoption of BMPs in South Tobacco Creek

South Tobacco Creek (STC) is a sub-watershed of the Red River in the rural municipality (RM) of Thompson (058) in Southern Manitoba. The STC watershed drains 7,638 ha of which 71% (5,409 ha) is under cultivation in a total of 333 individual fields owned by 42 farm owners and a Hutterite Colony. In the most recent census (2001), RM Thompson is comprised of 144 farms on 109,646 acres (44,372 ha). Average farm size in Thompson is 308.13 ha which is equal to 4.76 quarter sections. The farm size in STC averages about 125.79 ha (approximately 2 quarter sections), which is much lower than the average for the RM of Thompson. However, this is an under-estimate because portions of some farms in the Deerwood Soil and Water Management Association not included because they fall outside the watershed boundaries.

Historical land use data on crops, yields, and management inputs such as fertilizer, herbicide use, and type of tillage practice, was provided by the Deerwood Soil and Water Management Association for 353 fields from 1991 – 2006 in the watershed. This data was edited and supplemented with other information by Dr. Mohammad Khakzaban and staff from AAFC. This land use data was combined with soils data from the 'Manitoba Soil Database' (AAFC, 2002) including soil class, soil texture, and slope, and climate data including temperature and precipitation obtained from, Environment Canada (2005 and 2007), for the meteorological station at Miami Thiesen, Manitoba.. Information on crop prices for crops and forage were obtained as a 10 –year average from 1994-2003, to reduce the effect of year-to-year price variation. Prices for crops were obtained from SAF (2003) and for forage from personal communication with Sumach (2007). BMP management costs were obtained from MAFRI farm budgets models (MAFRI 2004a; 2004b) and validated by the literature where possible from SAF (2004).

The Deerwood data set provides the history of crop type, yield, field size, various field practices including spring and fall tillage, seeding and harvesting, straw management, fertilizer, manure and pesticide applications by field and by farm. Detailed information for the Steppler farm was obtained through a site tour on June 7th, 2006 and is can be found in Deng (2006). The historical data suggest the following land use trends in the watershed. First, spring wheat is the dominant crop in STC. When alternated with an oilseed, canola is the dominant oilseed in the rotation, as indicated by the inverse relationship between acres of spring wheat and canola in a given year. Furthermore, while spring wheat acres seem to rise and fall with price, canola acreage relationship to price is not as strong. Generally producers in the basin seem to follow a cereal-oilseed rotation, but if prices are favorable they follow cereals with cereals and oilseeds with oilseeds. This indicates that producers actively make tradeoffs between future productivity and current revenues, even if they are relatively small. While in the early period of data collection continuous cropping of wheat was observed on several fields, towards the latter periods of the study, farms seemed to increasingly adopt a cereal-oilseed rotation.

The major crops grown in Thompson are spring wheat (32,014 acres), canola (13,020 acres), barley (7,492 acres), alfalfa (5,282 acres) and oats (5,247 acres).[3] Only a very small portion of the land in RM Thompson is in summerfallow (3,222 acres), representing 3% of total area of farms (AAFC, 2004). Forage and pasture production have been on the rise in recent years (Turner, personal communication). The crops grown in STC in between 1991-2006 are summarized in Figure 3 and are similar to the agronomic patterns found in the RM Thompson overall.

As of 2006, 12 producers had cattle (29% of total farms), and approximately 20% of the area was in alfalfa, oats, forage, or pasture. The total amount of forage has been increasing steadily, from less than 5% in the early 90s, to over 10% of area since 2001. Forage provides benefits both for grazing cattle, as well as for improving soil quality. The number of cattle and the number of producers with cattle has increased steadily since 1990. Accordingly, forage fields have doubled from 1990 – 2000 or from 490 ha to 890 ha. The location of new forage fields seems to be determined by their proximity to other forage fields, rather than on sandier soils or places needing erosion control. This suggests that ownership of cattle seem to strongly influence

[3] We note that the scientific standard is to report metric units. However, since our research is on farm behaviour we chose to use acres instead of hectares because acres are better understood by most Canadian producers.

location of forage and also a tradeoff between erosion control and nutrient management if forage fields are used for grazing (Hope et al., 2002). Finally, there was no increased adoption of zero tillage by producers in the watershed over the time frame of the sample – with less than 15% of wheat and canola not tilled over the time period. This is less than the average rate of adoption in the prairies and signals the presence of potential barriers to adopting the zero till BMP that could be unique to the STC.

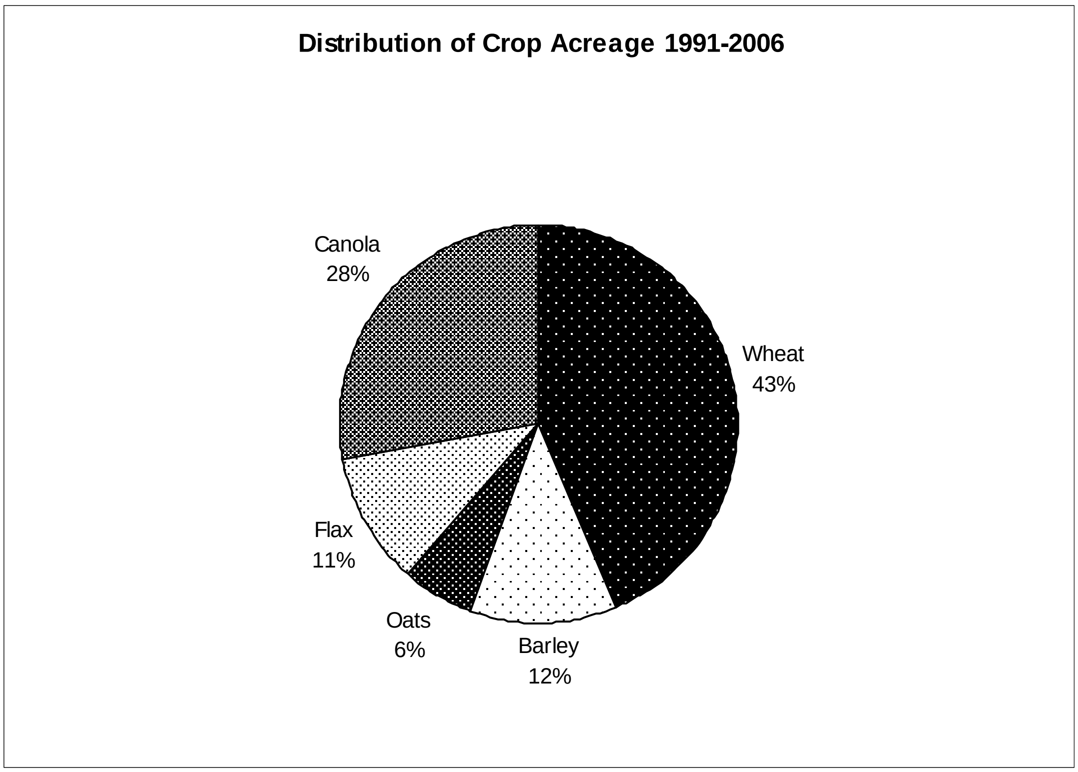

Figure 3. The distribution of crop acreage in South Tobacco Creek during 1991-2006.

Several BMPs are being tested experimentally on the Steppler farm. Within the STC watershed, the Steppler farm[4] is located near the town of Miami, approximately 150 km southwest of Winnipeg. The Steppler farm is a mixed farm with grain-production and beef cow operation, which is the dominant farm type in the watershed. The runoff from the Steppler farm

[4] Farm id 49 in the data set, on fields 154-157, 171-174, 178-194, 212-217, 305,306, 312, 328, 334, 353, 355, 361, and 364.

drains through South Tobacco Creek, and flows into the Red River and finally into Lake Winnipeg which has water quality problems, particularly related to phosphorous loads. Steppler farm was selected as a representative farm for the STC watershed (Deng, 2006). The size of the Steppler farm is 210 ha, with primarily soils of clay-loam. Annual cropping and cattle production are the main activities on the farm. Wheat, barley, canola, flax and alfalfa are the major crops in the rotation. Wheat, flax and canola are marketed as cash crops whereas barley and hay are only produced to feed cow-calves and self finish feeder cattle. Greenfeed oats are often seeded as cover crops in spring and harvested in fall after the hay cuts. Usually for the first cut hay, 4-5 round bails (around 1200 lbs. per round) are produced per acre. Alfalfa fields are returned to crop production after a 4-year rotation. As for the cattle operation, the current herd size is about 100 cows. Calves are weaned in November at a weight of 600 lbs. and wintered on the farm. Silage (greenfeed oats and hay) is fed to cattle starting from the beginning of January.

Methods

The farm behavior research requires the distribution of BMP costs across producers in the watershed. This requires the development of field and farm specific cost functions associated with BMP adoption. The net cost of adopting BMPs for producers includes both direct and indirect costs of adoption. In some cases, BMPs lead to an increase in productivity or a yield boost which counts as an additional private benefit of adoption. Direct costs include additional management and operating costs, and amortized capital costs where new investment in equipment is required. Indirect costs include the opportunity cost of not following the baseline (conventional) cropping pattern. Opportunity costs are the net benefits associated with conventional cropping systems with no BMPs applied.

In the analysis we assume that production functions for crops and livestock are separable. Although livestock may provide nutrient inputs and crops provide feed for livestock, we assume that there are no joint production benefits and that the cost of feed is exactly equal to the opportunity cost of not selling feed on to the market. Producers would benefit from nutrient application from manure however we were unable to capture this input in the existing data as there is no time series information on livestock numbers in the watershed. However, the value of manure inputs can be captured by the price of substitute chemical inputs. Finally, the presence of livestock might alter the type of farm and rotation patterns. This effect is partially accounted for in the forage crop model which is treated separately from grain and oilseed crops. The general methodology for estimating BMP costs is given in Figure 4 below.

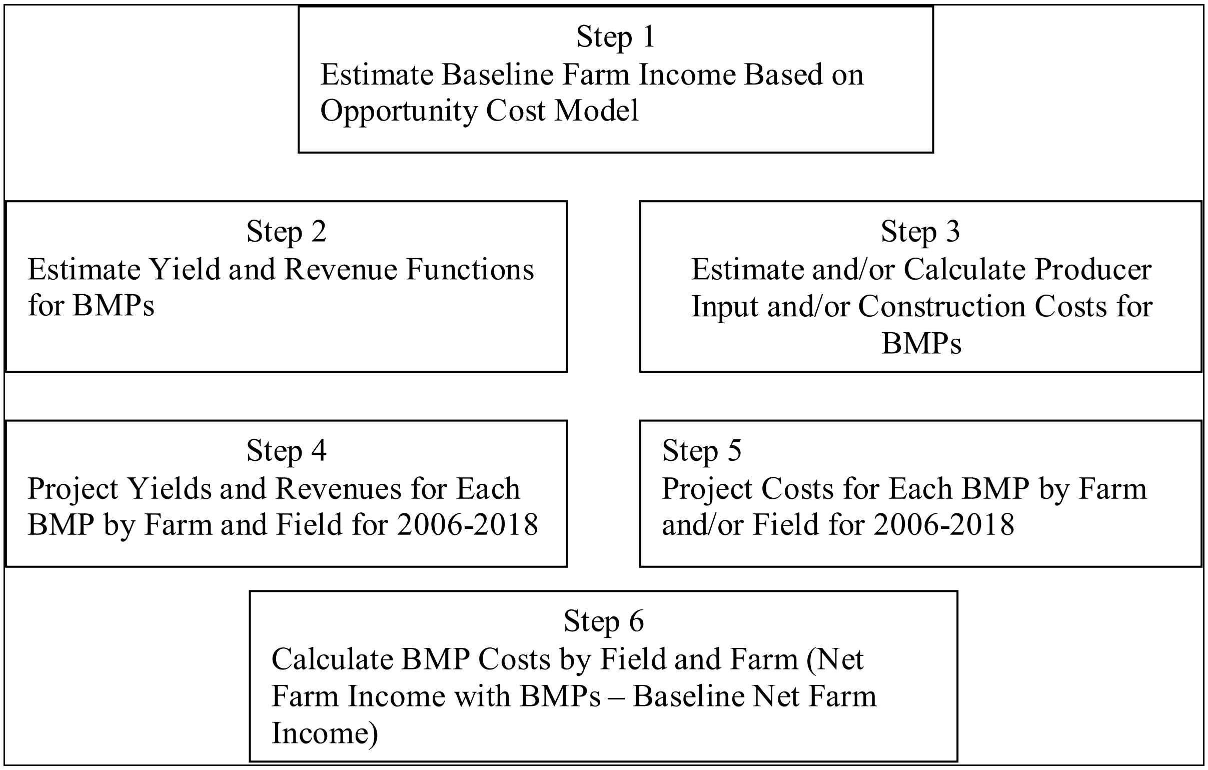

Figure 4. A diagram showing the procedures employed for developing BMP cost functions.

The Opportunity Cost Model

The estimation of opportunity costs forms the basis of all of the BMP cost projections used in the cost estimates developed in this study. The approach used in developing the opportunity cost model is summarized in Figure 5.

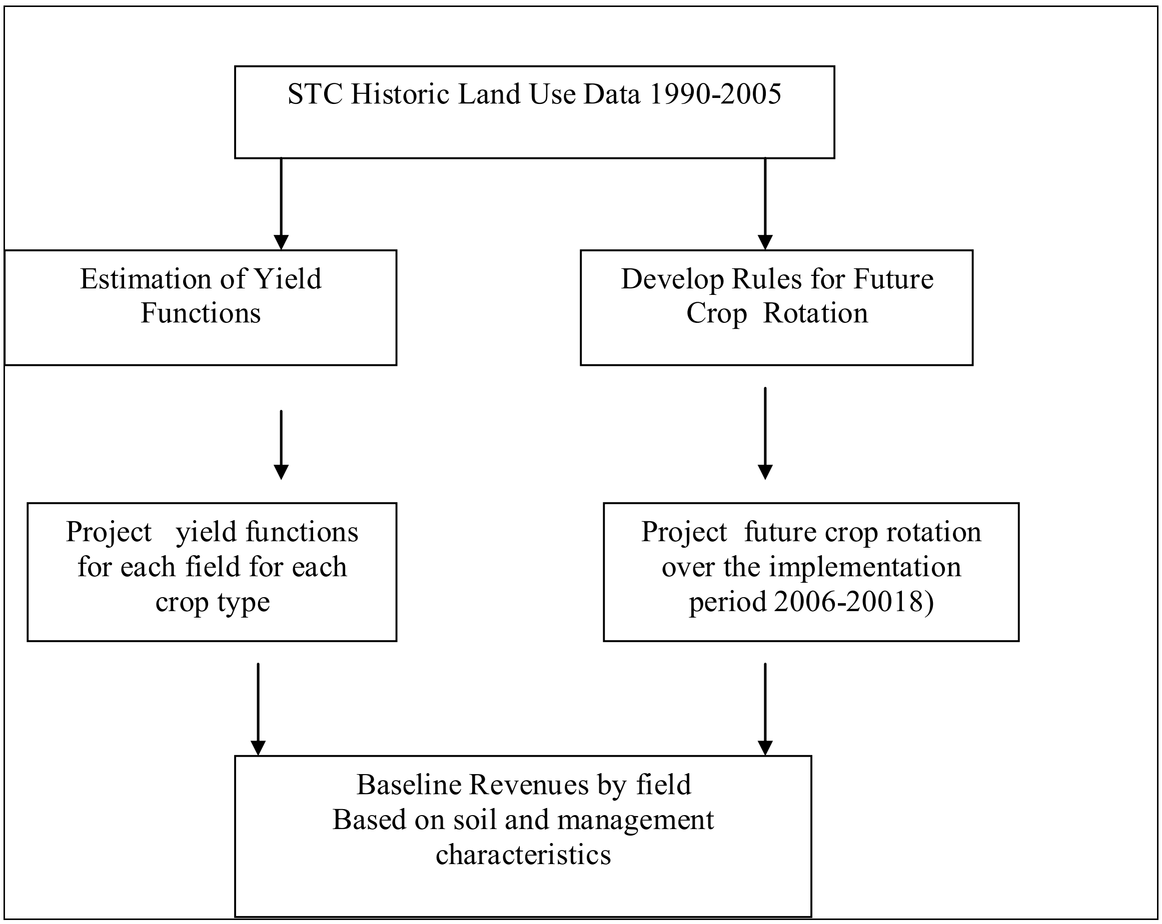

Figure 5. A diagram showing the opportunity cost model.

Rules for Assigning Future Crop Rotations

In order to project the opportunity cost of lost production, it is necessary to determine the baseline crop production pattern, in this case the projected crop rotation on each field. This step allowed projection of the appropriate yield model to the appropriate field in a given year to calculate any changes in revenue during that year. Based on the historic data we identified four types of crop rotations which were used to classify each field. The crop rotation types and rules to classify each field by type used for the projection model are:

1. cereal oilseed mix (beneficial crop rotation) – field had approximately 1/3 of time or five or more years in oilseeds historically (out of 16);
2. forage – field had seven or more years of forages out of 16 (with 6.6 years the average length of a complete forage cycle based on historical data in the watershed);
3. Pasture - fields reported with pasture were assumed to remain as pasture
4. Continuous cereal – all other crop rotations.

Assigning Crops to Rotations

Rules were also developed to assign specific crops to rotations for twelve years (2007-2018) based on the distribution of crop types given in Table 6. These rotations were:

- Beneficial Crop Rotation**:** For fields defined as having 'beneficial crop rotation' practices (i.e. 1 above), the crops were constructed to ensure that there are two consecutive years of cereals and one year of oilseeds (e.g., cereal – cereal – oilseeds or cereal – oilseeds- cereal, or oilseeds – cereal –cereal). For example if a field had cereals for years 2005 and 2006, an oilseed would be assigned in 2007, followed by two cereal crops.
- Forage Rotation: For fields assigned with a forage rotation, each farm is assumed to be in forage until it reaches the average length of forage time (seven years). Once forage is terminated it is replaced with a four year beneficial crop rotation until the next 7 year round of forage. For example, if a field was in forage from 2001-2006, it would be assigned a forage crop for 2007 and 2008, and then assigned a cereal, cereal, oilseed, cereal crop until 2012 when the forage cycle would resume.
- Pasture**:** Any field identified as pasture is assumed to remain pasture permanently.
- Continuous Cereal Rotation: For fields assumed to be in a continuous cereal rotation, crops were chosen so that there are four consecutive years of cereals followed by one year of oilseeds (e.g., cereal – cereal – cereal – cereal – oilseeds – cereal – cereal – cereal – cereal – oilseeds)

Assigning Crop Types to Crop Categories

Cereal crop categories were assigned the following crop types: wheat, barley and oats. Oilseed crop categories were assigned the crop types**:** flax and canola. In order to assign specific crops to each crop category we randomized the selection of cereals and oilseeds based on their relative distribution in the historical data set. The projections were constrained to approximately preserve both the ratio of the crop type relative to the number of observations, and the ratio of crop type relative to allocated land. This randomization process provided a relatively good approximation for both criteria for barley, oats and flax, but overestimated wheat and underestimated canola (Table 6).

Table 6. Historic and projected crop rotations: allocated crops and numbers of observations.

Crop	Historic 1991 – 2006 (16 years)		Projected 2007 – 2018 (12 years)	
	Acres	No. of observations	Acres	No. of observations
Wheat	69,887 (44%)	1,520 (43%)	68,293 (49%)	1,611 (49%)
Barley	19,224 (12%)	407 (12%)	14,196 (10%)	357 (11%)
Oats	8,937 (6%)	286 (8%)	14,678 (10%)	328 (10%)
Flax	17,543 (11%)	414 (12%)	18,550 (13%)	407 (12%)
Canola	44,399 (28%)	889 (25%)	24,180 (17%)	556 (17%)
Total	159,990	3,516	139,897	3,259

Estimation of Crop Yield Functions with and without BMPs

Crop yields with and without BMPs were estimated using the linear model shown in Equation 1 using SAS version 9.1:[5]

$$Y_i = \phi_1 + \phi_2 \frac{GS}{GDD} + \phi_3 \left(\frac{GS}{GDD}\right)^2 + \phi_4 N + \phi_5 N^2 + \phi_6 P + \phi_7 P^2 + \phi_8 Pest + \phi_9 SC1 + \phi_{10} SC2 + \phi_{11} NoTill + \phi_{12} Continuous + \phi_{13} legume + \sum_{j=1}^{41} \varphi_j D_j + \varepsilon, \qquad (1)$$

where[6] Y_i = yield of crop *i* (bushels per acre), ϕ_1 = constant, *GS/GDD* = weather variable, *SCi*= soil class dummy variables for Regosols and Brunisols respectively, *N* and *P* = nitrogen and phosphorous applications (kg/ha/year), *Pest* = pesticide application index, *NoTill* = 1 if zero till was employed and 0 otherwise, *Continuous* = 1 if crop type was the same in two consecutive years, *Legume* = 1 if legumes were planted the previous year, and D_j = dummy variables for each producer in the data.

