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Long Term Land Use Trends For Water Quality Protection

Ten Years of Monitoring in the South Tobacco Creek Watershed

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Canada

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MAY, 2002

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Cover Photos (clockwise from left)

1. A downstream view of South Tobacco Creek near the Highway 240 monitoring site.
2. Manitoba Escarpment viewed from below.
3. Pasture and backflood area in the upper reaches of South Tobacco Creek.
4. Looking east, from the Manitoba Escarpment to the lowland plain.

Acknowledgements

The authors express their appreciation to: the owners and operators of lands within the South Tobacco Creek watershed, for their long-term support in annually providing invaluable data as to their respective land management practices; Deerwood Soil and Water Management Association (DWSMA) for facilitating this study—with particular mention of Bill Turner, project technician; South Tobacco Creek Steering Committee members for their on-going support and encouragement; Lawrence Townley-Smith (PFRA Analytical Division, Regina) for critical insights and assistance with data analysis; Rick Rickwood (PFRA Analytical Division, Regina) for persistent graphics production, data tabulation and analysis; Ron Lewis (PFRA Manitoba Regional, Winnipeg) for conscientious maintenance of the long-term GIS-based data base; Jim Yarotski (PFRA Technical Resources Division, Regina) for supplying hydrologic data and evaluation, and his creativity in repeatedly augmenting short-term project funding; Dale Timmerman (PFRA District Office, Morden) for his local perspective and thoughtful hands-on encouragement; manuscript reviewers across the prairies who offered their comments and corrections to the document; and to PFRA Headquarters, Regional and District management for their long-term support under project circumstances that were often, at best, uncertain.

Catalogue #: A22-270 / 2002E
ISBN#: 0-662-32720-9

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Executive Summary

A detailed ten year land management study (1991-2000) was completed by PFRA as a means of assessing the state of land and water resources in the South Tobacco Creek watershed (75 km^2). The analysis and documentation of such long-term temporal and spatial land management trends is an essential precursor to understanding cause-effect relationships between agriculture and water quality. Annual land management and farming practices information was recorded by all 42 landowners in the basin (e.g. crops grown, fertilizer use, pesticides applied) for each of some 330 fields. At the same time, under a separate companion study conducted by Environment Canada (EC), water quality was sampled on an event-driven basis at three main gauging stations along the creek. This current report summarizes the land management portion of the study.

During the ten year study, spring wheat dominated crop production, although total spring wheat hectares dropped by about 35% after 1992. Canola production cycled up and down for the same period. Flax and barley areas increased three-fold and forage area doubled, but each constituted only 10-12% of the total crop area. Nitrogen was the most abundant nutrient applied, with total spring-applied N and P varying annually, and total fertilizer applications increasing somewhat overall. As canola production increased, so did spring-applied N, P and S. Total pesticide use increased gradually. MCPA and 2, 4-D use roughly corresponded with cereal production, while an increase in glyphosate use appeared to correlate with canola production and lower glyphosate costs in the last half of the monitoring period. Chopping was the most prevalent form of straw management, with a four-fold increase in hectares of baled straw being largely influenced by flax and barley production. Tillage practices were fairly consistent and do not suggest a shift towards zero tillage in the watershed. On average, only modest amounts of wheat and canola stubble (<15%) were not tilled in the spring and fall, and few fields remained consistently untilled from year to year. The principal means of tillage on wheat and canola hectares was with a heavy duty cultivator in the fall (>80%), and a light duty cultivator in the spring (>75%).

Specific relationships between land management and water quality trends in the South Tobacco Creek watershed are the focus of cooperative studies underway between PFRA and EC. It is apparent that hydrologic variability due to run-off and storm events has a powerful influence on stream loadings. Land management data from this report will be coupled with a pending analysis of seasonal variations in stream loading, and used to verify model predictions as to relevant land management and water quality relationships.

Table of Contents

1.0 Introduction

1.1 Study Origin

Following a century of agricultural settlement and associated land clearing and drainage, instances of flooding, erosion and sedimentation were of increasing concern to landowners in the South Tobacco Creek watershed, located approximately 100 km southwest of Winnipeg in south-central Manitoba **(Figure 1)**. A rainfall event in 1968 resulted in 1800 ha of crop damage while, in 1979, a more intense spring run-off event caused loss of topsoil on approximately 3000 ha (Deerwood Soil and Water Management Association, n.d.a). Various options to alleviate these damages were considered, including the construction of ditches, dikes, a large dam structure and a series of small-scale headwater retention dams.

In 1985, local landowners established the Deerwood Soil and Water Management Association (DSWMA) to deal with soil and water management issues. The organization serves a total area of 980 km^2, of which 75 km^2 (7,638 ha) makes up the South Tobacco Creek watershed.

Between 1985 and 1996, DSWMA initiated the construction of a network of 50 small-scale headwater retention dams built on private land. Of these dams, 26 directly impact on water management in the South Tobacco Creek watershed. These dams have been effective in reducing overall peak flows in the basin by up to 25 percent. High intensity run-off downstream of individual dams has also been reduced by as much as 90 percent (Deerwood Soil and Water Management Association, 2000).

In 1991 the DSWMA expanded their soil and water management efforts to look more directly at land use and water quality relationships through an agreement with the federal and provincial governments. A long-term analysis of land management trends was implemented with the cooperation of local landowners who provided detailed annual land management information on an on-going (ten year) basis. At the same time, flow and water quality parameters were measured in South Tobacco Creek. A twin watersheds study was also established on two small (5.6 ha and 4.2 ha) adjacent drainage areas in the watershed; one basin is being farmed under conventional tillage and the other under zero tillage. The purpose of the twin watersheds study is to compare run-off water characteristics (quantity and quality) and moisture retention differences between conventional and zero tillage.

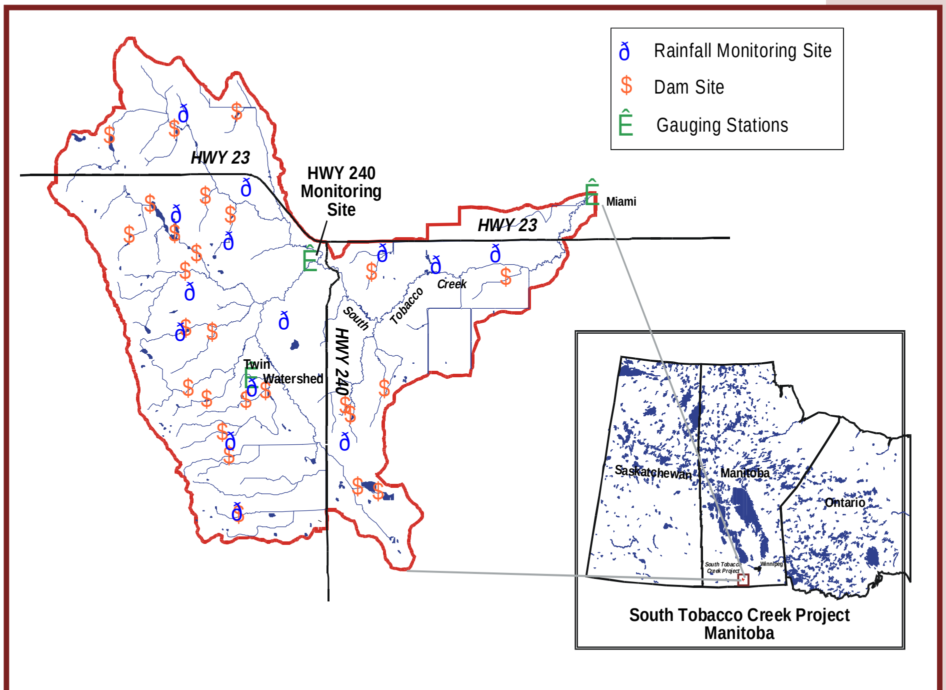

Figure 1: Location of the South Tobacco Creek watershed.

1.2 Study Purpose and Objectives

The need for a detailed land management study developed out of concern for the state of land and water resources in the basin. Study objectives were:

1. to conduct long-term baseline monitoring in order to determine temporal land management trends;
2. to attempt a correlation of land management trends with water quality trends;
3. where relevant, to establish cause - effect relationships between agricultural land management and water quality; and
4. to forecast future relationships between agricultural land management and water quality, based on current information and modeling predictions - to be addressed in a separate report.

The purpose of this current report is to document land management trends within the watershed, as a necessary precursor to establishing subsequent land management - water quality relationships.

1.3 Study Area

The South Tobacco Creek watershed drains 7,638 ha of which 71% (5,409 ha) is under cultivation in a total of 333 individual fields. The remaining 2229 ha in the basin are comprised of non-cultivated grasslands, trees, water bodies, road allowances and yard sites (Deerwood Soil and Water Management Association, n.d.b).

1.3.1 Soils, Topography and Climate

The majority of the study area is located on the uplands of the Pembina Escarpment and to a lesser extent directly below the escarpment in the lowlands of the Pembina Valley. Native escarpment vegetation including oak and poplar woodlands and grasslands have largely been cleared and converted to cultivated land since the onset of agricultural settlement in 1870. Cultivated soils of the escarpment are largely orthic dark gray loam - clay loam developed from a mixed till of shale, limestone and granite. Regosols are mainly found on steep slopes inappropriate for cultivation, where they support woodland vegetation **(Figure 2)**.