Regression equations were developed for the five most common crops - barley, oats, canola and flax (i.e., i = 1…5). Crop yields were measured in bushels per acre. Weather was represented by water ratio - built as a ratio of precipitation to growing degree days over 5 C.[7] The soil variables refer to soil class, texture and slope (texture and slope were found to be insignificant) obtained from the National Soils Database. GS/GDD is the explanatory variable for weather where GS is gross precipitation and GDD is growing degree days.[8] The ratio

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[5] Note that in theory we expect the relationships between management inputs and yields to be non-linear (i.e. to experience diminishing returns). However non-linear models were ruled out using Box-Cox tests. The reason that non-linear models did not perform as well as the linear model is that generally producers are not observed applying inputs above optimal levels. Therefore, we do not fell that diminishing returns from management would be observed in this producer data.

[6] Note that although this is a panel data set the subscript t has been eliminated from the equation for notational convenience.

[7] Water ratio was built using information on degree days over 5°C and precipitation from the Natural Resources Canada weather website for the meteorological station at Miami Thiesen, Manitoba.

[8] Following Cortus's study (2005), the precipitation was simply summed for the days within the growing season (May to September) to obtain growing season precipitation (GS). Daily growing degree days (GDD) were calculated according to the following equation:

$$Max\{0, [(MaxTemp + MinTemp)/2] - K\}$$

between GS and GDD constitutes a proxy for "water use to water demand" ratio that determines the growing condition for crops (Cortus, 2005).

Agricultural practices in the model included rates of N and P fertilizer application (kg/ha/year) as well as pesticide use and dummy variables for zero tillage. [9] Beneficial crop rotation benefits were estimated using the following lag variables: the variable Continuous Crop is a dummy variable if the same type of crop is grown in two consecutive years and the Legume lag variable identifies whether legumes were grown in the previous year.[10] No-till is a discrete variable indicating yes if there were absolutely no tillage operations in the spring or fall (Lafond et al., 1993)[11]. The role of individual producer management techniques and farm specific land quality variation was captured using producer dummy variables which identify which farm the field belongs to.[12]

Parameter estimates from OLS models of best fit for crop yield are shown in Table 7. Field and farm revenues were calculated by multiplying yields by ten-year average prices[13].

Table 7. Crop yield functions for five crops using the Deerwood Soil and Water Management Association data for 1991 to 2006.

Variable/ Coefficient	**Wheat**	**Canola**	**Barley**	**Flax**	**Oats**
Constant	6.605	50.119**	28.901**	9.061**	-46.538
GS/GDD	3.870**	-0.002	1.436	1.526**	9.288**
$(GS/GDD)^2$	-0.087**	-0.005	-0.031	-0.034**	-0.195**
SC1 (Regosols)	3.331**	1.932			-18.566

where K was the threshold temperature; For this research, 5 C. is used. MaxTemp was the maximum daily temperature, and MinTemp was the minimum daily temperature. The daily GDD values were summed over the growing season to obtain growing degree days for the year.

[9] The pesticide index was obtained from Khakbazan (2007). Nutrient applications included chemical applications only, and do not account for extra manure spread from livestock operations. Given lack of time series data on livestock in the current data, regression coefficients may overestimate the marginal contributions of fertilizer.

[10] Legumes refer to faba beans, field peas and beans (white, navy). There were about 20 observations of legumes in the historic data. Because of their small representation in this historic data they are not used in future rotation projections for 2007-2018.

[11] In zero tillage the only disturbance on the soil occurs during seeding (Lafond et al., 1993). We did not test for the percentage of residue being greater than 30%.

[12] Producer dummy variables were constructed for each year rather than just the current year allowing us to capture the effects of management changes due to changes in ownership over time could be captured over time.

[13] Average prices were calculated for a period of greater than 10 years going back from year 2004, using SAF data.

SC2 (Brunisols)			5.269**	0.682	
Total N		0.148**		0.053**	-0.021
$(\text{Total N})^2$	-0.203**	-1.859**	-0.192	-0.655**	1.114
Total P			-0.582**		
$(\text{Total P})^2$	0.235	0.312	3.880**	-0.023	1.103
Pest index	0.029	0.758**	4.556**	-0.366	0.582
No-till	4.762**	-5.506**	2.282	-2.553	-20.423**
Continuous crop	-1.870**	2.693	-0.226	-3.165**	-10.809**
Legume lag1	0.280	0.581	8.292		
Prod_1					
Prod_2	-12.094**	-11.596**	29.014**	0.767	26.392**
Prod_4	-5.914		2.277		13.275
Prod_5	-17.448**			-6.559	
Prod_8	-13.331**	-6.940		1.547	
Prod_9	6.497	-13.874**	23.246**		
Prod_10	-8.099**		4.469		
Prod_11	-9.720**	-14.821**			
Prod_12	-7.918**	-15.260**		-1.896	
Prod_13	-12.652**	-20.501**			
Prod_14	-11.230**	-20.340**		-3.684**	9.819
Prod_15	-11.380**	-23.127**		-2.759	
Prod_16	0.108	-10.008**	9.854	-3.266	27.626**
Prod_17	-10.815**		6.778	-1.813	29.225**
Prod_18	7.332**	-8.988**	-12.861**		
Prod_21	2.712	-15.905**			-45.247**
Prod_22	-13.789*				27.483
Prod_24	-5.199**	-13.783**	-13.615	4.015**	3.265
Prod_25	-11.511**	-17.420**	21.852**	-13.294**	
Prod_26	-10.382**		12.872**		23.849**
Prod_27	-11.710**	-16.902**	-13.611**		
Prod_28	-1.419	-12.254**		-1.670	25.487
Prod_29	-1.903	-20.638**	1.144		
Prod_31	-10.558**	-19.917**	-5.227	-3.766	
Prod_32	-1.963	-7.636**	19.168**	3.296**	0.171
Prod_33	0.400	-7.675**	23.952**	1.128	3.470
Prod_34	-7.672**	-14.321**	6.214	0.918	7.286
Prod_35	-2.957	-9.466**	13.143**	4.380**	25.315
Prod_36	-0.462	-9.386**		1.515	45.569**
Prod_37	-14.187**	-25.874**		2.066	
Prod_38	-5.029	-28.643**		1.895	
Prod_39	-5.169**	-14.331**	27.926**	-0.210	8.835
Prod_40	-7.707**	-16.300**	1.784	0.871	13.182
Prod_41	-4.798*	-19.943**	6.456	3.053**	10.730
Prod_42	-9.724**	-14.046**	-17.840**	-4.149**	1.498
Prod_43	-8.118	-1.937			21.868**

Prod_44	-1.882	-19.654**	12.939**	18.334**	
Prod_45	10.027**	-4.472	20.347**		
Prod_46	-23.431**				
Prod_47	-7.547**	-16.306**	11.881**	0.892	23.004**
Prod_48	-20.387**	-14.630**			
Prod_49	-8.779**	-17.021**	3.265	-0.920	4.590
Prod_50	-4.315	-10.471**	8.500	6.301**	8.615
Prod_51	0.387	-4.168	11.524		21.139**
Prod_52	-8.403**	-9.384**	18.191**	-0.999	14.778
Prod_53	-11.379**	-15.513**		0.632	25.874**
Prod_54	-1.959	-19.633**			26.141**
Prod_55	-7.699				19.422
Prod_56	-14.448**				-14.746
Prod_57	21.480**	2.488	34.466**		
Prod_58					16.173
Prod_59		-18.987**	12.410	-5.355	
Prod_60	-13.407**	-21.788**		-4.524**	
Prod_61	-13.149**		-7.547	-7.187**	
Prod_62	-6.969**	-12.815**			
R^2	0.347	0.330	0.409	0.323	0.319
Number of obs.	1,513	874	404	413	286

** signifies P<0.10

Discussion of Crop Yield Models

The effect of positive climate conditions is significant and exhibits the expected quadratic form, so that at some point there are diminishing returns from heat and moisture availability. In terms of management practices, growing the same crop two years in a row has a significant yield depressing effect on the second year crop for all crops except canola. For example, yields decline by 0.2 bu/ac for barley and by 10 bu/ac for oats. The impact of cultivating a legume crop the year before had a positive but insignificant impact on subsequent yields of wheat, canola and barley. Inorganic nitrogen application had a significant productivity impact on flax and canola, while the quadratic term (squared term) was negative for most crops indicating a detrimental effect from over use. The reason for the negative and significant coefficient on phosphorous for the barley equation is not clear. Zero tillage has a positive impact on wheat and barley yields, but a negative impact on the yields of other crops.

Crop Production Cost Model

Costs of production for each field in the historical data set were calculated using MAFRI budgets for the year 2004. Two adjustments to MAFRI budgets were made. First since we had actual values for fertilizer use by farmers of the STC, we replaced the MAFRI estimates with actual fertilizer use and multiplied them by MAFRI (2004a) fertilizer prices. Secondly, since MAFRI did not distinguish between conventional tillage and zero tillage, tillage costs for zero and conventional till were adjusted using with SAF 2004 budgets which are presented in Table 8.

Table 8. Estimates of the costs associated with zero tillage in South Tobacco Creek.

	Wheat	**Barley**	**Oats**	**Flax**	**Canola**	**Wheat**	**Canola**
Cost component	SAF (2004$/ac)	SAF (2004$/ac)	SAF (2004$/ac)	SAF (2004$/ac)	SAF (2004$/ac)	Nagy (2001$/ac) Cost differences [1]	Nagy (2001$/ac) Cost differences [2]
Herbicides	3.5	3.5	3.5	3.5	6.81	6.54	2.7
Fuel and oil	-2.7	-2.7	-2.7	-2.7	-2.7	-6.49	-5.58
Machinery repair	-1.15	-1.15	-1.15	-1.38	-1.15	-3.4	-3.09
Operating interest	0	0	0	0	0	0	-0.19
Hired labour	0	0	0	0	0	-1.72	-1.54
Machinery depreciation and interest on investment	-3.52	-3.52	-3.52	-3.52	-3.52	-5.45	-0.07
Unpaid labour	0	0	0	0	0	-2.93	-2.93
Total difference	-3.87	-3.87	-3.87	-4.1	-0.56	-13.45	-10.7

Herbicide costs increased by \$6.81/acre for canola and by \$3.50/acre for the other four crops. Fuel costs decreased by \$2.70/acre for all five crops. Machinery repair decreased by \$1.15/acre for all five crops. Machinery depreciation and interest on investment declined by \$/ac 3.52 for all five crops. Hired labour was assumed to remain constant under both cropping systems. Total savings for canola were \$0.56/acre; \$4.10/acre for flax and for the other three crops were \$3.87/acre.

In order to generate hypothetical costs from alternative crop rotation scenarios for each field it was necessary to develop a regression model for cost estimates for each crop type that could then be projected back into each field. A simple regression model was estimated similar to the yield model in Equation (1). This equation was:

$$c_i = \alpha_1 + \alpha_2 N + \alpha_3 P + \alpha_4 SC1 + \alpha_5 SC2 + \alpha_6 NoTill + \sum_{j=1}^{41} \gamma_j D_j + \varepsilon \qquad (2)$$

Where c_i = production cost for crop i (dollars per acre), *N* and *P* = total nitrogen and phosphorous applied (kg/ha/year), SC_1 and SC_2 are soil class type dummy variables for Regosols and Brunisols respectively, No Till = dummy variable = 1 if no till, and D_j = producer dummy variables to capture management effects.

The resulting parameter estimates for crop production costs are shown in Table 9. The constant shows the cost of production for conventional tillage for each crop when fertilizer cost is excluded. The coefficients for fertilizer are positive and significant. No-till increases the costs of production, significantly for wheat, and insignificantly for canola, barley, and flax. Zero till reduces costs for oats but the parameter is not statistically significant. The increased costs are most likely due to greater fertilizer applications under zero tillage.

Table 9. Parameter estimates from the production cost model.

Variable/ Coefficient	**Wheat**	**Canola**	**Barley**	**Flax**	**Oats**
Constant	125.196**	171.847**	124.397**	120.491**	113.393**
N	0.445**	0.369**	0.385**	0.276**	0.289**
P	-0.162**	0.555**	-0.528**	0.625	-0.139
No-till	5.570**	10.669	5.594	3.254	-8.544

SC_1 (Regosol)	7.771**	3.123			8.748
SC_2 (Brunisol)			0.221	-0.290	
Prod_2	-12.225**	-28.413**	20.255**	3.923**	13.125**
Prod_4	-30.084**		2.461		-2.463
Prod_5	-26.108**			-21.375	
Prod_8	-1.258	-36.683		-1.345	
Prod_9	5.937	-32.789	12.311		
Prod_10	-3.379		-4.518		
Prod_11	-26.220**	-62.558			
Prod_12	-12.358**	-48.682		2.863	
Prod_13	-33.541**	-59.383			
Prod_14	-6.670	-36.781		-2.553	13.597
Prod_15	-26.278**	-45.703		-5.615	
Prod_16	-10.178**	-36.547	-2.999	34.159	2.586
Prod_17	-4.585		20.914**	5.796	9.973
Prod_18	27.091**	0.752**	28.828**		
Prod_21	17.649**	3.102			32.133**
Prod_22	28.846**				19.249**
Prod_24	-7.351	-35.925**	-32.682**	18.672**	37.673**
Prod_25	-14.085**	-22.976	0.327	-22.475	
Prod_26	-17.675**		0.305		-0.644
Prod_27	-17.863**	-38.776	-5.354		
Prod_28	1.259	-27.019		7.686	-15.500
Prod_29	-24.599**	-40.140	-6.941		
Prod_31	-23.189**	-62.103	-13.125	-6.953	
Prod_32	8.988**	-25.009	-1.511	10.301	17.217**
Prod_33	4.591	-17.023	14.625**	-8.528	1.663
Prod_34	-17.799**	-53.460	8.983	-10.727	-11.249**
Prod_35	-19.086**	-37.827	1.751	-13.484	3.314
Prod_36	-5.468	-24.942		-11.150	33.338**
Prod_37	-15.631**	-66.390		-18.736	
Prod_38	-18.948**	-69.745		-18.664	
Prod_39	-2.032	-35.507	25.341**	5.983	5.240
Prod_40	-6.098	-29.437	-10.269	8.042	7.909
Prod_41	8.770**	-15.536	4.037	14.440	14.413**
Prod_42	-13.719**	-44.079	-3.532	-8.140	-18.581**
Prod_43	-30.328**	-59.692			4.517
Prod_44	16.402	-0.429**	28.544**	31.225	
Prod_45	15.058	-27.737	-7.590		
Prod_46	-15.197**				
Prod_47	13.652**	-13.686	9.584	-8.252**	29.935**
Prod_48	-33.350**	-61.087			
Prod_49	-1.706	-29.187	26.392**	12.701**	10.075**
Prod_50	-12.859**	-34.247	6.348	-0.718	-2.647
Prod_51	20.622**	-4.016**	32.770**		27.092**

Prod_52	0.059	-36.605	17.893**	-1.204	7.658
Prod_53	-9.950**	-41.122		-4.950	4.970
Prod_54	-6.989	-25.174			17.302**
Prod_55	-27.362				-21.634
Prod_56	-14.335**				-19.874
Prod_57	-33.336**	-64.810	-23.497		
Prod_58					24.742**
Prod_59		-62.809	-9.965	-6.526	
Prod_60	-16.343**	-59.342		-12.978	
Prod_61	-21.417**		-9.437	-20.265	
Prod_62	-6.963	-31.799			
R^2	0.585	0.569	0.712	0.417	0.589
Number of obs.	1,534	893	422	413	290

** signifies P<0.10

Forage Income Model

Figure 6 below describes stages in estimating the income to be applied to the forage BMP model. The opportunity costs of producing forage on a given field are equal to the lost farm income from producing the next best crop; which in turn is derived from the baseline crop rotation model developed above.[14] Econometric models were developed to generate equations for projecting forage yields and costs on to each field in the 2007-2018 period. Forage yield and cost functions were estimated using Equations 3 and 4 respectively:

$$m = \beta_1 + \beta_2 \frac{GS}{GDD} + \beta_3 Cattle + \beta_4 Time + \beta_5 Time^2 + \beta_6 ST_1 + \beta_7 ST_2 + \beta_8 ST_3 + \beta_9 Slope + \varepsilon, \qquad (3)$$

$$n = \chi_1 + \chi_2 \frac{GS}{GDD} + \chi_3 Cattle + \chi_4 Time + \chi_5 Time^2 + \chi_6 ST_1 + \chi_7 ST_2 + \chi_8 ST_3 + \chi_9 Slope + \varepsilon. \qquad (4)$$

Where m = revenue from forage sales (\$/ac), n = cost from forage production (\$/ac). β_1 = Constant, GS/GDD = weather variable, *Cattle* = 1 if producer owns cattle in 2007, *Time* = the age of the forage stand (years), ST_i = Soil texture dummy variables for clay, loam and alluvium, respectively, and *Slope* = 1 if slope is greater than 5%, 0 otherwise.

[14] Each year a field was in forage the opportunity cost was assumed to equal the mean annual farm income under the baseline rotation from 2007-2018. In addition, to be comparable, the opportunity costs of forage include only the variable costs portion of crop production costs. The fixed costs for crop production that were excluded were $55/ac/year for machinery, land and storage.

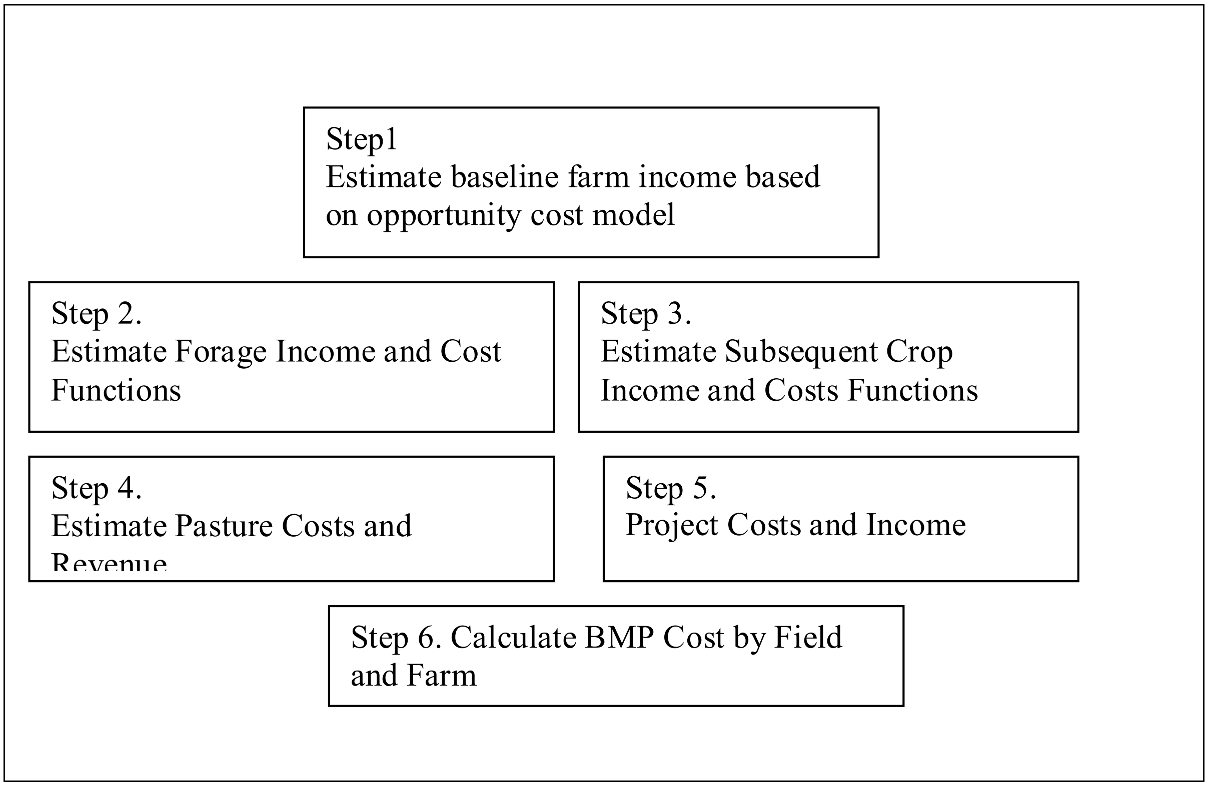

Figure 6. A diagram showing the calculation of forage conversion costs.

Forage revenue (in \$/ac) was calculated multiplying yield (in t/ac) by 10-year average price [15] Costs (in \$/ac) included variable costs for the year 2004 from MAFRI (2004b). [16] The variable *Cattle* indicates if the producer owned cattle.[17] The *Time* variable indicates continuous years of forage. Soil textural classes include loam, clay and alluvial and were obtained from the National Soils Database. *Slope* is a dummy variable showing whether the slope was greater than five percent or not.

[15] Based on personal communication with Sumach (2007), an average price of $59 / t between years 1994 through 2003 was obtained.
[16] The costs included seeding, pesticides, fertilizer, fuel, repairs, interest on capital, insurance and taxes
[17] It shows current ownership of cattle in the year 2007. We do not have time series data on this.

Discussion of Forage Cost and Income Models

The regression models for forage crop revenues and costs are shown in Table below. As expected forage income increased with time, but the negative squared term shows that at some point there are diminishing returns.[18] The weather variable had an unexpected negative (but insignificant) influence on income – possibly because more precipitation would water-log fields. All three soil types had positive influences on income, with alluvium being most significant[19]. Owning cattle significantly improved income as grazing cattle return nutrients to soil. Terrain with a slope >5% also has a positive effect on income – possibly because soil is less likely to be water logged.

Forage costs increase with time because forage needs more fertilizer; however, the significant negative squared term shows that these costs increased at a decreasing rate. The weather variable significantly increased costs, presumably because as precipitation or moisture increases, more fertilizer is being applied.[20] Clay and alluvial soils contributed to declining costs, albeit insignificantly, while loamy soils contributed to increasing costs. The reasons behind there findings are not quite clear. Cattle had no significant effect on costs. Parcels with grade seem to reduce costs, again possibly because they do not water-log and experience less nutrient leaching.

Table 10. Results of OLS regression models for forage income and costs.

Variable	**Cash inflow ($/ac)**	**Cash outflow ($/ac)**
Intercept	-1.841	57.108**
	(19.977)	(1.716)
Time	30.602**	-2.854**
	(3.989)	(0.343)
Time squared	-2.442*	0.259**
	(0.392)	(0.034)

[18] Forage specialists suggest that yield, and hence revenue, peaks between the four to five year stage after which it declines. Then, the forage stand is re-seeded after seven to 10 years.

[19] Alluvium includes soil particles of flood plain deposits on low lying areas. Clay has greater moisture and nutrient holding capacity, but becomes water logged and difficult to work with. Loam has a high composition of silt, clay and sandy textures and is suitable for horticulture crops (USASK, 2007).

[20] When soil moisture increases, more fertiliser could be effectively provided for plant uptake. Rain could also leach or wash the fertiliser off the field.

GS/GDD	-7.936	-23.223*
	(61.735)	(5.303)
Alluv	42.011*	-1.217
	(23.043)	(1.979)
Loam	16.849	2.296*
	(13.627)	(1.171)
Clay	15.504	-0.646
	(25.600)	(2.199)
Cattle	35.518**	0.016
	(9.301)	0.799
Slope	19.6837	-1.977*
	12.245	1.052
Number of observations	1105	1105

Note: ** represents statistically significant at P<.10 level; * represents statistically significant at P<0.20 level. Standard errors are in parentheses

An indirect benefit of forage production is the fertilization effect on subsequent crops. We estimate this yield boost due to forage using Equation 5 below:

$$\Delta Y_i = \eta_1 + \eta_2(\Delta N) + \eta_3(\Delta P) + \eta_4 ST_1 + \eta_5 ST_2 + \eta_5 ST_3 + \eta_6 \frac{GS}{GDD} + \eta_7 Time + \eta_8 Time^2$$
$$+ \eta_9 Sl_1 + \eta_{10} Sl_2 + \eta_{11} Sl_3 \qquad (5)$$

Where, ΔY_i = Change in crop yield after cultivating forage (in bu/ac), η_1 = constant, ΔN = change in nitrogen fertilizer applied after cultivating forage (lbs/ac), ΔP = change in phosphorus fertilizer applied after cultivating forage (in lbs/ac), and Sl_i = slope dummy variables for 0- 5%, 6- 9%, and 10- 15%, classes, respectively.

The change in yield (measured in bu/ac) was estimated for wheat and canola (i.e., i = 1, 2) after cultivating forage. The change in N and P was measured in lbs per acre. The other variables have been described before. The results of the model are shown in Table. The model was expected to produce a positive shift in crop yield (constant), but showed an insignificant negative constant[21]. The weather variable was positive and significant for canola (but not

[21] A possible reason for the negative constant (intercept) could be that subsequent crop yields were influenced by factors not considered, like pests for example. As well, crop yields may not change significantly without adding more nutrients.

wheat). It may be that an increase in water supply to demand ratio improved subsequent canola yields.

Increased use of N fertilizer (significantly), and P fertilizer (insignificantly), enhanced both wheat and canola yields. An additional pound of N increased wheat and canola yields by approximately, 0.5 bu/ac, and 0.3 bu/ac, respectively. Further comparison of fertilizer use on wheat and canola (cultivated after forage) shows that on average, fertilizer application after forages increases by about 3lbs/ac. However, when this 3lb increase was multiplied by the estimated yield enhancing coefficients (0.5 and 0.3 bu/ac), wheat and canola yields increased by 1.5 lbs/ac and 0.9 lbs/ac (relative to pre-forage yields) respectively. The product of these yield increases by wheat and canola prices[22] ($4/bu and $7.50/bu, respectively), gives additional revenue of $6/ac and $6.80/ac respectively[23]. The product of fertilizer use increase (3lbs/ac) and fertilizer price (0.3$/lb MAFRI, 2004b) gave us additional costs of $0.9/ac. Therefore, we conclude that the benefits of forage to subsequent crops are due to increased productivity of N applications after the forages are removed.

Table 11. The impacts of growing forage in previous periods on cereal and oilseed crops.

Variable	Wheat yield difference	Canola yield difference
Constant	-1.14	-2.515
	(7.709)	(5.297)
Slope 9-15%	0	0
	(0)	(0)
Slope 5-9%	0.401	-1.827
	(7.696)	(5.986)
Slope 0-5%	0.272	-3.664
	(9.001)	(8.51)
Other texture	0	0
	(0)	(0)
Clay	0	0
	(0)	(0)
Loam	0.061	1.827
	(6)	(5.986)
Alluv	0	0

[22] 10-year average prices from MAFRI (2004).
[23] Extending such benefits of wheat to the other three cereals, and of canola to flax, the additional revenues are; $3.6/ac, $2.5/ac, and $6.8/ac, for barley, oats, and flax respectively. These benefits are rather conservative compared with literature on yield boosting estimates from forage conversion.

	(0)	(0)
Time squared	0.08	-0.344
	(0.279)	(0.6)
Time	-0.4	2.859
	(2.514)	(4.221)
Water ratio	-220	**55.22****
	(483.8)	(18.4)
PΔ	0.479	0.829
	(1.145)	(0.923)
NΔ	**0.499****	**0.257***
	(0.169)	(0.149)
Number of observations	35	20
R^2	0.363	0.756

Note: ** represents significance at P<0.10 level; standard errors are in parenthesis.

The costs of adopting the forage BMP were calculated by projecting a forage rotation onto each field using the projection formula developed under the rules for future crop rotations. In particular, if no forages were planted on the field, a forage rotation is started in 2007, continues for 7 years, and is then followed by a 4 year cereal/oilseed rotation. Similarly, if forages were in place in 2007, they are assumed to continue until 7 years are completed then followed by a cereal/oilseed rotation.

Estimation of Pasture Costs and Revenue

Finally, fields that are in pasture were assumed to remain in pasture permanently. The net benefits of pasture are calculated and added to the forage BMP. Pasture costs were based on estimates from MAFRI 2007.[24] Pasture revenue was estimated by multiplying the number of animals the pasture could carry by the maximum number of days the pasture could be grazed.[25] Using information specific to STC we assumed a fertilized pasture could carry 0.25 animals per ac, for 120 days, at a rate of $1.10 per day.[26] This provides $33/ac for the entire grazing season.

[24] Costs include land development, herbicide, fertilizer, fuel and repairs, interest on capital, land taxes and labor costs.
[25] A 1,000 lb cow with a suckling calf at her side is referred to as one animal unit.
[26] Based on personal communication with J. Thorton, MAFRI, August 22, 2007.

For an un-fertilized pasture, we assumed it would carry 0.27 animals per acre for 90 days, at a rate of $0.75 per day. This would provide $18/ac for the season.[27]

Crop Production and Opportunity Cost Projections

The crop rotation rules developed in Step 1were used to project baseline crop types for each field from 2007-2018. The regression models for costs and yields (estimated equations 1-4) were used to project baseline opportunity costs for each field under the assigned baseline rotation assuming conventional tillage (i.e. the No Till dummy variable was set to 0 for each field). In order to examine the impacts of zero-tillage on farm income a similar projection was run assuming all crops on all fields were cultivated using zero tillage (i.e. the No Till dummy variable was set to 1). Similarly, to assess the impact of forage conversion a projection which assumed all fields are converted to forage rotation was imposed. For all projections, the weather variable (GS/GDD) was assumed to be constant and based on the average GS/GDD for the field over the period 1991-2006. Similarly, N and P applications were based on average historic inorganic N and P applications for each individual field and crop. There were no stochastic elements in these projections. The opportunity cost model was used to determine the net 12-year non-discounted cost associated with each BMP for each field.[28] Costs were then aggregated to the producer level.

[27] This method assumes greater involvement by the land owner, using their own labor and management skills to graze the pasture with cattle that have been leased out to him/her. It assumes greater risk and return, than merely renting out the pasture. It is referred to as custom grazing.
[28] Note that we did not discount the costs because the discount factor interacts with the experimental setting.

Analysis of On-Farm BMP Costs

The costs of adopting BMPs were assessed for zero tillage, riparian management, forage conversion and holding ponds. Specific assumptions for costing each BMP are presented in each section below.

The Zero Tillage BMP

Table 12 summarizes the average impact of zero tillage on farm income for all crops. Only wheat and barley yield estimates increased due to zero tillage adoption (between 4.76 bu/ac and 2.28 bu/ac respectively). The other crops had estimated yield declines (from -2.55 bu/ac for flax and -20.22 bu/ac for oats). These declines signify revenue losses to the producer. Costs increased for all crops except for oats. For wheat the net result is an increase in net income of $13.47/acre. However, for the other crops, the cost increases outweighed any yield gains from zero tillage. The results suggest that unless the area cultivated with wheat is large enough to compensate for losses to the other four crops, there will be an average net cost to the producer of adopting zero tillage as a BMP in this watershed.

Table 12. The impacts of adopting zero-tillage on farm income by crop in South Tobacco Creek, Manitoba.

Crop	**Change in Yield Bu/ac**	**Price $2004/bu**	**Change In Revenues $2004/ac**	**Change in Costs $2004/ac**	**Change in Net Income $2004/ac**
Wheat	4.76**	4.00	19.040	5.570**	13.47
Barley	2.28	2.40	5.472	5.594	-0.12
Oats	-20.42**	1.65	-33.693	-8.544	-25.15
Flax	-2.55	7.50	-19.125	3.254	-22.38
Canola	-5.51**	7.50	-41.325	10.669**	-51.99

The zero tillage BMP cost curve was derived by plotting the 12-year cumulative BMP cost against cumulative acres starting with the least expensive on a per acre basis (see Figures 7 and 8). Each point in the curves identifies an individual producer in the watershed.

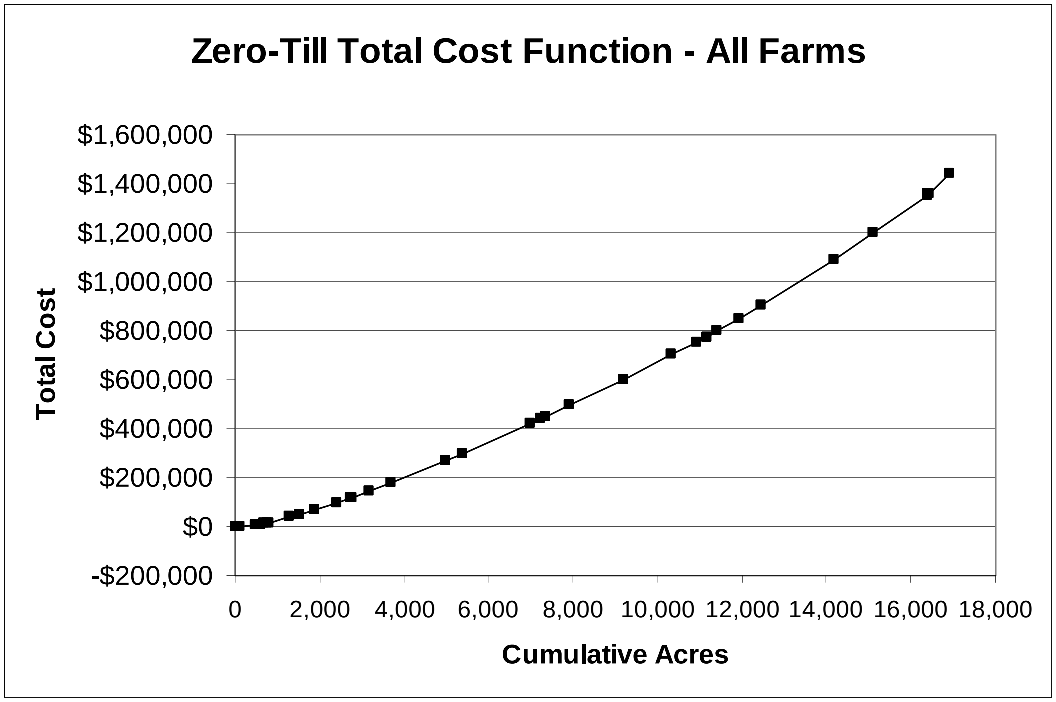

Figure 7. The total cost function for adopting zero tillage for the 36 producers in South Tobacco Creek, Manitoba.

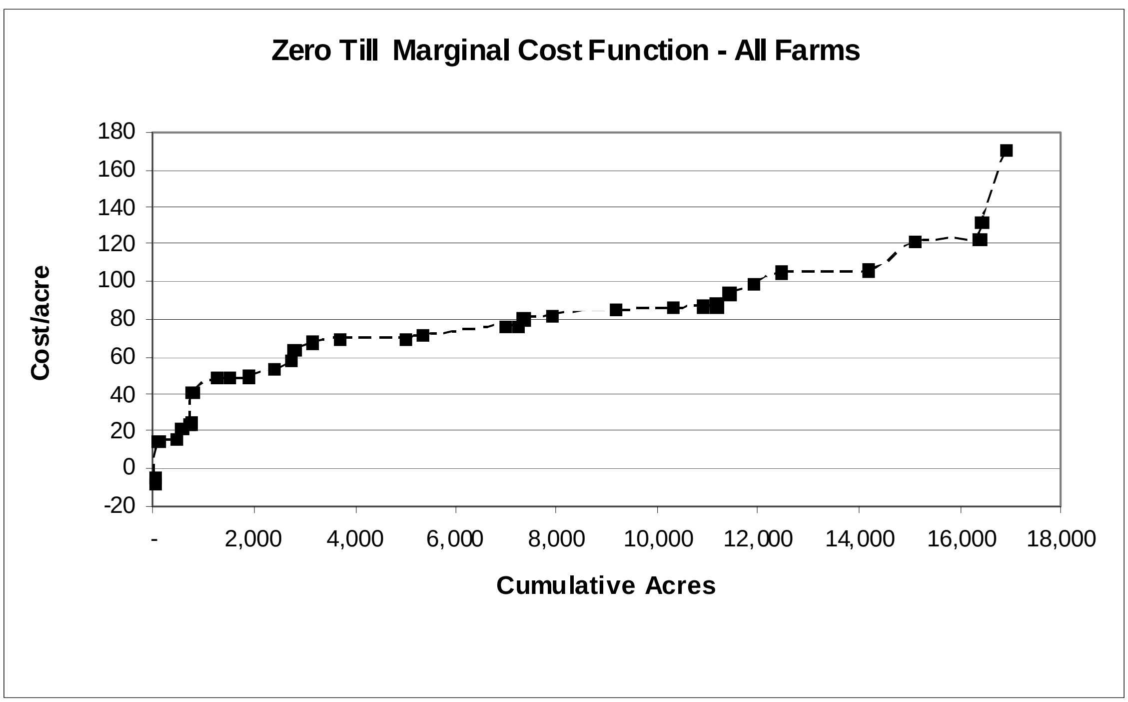

Figure 8. The marginal costs for adopting zero tillage for the 36 producers in South Tobacco Creek, Manitoba.

Zero tillage is often seen as a cost effective BMP. Our results, however, show that a policy directed at increasing the extent of adoption of zero tillage will be costly (Fig. 7). Over the 12 year horizon in the cost projection model, adopting zero tillage ranges from a benefit of $8.19/ac/12 years (approximately $0.70/ac/yr) to a cost of $170.39/ac/12 years (approximately $14.20/ac/yr). Zero till seems to benefit only two producers; all the other producers experience a reduction in net income. The zero-tillage marginal cost curve (Fig. 8) is an upward sloping convex curve exhibiting the desired properties of increasing marginal costs as less suitable lands are brought under conservation tillage. Note that the two producers who would enjoy increased revenues as a result of adopting this BMP exhibit negative marginal costs in Figure 8.

The regression results as well as personal communication with several producers in the watershed suggest that the agro-environmental context plays a large role in determining adoption of this BMP. In fact, zero tillage is not widely adopted in the STC watershed, and where it is being applied experimentally, producers indicated during an informal discussion that they would likely be abandoning the practice once the experiment was over. Reasons given included increased labor costs associated with moving equipment in poorly drained sites during planting season, and the need for larger farm sizes in order to reduce the average cost of equipment.

The Riparian Area Management BMP

Only six producers have riparian areas that could be brought into a riparian management BMP in STC.[29] Riparian management consists of costs of off-site watering of livestock, costs of fencing to keep livestock out of riparian areas, and opportunity costs of lost crop production in the riparian area.[30] The length of fence required was assumed to be equal to the perimeter of the riparian area. The cost per unit length of fence was assumed to be $2.11 per meter based on MAFRI (2007) cost of production estimates. An annual fencing maintenance cost of 2% per meter was assumed. Off-site water trough costs were obtained from MAFRI (2007) budgets. The costs were assumed to be $4000 per 150 cows, or $26.67 per cow. An annual trough

[29] Areas eligible for riparian area management were provided by Wanhong Yang (personal communication, September 2007).
[30] We assume that the riparian area is converted to natural vegetation in all cases, although it is possible that some of the area might be converted to forage instead.

maintenance cost of 2% was also applied. Finally the opportunity cost of lost crop income from the riparian area was calculated using the opportunity cost model. The riparian area was assumed to be as productive as the rest of the producer's fields. The opportunity cost is then equal to the average annual net cash income lost from not being able to grow the baseline crops under conventional tillage.

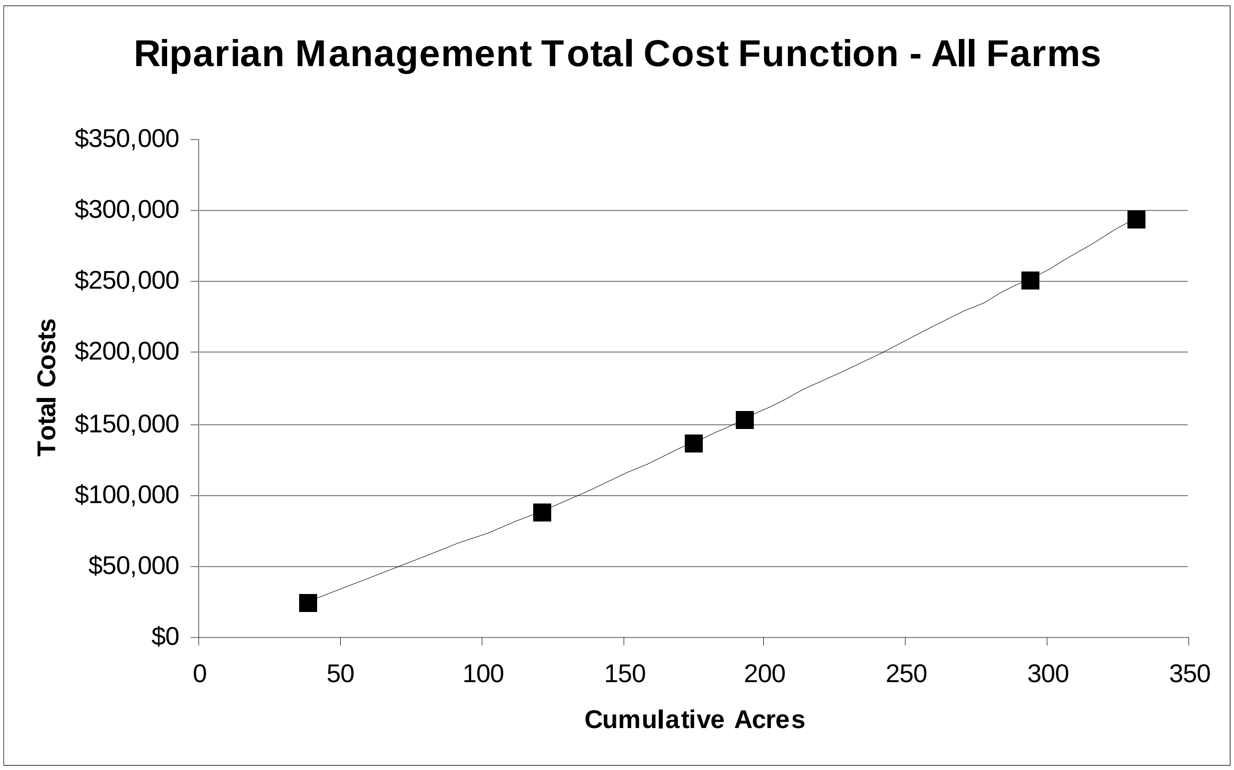

Figure 9. The total cost function for adopting riparian area management for the 6 producers in South Tobacco Creek, Manitoba.