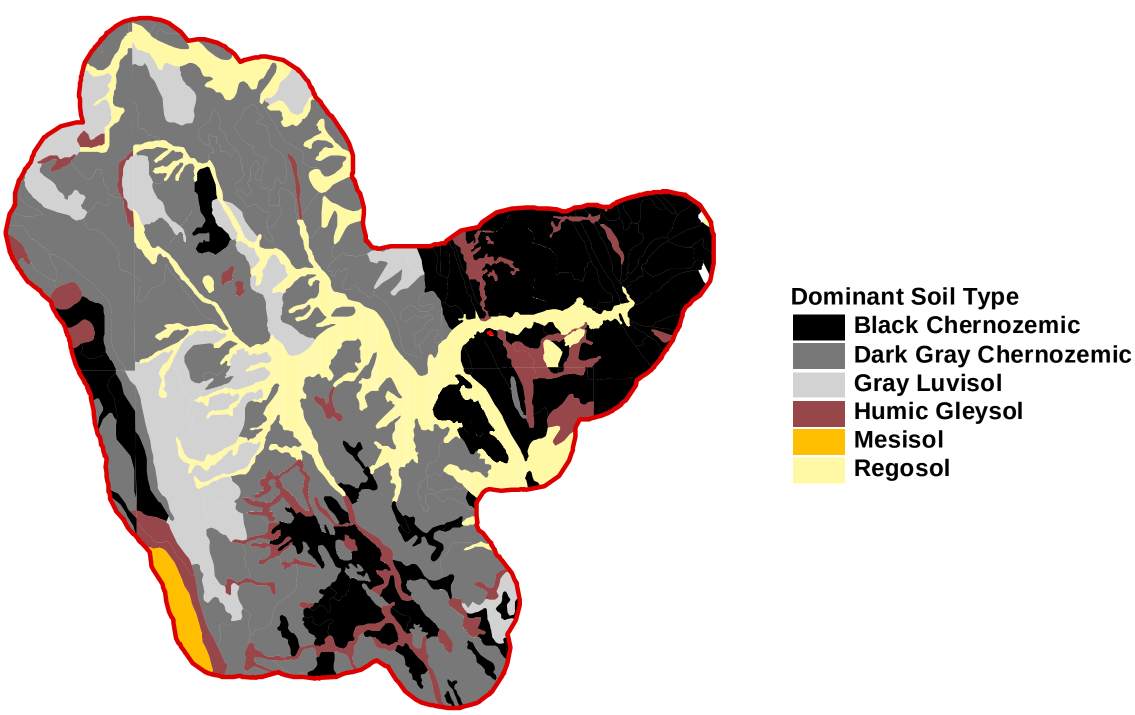

Figure 2: Dominant soil types, South Tobacco Creek watershed.

The climate is semi-arid with pronounced seasonal variations. Differences in terrain result in slight variations in average annual temperature (2.2°C - 3.3°C) above and below the escarpment. The growing season begins in the second half of April and ends in early October with an annual average of 127 frost free days, as measured at the twin watersheds site **(Figure 3)**. Mean annual precipitation is influenced by escarpment location, ranging from nearly 590 mm on the uplands to 500 mm below the escarpment. Approximately 75 percent of this precipitation occurs as rainfall from April to October while the remainder falls as snow during the five winter months **(Figure 3)**.

1.3.2 Farm Demographics

The 42 landowners in the basin provided land management information throughout the monitoring period (1991 - 2000). Farm holdings within the basin range from 30 ha to several thousand hectares and include private, corporate and Hutterite colony holdings. Farm types include grain, specialty crop and mixed operations (grain and livestock). Crop type varies annually and is dominated by cereals, forages and oilseeds, with specialty crops such as beans and field peas to a limited extent **(Figure 4)**. Livestock production diversified over the monitoring period to finally include cattle (1,100 head), swine (570 sows - farrow to finish), chickens (20,000), buffalo (23 head) and sheep (33 head) operations (Turner, 2001). Specific livestock numbers and locations were not monitored as part of the study.

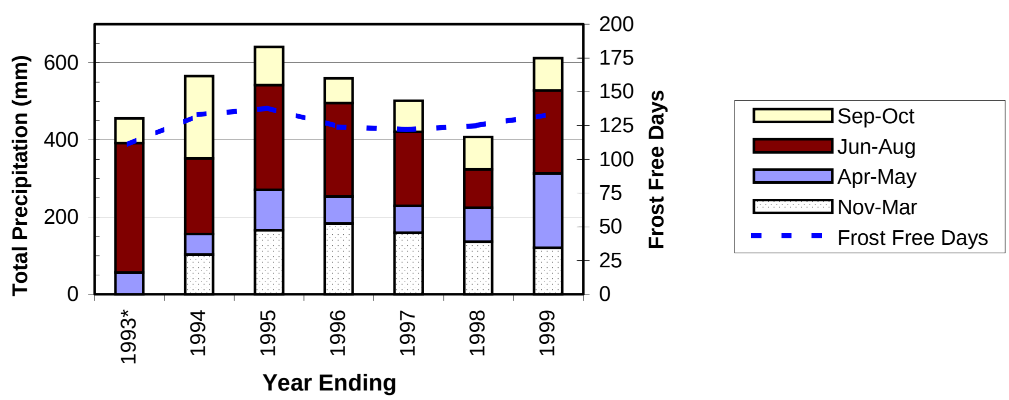

Figure 3: Frost free days (Twin Watersheds) and precipitation (Miami/ Orchard stn), STC watershed. ****1993, Nov-Mar precipitation data not available.***

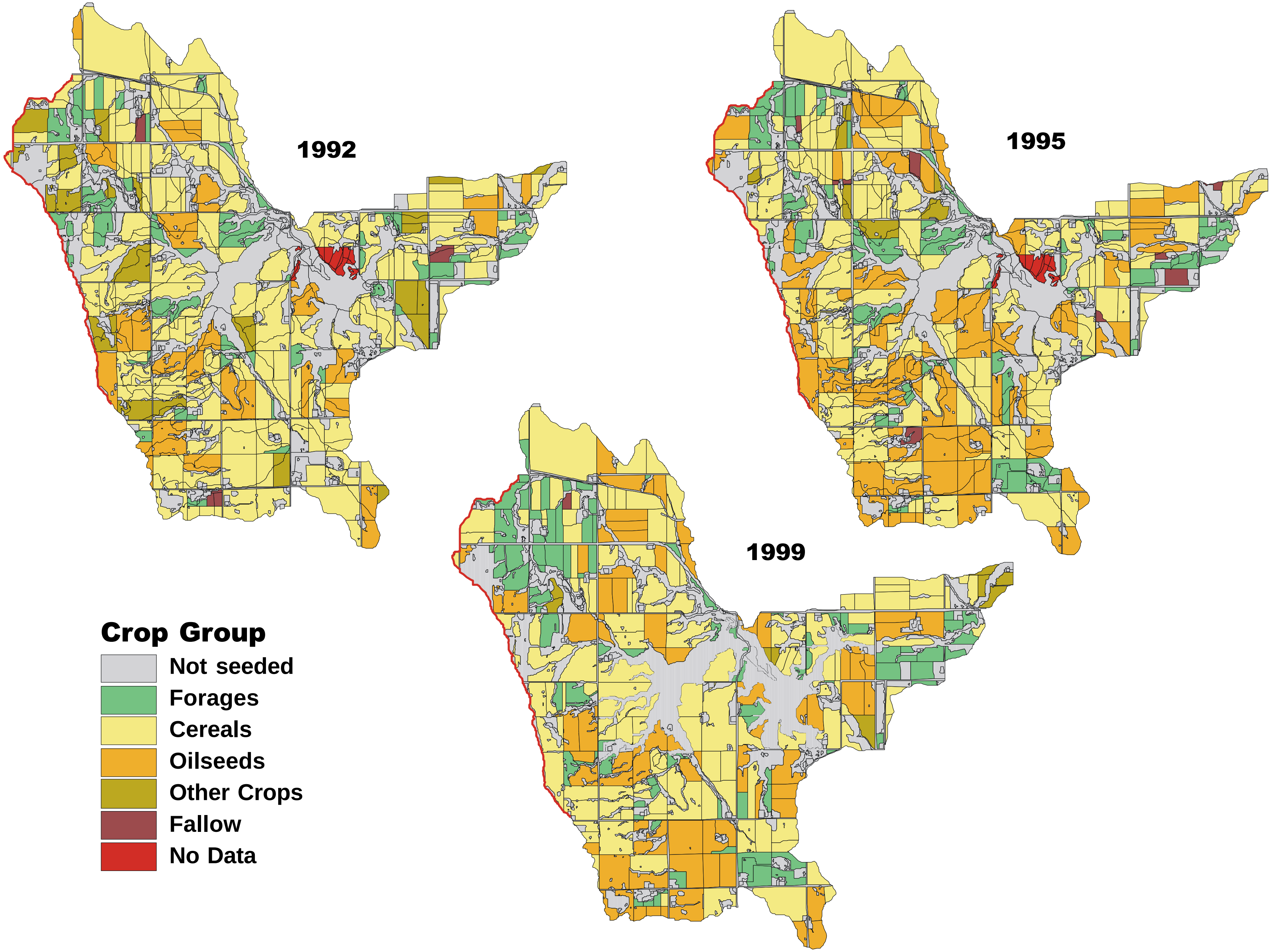

Figure 4: Crops grown, South Tobacco Creek watershed.

2.0 Literature Review

2.1 Agricultural Nonpoint Source Pollution

Agricultural activities have the potential to cause impairment of our nation's surface and groundwaters. Unlike point source pollution, which has an identifiable single point of entry into a water body, nonpoint source pollutants derive from diffuse sources (Leeds et al., 1996). For a given land management mix, the quantity of agricultural nonpoint source pollutants entering the water is largely dependent on rainfall and snowmelt runoff patterns. There is currently little consensus as to the severity and extent of water degradation by nonpoint agricultural activities. However, recent incidents such as E.Coli contamination of the water supply in Walkerton, Ontario, are evidence that water quality is at risk.

The agricultural sector can contribute to water pollution through six main categories of contaminants including: sediments, nutrients, acids, salts, toxic chemicals and pathogens. The degree to which any one of these becomes a factor in specific instances of contamination depends largely on the environmental and socioeconomic systems wherein the water body is contained. The watershed approach has been identified as the most appropriate method for addressing water stewardship.

2.2 Watershed-Based Resource Management

A watershed can be defined as a geographic area of land, bounded by topographic features that act to drain waters to a common destination (Fisheries and Oceans Canada, 2001). Watersheds are increasingly used as the foundation for assessing the health of our ecosystems, as land managers continue to recognize the environmental, economic and social benefits of managing lands to protect waterways. Watershed-based resource management is considered to be the best process of determining appropriate anthropogenic uses, modifications and protection of land and water resources (Michigan Department of Environmental Quality, 1998). The management of watersheds will vary considerably across different landscapes due to variables such as precipitation, topography, soil conditions, vegetation and economic activity.

2.2.1 Geophysical Implications

Because a watershed's geographical area is defined by naturally occurring hydrologic boundaries, it is a logical unit for the basis of natural resource management. By tracking the fate of precipitation through the processes of evapotranspiration, infiltration, and overland flow, it is theoretically possible to identify the pathways of pollutants that might accompany the water (such as nutrients and sediments). Ultimately, the delivery patterns of these materials to particular water bodies can be determined (Rouge River Remedial Action Plan Advisory Council, 1996). Analysis at the watershed level theoretically allows for the identification of stressors as well as their destinations in the system. It also provides a foundation for better determining what actions are necessary to protect or restore the resource (United States Environmental Protection Agency, 1996a).

2.2.2 Socioeconomic Implications

The process of identifying possible stakeholders in resource management issues is simplified within the watershed unit. Stakeholders may represent various sectors and interests, including: agriculture, wetland protection, forestry, tourism, waste management, air pollution, human and livestock water supplies, and wildlife habitat protection. The challenge becomes one of identifying common goals and values, both environmental and economic, and pooling resources to meet these goals (United States Environmental Protection Agency, 1996b). When alternative actions are being considered by the stakeholder group, the watershed unit provides a basis for analyzing cause - effect relationships within a well-defined system. Decisions governing use of the watershed should reflect a balancing of economic and environmental needs.

2.3 Applying the Watershed Approach

Over the past twenty years, the watershed approach has been increasingly applied and adapted to resource management issues in North America. In Canada, numerous water quality studies in the Great Lakes Basin in the 1970's provided a methodological foundation for future watershed projects (Perrone et al., 1997). Conservation districts and authorities based on watershed boundaries have also been established across Canada in recent years. Within the United States, delivery of The Rural Clean Water Program (1980) was initially a ten year project to control and manage agricultural nonpoint source pollution. The concept of this program has since been incorporated into new funding mechanisms which focus on watershed solutions to water quality issues (Meek et al., 1992).

The diversity of completed and ongoing watershed studies in North America is extensive. This is a result of variations in landscape and land use across the continent. A watershed can be classified according to its predominant ecological function such as those of a prairie or alpine nature. It can be further classified according to the primary land use within the basin such as agricultural, forestry, recreational or urban. Comparisons between studies in terms of study area, methodology and conclusions drawn must therefore be made with caution.
In terms of study methodology, the majority of watershed studies can be grouped as baseline monitoring, best management practice (BMP) or a combination of both. Baseline monitoring involves the compilation of a benchmark data set and the identification of existing land management and water quality trends. The strength of a long term baseline study lies in its ability to provide an accurate depiction of the net effect of changing (past - present - future) land management practices on water quality. This type of analysis ideally sets the stage for the introduction of BMPs.

Looking upstream on South Tobacco Creek, near the Highway 240 monitoring site.

Best management practices often form the basis of watershed-based pollution prevention studies. They involve the manipulation of given land management activities in order to assess the impact on water quality. Often, time constraints result in a lack of baseline monitoring before BMPs are implemented. Without initial baseline monitoring, it is difficult to determine if BMP implementation is necessary and, if so, the effectiveness of the specific practices applied.

The following examples are illustrative of North American experiences with baseline monitoring and best management practices within agricultural watersheds.

2.3.1 Selected Watershed Studies

Haynes Creek, Alberta

Haynes Creek watershed near Lacombe, Alberta, is a relatively small watershed (approximately 16,600 ha) chosen for an extensive monitoring study aimed at determining direct effects of site-specific agricultural activities on surface water quality. This watershed was identified as being representative of an area with high intensity mixed agriculture (grain and livestock), well-drained landscapes and being prone to water erosion processes (Anderson et al., 1998a). Study design included two years of intensive water quality sampling at

17 monitoring sites within the basin. The monitoring sites fell into one of four categories: cultivated crops, stream and tributary, cow-calf wintering, and a control site consisting of aspen and underbrush cover. Land use, including crop type, was determined using census data from Statistics Canada. Collection of other land management data was limited to specific parcels of land and included landowner supplied information regarding fertilizer use, pesticide application, tillage practices and cattle numbers. Water samples from each of the 17 sites were analyzed for nutrients, dissolved solids, bacteria, some major ions, color, turbidity and some pesticides.

Results of the study were limited by the lack of rainfall-induced run-off during the spring to fall season. During two years of water sampling, run-off occurred only during spring snowmelt (Anderson et al., 1998a). Water downstream of cattle wintering grounds contained higher concentrations and mass loads of nutrients and suspended solids than did water upstream of these wintering sites. Cultivated fields with functional grassed waterways resulted in lower levels of nutrients and suspended solids in run-off. Field losses of nitrate and phosphorus were deemed to be environmentally and economically significant. Overall, water in Haynes Creek had higher nutrient and pesticide levels than streams which drained less intensively farmed land (Anderson et al., 1998b).

Crowfoot Creek, Alberta

In response to previous studies which identified high concentrations of nutrients and coliform bacteria in the Bow River watershed of Alberta, the Crowfoot Creek watershed was selected as the location for a detailed assessment of surface water quality in relation to agricultural land management practices (Alberta Agriculture, Food and Rural Development, 2000). The Crowfoot Creek watershed covers an area of about 160,000 ha, approximately 100 km east of Calgary. Baseline water quality monitoring took place at 28 sites over a four year period (1996 - 1999). Results revealed that total phosphorus in the creek exceeded Alberta's interim water quality guidelines (0.05 mg/L) most of the time, and were highest during spring run-off. Nitrogen also exceeded guidelines, but mainly during spring run-off and rainfall events. Of the numerous pesticides monitored, MCPA, diacamba, and 2,4-D were detected frequently and sometimes exceeded irrigation water quality guidelines. Cow-calf operations in the area likely contributed to the levels of fecal coliform bacteria. Fecal coliform bacteria counts were found to exceed guidelines for irrigation water for much of the year (Alberta Agriculture, Food and Rural Development, 2000).

A <u>second study</u> related to regional land use also included the Crowfoot Creek watershed as well as the Rosebud River and Serviceberry Creek watersheds in south-central Alberta. This project created a detailed land resource and agricultural production database to help identify the relationship between land management and water quality (Beever and Marciak, 2000).

The second study involved the linkage of 1991 and 1996 Canada Census of Agriculture data to AGRASID soil landscape polygons for the area. For each of the AGRASID polygons, six themes were drawn from the Census of Agriculture data: land use; land management; livestock; conservation practices; seeding tillage practices; and weed control on summerfallow. Each theme was analyzed separately for 1991 and 1996 and a comparison was made between the two years. From this comparison, land management trends were identified. Trends were used to identify possible risk factors to water quality in the watershed as a whole, as well as within individual landscape polygons (Beever and Marciak, 2000).

A <u>third study</u> is underway (in the same geographic area) to link detailed water quality information with the land resource and production database. This will allow for an overlaying of water quality mapping with land management mapping in order to visualize the relationship between them (Madawaska Consulting, 2000).

In light of the findings from the baseline monitoring studies mentioned above, several best management practices have been implemented within the Crowfoot

Creek watershed. These include techniques such as off-stream solar powered watering systems, livestock access ramps and fencing, as well as the planting of grassed buffer strips along cropland borders and the diversion of livestock run-off onto flat cropland. The impact of these practices has not yet been formally assessed.

North Castor River, Ontario

The North Castor River sub-watershed (9,200 ha) is part of an ongoing study within the larger South Nation River watershed which drains an area of 390,000 ha in eastern Ontario. The study involved testing of the Agricultural Non-Point Source (AGNPS) computer model. The North Castor River is used for a variety of purposes including drinking water supply, livestock watering, crop production and recreation. Given that the North Castor sub-watershed is characteristic of the larger watershed (in terms of soils, landscape and land management techniques), it was chosen as the site for initial application of the computer model. The goal was to assess the model's ability to predict water quality response to land use change (South Nation Conservation, 2001). The model predictions will ultimately contribute to water quality management in the watershed.

In order to calibrate the AGNPS model to the sub-watershed, data was collected over a two year period and included information regarding land use, topography, soils, precipitation, temperature, and water quality. Once calibrated, AGNPS was used to identify areas within the watershed that were contributing to high nitrogen, phosphorus and sediment loading in surface waters. The model's identification of pollution-producing areas was verified through first hand knowledge of local landowners. These areas became the focus of model simulations that considered the effect of various land use change scenarios on water quality. Such scenarios included:

- existing land use (no change)
- implementation of best management practices (BMP) - such as bank stabilization, manure storage and handling, reforestation, reduced fertilizer and pesticide use
- a 25 percent increase in forest cover
- a 25 percent reduction in fertilizer application
- an increase in urban area by 25 percent.

Effects on run-off, sediment yield, and N and P concentrations resulting from a single 3.8 cm (1.5 inch) rain storm were modeled for each scenario.

Initial model predictions were contradictory. The model has been revised and is being re-run. New results are pending. These will be used to focus watershed management efforts within the North Castor River sub-watershed. The AGNPS model will also be used to project water quality scenarios within the entire South Nation River watershed.

St. Alban's Bay, Vermont

The St. Alban's Bay watershed study represents an example of the numerous studies which took place in the United States under the Rural Clean Water Program. Its methodology is indicative of the best management practice approaches that have dominated watershed management in the United States over the past twenty years.

Naturally wooded escarpment with hayland in the foreground, South Tobacco Creek watershed.

The St. Alban's Bay watershed drains about 13,000 ha of agricultural, forested and urban land into the St. Alban's Bay of Lake Champlain. Agriculture is the main land use in the basin and is dominated by dairy farming. Corn is the principal cultivated crop, although hayland occupies approximately 35 percent of the watershed (Meals, 1992a). Eutrophication resulting from nonpoint source contamination had been a problem in the bay for years. Nonpoint sources included sediment from cropland erosion and run-off from animal and milkhouse waste.

The study took place over an eleven year period (1980 - 1991) and involved the tracking of annual land management activities and weekly water quality sampling, with the intent to correlate the two. Land management monitoring included livestock numbers; type and time of manure application; crop type and location; type, time, and amount of fertilizer and pesticide applied; type of milkhouse and effluent disposal techniques; and drainage type and location. Best management practices in the form of improved animal waste systems and goals for animal units, nitrogen and phosphorus applications were implemented within the initial four years of the study. Water samples were analyzed for turbidity, total suspended solids, total phosphorus and nitrogen and fecal coliform bacteria. Because monitoring and BMP implementation began concurrently, clearly defined pre and post treatment periods did not exist. Therefore trends over time provided only a proxy for evaluating changes in water quality (Meals, 1992b).