The aggregated and 10-year BMP cost of each riparian area is shown in Figure 9. The graph shows the costs of increasing the number of areas under riparian management increases linearly, suggesting that fencing costs and off-site watering costs overwhelm the variability associated with lost farm income from not cropping the riparian area. The costs range from $16,603/field/10years for a 16 acre field to $98,000/field/10years for a 100 acre field. The linear shape of the cost function suggests that there is little heterogeneity between producers. The lack of heterogeneity suggests that riparian management is not a good candidate BMP for using an auction or price discovery mechanism. Instead payments based on observable fencing and watering trough costs should probably be considered.

The Forage Conversion BMP

Forage BMP adoption costs were assessed by converting fields not in a forage rotation to a forage rotation starting in the year 2007-2018. The regression models were used to project direct forage costs and revenues for the years the fields would be in forage, as well as yield boosts for crop rotations following after forage from 2007-18. The opportunity cost model was used to project lost income from the next best alternative crop.

Cost functions for the forage BMP are illustrated in Figures 10 and 11. This forage BMP is costly for every producer except one, with costs ranging from \$7/acre/10 years to \$608/acre/10 years. The cost relationships are similar in shape to the zero-tillage BMP in that it exhibits increasing marginal costs. Note however, that there is a large difference in the magnitude of costs under these two BMPs – enrolling all fields in forage costs over \$2.5 million relative to approximately \$1.6 million to convert all fields to zero tillage. This emphasizes the fact that the most cost effective pollution abatement strategy will depend on the relative environmental benefits generated by each of these practices.

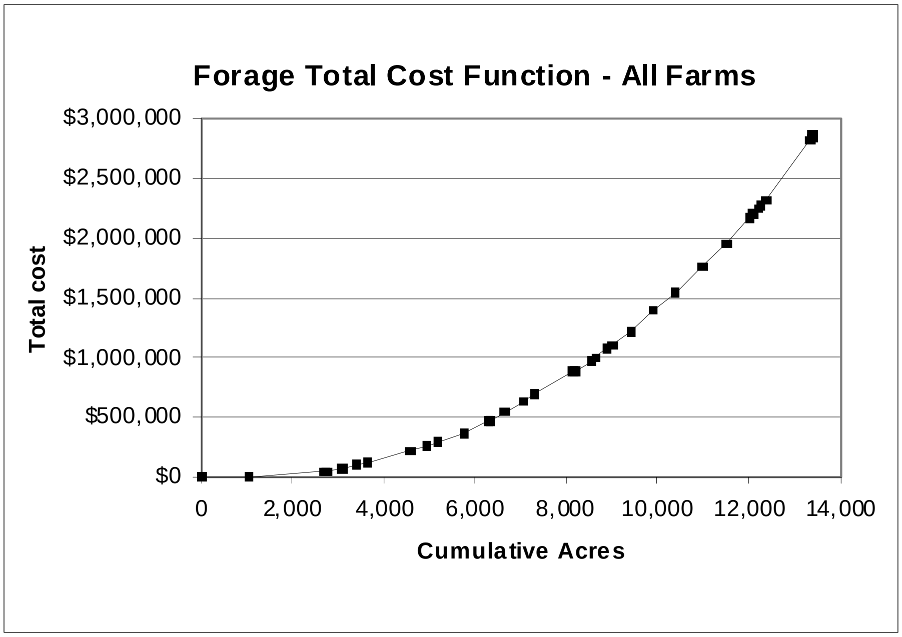

Figure 10. The total cost function for adopting the forage conversion BMP for the 36 producers in South Tobacco Creek, Manitoba.

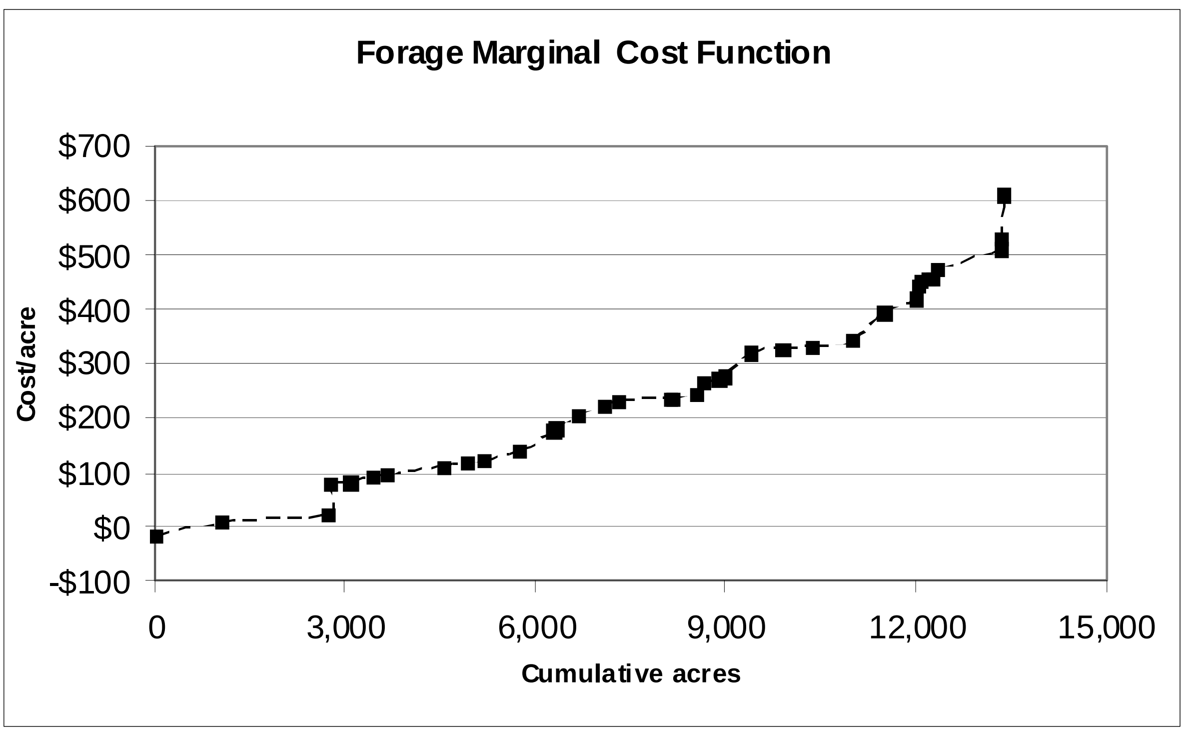

Figure 11. The marginal cost curve for adopting the forage conversion BMP for 36 producers in South Tobacco Creek, Manitoba.

The Holding Pond BMP

The estimation of the costs of constructing holding ponds started with identifying all the producers who held livestock in 2006. Based on discussions with AAFC staff it was determined that 12 producers had livestock and could consider adopting the holding pond BMP. The cattle yards for these producers were located in a GIS and suitable locations for the holding pond sites were identified based on drainage areas. This permitted the estimation of runoff quantities and this information along with the number of head of livestock determined the required volume of excavation of the holding pond. These estimates, derived by Jim Yarotski and colleagues, ranged from 41 to 3692 m^3 with an average volume of 1374.12 m^3.

Once each volume was determined, we developed an estimate of the cost per cubic metre to excavate the pond using information from the costs of the one existing holding pond constructed with assistance of AAFC staff on the Steppler Farm. This holding pond was 1750 m^3 and cost $11,935.63 to construct; which yielded an estimated $6.82/m3 for holding pond construction.

We note that in our cost estimates we omitted the costs associated with the annual removal of water and associated nutrients and other water borne material from these ponds. This may be a significant expense to producers (Turner, 2008). Little research to date has been conducted in methods that could be used to deal with this removal, so we left this cost out of our estimates. Despite its possible economic significance, however, we note that this extra cost would be a function of the volume of each pond and its inclusion in the total cost function would only serve to shift the cost function upwards in a similar manner for each producer. Thus, the relative differences in the costs of the ponds would be the same with and without water removal costs.

Figure 12 displays the total cost function for adopting the holding pond BMP for the 12 producers in STC. This function clearly identifies two groups of producers – one consisting of six “low-cost” adopters and another group of six “high-cost” producers. These two groups are also identified in the marginal cost function (Figure 13) which displays the cost per head associated with the adoption of this BMP by the 12 relevant producers.

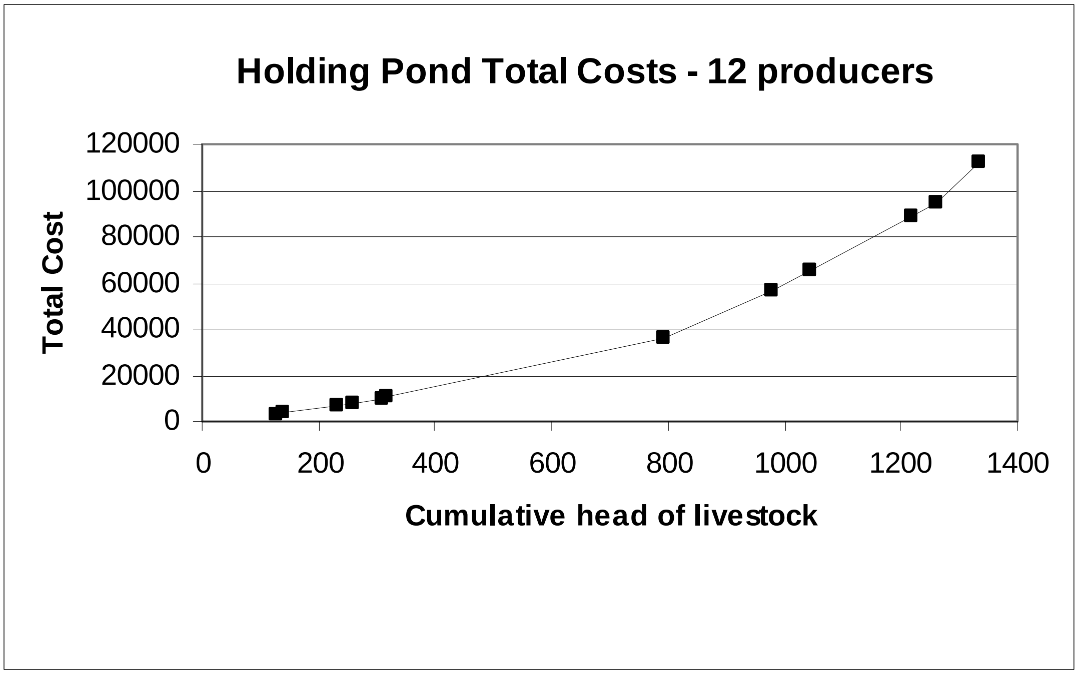

Figure 12. The total cost function for adopting the holding pond BMP for 12 producers in South Tobacco Creek, Manitoba.

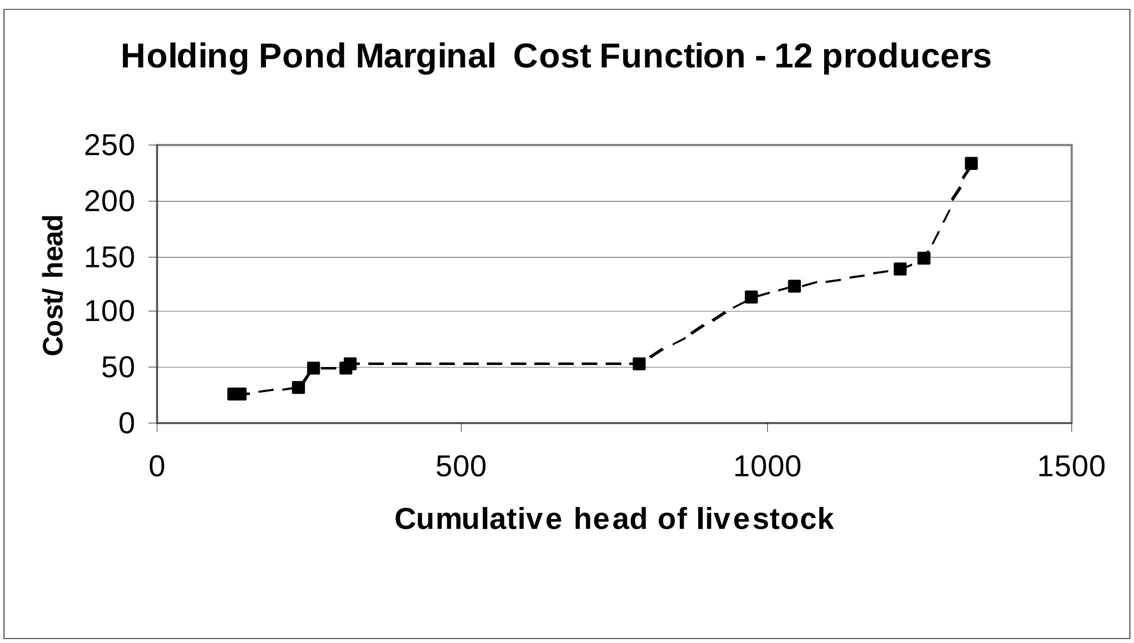

Figure 13. The marginal cost function for adopting the holding pond BMP for 12 producers in South Tobacco Creek, Manitoba.

Discussion

These estimated adoption cost functions are among the first we have seen at the watershed level in Canada for BMPs. Each of these cost functions can be used in different policy scenarios. For example, the total cost functions examine the total costs of adoption in this Manitoba watershed and identify where each producer lies on the curve. Thus, for the holding pond BMP the cheapest pond is associated with the producer closest to the origin of the graph. Given any fixed incentive budget that is intended to meet the full costs of adoption for each producer should start with the most inexpensive producer and work up to more expensive ones until the total incentive payments equal the existing budget. We note that for this BMP, the first 6 producers would require a total payment of close to $20,000 to fully cover the costs of excavation.

The marginal cost functions denote the economic supply relationships inherent in these BMPs. In essence these cost functions estimate the costs borne by producers to supply the public with BMP "services". The information presented above, however, conducts this supply analysis using the unit of agricultural production (acres or head of livestock). While these relationships may be interesting it must be pointed out that the underlying reasons for the public to provide incentives for producers to adopt these practices is to reduce pollution associated with agricultural practices. Whether the costs per unit of agricultural production match with the supply of pollution abatement services is an open question to which we now turn.

Watershed Level Cost Relationships

The main disadvantage of performance based policy design is that it is difficult to know the environmental benefit a BMP will have on a specific parcel of land unless spatially explicit analysis had been conducted *ex-ante*. This has made it more convenient to use practice based policy instruments. Spatial targeting of agri-environment policy can tie practices to environmental improvements and therefore improve the cost-effectiveness of an agri-envrionmental payments program. For example, Westra (2003) used a complex integrated environmental-economic model to capture the heterogeneity of agricultural systems and regional differences within a watershed. The analysis concluded that significant cost-savings can be achieved in reducing non-point pollution by targeting BMPs to specific regions of a watershed. Eigenraam et al. (2007) also develop a model to identify the environmental benefits of BMPs on specific parcels of land for their Eco-Tender pilot program in Australia.

We were able to conduct preliminary analysis of abatement costs for the holding pond BMP. These were based upon linking the holding pond locations with the hydrologic model for South Tobacco Creek developed by Dr. Yang's research group at University of Guelph. This hydrologic model develops estimates of abatement of phosphorus, nitrogen and sediment from the cattle yard runoff for each producer. The procedures used to develop the abatement cost function for this BMP are similar to those described above. The cost per kg abated for each pollutant was estimated, and functions were developed starting with the cheapest per kg abatement level followed by the next and so on.

Typically, these abatement cost functions are developed using an environmental benefits index approach (EBI). This index allows researchers to include all sources of pollution or other environmental services in one metric. Essentially the pollutants must be weighted according to their relative importance as an externality. In discussions with Jim Yarotski and other WEBs managers, it was pointed our that phosphorus abatement is of high interest in Manitoba due to excessive nutrients being added to Lake Winnipeg from agricultural production in various watersheds and also from other sectors such as municipal wastes. Further communication with experts from Environment Canada (Dr. Jane Elliot[31]) yielded a suggestion that for the province of Manitoba the relative importance as a percentage for each pollutant as an impact was phosphorus 45%, nitrogen 35% and sediment reduction 20%. In other words phosphorus reduction is of the highest importance, followed by nitrogen, then sediment. Dr. Elliot also suggested secondary weighting criteria that could be considered because the three pollutants are found in different relative concentrations in the environment. This would suggest that the amounts required to have an impact on the environment varies. She used water monitoring data from 1993 to 2001 in South Tobacco Creek to propose that reducing phosphorus by 1 kg one must reduce nitrogen by 5 kg and sediment by 150 kg.

This information is provided in this report to show that the construction of an EBI in the STC watershed seems to be possible, but that water quality experts must be engaged in this exercise. We add that other environmental services could be considered, such as wildlife or fish habitat. This could be important, for example, with the riparian area management BMP and other BMPs involving wetlands. We point out that in economic considerations of BMP adoption and possible incentives, it is important to include all of the possible environmental services provided by adoption of BMPs.

In the case of holding ponds in this study the hydrologic estimates of abatement of the three pollutants suggested that their levels of reduction were close to being linear transformations of each other. Thus, considering phosphorus reduction alone also achieves similar relative abatements levels of nitrogen and sediment in the watershed.

We develop this abatement cost relationship for phosphorus only in Figure 14. It is noteworthy that in comparison to the marginal cost curve for livestock (Fig. 13), the pattern of producers along the curve is quite different. There is a marked difference in the dispersion of producers along the curve in Figure 13 when compared to the curve in Figure 13. This is a result of differences in drainage runoff as well as livestock numbers. The result of this is a greater degree of heterogeneity in the costs per unit abatement over the costs per head of livestock.

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[31] This information arose in email correspondence between Jim Yarotski and Jane Elliot in December 2007 upon request of the senior author of this report.

Ignoring this heterogeneity and basing incentive policies on livestock or the total costs of adoption, would ignore the important contributions that each producer could make towards overall abatement in the watershed. These contributions are related to the physical features of the farm landscape as well as the different production practices and operations on each farm. For this BMP the function is quite flat. This suggests that while levels of phosphorus abatement may be quite different among the 12 farms, the costs of abating these phosphorus amounts lie in a fairly narrow range.

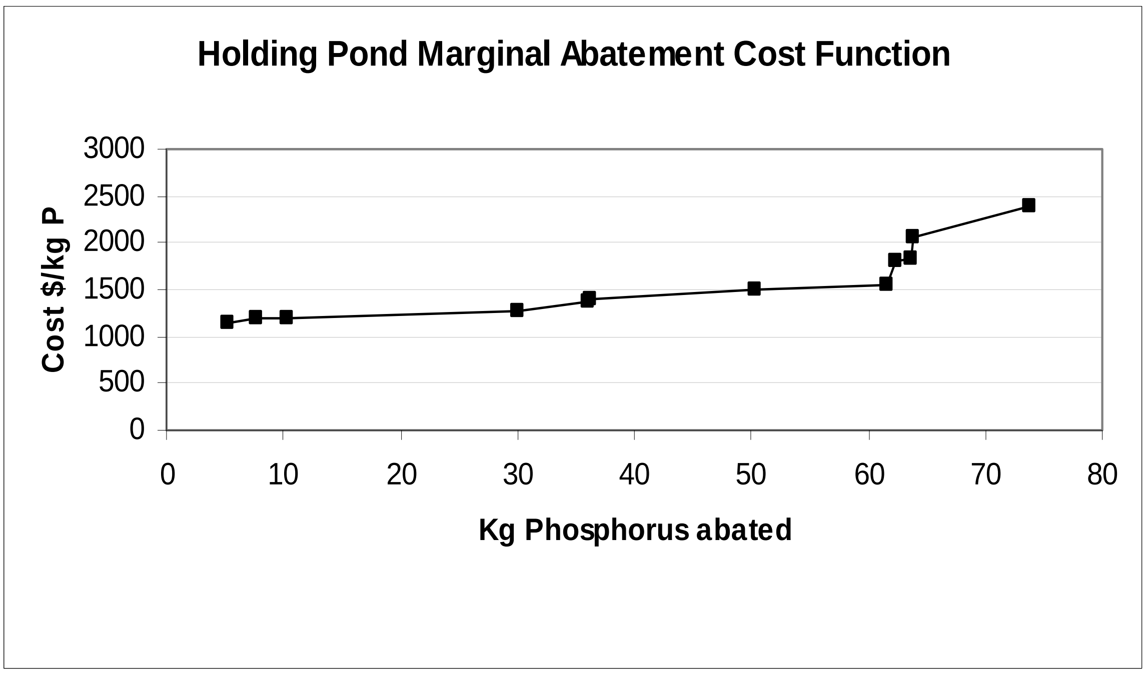


Figure 14. The marginal abatement of phosphorus cost function associated with adopting the holding pond BMP for 12 producers in South Tobacco Creek, Manitoba.

In order to illustrate these features of abatement for holding ponds in the watershed we display the phosphorus abatement levels and the cost per unit abatement for each of the 12 producers in Table 13. This information clearly shows that the highest abatement level for a single producer (ID 50, 19.62kg P) is not the most expensive – rather a holding pond on this producer's property is the fourth cheapest. Thus, the distribution of the producers along the marginal abatement cost curve (Fig. 14) is completely different than that for the marginal costs per head of livestock (Fig. 13). To further suggest the utility of this information, if we had an adoption budget of $25,179 to provide incentives to abate phosphorus using this BMP we could not find a combination of producers among the 12 that could collectively abate more than this one producer for the same costs.

Unfortunately abatement levels are not available yet for the other BMPs so we cannot construct these environmental-economic relationships for zero-till, forage conversion and riparian area management. When this information becomes available these relationships can be constructed for each BMP as well as for all four BMPs collectively. The marginal abatement costs functions over all BMPs collectively should be a goal of any future study in this watershed.

Table 13. An illustration of the differences in the costs of phosphorus abatement in comparison to other adoption parameters in South Tobacco Creek, Manitoba.

Farm ID	P($/ton)	P(kg)	Cost/head	Total Cost
33	$1,146	5.27	$147	$6,043
16	$1,189	2.46	$31	$2,919
26	$1,196	2.64	$25	$3,151
50	$1,283	19.62	$53	$25,179
40	$1,383	6.04	$123	$8,361
47	$1,387	0.3	$53	$423
49	$1,489	14.07	$113	$20,951
4	$1,558	11.19	$233	$17,439
62	$1,794	0.71	$47	$1,282
58	$1,832	1.33	$48	$2,435
43	$2,053	0.14	$25	$280
34	$2,382	10.07	$138	$24,000

Adoption of BMPs under Conservation Auction Policies

Greencover and other conservation programs like APF implemented by AAFC implement a practice based payment that is essentially a flat payment structure with little room to negotiate with landowners over the total amounts payable. While the flat payment structure suffers all the disadvantages of the practice based program when constrained by a fixed budget, it also has higher adverse selection problems where lands that provide low quality environmental benefits drive lands with high quality environmental benefits out of the market.

One choice is to compensate landowners based on the level of the costs they face for generating environmental improvements by making them reveal their cost using auctions. Compensating them based on costs allows the policy maker to offer farmers the chance to make bids on how cost-effectively they can provide a unit of ecological good or service, and use this information to select them. Such auctions make allocation of public funds more cost-effective/efficient. The buyer in these auctions, typically the government, can use indicators of the environmental benefits attached to each land (such as in the US CRP or Australian Bush Tender) so that the public can purchase environmental goods or pollution abatement from those lands that provide the most environmental benefit at the least cost (as budget is usually constrained), or the greatest level of mitigation, or provide the land owner with the least profit/rent.

The design of efficient auctions typically takes place in laboratories/ auction test beds. This approach to design was initially suggested and explored by Charles Plott who used economic laboratories to design market based policy instruments for providing rights to private firms to use airwaves for personal communication devices such as cell phones (Plott 1994). In an environmental context these experiments require information on the distribution of the environmental benefits and the costs associated with producing them. The benefits are spatially distributed based on geophysical factors like soils, weather, slope and proximity to the watershed, while the same factors as well as management choices are factors underpinning cost distributions. The cost curves show the combined marginal cost of water quality improvements borne by all the producers in the watershed. In reality these costs would not be known by the buyer/government. However, in an economic experimental laboratory the experimenter can use the distribution of on-farm cost estimates to approximate this function. These 'actual' costs then become the baseline used to compare the performance of various policy scenarios that are obtained by altering the design features of the contract. This on farm cost study attempts to find these 'actual' costs of the relevant BMPs that become the baseline discussed.

Current policies for adoption of Beneficial Management Practices in STC

A significant policy contribution to generating environmental improvements in Canada's agricultural landscapes is the adoption of beneficial management practices. These BMPs are agricultural production practices that "minimize and mitigate impacts and risks to the environment, by maintaining or improving the quality of soil, water, air and biodiversity; ensure the long term health and sustainability of natural resources used for agricultural production; and support the long-term economic and environmental viability of the agriculture industry," (reference)

Operating through Canada's National Environmental Farm Planning Initiative, the National Farm Stewardship Program (NFSP) provides technical and financial assistance to producers and land managers to support the adoption of BMPs. In Manitoba the delivery of this program is through the *Farm Stewardship Association of Manitoba* (FSAM). Producers eligible for financial support must have an Environmental Farm Plan which is an environmental assessment of their farm operation outlining potential risks and benefits of their operation and the formation of an action plan to mitigate any associated agri-environmental risks. These EFPs are voluntary, anonymous, and in most cases self-administered. While there may be very good reasons for volunteerism, anonymity and self administration, these features of the policy has made it difficult for researchers to understand the regional needs for uptake of BMPs and the actual levels of adoption of individual BMPs in geographic locales (e.g. watersheds).

This program is essentially a voluntary initiative for the adoption of BMPs. The eligible payments for adoption do not represent the full costs of adoption, but are only partial costs ranging from 30-50% up to some maximum amount. As we will show this financial support falls short of the estimated costs of adoption for the majority of producers in STC. Thus, given the government's budget for BMP adoption one could expect few producers in STC to adopt BMPs and hence access these NFS payments.

We utilize the NFSP payment amounts for the 36 producers in STC as the budget to be used to provide water quality improvement services in the watershed. Given that we are examining four BMPs, the associated NFSP BMPs were matched and the potential incentive payments were calculated. These BMPs and payments are shown below:

1. STC BMP Run-off Holding Pond was deemed similar to the NFSP BMP 5: Farmyard Runoff Control. The payments for eligible producers are 50% cost share to a maximum amount of $20,000.

2. STC BMP Zero-till was similar to the NFSP BMP 14: Improved Cropping Systems. Here the payments are 30% of producer costs up to a maximum amount of $15,000 per producer.

3. STC BMP Riparian Area Management was similar to the NFSP BMP 10: Riparian Area Management. Here the payments are 50% of costs up to a maximum amount of $20,000 per producer.

4. STC Forage Conversion. This BMP was difficult to match to a NFSP BMP. Hence we used the payments from a different program covered under Greencover Canada (see http://www.agr.gc.ca/env/greencover-verdir/conv_e.phtml).[32] This payment program involves two one-time payments. The first is $20/acre for seeding or planting tame forage or trees and signing a Contribution and Land-Use Agreement, or $75 per acre for seeding native species and signing a Contribution and Land-Use Agreement. The second involves an additional $25/acre payment after perennial cover is established and Greencover Canada staff inspects and issues a Certificate of Stand Establishment.

Utilizing this budgetary information and determining the number of producers in the STC watershed that could adopt these BMPs, we developed estimates of the funding available to provide financial incentives to these producers. This information is summarized in Table 14 and suggests that the incentive payments are not large enough to provide the funding necessary to meet the total costs if every producer in STC adopted one of the four BMPs. Note that since the

[32] Note that this program has since been discontinued.

NFS program only pays a portion of the costs for any one individual producer, based on our estimates of the individual producer costs of adoption the funds are not enough to pay for BMP adoption for any BMP for any producer in the watershed. Scarcity of financial resources to meet producer costs could be one of the reasons why few of the BMPs under examination are adopted in this watershed.

Table 14 . A summary of the number of affected producers in the South Tobacco Creek Watershed and estimates of the total costs of adoption and budget available for four beneficial management practices.

BMP	**Number of affected producers in STC**	**Estimated total costs of 100% adoption over 10 years**	**Available Budget (NFS Payments)**	**Estimated reduction of pollutants with 100% adoption**
Riparian area management[1]	6	$294,884	$100,434	P – 69.9 kg N – 275 kg Sediment – 55.1 t
Holding ponds[2]	12	$112,462	$56,231 (~$57/head)	P –73.85 kg N – 416.26 kg Sediment – 28.47 t
Zero-till	36	$1,444,175	$433,253 (~$94/acre)	Not yet available
Forage conversion	36	$2,860,727	$858,218 (~$62/acre)	Not yet available

[1] Riparian areas only fall within the farms of 6 producers in the watershed

[2] Only 12 of the 36 producer have livestock in 2006 and would be eligible for constructing a holding pond.

These observations led us to suggest auctions as a potential vehicle to promote BMP adoption (see also Weber and Boxall 2007). This policy instrument, as noted above, involves taking the existing government NFS budget that would be allocated for NFS payments in STC and allows the producers to compete for it in a bidding process. The remainder of this report outlines how we set this up in an experimental economics laboratory and provides some of the findings of this preliminary research.

Examination of the Potential for Auctions to Induce Adoption and Increase Levels of Pollution Abatement: The Design of the STC BMP Auctions

In establishing our laboratory auction testbeds we were heavily influenced by the research reported by Cason et al. (2003) and Cason and Gangadharan (2005) (hereafter called the Cason group) who utilized auctions to examine BMP adoption in watersheds in Australia. Similar to this Australian research we utilized students as subjects – in our case from a pool of largely undergraduate students recruited from the University of Alberta we created using ORSEE software (Greiner 2004). Each experiment in this current phase of the STC research involved an auction for one specific BMP. Since we first had information on the holding pond BMP in the initial stages of this research, the experimental design was tailored to study this BMP. This meant that each experiment had 12 subjects as there were 12 producers in STC who should consider adopting this BMP.

Subjects made sealed-offers for payments to adopt the holding pond BMP based on different costs and qualities. The Cason group's research imposed heterogeneity on costs and quality by randomly drawing costs and environmental benefits for each BMP (called land use change in their research papers) independently for each seller each period. In this STC research we had detailed cost information for each producer in the watershed as discussed above, as well as environmental benefit information for each producer with and without BMP adoption. This environmental benefit information involved estimates of the abatement of phosphorus, nitrogen and sediment generated from the hydrologic model developed by Dr. Wanhong Yang's research group. This knowledge of the costs and environmental benefits allowed us to exploit the actual heterogeneity found in STC across the subjects in the experiment. This is similar in spirit to Tisdell's (2007) approach of bringing biophysical models into the economic laboratory. Thus, in the holding pond experiments each subject represented one of the 12 actual producers in the watershed and the farms differed by their associated costs of adoption and pollution abatement levels.

These procedures differed slightly for the other BMP auctions we ran. For forage conversion and zero-till essentially all 36 producers in the watershed would be eligible for payments under the NFS program. Conducting experiments with 36 subjects would be difficult;

hence we constrained the participation levels in these two BMP auctions to 12 subjects. To capture the heterogeneity in costs among the producers for these two BMPs, we drew farms from the 36 to represent the cost functions shown in Figures 6 and 9. Table 15 shows the costs for each of the 12 subjects in the three BMP experiments.

Table 15. A summary of the costs of adoption for each of the three BMPs examined for 12 representative farms in the experimental economics laboratory.

Subjects	**Holding Pond**			**Zero till**			**Forage Conversion**		
	Farm ID[1]	Total Cost ($)	Cost/head	Farm ID	Total Cost ($)	Cost/acre	Farm ID	Total Cost ($)	Cost/acre
1	43	280	25	49	6486	6.2	26	5,736	15.8
2	26	3,151	25	62	26,031	79.3	52	2,033	40.5
3	16	2,919	31	51	43,607	115.8	4	11,956	48.5
4	62	1,282	47	34	93,691	175.0	34	28,505	53.3
5	58	2,435	48	50	88,164	218.1	44	36,211	69.0
6	47	423	53	43	9,318	233.8	32	124,591	76.2
7	50	25,179	53	21	89,384	241.0	24	46,424	82.3
8	49	20,951	113	16	23,706	273.0	49	98,713	86.0
9	40	8,361	123	44	210,742	339.4	41	22,978	87.1
10	34	24,000	138	32	212,355	416.7	47	183,532	105.8
11	33	6,043	147	36	50,177	474.1	33	155,035	121.9
12	4	17,439	233	9	18,968	608.5	9	4,107	131.8

[1]This relates the costs back to the actual farms in the Deerwood Association data. Note that for zero-till and forage conversion these 12 farms are draws from the 36 farms that represent the distribution of costs in the cost functions derived in the previous chapter.

An important issue in these experiments is the information about the farms available to each subject. Cason et al (2003) found that revealing the levels of the environmental improvements associated with each auction participant resulted in offers that misrepresented the costs of adoption more for “high quality” (in terms of abatement potential) farms. This resulted in lower abatement levels and high seller profits than similar trials in an absence of this environmental information. Thus, as with Cason and Gangadharan (2005) we did not reveal abatement levels associated with each farm in our experiments. We also did not reveal to our subjects any information about other subjects’ costs.

In the Cason group’s auctions (and indeed other auctions such as the CRP and Bushtender) offers provided by bidders were ranked according to their contribution to improving environmental quality. Some of these are measured using indices which assess multiple contributions towards environmental improvements and hence the term Environmental Benefits Index (EBI) is a common term used to describe the assessments. Thus, a common offer ranking approach in these environmental auctions to date has been to maximize EBI (called max EBI below).

In our STC auctions we were able to develop estimates of abatement associated with adoption of the holding pond BMP at each of the 12 farms. This information was not available for the other BMPs from Dr. Yang's hydrologic model. Thus, we were able to follow the max EBI offer-ranking strategy with this BMP. However, in this WEBs research we also examined two other offer-ranking strategies. The first was to select offers based on a strategy to maximize participation of producers in the auction (labeled max participation), or in other words to select offers that provide the greatest numbers of winners in the auction. The reason this strategy was examined is that participation in farm environmental programs seems to be a commonly reported goal in Canadian agri-environmental policy (e.g. Alberta Environmental Farm Plan Company 2007; and see http://www.agr.gc.ca/acaaf/card/cardsuccessstories_regional_e.html).

The second offer ranking strategy examined involved maximizing the number of head of cattle or number of acres included in the adoption of the BMP. This strategy, called max coverage, was chosen to see how well it could approximate the abatement levels associated with the max EBI approach. Given that a significant level of information and analysis is required to develop estimates of pollution abatement for producers in each watershed in Canada, we decided to examine a strategy that could approximate the max EBI approach for those watersheds that had little hydrologic information. While the max EBI strategy could possibly be the best in terms of pollution abatement, we feel that very few watersheds in Canada would have the information necessary to attempt this procedure.

There are two pricing rules typically used in procurement auctions. The most common is the discriminative-price auction in which winning bidders receive the value of their actual offers as payments. In this pricing format the seller earns no surplus (profits) if he/she submits an offer equal to their opportunity costs of adopting the BMP. Thus, there exists an incentive to inflate their offers above their costs. In formulating their offers, producers would trade off gains from winning with an inflated offer to the risks of not winning a contract with an inflated offer (losing a contract to a competitor).

The second pricing rule is the uniform-price auction in which all winners receive the same price. Typically this price is determined by the lowest rejected offer. In this pricing approach inflating one's offer serves to decrease the probability of winning because it does not change the payment received. Thus, there is no tradeoff between winning with an inflated offer and losing to a competitor. The draw-back with this pricing rule is that the buyer is guaranteed to pay winning producers prices that are higher than their opportunity costs.

Ferraro (2008) notes that there is not sound theoretical guidance on which pricing rule to use and points out that experiments and agent based models have been employed to examine the implications of the two rules. McKee and Berrens (2001) and Cason and Gangadharan (2005) found that discriminative actions are less costly to the agency than uniform-price auctions for a given environmental objective. Others have employed formats that allow learning by bidders and have achieved opposite conclusions. Because of the lack of sound guidance in choice of the pricing rule, we employed both in our BMP auctions in order to compare outcomes both on environmental outcomes and economic efficiency metrics.

Given the three offer-ranking strategies and the two pricing rules, this leads to a 3 X 2 experimental design for each auction. In this initial research we develop auctions for each BMP separately. Hence, the full design with <u>one repetition</u> involves six separate experiments or treatments. Since it is difficult to generate sound conclusions from experiments with one repetition, we employed multiple repetitions and report measures of central tendency and dispersion of offers for each treatment.

Each experiment involved 12 subjects who submitted sealed offers in each of 15 periods. Prior to the beginning of each experiment subjects viewed a Powerpoint presentation which outlined the rules and procedures of the auction. Subjects were informed that the experimenter purchases the lowest priced items per unit of environmental quality, or head/acres for the max

EBI and max coverage ranking rules respectively. For the max participation ranking strategy subjects were told that the experimenter would order the offers by the total offer price and the budget will be spent on offers from the lowest upward until all the funds were spent. Subjects were not allowed to communicate with each other to reduce opportunities for collusion.

Offers were submitted on computers using the ZTREE experimental economic software system (Fischbacher 2007). Subjects could not see other subjects' offers (hence sealed offers). In each of the 15 periods, the offers were collected by the software system and were sorted and ranked according to the ranking strategy employed. Offers were then purchased up until the budget was exhausted or the environmental target was reached. Once this was done the results were reported to the subjects electronically on their computers. The next period then started. This continued until 15 periods had elapsed. These procedures were followed in every experiment conducted using the budget based auction goal.

During the experiments each round was set using the software to be 1 minute. The average length of each session length was approximately 45-50 minutes, including reading the instructions and determining payments to each subject. For simplicity the producer revenues and costs were presented to the subjects as in smaller scale units so that they could understand their take-home payments. We converted each $1,000 in "real" costs to $1 in the experiment. Thus, every additional experimental dollar the subjects' farms generated the student took $0.10 home. Subjects earned between $15 - $35 a session, with an average per subject payment of $23.

In the next section we report results from about 25 experiments. The treatments employed in these experiments are summarized in Table 16. Note that given time constraints only two replications were possible for most treatments. Thus, the results reported should be treated as preliminary. We plan to add more (to a maximum of three) in future research. We also conducted other auctions that we do not report results for. These auctions served as pilots to test our experimental procedures and the software or involved issues such as computer failures and the results had to be discarded. In all we conducted about 35 experimental auctions, 32 with students and 3 with a sample of producers and others in the STC watershed.

Table 16. A summary of the experiments conducted using students under various experimental design treatments.

Auction Goal	Offer Ranking Rule	Number of sessions		
		BMP		
		Holding Pond	Zero-till	Forage Conversion
Budget based	Max Participation	2 Uniform [a] 2 Discriminative [b]		
	Max Coverage	2 Uniform 2 Discriminative	2 Uniform 2 Discriminative	2 Uniform 1 Discriminative
	Max EBI	2 Uniform 2 Discriminative		
Target based	Max Participation			
	Max Coverage	2 Uniform 0 Discriminative		
	Max EBI	2 Uniform 2 Discriminative		

[a] Pricing rule treatment where "winning" bidders are paid the amount offered by the highest "losing" bidder.
[b] Pricing rule treatment where "winning" bidders are paid the amounts they actually offered.

Results and Discussion

Expected Results

We report results for the experimental auction using several measures. The first is economic efficiency which is the cost of abatement per unit of pollution. We had information for the holding pond BMP so were able to calculate this measure for all treatments employed. We could not do this for the zero till and forage conversion BMPs, but hope to in the future. Dr. Yang's hydrologic model provided abatement levels of phosphorus, nitrogen and sediment. We noted that for the holding pond BMP these pollutants were highly correlated and linearly related. So we present the efficiency measures in cost per kg of phosphorus abated since phosphorus is a pollutant of significant interest in Manitoba.[33]

We also report on the efficiency of the auction in terms of the total amount paid to winning bidders. This includes the portion of the budget spent and the amount of total payments

[33] This was also mentioned to us in meetings with WEBs management staff in Edmonton in August 2007.

that were greater than costs of adoption for the winners. We call this surplus over costs rent, as this is the term used to describe this in the economic literature.

In order to compare auction results we developed a set of “expected” or base-line results which essentially rely on the subjects bidding their costs. We utilized a procedure called the “greedy algorithm” to develop these expected findings. This approach takes pricing and offer-ranking rules and selects winners (who bid their costs) in each auction until the budget is exhausted. This allows us to determine who “should” win the auction and how much of the budget would be spent assuming that subjects submit offers equal to their costs of adoption.