Study results indicated that stream nutrient concentrations did not change significantly in response to changes in land management. Similarly, water quality was not clearly correlated with either cropping patterns or manure management. However, bacteria counts in the water appeared to relate to animal density.

2.3.2 Underlying Trends in Studies Reviewed

Variations in watershed management studies over the past twenty years have been such that direct comparisons between them can be extremely difficult to make. However, similarities often exist in the conclusions drawn and recommendations made for future water quality improvement efforts.

Due to the annual nature of land management activities and the variable precision in landowner data collection, water quality data is often aggregated to annual values to compare it with land management data. Aggregating data to annual values is a limiting factor in many studies attempting to correlate land management with water quality, since the sophistication of possible statistical analyses thereby diminishes (Meals, 1992a).

A second limiting factor amongst watershed studies is the lack of control and accounting for hydrologic and climatic variation. It is often speculated that temporal and spatial variations in loading values are due at least partially to variables such as stream discharge. In some cases it has been suggested that loading concentration variability is more closely correlated with hydrologic variation than with changes in land treatment (Anderson et al., 1998b). Given that all variables other than land treatment are constant, a twin watersheds approach is meant to alleviate this lack of control over hydrologic and climatic variation. It may also be necessary to include monitoring of in-stream influences such as soil interactions and pollutant transport mechanisms as part of an effective water quality analysis (Meals, 1992a).

Where time constraints often result in little or no baseline monitoring prior to the introduction of BMPs, it becomes extremely difficult to identify cause and effect relationships between water quality and land treatment practices. As well, where several BMPs are simultaneously introduced, their individual impacts on water quality become confounded.

3.0 Methods

3.1 Collecting Land Management Information

Detailed annual land management information was recorded by all landowners for each field under their control from 1991 to 2000, however most of this analysis excludes 2000 data. Land management information included:

- **crop type:** seeding date; type of seeding equipment.
- **chemical fertilizer application:** type (N,P,K,S); date and rate of application; application method (seed placed, broadcast, spring or fall banded).
- **manure application:** method, rate and date. (Note: No analysis of this data)
- pesticide application: type of formulation; date and rate of application.
- **harvest date**
- **straw management:** chopped, burned, or baled.
- **spring and fall tillage:** equipment used; number of operations.

In addition to the land management information, crop residue measurements were taken annually on select fields, upon completion of spring tillage and seeding operations. This was done using the line-transect method, wherein a 25 foot rope with marks at one foot intervals, acted as the measuring device. Percent residue cover was measured by counting the number of marks on the rope that were directly over plant pieces of at least 1.9 cm in length. Total percent of residue cover was obtained by measuring four separate field transects and adding together the individual qualifying counts.

Field information for all data sets (crop grown, chemical fertilizer applied etc.) was compiled and analyzed using ArcView GIS mapping software. Further analysis of annual land management patterns employed Excel spreadsheet capabilities. All data was aggregated to annual values to allow for consistent comparisons between trends. In future analysis of seasonal land management and water quality relationships, seasonal, rather than annual totals, will be reviewed.

3.2 Water Quality Sampling

Regular runoff monitoring and water quality sampling (1992 - 2000) occurred at two gauging stations on South Tobacco Creek, and at the Twin Watershed site **(Figure 1)** as follows:

- **Highway 240 site** (drains the upper 3,403 ha of the watershed): sampling on an event-driven basis by a water level recorder and an automatic sampler; grab sampling during short-term runoff events
- **Miami site** (entire 7,638 ha of the watershed): sampling on an event-driven basis through the use of a data logger, depth sensor gauge and automatic sampler; grab sampling every 2 weeks during low stream flow and more often during short-term runoff events
- **Twin Watershed site** (drains 9.8 ha): automated sampling on an event-driven basis through the use of a data logger, depth sensor gauge, and water sampler; grab sampling during short-term runoff events

Other sampling locations included an upper-basin, pristine (natural wooded) site, and flow-event grab samples in the upper reaches of the creek. Water samples were analyzed, using standard Environment Canada procedures, for a variety of parameters including:

- non-filterable residue (sediment)
- dissolved and particulate phosphorus
- dissolved and particulate nitrogen
- nitrate; ammonia, ionized ammonia
- dissolved and particulate organic carbon
- bicarbonate, total dissolved solids, pH, conductivity
- calcium, magnesium, potassium, sodium
- fluoride, chloride, silica, sulfate
- pesticides (1993 - 1996 only).

Concentrations for major sampling parameters were integrated with stream flow data to determine preliminary sediment, nutrient, and other loadings in the creek (Ross, 1999). Under a separate study, pesticides were routinely monitored and analyzed from 1993 to 1996 only. Concentrations were recorded for the four major herbicides used in the basin: 2,4-D; dichlorprop; MCPA and bromoxynil, as well as for other limited testing. Water quality findings for pesticide content have been published separately (Rawn, 1995).

4.0 Results

4.1 Cropping Patterns

Annual cropping patterns were tracked in order to identify the primary crops being grown, as well as overall cropping trends in the basin. A crop rotation analysis was completed to identify the primary rotation for cultivated crops and to determine if there was any shift in rotation trends over time. Forage production was also considered, focusing on changes in total area and location over time.

4.1.1 Primary Annual Crops

Primary annual crops include: spring wheat, canola, flax and barley **(Figure 5)**, based on their percent of the total area (5,409 ha) under cultivation in the basin. On average (1991 - 1999), 38 percent (2,060 ha) of total cultivated hectares were seeded to spring wheat, although annual wheat production fell off considerably from a maximum of 2,900 ha in 1992 to a minimum of 1,200 ha in 1998. Canola production cycled significantly, ranging from 450 ha to 1,600 ha, and accounted for an average of 19 percent (1,000 ha) of the total cultivated area. Both flax and barley production gradually increased between 1991 and 1996, each making up only about 10 percent on average of the cultivated area.

Inverse trends in number of seeded hectares were exhibited for wheat and canola production throughout the nine year period, albeit a significant decline in overall wheat hectares accompanied a fairly consistent fluctuation in canola production over time. Barley and flax production increased threefold, though total increases for each (about 450 hectares) were quite small. Flax production peaked in 1995 at 780 hectares and has declined since then. Manitoba's provincial cropping trends (not shown) for wheat, canola, barley and flax were roughly similar, though with less dramatic fluctuations.

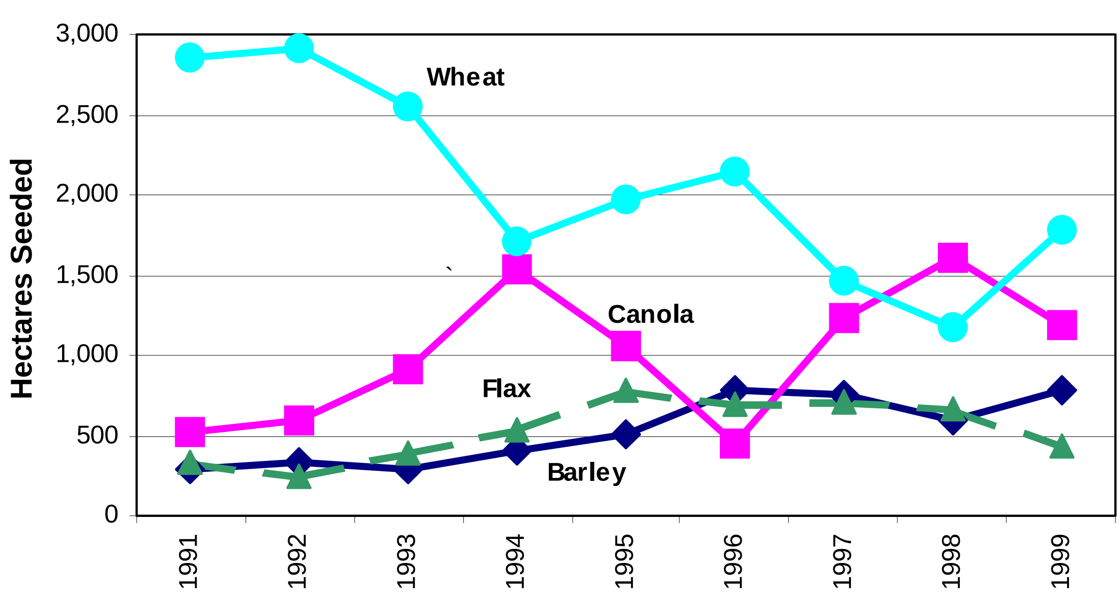

Figure 5: Wheat, canola, flax and barley area, South Tobacco Creek watershed.

Changes in cereal grain production trends closely coincided with shifts in crop prices **(Figure 6)**. For example, overall wheat

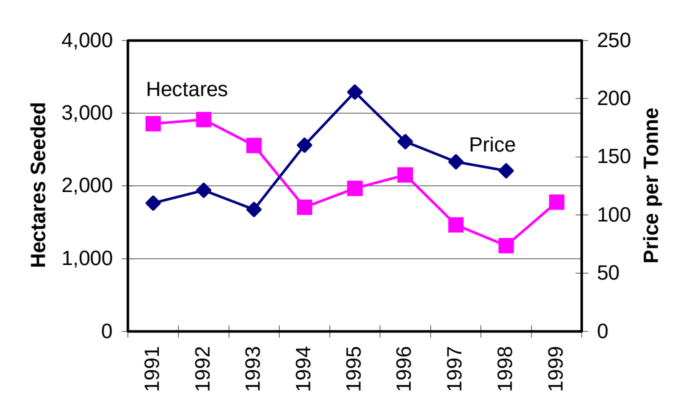

Figure 6: Wheat area and price, STC watershed.

production increased in 1995 and 1996, with crop choices appearing to reflect the previous year's prices during the same period, and perhaps thereafter. In contrast, canola production dropped dramatically during the 1995 - 1996 period, despite stable canola prices approaching $397 per tonne **(Figure 7)**. Cereal production typically

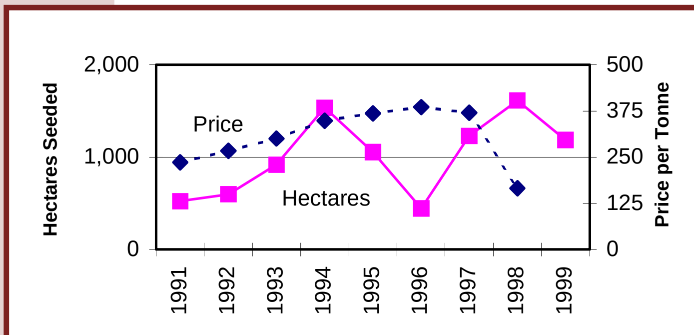

Figure 7: Canola area and price, STC watershed.

involves less risk than growing canola. Hence, rising cereal prices, in combination with reduced risk, may explain the shift from canola to cereals despite maximum canola prices. Other explanations for the decline in canola production may include an infestation of army worms that occurred from 1995 - 1996, and a need to break the cycle of steadily increasing canola hectares from previous years.

In 1997 and 1998, both wheat and barley production declined as had their prices in the previous years. In contrast, canola production escalated to almost 1,600 hectares by 1998 in keeping with increasing prices from the year before, thereafter falling as the price dropped substantially by 1998. Independent of crop price, the introduction of Round-Up Ready Canola may have also had an influence on the increased area planted.

Analysis of crop rotations was based on annual hectares of wheat, barley, canola and flax, and the probability of one crop being followed by each of the other crop types in subsequent growing seasons. Generally, producers in the basin appeared to follow a cereal - oilseed rotation. However, it was evident that market prices influenced production decisions and sometimes resulted in cereal - cereal or oilseed - oilseed rotations. Wheat stubble was predominantly sown to canola. The exception occurred in 1996 when canola production dropped dramatically. Wheat, barley and flax were almost evenly distributed on wheat stubble during 1996. Although there were some cereal - cereal rotations within the basin, preference for a wheat - canola sequence appeared to increase toward the end of the monitoring period. Canola stubble was primarily seeded to cereals each year. In less than one percent of cases was canola grown on canola. Typically, barley stubble was sown to canola, however an exception occurred in the spring of 1996 when almost 70 percent of the barley stubble was seeded back to barley. This may be explained by a dramatic increase in barley prices in 1995 (not shown) and the reduced risk associated with growing barley in comparison to canola.

4.1.2 Forage Production

The location of the South Tobacco Creek watershed within an upland (escarpment) landscape, is associated with erosion-prone and otherwise sensitive agricultural land. Forage (non-native pasture) hectares included cultivated lands designated as alfalfa, legume-grass mix (forage), hay (grass only) and pasture. On average, forage accounted for about 12 percent of the total cultivated area. Though representing a relatively small portion of the basin, total forage production increased steadily, doubling from approximately 490 hectares in 1991 to 890 hectares in 1999 **(Figure 8)**. An analysis of the location of forage production

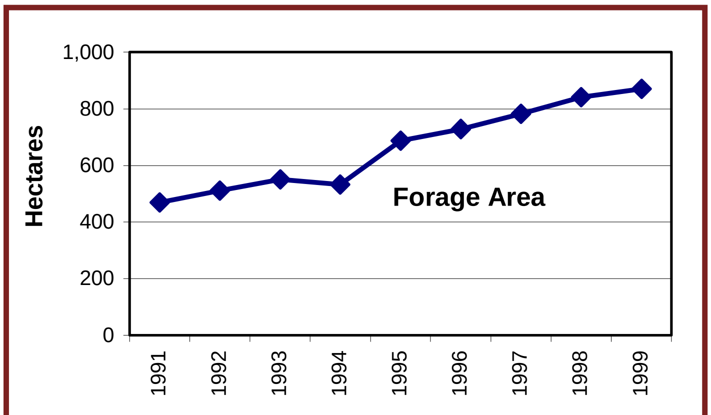

Figure 8: Forage production, STC watershed.

area in the basin was completed to determine if landowners might be employing the strategic placement of forage as a means of runoff erosion control. However, the location of new forage fields did not appear to coincide with proximity to drainage channels or possible run-off erosion control practices. Rather, proximity to other forage fields (perhaps originally established on sandier soils) prone to wind erosion seemed to be the dominating factor in the location of new forage fields. Cattle production needs may have largely influenced a landowner's decision to produce forage.

4.1.3 Preliminary Water Quality Implications

Relationships between crops grown and specific water quality parameters will be determined as a subsequent part of this study. However, it seems that certain events within the monitoring period might be strategic opportunities for assessing relative land management impacts on water quality. For example, canola production typically requires higher nutrient and pesticide inputs, therefore stream loadings during or following a season of high canola hectares may reflect increased use of nutrients and pesticides. The possibility of increased silt loading during canola production also exists due to the decrease in residue cover associated with land seeded to canola.

An increase in forage area is likely to reflect an increase in cattle production in the basin or off-site hay sales, and may point to both potential positive and negative impacts on water quality. Again, such impacts may well be evident only in seasonal rather than annual trends, and may be contingent on the location of sampling sites.

4.2 Chemical Fertilizer Application

The objective of the chemical fertilizer tracking component of this study was fourfold:

- to determine trends in total agricultural applications in the watershed
- to identify trends in application techniques
- to relate fertilizer trends to annual crop production
- to set the stage for examining possible relationships between fertilizer application and water quality in South Tobacco Creek.

The four main fertilizer nutrients being applied were nitrogen, phosphorus, potassium and sulphur. Landowners provided information on the rate, method and date of application. Methods of application included broadcasting, spring banding, fall banding and seed-placement during planting. Various factors such as cash flow, precipitation, crops grown and previous experiences, influence the land manager's choice of application method. Broadcast applications allow for greater flexibility in timing of application, whereas seed placement tends to enhance the efficient use of the fertilizer.

4.2.1 Nitrogen Applied

On average, spring applied N increased by 17 percent over the years, from a low of approximately 276,000 kg in 1993 to applications approaching 330,000 kg near the end of the monitoring period **(Figure 9)**. Maximum N application was approximately 350,000 kg in 1994.

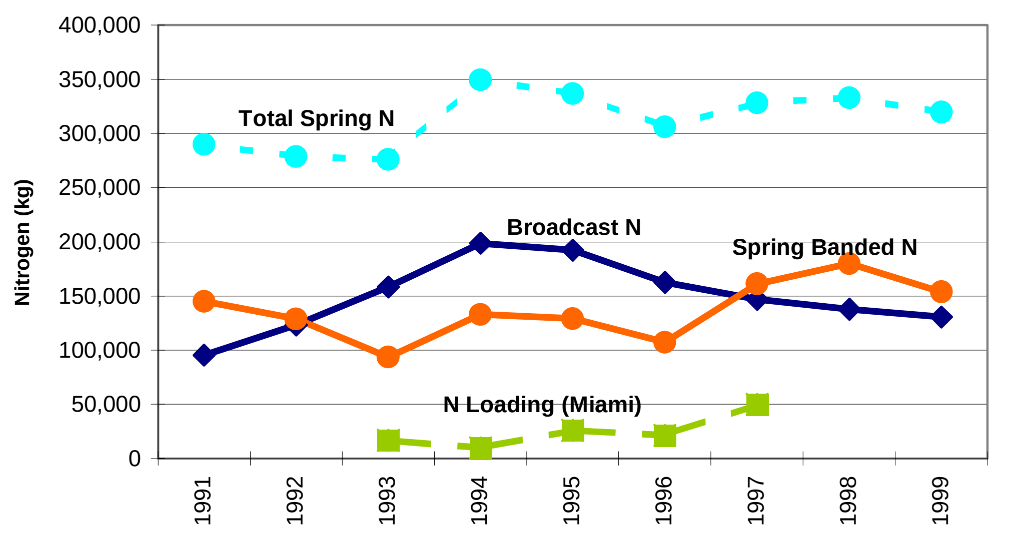

Figure 9: Nitrogen fertilizer application, and N stream loading at Miami station, South Tobacco Creek watershed.

Broadcast N represented the most common form of N application (95,000 - 199,000 kg) but this was equaled or exceeded about half the time by spring banded applications. Seed-placed and fall banded N (not shown) accounted for a small portion of total applications. All broadcast, fall banded and spring banded N were applied at similar rates of approximately 72 kg/ha, with seed-placed application rates being much lower (12 kg/ha). A comparison of Figures 5 and 9 reveals that canola production and total spring N shared a similar trend over time. Being a high input crop, greater canola hectares are associated with an increase in annual nitrogen use.

Preliminary Water Quality Implications

A cursory attempt was made to correlate annual N loading for South Tobacco Creek (1993 - 1997) with N application, based on published findings (Ross, 1999) for water samples from the Miami sampling station **(Figure 9)**. A direct long term correlation between stream loading and land application was not evident. Assuming all stream loading was due to fertilizer N (a gross assumption), stream loading during most years averaged six to eight percent of applied N and might have varied in proportion to total spring N applied (i.e. six percent in 1993; eight percent in 1995; seven percent in 1996). There are, however, two significant exceptions in the five year time line. In 1994 when basin N application was at a maximum (350,000 kg), annual stream loading was at a minimum of applied N (three percent). As well, in 1997 when annual stream loading was at its maximum (twice the previous year), fertilizer application had not increased appreciably over the previous year **(Figure 9)**.

Water quality studies elsewhere indicate that nutrient loading may be more closely related to stream discharge than to land management practices (Anderson et al., 1998b). This was likely exemplified in 1997 when a heavy spring snowfall created high flow conditions in the stream. In the absence of increased fertilizer application, total annual N loading at the Miami station increased dramatically during the year.

In order to effectively incorporate hydrologic variability into future nutrient loading analysis, a comparison of seasonal storm-event loadings and relationships is being undertaken.

4.2.2 Phosphorus Applied (P_2O_5)

The amount of total spring-applied P (P_2O_5) has also increased by about 17 percent over the years, from a low of approximately 100,000 kg in the early 1990's to applications reaching 120,000 kg by the late 1990's **(Figure 10)**. Maximum applications of 123,600 kg were recorded in both 1994 and 1998.

As with N, similar cost and cropping factors influence the method of P application. Seed-placed fertilizer represented the largest portion (average of 63,000 kg) of P applied in the basin, with the remainder made up of broadcast and spring banded P. A minimal amount of P was applied through fall banding in most years (not shown). Application was generally at rates of approximately 30 kg/ha. Years of highest total spring applied P generally corresponded with those of higher canola hectares **(Figures 5, 10)**.