Figure 15 summarizes some of these results for the holding pond BMP. The first histogram shows that under the max participation strategy more producers would “win” the auction – the max EBI approach would result in fewer winners than either of the other two ranking strategies. However, max EBI would be expected to perform the best at phosphorus abatement as shown in the second histogram in the top row. The bottom row shows two histograms that summarize budget outlays and the portions of this outlay that is expected to be rent. The max participation strategy with the uniform price rule has the highest portion of rent. Indeed as predicted under the uniform pricing rule, a considerable portion of the total payment under any offer-ranking approach examined is rent. Rent is nor predicted to be collected by winners under the expected discriminative pricing rule as the greedy algorithm assumes that subjects would bid their costs. The experiments will “real” subjects will show whether this assumption is realized.

Experimental Results

Tables 17 to 19 display results of the experimental auction along with the expected results for the holding pond BMP under the max participation, max coverage and max EBI ranking strategies for both pricing rules. Note that in each cell the result represents the average result of two trials for each offer-ranking strategy. To facilitate the discussion of this information, we construct figures of several salient features from the tables to compare the results.

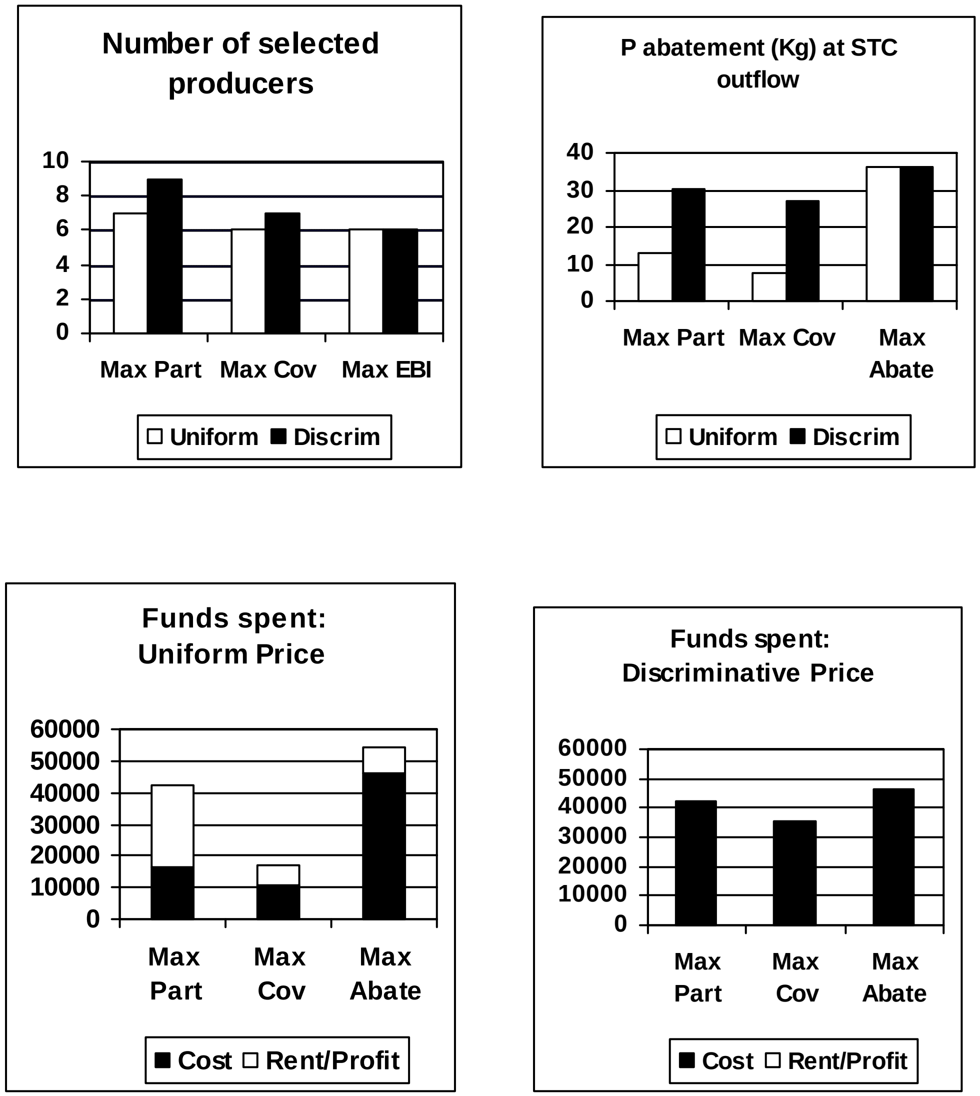


Figure 15. Summaries of various expected outputs for the holding pond auctions using the greedy algorithm.

Table 17. Results for the holding Pond BMP under the maximum participation of producers offer ranking strategy.

MAXIMUM PARTICIPATION OF PRODUCERS[1]

Measures	Uniform Payment				Discriminative Payment			
	Expected	Experiment Rounds			Expected	Experiment Rounds		
		1-5	6-10	11-15		1-5	6-10	11-15
Number of farms	7	6.7	6.8	7.2	9	5.6	5.0	5.1
Number of head	359	481	434	450	502	416	337	412
Budget expended ($)	42,298	50,348	49,914	50,224	42,332	48,063	47,386	50,769
Rent ($)	25,766	20,441	24,904	21,501	0	20,042	24,621	23,437
Payment/farm min ($)	6,043	7,581	7,203	6,985	280	3,590	4,918	7,222
Payment/farm max ($)	6,043	7,581	7,203	6,985	17,439	14,763	12,012	11,371
Payment/farm average ($)	6,043	7,581	7,203	6,985	4,704	8,704	9,622	9,969
Payment/head min ($)	48	49	50	49	25	44	73	74
Payment/head max ($)	755	861	900	873	233	1,183	1,021	817
Payment/head average ($)	118	125	130	126	84	133	164	156
Phosphorus abated (kg)	12.85	21.69	17.31	21.36	30.08	20.62	17.30	20.36
Cost P abated ($/kg)	3,293	2,321	2,883	2,351	1,407	2,331	2,740	2,494

[1] Note that each number is the average of two experimental trials.

Table 18. Results for the holding Pond BMP under the maximum coverage of livestock offer ranking strategy.

MAXIMUM COVERAGE OF THE RELEVANT AGRICULTURAL UNIT OF PRODUCTION[1]

Measures	Uniform Payment				Discriminative Payment			
	Expected	Experiment Rounds			Expected	Experiment Rounds		
		1-5	6-10	11-15		1-5	6-10	11-15
Number of farms	6	4.9	6.4	6.6	7	4.3	3.5	4.3
Number of head	318	572	639	741	793	673	550	510
Budget expended ($)	16,857	39,899	40,959	46,204	35,689	50,680	36,337	39,569
Rent ($)	6,368	2,394	1,877	10,059	0	15,289	11,954	17,621
Payment/farm min ($)	424	2,164	785	518	280	1,756	3,697	1,291
Payment/farm max ($)	6,732	20,118	20,343	27,812	25,179	33,765	27,861	26,238
Payment/farm average ($)	2,810	8,609	6,519	7,052	5,096	12,270	11,977	10,515
Payment/head min ($)	53	74	66	62	25	55	67	68
Payment/head max ($)	53	74	66	62	53	103	85	81
Payment/head average ($)	53	74	66	62	45	76	74	77
Phosphorus abated (kg)	7.58	25.21	25.92	27.79	27.19	27.52	21.26	17.05
Cost P abated ($/kg)	2,225	1,583	1,580	1,662	1,312	1,842	1,709	2,320

[1] Note that each number is the average of two experimental trials.

Table 19. Results for the holding Pond BMP under the maximum abatement of phosphorus offer ranking strategy.

MAXIMUM COVERAGE OF THE ENVIRONMENTAL EXTERNALITY (PHOSPHORUS) COMING FROM PRODUCTION[1]

Measures	Uniform Payment				Discriminative Payment			
	Expected	Experiment Rounds			Expected	Experiment Rounds		
		1-5	6-10	11-15		1-5	6-10	11-15
Number of farms	6	5.0	6.2	6.6	6	4.1	3.6	4.4
Number of head	813	669	702	795	813	485	601	551
Budget expended ($)	54,101	43,192	43,711	50,798	46,076	45,663	43,885	48,436
Rent ($)	8,025	-4,953	2,138	2,025	0	3195	3,634	1,672
Payment/farm min ($)	454	1,531	209	237	423	2,639	5,991	3,552
Payment/farm max ($)	29,216	21,615	24,773	26,323	25,179	24,635	28,573	24,770
Payment/farm average ($)	9,017	9,006	7,440	7,742	7,679	11,858	14,772	12,215
Payment/head min ($)	31	23	18	20	25	39	40	48
Payment/head max ($)	191	173	179	183	147	204	188	204
Payment/head average ($)	67	68	66	65	57	100	79	91
Phosphorus abated (kg)	36.33	35.04	33.45	36.75	36.33	29.14	31.00	31.61
Cost P abated ($/kg)	1,489	1,233	1,307	1,382	1,268	1,567	1,416	1,532

[1] Note that each number is the average of two experimental trials.

Figure 16 shows the levels of phosphorus abatement for each pricing rule and offer-ranking strategy. These relationships are plotted relative to their expected abatement performance once the BMP was linked to the hydrologic model and abatement levels could be assessed for each farm individually. The figure shows that the predicted abatement amount from the experiments for the maximum EBI strategy for both pricing rules lie quite close to the 100% level. Given that abatement levels for the maximum EBI strategy are higher than the other two strategies examined (Fig. 15) we suggest that this strategy clearly performs the best in terms of overall abatement. The discriminative pricing approach appears to generate slightly reduced abatement in comparison to the uniform strategy. This finding is based on two experimental trials using each pricing rule, so we are reluctant to draw firm conclusions regarding the prcing rule design at this stage of our research.

The other offer-ranking strategies do not perform as well – in particular the maximum participation strategy performs quite poorly under both pricing rules. This coupled with its overall lower level of abatement (Fig. 15) suggests that it is not a good candidate for designing auctions for pollution abatement. The maximum coverage approach does perform better than the participation approach, however, and at this stage should not be removed as a feasible approach to auction design in abating non-point source pollutions in agricultural watersheds.

Figure 16 shows the cost effectiveness of winning offers across the experiments for each offer-ranking strategy and pricing rule for the holding pond BMP. In this figure the results are presented as a percentage of the expected results – thus any line along the 100% level is consistent with the expected cost/kg of P abated. This information in Figure 17 clearly shows the most expensive offer-ranking strategy under either pricing rule is maximum participation. The maximum EBI strategy lies quite close to the 100% line suggesting that this rule performs in the experiments as predicted from our greedy algorithm results. The maximum coverage strategy falls between these two ranking strategy relationships, but is closer to the maximum EBI than the maximum participation strategy. We conclude from these findings that the maximum participation approach to selecting offers is clearly not a cost effective strategy for abating pollution in this watershed.

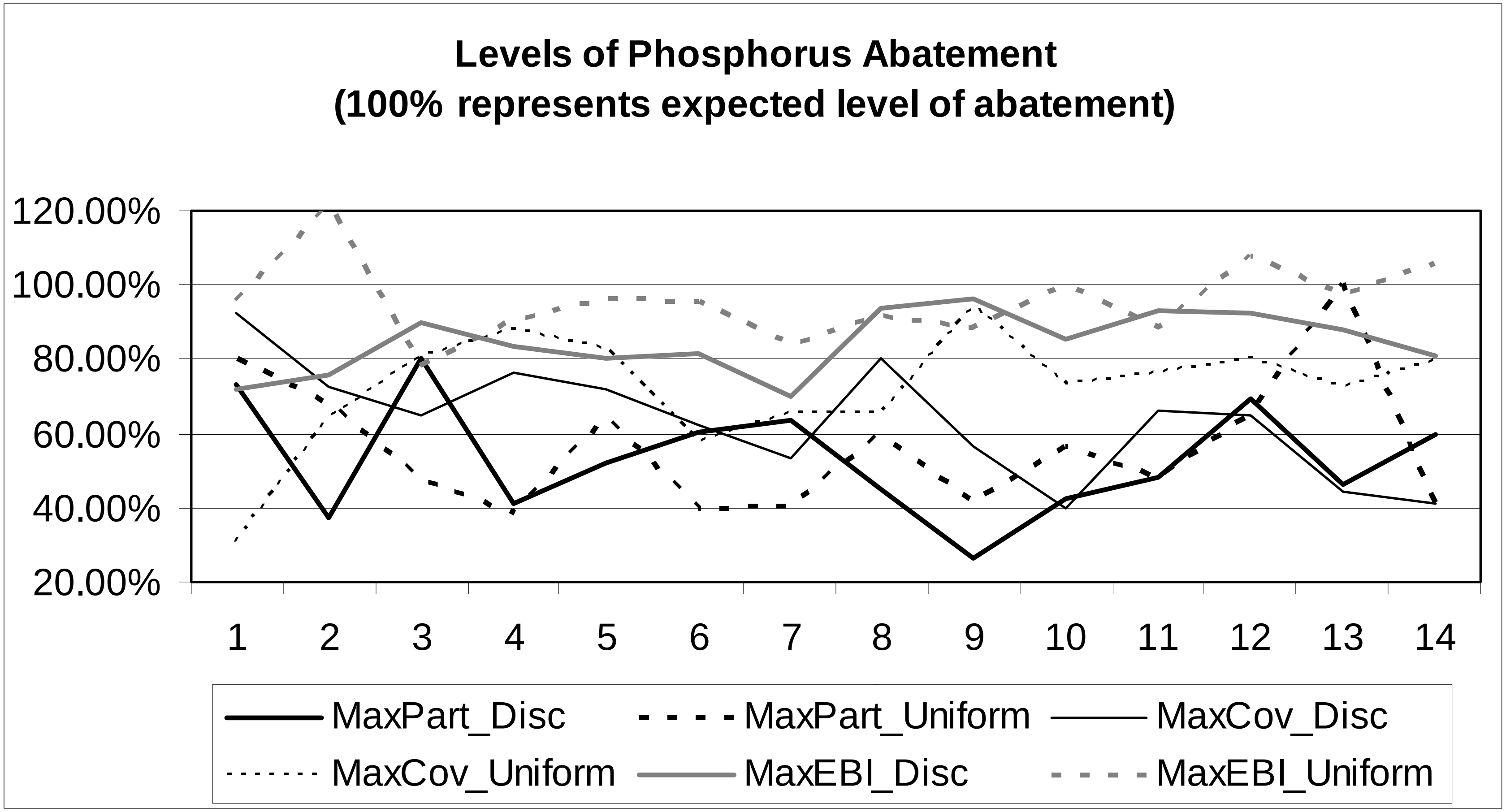


Figure 16. A summary of the levels of abatement of phosphorus for each pricing rule and offer-ranking strategy for the holding pond BMP.

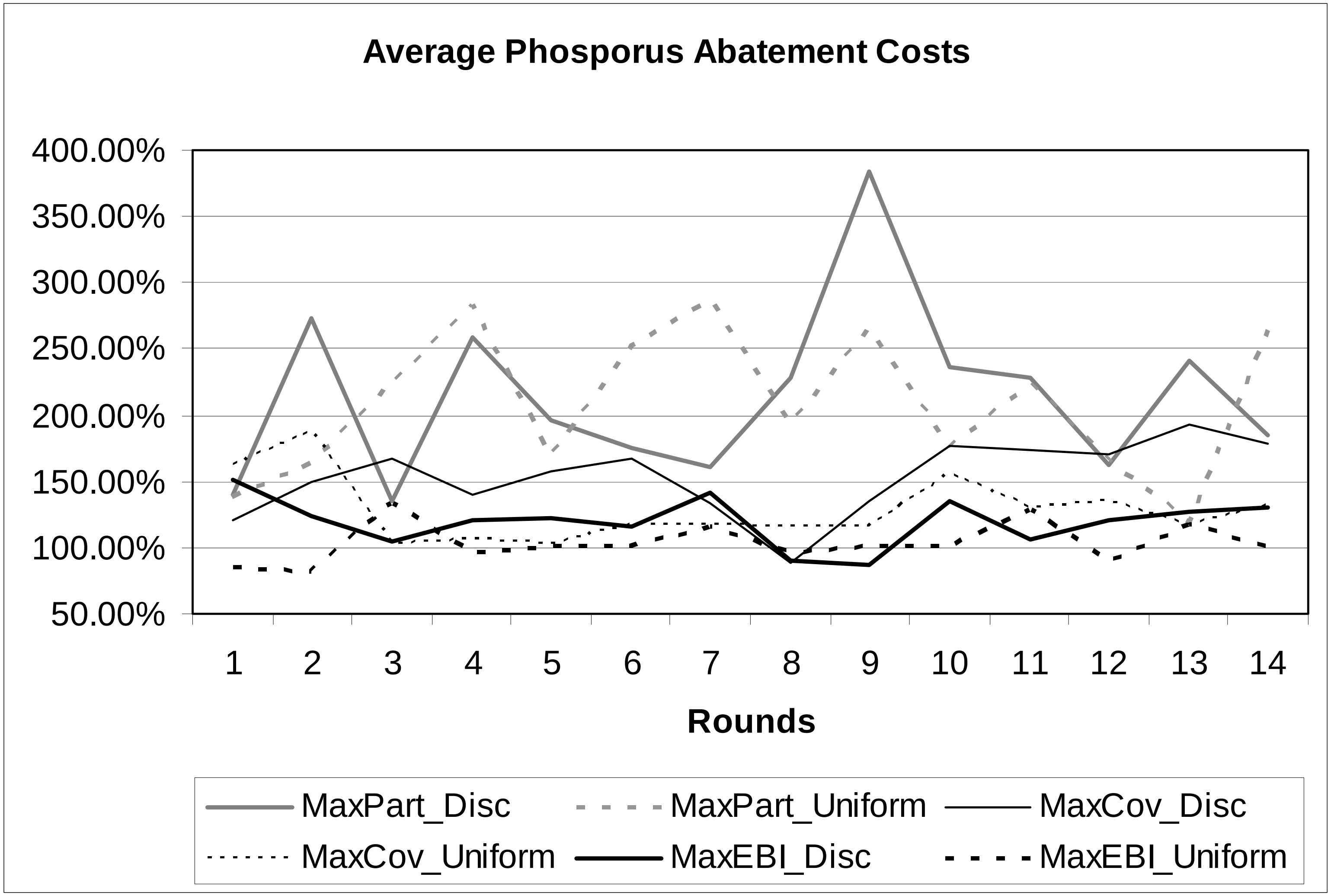


Figure 17. A summary of the costs/kg of phosphorus abatement for each pricing rule and offer-ranking strategy for the holding pond BMP.

We were unable to compare all of the holding pond results to the other BMPs because the hydrologic model results are not yet available for the other BMPs in STC. We did examine auctions for the adoption of zero till and forage conversion under the maximum coverage strategy, however. These results appear in tabular form in Tables 20 and 21. Some of the findings are compared in Figure 18. The information in Figure 18 suggests that the costs per acre contracted through the auction using the uniform pricing rule are greater than the discriminative pricing rule. This observation holds for the zero till and forage conversion BMPs, but not necessarily for the holding pond BMP. Although portions of the uniform curve are above the discriminative one, this does not appear in every period. We feel that further research is required to fully understand the implications of the pricing rules in these BMP auctions.

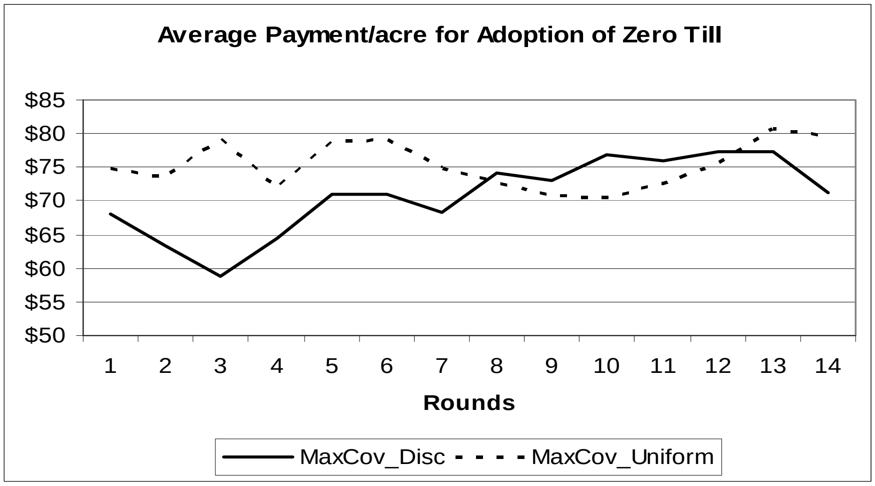
There are a number of other observations that can be made from the results. For the holding pond BMP, inspection of the data summarized in Table 19 revealed that the levels of phosphorus abatement differed between the two pricing rules. For the maximum coverage strategy and the uniform price case we observed that in periods 11-15 27.8 kg of phosphorus was removed from the system by the successful bidders. In the discriminative case only 17.5 kg of phosphorus was removed. These numbers are smaller than those for the maximum EBI strategy where 36.75 kg and 31.61 kg of phosphorus were removed by successful bidders in the uniform and discriminative pricing cases respectively. Nonetheless the environmental improvements, while greater for the strategy used to generate improvements specifically as expected, were larger for the uniform rule than the discriminative rule. This observation requires further testing in the experimental laboratory in the future.