Preliminary Water Quality Implications

A correlation between total spring-applied P and annual P loading at the Miami station may have existed but with similar exceptions to those already noted under the analysis of N loading **(Figure 10)**. For example, assuming all stream loading was due to fertilizer P (again, a gross assumption), and reducing P_2O_5 to actual P applied, during most years total stream loading might have averaged as much as six to nine percent, even eleven percent, of soil-applied P. An exception occurred in 1994, when maximum P fertilizer application neared 124,000 kg yet annual stream loading was at its lowest (three percent of applied P), clearly indicates that other factors influence stream loading. Hence, seeking to directly relate soil-applied P to stream loading is overly simplistic.

A future evaluation of seasonal P loadings at specific locations along the stream may reveal a relationship between soil-applied P and P loading to the stream. However, P loading in streams of this nature may be more directly governed by in-stream channel erosion than by agricultural run-off (Ross, 1999). As with N loading in 1997, P loading was strongly affected by increased precipitation in the spring. This reflects the powerful influence that hydrologic variability can have on stream nutrient loading. In general, N and P loadings to South Tobacco Creek fell within the normal range for streams located within rural cropland areas (Ross, 1999).

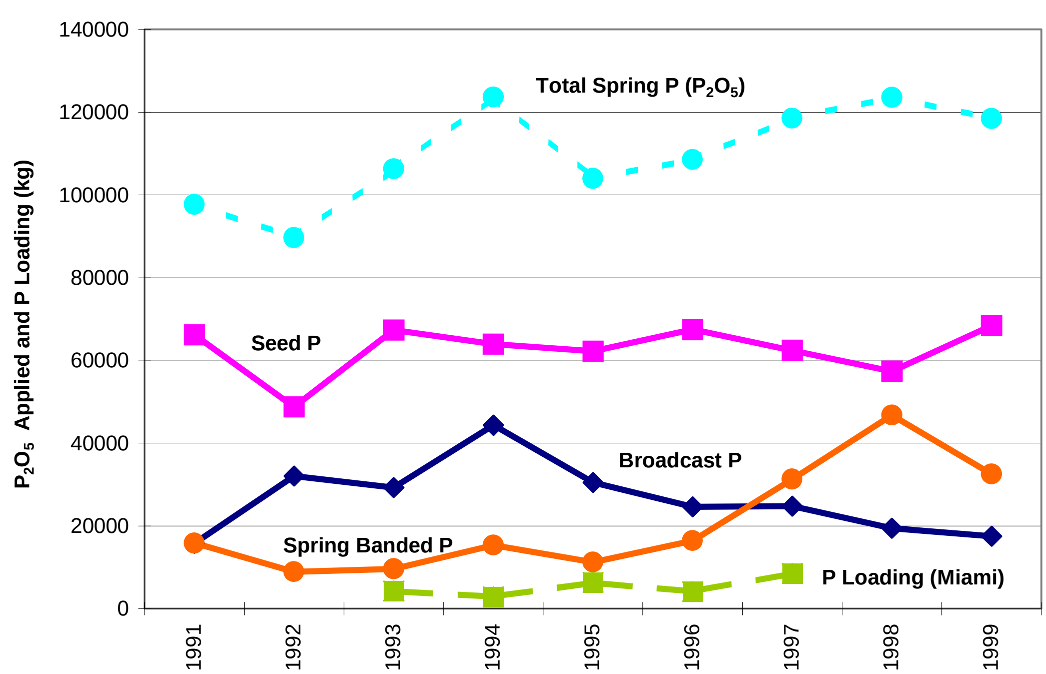

Figure 10: Phosphorus application, and stream loading at Miami station, South Tobacco Creek watershed.

4.2.3 Potassium and Sulphur Applied

Compared to N and P applications, total spring-applied potassium (K) was low (5,000 - 29,000 kgs) for all years **(Figure 11)**. As K is not generally a limiting nutrient in prairie soils it was applied to only a small portion of the basin, ranging from 300 ha in 1991 to three times that area (950 ha) in 1997. Seed-placed and broadcast K were at similar levels during the first half of the decade but seed-placed K increased dramatically in 1997. Fall banded K (not shown) represented a very small portion of total K applied.

Total spring sulphur (S) applications were in a similar range (6,000 - 36,000 kg) to that of K applications, but only a tenth and a third of N and P applications respectively **(Figure 12)**. Broadcast S represented the largest portion of the chemical applied in the basin. Total spring S and broadcast S patterns very closely resemble the canola production curve for the basin **(Figures 5 and 12)**. Fall banded applications (not shown) were minimal in all years.

No attempt was made to correlate either K or S applications with nutrient loading in the creek. Implications for water quality are unknown.

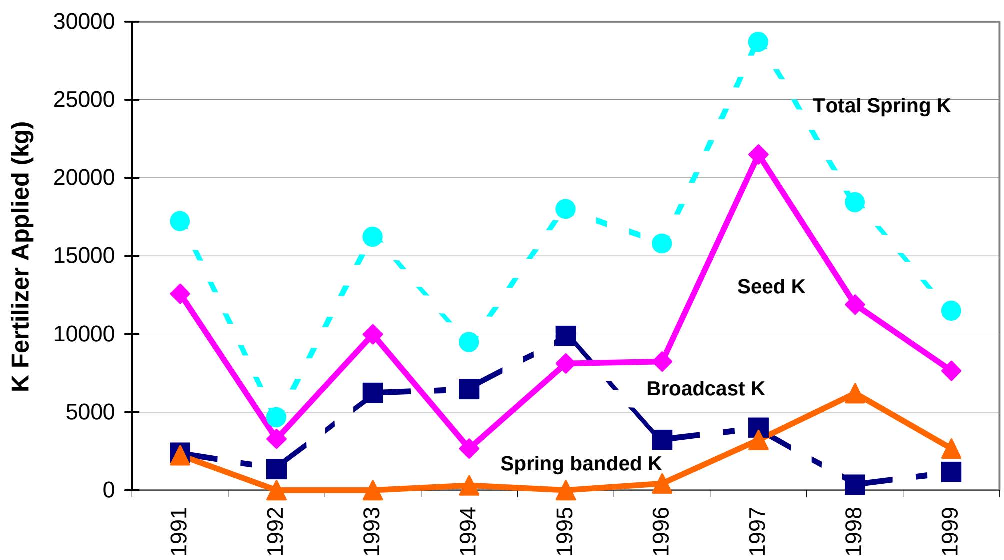

Figure 11: Potassium application, South Tobacco Creek watershed.

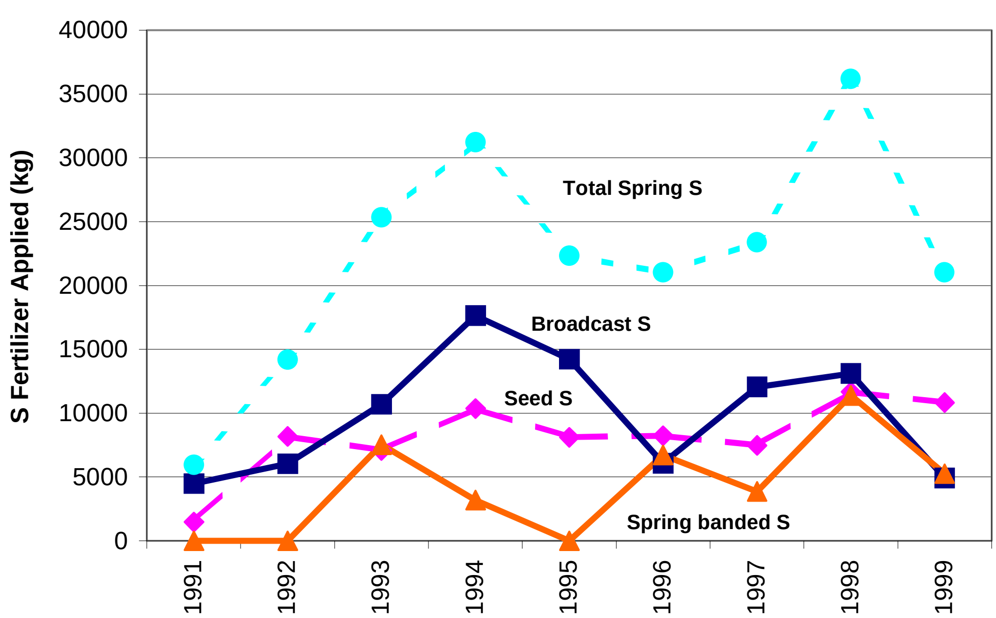

Figure 12: Sulphur application, South Tobacco Creek watershed.

4.3 Pesticide Application

Pesticide (herbicide, insecticide, and fungicide) use was analyzed in order to:

- determine trends in total annual application in the watershed
- identify trends in the relative use of various active ingredients
- relate the application of pesticides to crop production

The pesticide analysis was based on 'active ingredient' to avoid confusion with changes in pesticide product names. The analysis focused on the nine commonly used active ingredients in the basin. Landowners recorded the rate (litres or kilograms per acre) and date of pesticide application.

4.3.1 Active Ingredients

Pesticide use is influenced by factors such as crop choice, product price, precipitation and pest populations. Total use of the nine most commonly used active ingredients rose gradually over the monitoring period **(Figure 13)**. Three active ingredients - MCPA (839 kg annual average), glyphosate (420 kg annual average), and 2,4-D (416 kg annual average) - made up the majority of the nine active ingredients analyzed, and so governed the curve for total pesticide use. Curves for MCPA and 2,4-D use have been combined. MCPA applications dominated throughout the monitoring period while 2,4-D use was static to declining slightly. These two active ingredients belong to a larger group known as 'growth regulators'. MCPA and 2,4-D use roughly corresponded with wheat production, as both wheat hectares and growth regulator use fluctuated similarly throughout the monitoring period.

Glyphosate is the active ingredient found in the pesticide commonly known as Roundup®. During the monitoring period, glyphosate use increased, with applications approaching 900 kg annually in 1998. Canola production was at a maximum during this period but had been nearly as high in 1994 **(Figure 13)**. This latter correlation between glyphosate applied and canola hectares may have been partially due to the introduction of Roundup Ready Canola®, as well as the decreasing price of Roundup®. The remaining six active ingredients included bromoxynil, dichlorprop, sethoxydim, ethafluralin, benomyl and tralkoxydim **(Figure 14)**. All applications of these ingredients, with the exception of benomyl in 1998, were below 500 kg annually. Tralkoxydim (enzyme inhibitor) applications were highest in 1992 at approximately 400 kg and then diminished significantly thereafter. Benomyl (fungicide) was not used in the first half of the monitoring period, and peaked at 570 kg in 1998. Bromoxynil use was fairly consistent over the years. Applications of the remaining active ingredients varied from year to year.

4.3.2 Preliminary Water Quality Implications

Pesticides in the water were monitored and routinely analyzed from 1993 to 1996 only (Rawn, 1995). Temporal concentration trends were determined for the four main residual herbicides used in the basin: 2,4-D, dichlorprop, MCPA and bromoxynil. Glyphosate generally degrades very quickly thus it was not monitored or measured as part of the water quality study. It was determined that stream water concentrations of these herbicides were highest during local crop application periods. Spring melt and run-off waters tended to have higher concentrations of herbicides when there had been no run-off during the previous fall. However, in-stream pesticide concentrations were rapidly reduced to below detection levels, and concentrations were always well below Canadian guidelines for the protection of aquatic organisms and generally below the more stringent European standards. A more complete analysis of the relationship between pesticide applications and stream loadings is planned.

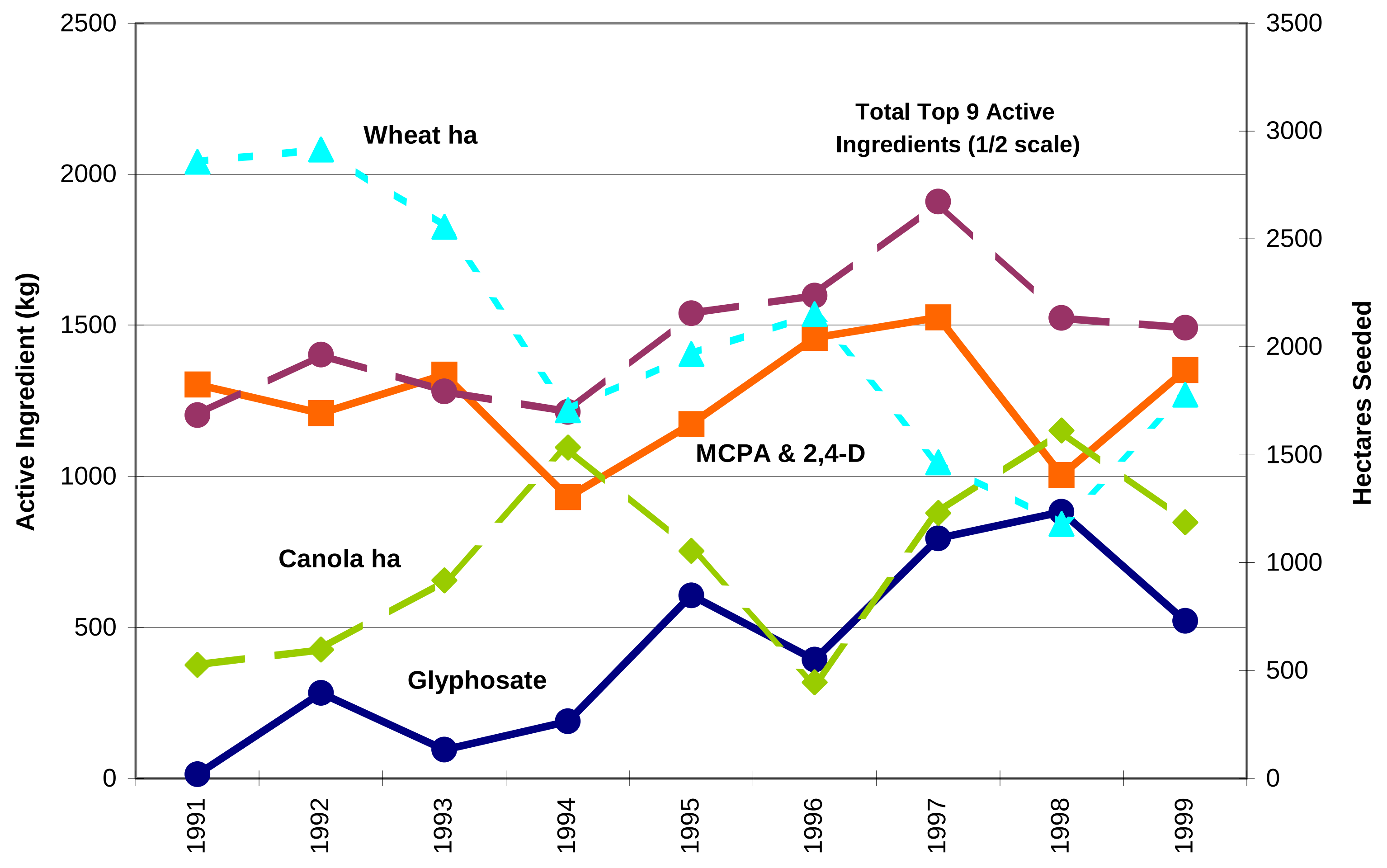

Figure 13: Relating active ingredient use to crop production, South Tobacco Creek watershed.

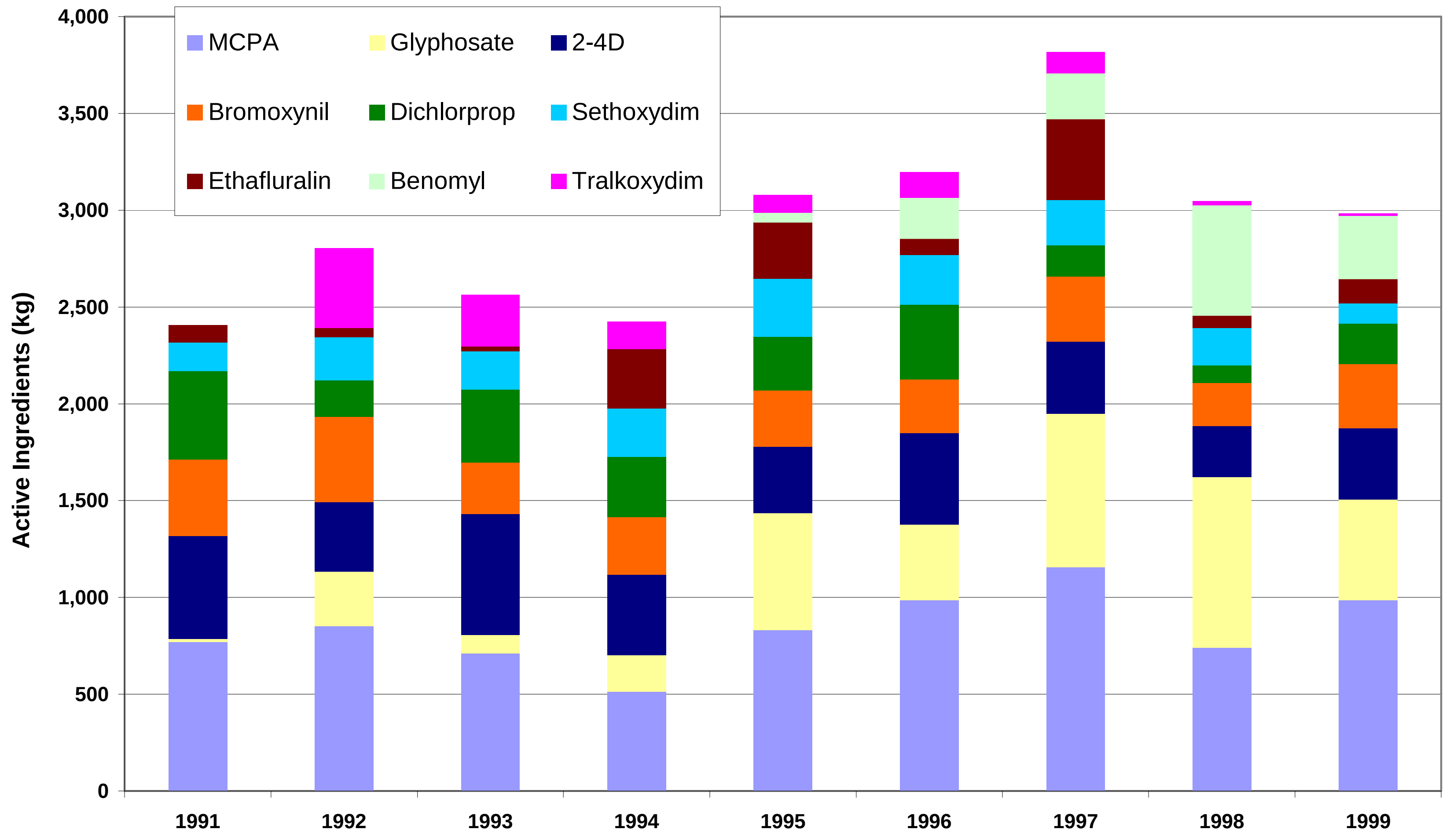

Figure 14: Pesticides - top nine active ingredients, South Tobacco Creek watershed.

4.4 Straw Management

Straw management practices were tracked as an indicator of residue cover and the potential for excessive run-off and erosion. Straw management trends and factors which may have influenced the landowners' choices were considered. Straw management categories included: baling, burning (of swaths, partial burning, the entire field) and straw chopping.

4.4.1 Straw Management Trends

Straw chopping and baling were the two most prevalent types of straw management. Chopping occurred on approximately 57 percent (3,090 ha) of the cultivated area, fluctuating by roughly 800 ha over a five year period **(Figure 15)**. On the other hand, baled hectares increased steadily from approximately 400 ha in 1992 to 1,600 ha in 1997 and then declined to about 1,000 ha by 1999. Chopping and baling trends are consistently the inverse of one another, indicating they are substituted for each other, however chopped hectares were always the greater of the two.

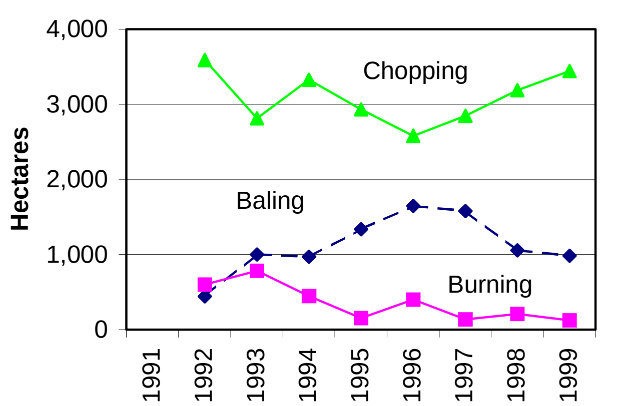

Figure 15: Straw management, STC watershed.