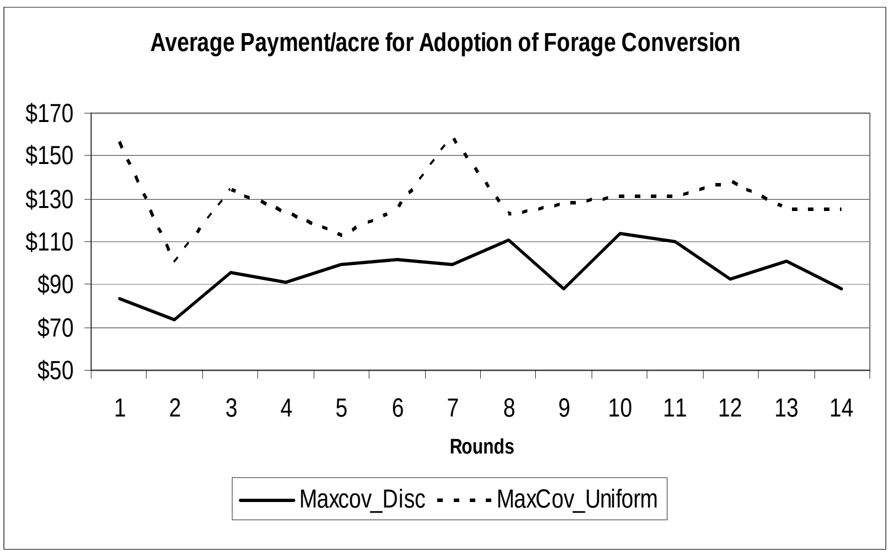
Table 20. Results from experimental auctions for the adoption of the zero till BMP under the maximum coverage offer ranking strategy.

MAXIMUM COVERAGE OF THE RELEVANT AGRICULTURAL UNIT OF PRODUCTION (ACRES)								
	Uniform Payment				Discriminate Payment			
Measures	Expected	Experiment Rounds			Expected	Experiment Rounds		
		1-5	6-10	11-15		1-5	6-10	11-15
Number of farms	4	4.4	4.5	4.9	6	4.5	4.0	4.5
Number of acres	1,194	1,975	2,074	2,089	3,353	2,752	2,299	2,285
Budget expended ($)	181,373	148,592	162,123	161,687	209,032	180,168	150,189	170,218
Rent	133,143	14,710	20,947	38,196	0	1,593	27,397	18,822
Payment/farm min ($)	25,001	10,362	14,166	11,833	2,033	5,688	12,109	6,930
Payment/farm max ($)	82,431	70,764	64,748	58,475	124,591	118,200	102,534	90,788
Payment/farm average ($)	45,343	35,646	36,309	34,584	34,838	40,347	44,185	38,197
Payment/acre min ($)	69	74	74	77	15	20	57	68
Payment/ acre max ($)	69	74	74	77	76	80	79	79
Payment/ acre average ($)	69	74	74	77	62	65	73	75
Phosphorus abated (kg)								
Cost P abated ($/kg)								

Table 21. Results from experimental auctions for the adoption of the forage conversion BMP under the maximum coverage offer ranking strategy.

MAXIMUM COVERAGE OF THE RELEVANT AGRICULTURAL UNIT OF PRODUCTION (ACRES)								
	Uniform Payment				Discriminate Payment			
Measures	Expected	Experiment Rounds			Expected	Experiment Rounds		
		1-5	6-10	11-15		1-5	6-10	11-15
Number of farms	2	2.4	2.9	2.9	5	4.2	3.8	3.2
Number of acres	1,376	1,443	1,548	1,568	2,692	2,309	2,169	1,889
Budget expended ($)	159,657	174,368	207,877	200,981	257,980	204,336	216,474	184,152
Rent ($)	127,140	66,237	117,841	108,176	0	18,852	61,998	64,432
Payment/farm min ($)	38,067	52,374	36,235	34,373	6,486	5,808	8,126	14,126
Payment/farm max ($)	121,590	102,639	121,513	121.008	93,691	105,500	108,600	89,572
Payment/farm average ($)	79,828	74,424	79,472	70,623	51,595	49,219	58,779	57,435
Payment/acre min ($)	116	125	133	128	6.2	6	8	13
Payment/ acre max ($)	116	125	133	128	218	220	225	215
Payment/ acre average ($)	116	125	133	128	95.8	89	103	97
Phosphorus abated (kg)								
Cost P abated ($/kg)								





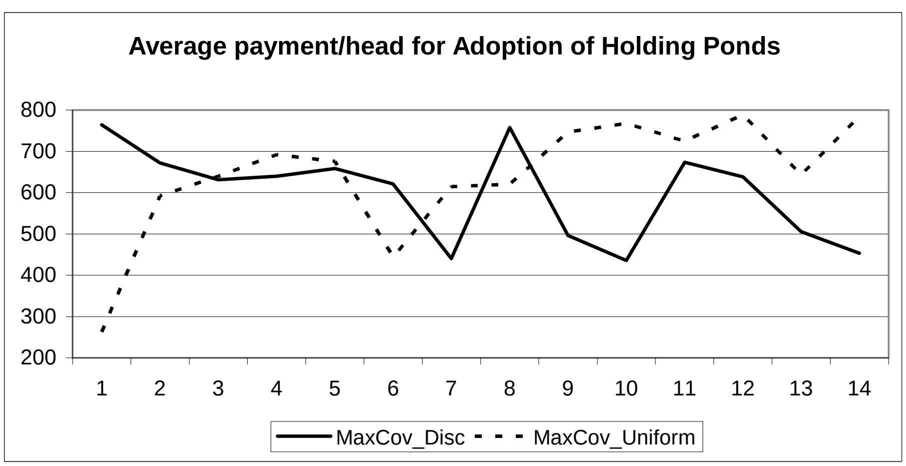


Figure 18. Average payments per acre or head under two auction pricing rules for the maximum coverage offer-ranking strategy for the adoption of three BMPs in experimental economic laboratory settings.

Target Based Auctions

The results reported above used the NFS budgets as the major constraint in the experimental auctions. In reality the conservation agent (e.g. government) has at least two options to select as a cut-off point for a conservation auction: budget based as we used above, or target based. In the budget based auction, the policy maker sets aside a fixed amount of dollars for the given purpose, and the participating landowners' offers are ranked and then selected from lower offers upward until the entire budget is spent. The advantage of this type of auction is that the program's cost is well-known in advance, there are no financial surprises and it can be easily planned. However, there is uncertainty about the level of environmental quality improvements that can be achieved with the budget based approach.

In the target based auction the regulator sets an environmental quality improvement target that it wants to achieve. For example, the regulator could want to achieve 30 kg of phosphorus abatement or cover 700 head of cattle under some alternative management practice. In such an auction the regulator selects the cheapest offers until the target is achieved. The advantage of this type of goal setting is that it ensures the required environmental quality improvement, but the cost of doing this is uncertain.

In the laboratory we examined the potential difference between the two goal setting approaches using the holding pond BMP. First we conducted experiments using a fixed budget as described above and developed estimates of the level of phosphorus abatement (see Table 19). Taking this level of abatement, we then used this level as a target in two subsequent auction experiments. Both the maximum coverage and the maximum EBI offer-ranking strategies were examined.

The results suggest that the budget based auction can lead to a more cost efficient conservation. Figure 19 displays some results of these experiments. The first panel shows that for the case of the maximum EBI ranking strategy and uniform pricing rule the budget based abatement prices are clearly below the target based prices. Using the maximum coverage ranking strategy, however, the budget based prices start high, but after several rounds as the subjects learn the rules of the auction setting, the budget based auction prices become more cost efficient than the target based prices. In the case of discriminatory pricing, however, the budget based auction can lead to higher abatement costs on average than the target based approach (Figure 20).

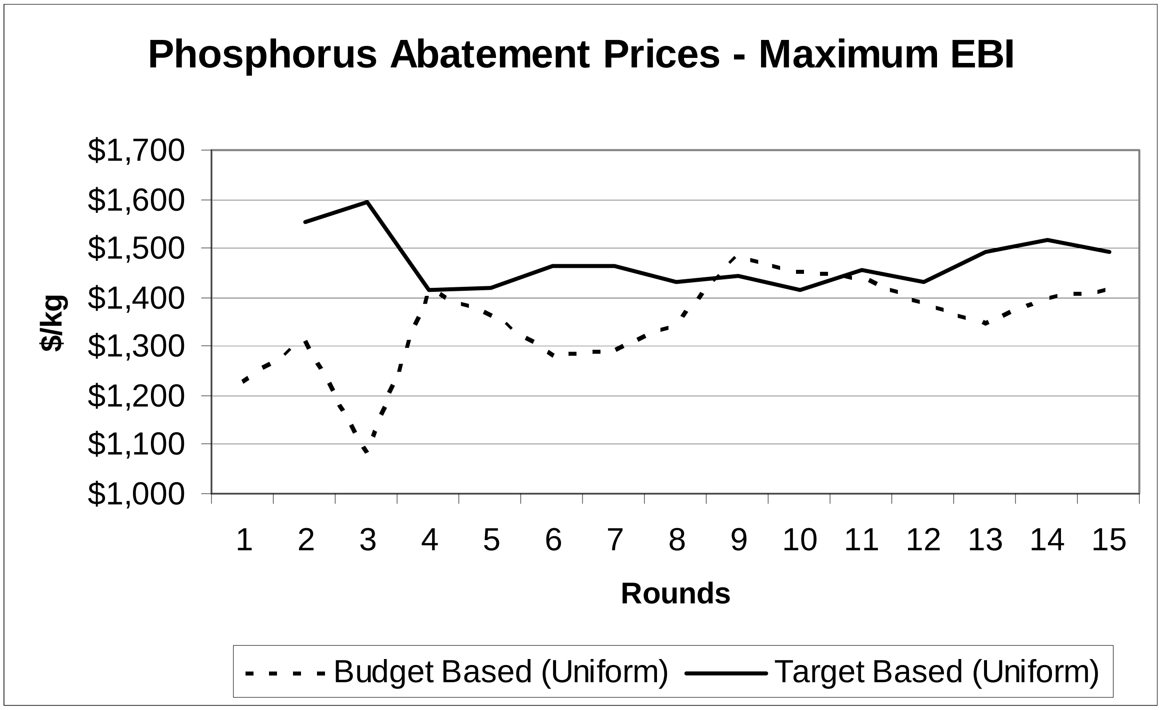
These results are not consistent with those reported by Schilizzi and Latacz-Lohmann (2007). They found that the budget based auction outperformed a target based one in a multiple round auction setting. Our results suggest that both formats perform relatively the same. They claim that by design the target based auction constrains the number of bidders, while the budget based one allows more winners to be included resulting in higher-cost participants being selected in turn raising the average cost per unit abatement. Once again we feel our results are preliminary pending further rounds of experiments to confirm our findings. We do note that with 15 rounds in our experiments there is potential for participants to learn to "game" the auction. This is an observation made by Schilizzi and Latacz-Lohmann (2007) to which we have no reply at this point of our research.

A Comparison of Student Participants with Actual Producers

We were fortunate to be able to attend the 2008 Annual Meeting of the Deerwood Soil and Water Association on March 10, 2008. At this meeting we were permitted to bring our laboratory and host three sessions of experiments with producers and several other participants. These sessions were not strictly the same as those we ran at the University of Alberta with students as it was impossible to tightly control the conditions – for example the novelty of the demonstration did not permit us to enforce a lack of communication. We decided to conduct 10 rounds per experiment rather than 15. We also learned that our visual experimental interface on the computers was somewhat confusing to the producers.

Nonetheless we conducted three experiments: two maximum EBIs (one uniform and one discriminative price) and one maximum coverage (uniform price) auction. The maximum EBI auctions were conducted first and these served to be learning experiences for the participants – they had opportunities to learn how to submit bids and something about the strategies. For these reasons we have not analyzed the results and do not wish to draw firm conclusions from them. However, the final auction conducted during this meeting we do feel provided some interesting results.

Figure 21 shows that in this maximum coverage approach the prices ($/head) converged to the expected $53/head for both the students and the producers. The producers' selected uniformly priced offers converged to the expected price from below, while the students' selected offers converged from above. The similarity in these results is striking, and mirrors some of the similar comparative findings emerging from Australian research and those in the US (e.g. Cummings et al. (2004). While we are excited by this one experimental result, it is clear that further comparisons should be made to "test the testbed" approach using students.



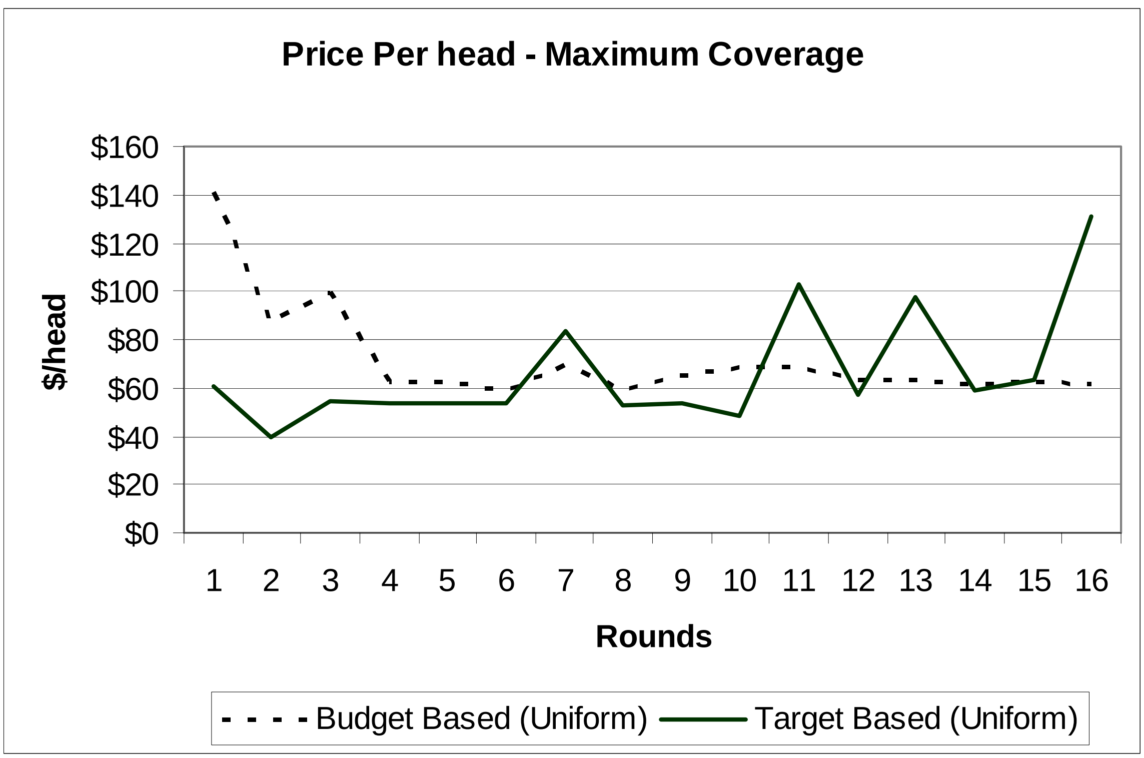


Figure 19. Results from budget based and target based auctions for two ranking strategies. The top panel is for the maximum EBI strategy and the lower panel is for the maximum coverage strategy.

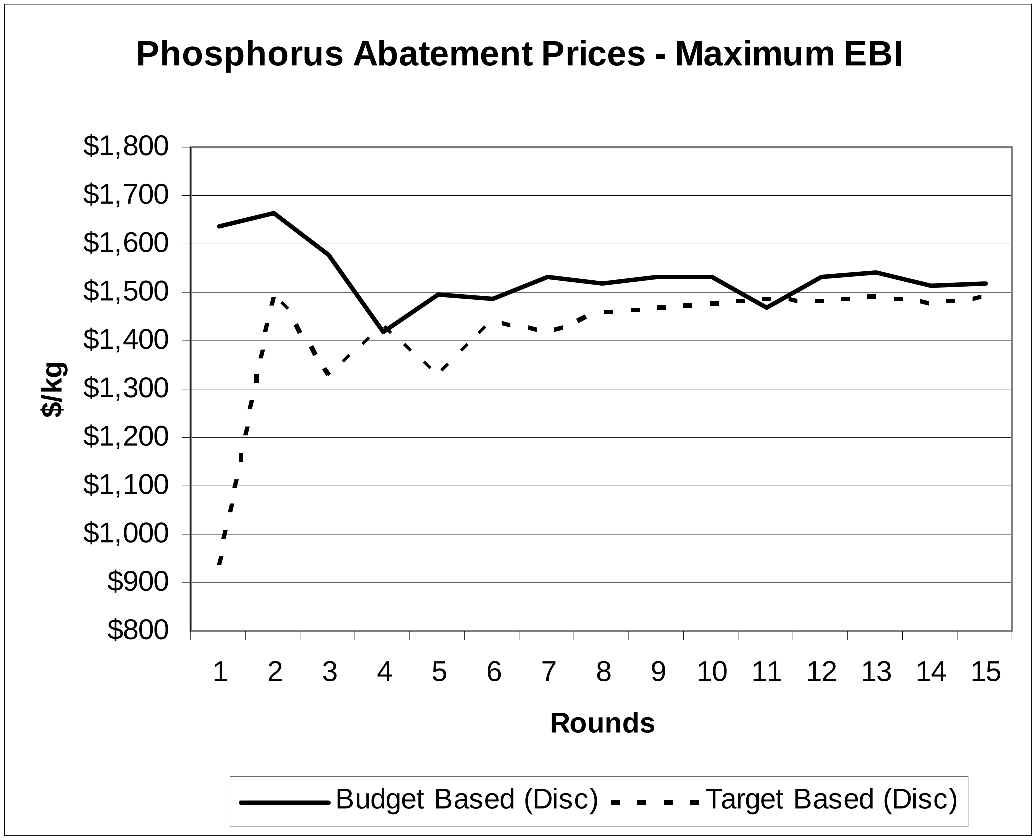


Figure 20. The average price of phosphorus abatement from two budget based and two target based auctions for the maximum EBI strategy using discriminative pricing.

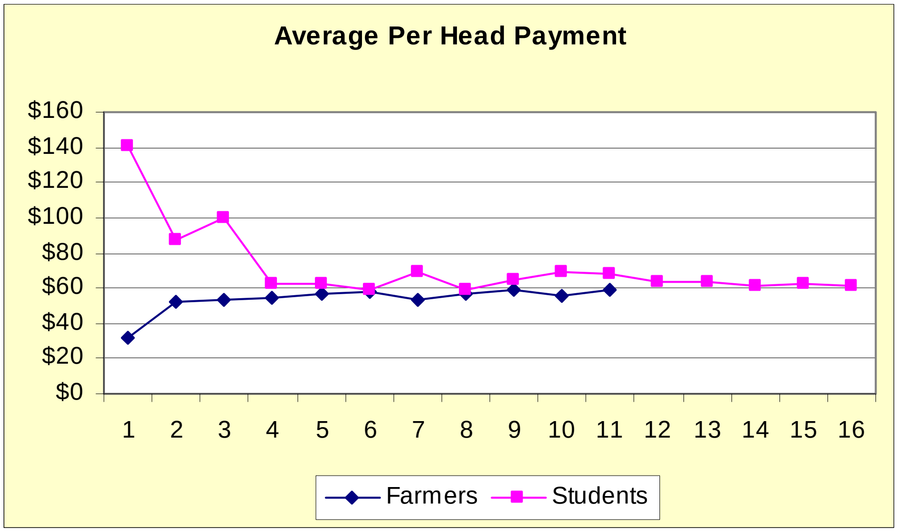


Figure 21. A comparison of the prices derived in the experimental laboratory by student and producer subjects for the maximum coverage uniform price auction for the holding pond BMP.

Problems, Lessons Learned and Future Research

We have felt privileged to be able to have conducted this research using some of the valuable information available in the watershed. Indeed, the levels of financial support and the participation of colleagues from the government, NGOs and academia has truly been remarkable. The literature on the use of auctions to generate environmental improvements is in its infancy and has focused largely on comparing the auction approach with fixed price schemes. These fixed price schemes are generally not found in Canada and thus much of this previous research we feel has had limited relevance in the Canadian context.

While our research has been constrained by lack of data and some time considerations generated through the government budgetary system, we have still learned a lot. In particular, we note that our research is rather preliminary and that further examination of the auction approach is worthy of investigation. We briefly summarize some of the specific things we learned and some of our research ideas below.

1. The authors of this report have not been experienced in the use of experimental economics as a research technique to understand policy approaches to addressing non-point source pollution issues. This research has allowed us to examine the technique and understand its strengths and weaknesses. As a result of this work we have developed a mobile experimental computer laboratory that we tested at the Deerwood annual meeting. We think that further experiments with producers need to occur, and having this lab will greatly facilitate this endeavor.

2. Our current suite of single BMP tests should be completed. In particular the maximum EBI strategy for zero till and forage conversion needs to be completed. This will require linkages to the hydrologic model which hopefully will be developed soon. These auctions could also include other BMPs that are being examined in other projects such as wetland restoration in STC.

3. Our auctions to date have involved single BMPs. While this is necessary given the information we had (i.e. only the holding pond BMPs could be linked to the hydrologic

model), it is apparent to us that the combined effect of BMPs on producer costs and cost effective environmental improvements must be considered in our experiments. In reality producers might face a "menu" of BMPs and select one or more from this list given the available incentives. We think that our next research steps need to consider this. In order for this to occur we first need to develop an overall abatement supply function for the STC watershed possibly including even other BMPs such as wetland retention/restoration.

4. Continuing on this vein, given our detailed understanding of adoption costs and the hydrologic modeling conducted by Dr. Yang's group in STC we think that spatially explicit models of BMP adoption should be considered. These models should initially perhaps not involve auctions – just spatial targeting initiatives in the watershed. Spatial optimization model can be used to develop these targets. In considering auctions in this framework, "smart markets" need to be considered in which an optimization model is included in each auction round to select winning offers. This will be a challenging undertaking because this optimization model will have to operate in the background between auction rounds and must operate swiftly so that auction participants do not get bored and lose interest during the process.

5. Our current auction designs have not allowed communication among the players. This is obviously an unrealistic situation as producers may collude to "game" the auction. In particular, we need to explore this in the context of a number of the BMPs that could require repeated bidding on a quantity basis (e.g. forage conversion whereby producers choose the number of acres to convert). We think that we need to rerun a smaller subset of our completed auctions to date with communication. This will enable us to isolate the effect that this has on auction results and performance.

6. Our current box of policy options to test could include some group incentives. Watershed associations are growing in number in Canada and devolving some responsibility for pollution abatement to the local level may be worthy of examination. We propose to examine group payment strategies and to understand how to develop

auctions to reduce opportunities for players to collude (or to collude for environmental benefit). This may involve further examination of the target based approach to auctions.

7. We learned that the experimental interface between the auction and producers needs to be significantly different than that we use with students. In our three trials the producers commented that the interface did not feel accurate and that they did not "see a farm" in the experiment. This needs to be addressed if we do further experiments with producers instead of students.

References

AAFC. 2002.(Agriculture and Agri-Food Canada) *Manitoba Soil Database*. Accessed at: https://web2.gov.mb.ca/mli.

AAFC. 2003. (Agriculture and Agri-Food Canada). Economics of Zero Tillage. Accessed at: http://www.agr.gc.ca/pfra/soil/swork1x.htm

AAFC. 2004. (Agriculture and Agri-Food Canada). Assessing the water quality benefit of BMPs at watershed scales across Canada. Project Booklet. Ottawa, Ontario.

AAFC. 2007. (Agriculture and Agri-Food Canada).Forage. Accessed at: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1174594338500&lang=e

AAFC. 2008. (Agriculture and Agri-Food Canada). Alternatives to direct access livestock watering. Accessed at:
http://www.agr.gc.ca/pfra/water/directac_e.htm

Alberta Environmental Farm Plan Company. 2007. Report to Industry. Volume 3, Number 12 December 2007, Edmonton Alberta.

Anderson, A. 2005. The Swedish 1990 Agricultural Land Reform- Adjustments of the Use of Land. 11th International Congress of the European Association of Agricultural Economists Proceedings. August 24-27, 2005. Copenhagen, Denmark.

Bailey. 1987. Quoted in M. Entz, Entz, M.H. 2006. Benefits of Alfalfa in Crop Rotations. Accessed on October 19, 2007 at:.
<<www.mbforagecouncil.mb.ca/.../7_MartinEntzAlfalfainrotations.pdf. >>

Barclay, G. Provincial Forage Specialist. Saskatchewan Agriculture and Food. Personal communication on: August, 10, 2006.

Bradshaw, B., Doal, H. and B. Smit. 2004. Farm level adaptation to climatic variability and change: crop diversification in the Canadian prairies. *Climatic Change*, 67:119-47.

Boame, A. 2005. Zero Tillage: A greener way for Canadian farms". *Statistics Canada. Catalogue no*. 21-004-XIE.

Blackwell, P.S., T.W. Green, and W.K. Mason. 1990. Responses of biopore channels from roots to compression by vertical stresses. *Soil Science Society of America Journal* 54:1088-1091.

Bowren, K.E. and D.A. Cooke. 1975. Effects of legumes in cropping systems in northeastern Saskatchewan. *Canadian Journal of Plant Science* 55:351.

Brandt, S.A. and C.H. Keys. 1982. Effect of crop rotations on soil moisture levels. p. 38-48. *In*: Proc. Soils and Crops Workshop, University of Saskatchewan, Saskatoon, S7N 0W0.

Bruulsema, T.W. and B.R. Christie. 1987. Nitrogen contribution to succeeding corn from alfalfa and red clover. *Agronomy Journal* 79:96-100.

Bullied, W.J. and M.H. Entz. 1994. Using herbicides instead of tillage to remove forage stands. p. 177-183. *In*: Proc. Manitoba AgriForum. 16 Lowell Pl., Winnipeg, MB.

Caswell, M. K. Fuglie, C. Ingram, S. Jans, and C. Kascak. 2001. *Adoption of Agricultural Production Practices: Lessons Learned from the U.S Department of Agriculture Area Studies Project*. Agricultural Economic Report No. (AER792) 116 pp. Accessed at:
<< http://www.ers.usda.gov/Publications/AER792>>

Campbell, C.A., R.P. Zentner, H.H. Janzen, and K.E. Brown. *Crop Rotation Studies in the Canadian Prairies*. Research Branch, Agriculture and Agri-Food Canada. 1990

Campbell, C.A., G.P. LaFond, A.J. Leyshon, R.P. Zntner, and H.H. Janzen. 1991. Effect of Cropping Practices on the Initial Potential Rate of N Mineralization of Thin Black Chernozem. *Canadian Journal of Soil Science* 71: 45-53.

Campbell, C.A., G.P. Lafond, R.P. Zentner, and Y.W. Jame. 1994. Nitrate leaching in a Udic Haploboroll as influenced by fertilization and legumes. *Journal of Environmental Quality* 23:195-201.

Cason, T.N., L. Gangadharan, and C. Duke. 2003. A laboratory study of auctions for reducing non-point source pollution. *Journal of Environmental Economics and Management* 46:446-471.

Cason, T.N. and L. Gangadharan. 2005. A laboratory comparison of uniform and discriminative price auctions for reducing non-point source pollution. *Land Economics* 81:51-70.

Cavers and Eilers. 1994. Quoted in M. Entz, Entz, M.H. 2006. Benefits of Alfalfa in Crop Rotations. Accessed on October 19, 2007 at:
<<www.mbforagecouncil.mb.ca/.../7_MartinEntzAlfalfainrotations.pdf. >>

Claassen, R. [and 12 other authors]. Agri-environmental Policy at the Crossroads: Guideposts on a Changing Landscape*.* Economic Research Service (AER-794). USDA.

Cortus, B. The Economics of Wetland Drainage: A Case Study in Canada's Prairie Pothole Region*.* M.Sc. Thesis, Department of Rural Economy, University of Alberta, Edmonton, AB.

Cummings, R.G., C.A. Holt and S.K.Laury. 2004. Using laboratory experiments for policymaking: An example from the Georgia Irrigation Reduction Auction. *Journal of Policy Analysis and Management* 32:341-363.

Deng, Y. 2006. Watershed Evaluation of Beneficial Management Practices in the South Tobacco Creek Subwatershed- On-farm Modeling Component. *Project Report.* Department of Rural Economy, University of Alberta, Alberta.

Eigenraam, M., L. Strappazzon, N.Lansdell, C. Beverley, G. Stoneham. 2007. Designing frameworks to deliver unknown information to support MBIs. *Agricultural Economics* 37: 261-269.

Entz, M.H. 1994. The role of forages in prairie crop rotations: 1994 annual progress report. Department of Plant Science, University of Manitoba, Winnipeg, MB.

Entz, M.H., W.J. Bullied, and F. Katepwa-Mupondwa. 1995. Rotational benefits of forage crops in Canadian prairie cropping systems. *Journal of Production Agriculture* 8:521-529.

Entz, M.H. 2006. Benefits of Alfalfa in Crop Rotations. Accessed on October 19, 2007 at:.<<www.mbforagecouncil.mb.ca/.../7_MartinEntzAlfalfainrotations.pdf. >>

Entz. M., P. Ominski, R. Mohr, A. Schoofs, D. Forster, W. Bullied, and S.Shortliffe, K.Bamford.2008. Forages Improve Efficiency of Prairie Cropping Systems. University of Manitoba. Accessed at: http://www.umanitoba.ca/afs/plant_science/extension/agrif95.html

Environment Canada. 2005. Canadian Daily Climate Data on CD-ROM - Western Canada. Environment Canada. Climate Products and Publications Division. Downsview, ON.

Environment Canada. 2007. Climate Data Online. Accessed at: << http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html>>

Ferguson, W.S. and B.J. Gorby. 1971. Effect of various periods of seed-down to alfalfa and bromegrass on soil nitrogen. *Canadian Journal of Soil Science* 51:65-73.

Ferraro, P.J. 2008. Asymmetric information and contract design for payments for environmental services. *Ecological Economics* (Forthcoming).

Fischbacher, U. 2007. Z-Tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics* 10:171-178.

Gebramedhim, B. and G. Schwab. 1998. The economic importance of crop rotation systems: Evidence from the literature. Michigan State University, Department of Agricultural Economics Staff Paper No. 98-13.

Greiner, B. 2004. The online recruitment system for economic experiments. Accessed at:<http://www.orsee.org/ >

Gitau, M. W., T.L. Veith, W. J. Gburek. 2004. Farm-level optimization of BMP placement for cost–effective pollution reduction. *American Society of Agricultural Engineers ISSN 0001−2351.* Vol. 47: 1923−1931.

Gray, R.S., J.S. Taylor and W.J. Brown. 1996. Economic factors contributing to the adoption of reduced tillage technologies in central Saskatchewan. *Canadian Journal of Plant Science* 76: 661-668.

Hamilton, C. and M. Khakbazan. 2006. A bibliography of Watershed Evaluation of beneficial management practices". Unpublished Report, Watershed Evaluation of Beneficial Management Practices Program, Brandon, MB.

Homes, S. 2000. Literature review: riparian health and water quality: function, design and management of riparian buffers. Internal Document Cows and Fish Program, Alberta Riparian Habitat Management Program, Lethbridge, AB

Hope, J., D.B. Harker and L. Townley-Smith. 2002. Long term land use trends for water quality protection. PFRA Planning and Analysis Services, Agriculture and Agri-food Canada. Regina, SK.

Hoyt, P.B. and R.H. Leitch. 1983. Effects of forage legume species on soil moisture, nitrogen and yield of succeeding barley crops. *Canadian Journal of Soil Science* 63:125-136.

Kelner, D.J. 1994. Short-term alfalfa stands in cropping systems: Benefits related to nitrogen. MSc. Thesis, Dept. of Plant Science, University of Manitoba, Winnipeg, MB.

Khakbazan, Mohammad, 2007. On-Farm Economic Model Data Set for South Tobacco Creek, Interim Report, Watershed Evaluation of Beneficial Management Practices Project.

Lafond, G.P., R.P. Zentner, R. Geremia, and D.A. Derksen. 1993. The effects of tillage systems on the economic performance of spring wheat, winter wheat, flax, and field pea production in east central Saskatchewan*.* *Canadian Journal of Plant Science* 73:47-54.

Lang, K. 2006. From Grain to Grass: A 6 –Year Analysis*.* Western Beef Development Centre, Saskatchewan.

Lynch, L. and R. Tjaden. 2000. When a Landowner Adopts a Riparian Buffer*.* Maryland Coorperative Extension. Fact Sheet 744

MAFRI. 2004a. (Manitoba Agriculture, Food and Rural Initiative) Cost of Production of Crops.

MAFRI. 2004b. (Manitoba Agriculture, Food and Rural Initiative) Cost of Production of Hay.

MAFRI. 2007. (Manitoba Agriculture, Food and Rural Initiative).Business and Economics*,* Manitoba Agriculture, Food and Rural Initiatives*.* Accessed at: <http://www.gov.mb.ca/agriculture/financial/farm/software.html>

McKee, M. and R.P. Berrens. 2001. Balancing army and endangered species concerns: Green vs green. *Environmental Management* 27:123-133.

Meek, B.D., DeTar, W.R., Rolph, D., Rechel, E.R., and L.M.Carter. 1990. Infiltration rate as affected by an alfalfa and no-till cotton cropping system. *Soil Science Society of America Journal* 54:505-508.

Nagy, C.N. 1997. An economic assessment of alternative cropping systems for the Saskatchewan parklands. M.Sc. thesis. Department of Agricultural Economics, University of Saskatchewan, Saskatoon, SK.

Nagy, C.N. 2001. An economic and agronomic analysis of reduced tillage. Prepared for Monsanto Canada Inc., Centre for Studies in Agriculture Law and the Environment (CSALE).

National Farm Stewardship Program. 2006. Beneficial Management Practice Descriptions.

Ominski, P.D., M.H. Entz, and M. Goodwin. 1994. Using alfalfa to control weeds: A comparative study. P. 170-176. *In*: Proc. Manitoba AgriForum, 16 Lowell Pl., Winnipeg, MB, R3T 4H8.

Park, W.M. and D.G. Sawyer. 1987. Cost effectiveness of alternative subsidy strategies for soil erosion control. *Southern Journal of Agricultural Economics* 19:21-32.

Poyser, E.A., R.A. Hedlin, and A.O. Ridley. 1957. The effect of farm and green manure on the fertility of blackearth-meadow clay soils. *Canadian Journal of Soil Science* 37:48-56.

Plott, C.R. 1994. Experimental design methods in economics and political science: The design and testing of policy options. *Human Dimensions Quarterly* 1:5-8.

Rein, F.1999. An economic analysis of vegetative buffer strip implementation. Case study: Elkhorn Slough, Monterey Bay, California . *Coastal Management* 27:377 – 390.

SAF. 2003. (Saskatchewan Agriculture, Food). Agricultural Statistics. Saskatchewan Agriculture Food and Rural Revitalization. Policy Branch. Regina, Saskatchewan.

Samarawickrema, A.K. and K. Belcher. 2005. Net greenhouse gas abatement and economics of annual crop management systems. *Canadian Journal of Agricultural Economics* 53: 385-401.

Samarawickrema, A. 2005. Economics And Greenhouse Gas Abatement Of Tillage Systems In The Black Soil Zone Of Saskatchewan. M.Sc. Thesis, Department of Agricultural Economics, University of Saskatchewan, Saskatoon, SK.

Schilizzi, S. and U. Lactacz-Lohmann. 2007. Assessing the performance of conservation auctions: An experimental study. *Land Economics* 83:497-515.

Siemens, L.B. 1963. Cropping systems: An evaluative review of the literature. Department of Plant Science, University of Manitoba, Winnipeg, MB. 89pp.

Sheaffer, C.C., S.R Simmons, and M.A. Schmitt. 2001. Annual medic and berseem clover dry matter and nitrogen production in rotation with corn. *Agronomy Journal* 93:1080-1086.

Sohngen, B. and M. Nakao. The Effect of Soil Quality on the Costs of Reducing Erosion with Filter Strips. Department of Agricultural, Environmental and Development Economics, University of Ohio, Ohio State University, Ohio.

Soil Conservation Council of Canada, Global Warming and Agriculture: Best Management Practices. 2003. Accessed at: http://www.soilcc.ca/fact/pdfs/BMP%20Factsheet%20Eng2.pdf

Sonntag, G.J. R.P. Zentner, and D.A. Derksen. 1997. Specialty crop management study: Economics and energy performance. Final Report. PERD R&D Progr. Semiarid Prairie Agric. Res. Cent., Swift Current, SK..

Sparling, B. and C. Brethour. 2007. An economic evaluation of beneficial management practices for crop nutrients in Canadian Agriculture. Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Portland.

Sumach, D. 2007. MAFRI. Personal Communication. July 16, 2007

Thornton, J. 2007. MAFRI . Personal Communication. August 22, 2007

Tisdell, J. 2007. Bringing biophysical models into the economic laboratory: An experimental analysis of sediment trading in Australia. *Ecological Economics* 60:584-595.

Turner, B. 2006. Personal communication with Bill Turner, Deerwood Soil and Water Management Association, Miami, Manitoba, June 7, 2006, and in Winnipeg March 11, 2008.

Turner, B. 2008. Personal communication with Bill Turner, Deerwood Soil and Water Management Association, Winnipeg, March 11, 2008.

USASK, 2008. (University of Saskatchewan).*Soil Texture.* Accessed at: <<http://www.gardenline.usask.ca/misc/soil.html>>

Uusi-Kamppa, J., Braskerud, B., Jansson, H., Syversen, N., and R. Uusitalo. 2000. Buffer zones and constructed wetlands as filters for agricultural phosphorus. *Journal of Environmental Quality* 29:151-158.

Vaisey, J., T. Weins and R. Wetlaufer. 1996. The Permanent Cover Program: Is Twice Enough? Accessed at:
<http://www.agr.gc.ca/pfra/pub/pcpaper2.htm>

Veith, T.L. M. L. Wolfe, and C. D. Heatwole. 2004. Cost−Effective BMP Placement: Optimization Versus Targeting. *American Society of Agricultural Engineers ISSN 0001−2351.* Vol. 47(5):1585−1594.

Watson, D., J. Miller, P. Boxall and J. Unterschultz. 2000. The economics of riparian grazing management: A literature review. Project Report 00-06, Department of Rural Economy, University of Alberta, Edmonton, Alberta. 15 pp.

Weber, M. and P.C. Boxall. 2007. The farm behaviour component of the integrated economic-hydrologic model: Background and proposed experimental protocols. Report to the WEBs management team. Available from the authors.

Weersink, 2001. Multifunctionality: Applying the OECD Framework A Review of Literature in Canada. Paper Presented to the OECD as part of the a Multifunctionality Workshop.

Westra. 2003. Effects on Farm Income and the Environment from Targeting Agricultural Best Management Practices (BMPs). Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Mobile, Alabama, February 1-5, 2003.

Wicks, S. and R. Howitt. 2005. Optimal sustainable agricultural decisions: A mixed integer approach. Paper Presented at the American Agricultural Economics Association 2005 Annual meeting, July 24-27, Providence, RI. Accessed at: http://ageconsearch.umn.edu/handle/123456789/16622

Yang,W., M. Khana, R. Farnsworth, and H. Onal. 2003. Is geographical targeting cost-effective? The case of the Conservation Reserve Enhancement Program in Illinois. *Review of Agricultural Economics* 27:70-88.

Yang, W. and A. Weersink. 2004. Cost-effective Targeting of Riparian Buffers. *Canadian Journal of Agricultural Economics* 52:17-34.

Yang W., C. Sheng, and P. Voroney, 2005. Spatial targeting of conservation tillage to improve water quality and carbon retention benefits. *Canadian Journal of Agricultural Economics* 53:477–500.

Yang, W., A. Rousseau, and P.C. Boxall. 2007. An integrated economic-hydrologic modeling framework for the watershed evaluation of beneficial management practices. *Journal of Soil and Water Conservation* 62(6):423-432.

Yiridoe E.K. and A. Weersink. 1998. Marginal abatement costs of reducing groundwater-N pollution with intensive and extensive farm management choices. *Agricultural and Resource Economics Review*, (October 1998): 169-185.

Zentner, R.P., D.D. Wall, C.N. Nagy, E.G. Smith, D.L. Young, P.R. Miller, C.A. Campbell, B. G. McConkey, S.A. Brandt, G.P. Lafond, A.M. Johnston and D.A. Derksen. 2002. Economics of Crop Diversification and Soil Tillage Opportunities in the Canadian Prairies. *Agronomy Journal* 94:216-230

Zentner, R.P. G.P. Lafond, D.A. Derksen, D.D. Wall, R. Geremia, and B.J. Blomert. 1999. The influence of conservation tillage on economic returns and riskiness of cropping systems in the

Thin Black soil zone. Pp. 98-108. *In* Soils & Crops '99. Proceedings of a Workshop, Saskatoon, SK, Canada. 25-26 Feb. 1999.