Total straw burning accounted for only about six percent (340 ha) of cultivated hectares on average, with the vast majority (330 ha) being swath burning. Straw burning declined steadily throughout the monitoring period, from a maximum of about 800 ha in 1993 to only 120 ha in 1999 **(Figure 15)**.

4.4.2 Factors Influencing Straw Management

Straw management practices did not clearly correspond with the production of any one crop type, but did reflect combinations thereof **(Figures 5, 15)**. The rise in the curve for baled hectares corresponded to the combined total of flax and barley increases - wherein the majority of each of these crops would have been baled. Some wheat straw was also baled, but as hectares of straw chopping nearly equate to total wheat plus canola hectares, amounts are minimal. Most wheat and canola straw is being chopped and spread for later incorporation into the soil.

Other factors might have a lesser influence on trends in baled hectares. These include a slight increase reported in basin cattle numbers (not documented) - hence the need for more baled feed and bedding. As well, annual variability in weather will affect the number of hectares required to obtain the same number of bales—depending on amount and timing of precipitation, as well as total heat units, hence total straw biomass production. In some areas, straw is marketed for straw board production, but South Tobacco Creek is outside the designated distance to the nearest processing plant and straw was not being sold for that purpose.

4.4.3 Crop Residue

Residue measurements were completed annually on a select number of fields representing high and low residue cover. However, the number and location of fields sampled were not consistent over the years. In view of this limited set of field measurements, a modeling procedure was used to estimate residue cover on all fields. But calibration of model estimates using the limited field measurements was ineffective, and the analysis was terminated. Hence, results of the straw management and tillage practice analyses were used as secondary indicators of the potential for soil erosion.

4.4.4 Preliminary Water Quality Implications

Given that straw baling results in reduced residue cover, the possibility exists that increased baling will lead to increased sediment loading to the creek. In order to evaluate possible relationships, spring sediment loading for specific reaches of the creek will need to be compared to the amount of baling on selected fields during the previous season. The amount and intensity of snowmelt, precipitation and run-off prior to crop emergence, and field slope and proximity to watercourses will also be factors. An evaluation of seasonal loading data and specific field management practices will be required to establish such residue management - water quality relationships.

4.5 Tillage Practices

Fall and spring tillage practices were tracked on wheat and canola stubble as secondary indicators of residue cover (in addition to straw management). Trends relate to the principal types of tillage used—a heavy duty cultivator in the fall, and a light duty cultivator in the spring. Trends are in terms of total seasonal area treated, and number of tillage operations.

4.5.1 Fall vs. Spring Tillage

In the fall, on average, 85 percent of wheat stubble was tilled with a heavy duty cultivator **(Figure 16)**. A modest increase in total hectares tilled occurred towards the end of the monitoring period. The amount of land receiving one operation (with a heavy duty cultivator) appeared to decline slightly over time, while the two-operation area nearly doubled to 31 percent of wheat hectares. Shifts in number of tillage operations are largely dependent on seasonal factors such as timing and amount of precipitation. Most fall canola stubble (85 percent) was also tilled with a heavy duty cultivator (data not shown), with the total area tilled increasing minimally over time. Modest amounts (less than 15 percent) of wheat and canola stubble did not receive fall tillage.

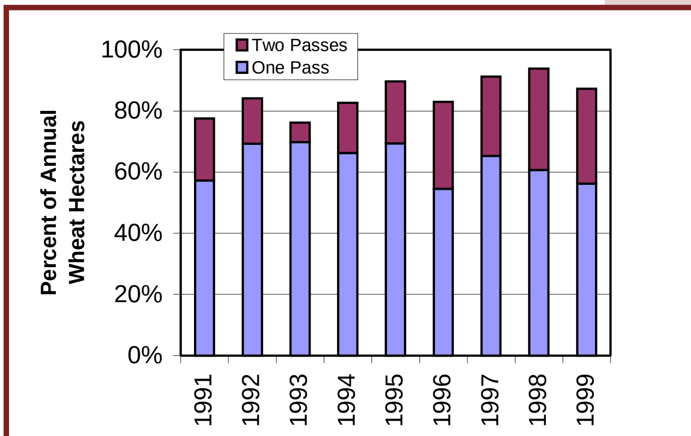

Figure 16: Fall tillage of wheat stubble, heavy duty cultivator, South Tobacco Creek watershed.

In the spring, on average, 82 percent of wheat stubble was tilled with a light duty cultivator **(Figure 17)**, and the area tilled declined towards the end of the study. No apparent trends exist in the number of first and second tillage operations over time, however landowners seem to have eliminated a third operation from their tillage operations. Light duty cultivation also occurred in the spring on most (75 percent) canola stubble (data not shown). The total area tilled remained relatively constant over the monitoring period and despite two years (1998 and 2000) of reduced tillage, no downward trend is clearly apparent.

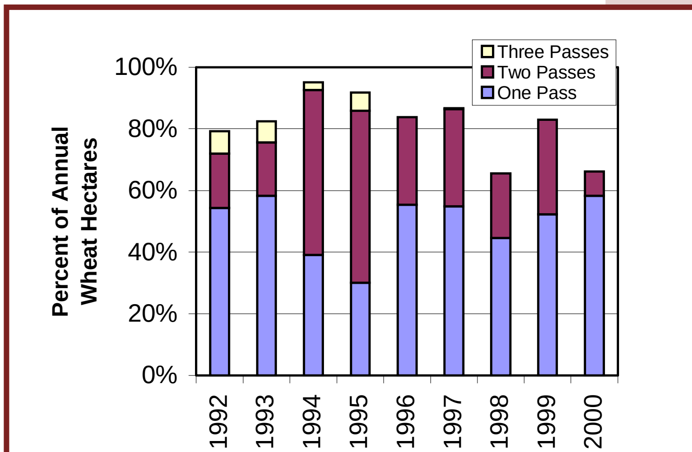

Figure 17: Spring tillage of wheat stubble, light duty cultivator, South Tobacco Creek watershed.

4.5.2 Untilled Land, Reduced Tillage

On average, only modest amounts of wheat stubble were not tilled in the spring (14 percent), or fall (9 percent; **Figure 18**). Results for canola stubble were similar. The area of wheat stubble remaining untilled in the fall dropped to below five percent in the last half of the study, while the amount of untilled spring stubble fluctuated widely during the same period.

Zero tilled (no-till) lands are stubble hectares which consistently remain untilled after harvest and are not tilled before seeding in the subsequent spring. A detailed analysis of the number of individual fields meeting this criteria was considered unnecessary, as trends in tilled and untilled land **(Figures 16 - 18)** clearly do not support a shift towards zero tillage in the watershed.

Results from the tillage analysis on wheat stubble may point to a reduction in total area tilled and reduced number of tillage operations in the spring only. Similar trends do not apply for canola stubble.

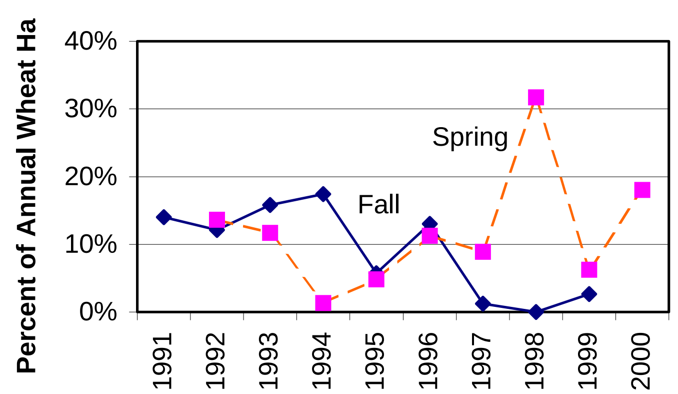

Figure 18: Seasonal untilled* wheat stubble, STC watershed. ****Untilled - not tilled current season only***

5.0 Conclusions

The primary purpose of this report was to identify temporal land management trends in the South Tobacco Creek watershed based on benchmark data collected by landowners over a ten year monitoring period. This analysis is a necessary precursor to evaluating the relationships between agricultural land management and water quality. Where relevant, a preliminary attempt was made to identify such correlations, however detailed water quality analyses will be addressed in conjunction with Environment Canada as part of a separate report.

5.1 Land Management Patterns

Land management information collected for this study included details on: crops grown, chemical fertilizer use, pesticide use, and straw management. Land management data was compiled and analysed within a GIS environment.

5.1.1 Cropping Patterns

Cropping trends within the South Tobacco Creek watershed were similar to those for the province of Manitoba, although the watershed trends fluctuated more dramatically. Of the primary cereal and oil seed crops grown (spring wheat, canola, flax, barley), spring wheat dominated production, although total spring wheat hectares dropped considerably (about 35 percent) since 1991. Canola production cycled up and down for the same period. Within the scope of declining wheat production, when wheat increased, canola decreased, and vice versa. Flax and barley hectares increased three times and forage hectares doubled, each constituting only a small portion (10, 10 and 12 percent respectively) of the total crop area, but in total, roughly corresponding to the percent decrease in wheat acreage.

Wheat production decisions seemed to dictate the type and amount of annual crops produced in the watershed. During the mid 1990s, the decision to grow wheat (and subsequent fluctuations in wheat production) was largely reflective of the previous year's wheat prices. Given profitable grain prices, producers appeared prepared to forfeit maximum returns from canola production in favour of the reduced risk associated with growing cereals (wheat and barley).

5.1.2 Chemical Fertilizer

Nitrogen was the most abundant nutrient applied, with total spring-applied N and P increasing somewhat over the years. Preferred method of N application varied between broadcasting and spring banding, whereas P was most commonly placed with the seed. Choice of application amount and method is a balance between factors such as crops grown, cash flow, and timing of precipitation. Broadcast applications allow for greater flexibility in timing of application, whereas seed placement tends to enhance the efficient use of the fertilizer. Compared to N and P fertilizer, spring-applied K and S were added to only a small portion of the basin. There is a direct relationship between increasing canola production and increasing spring-applied N, P, and S.

5.1.3 Pesticides

Total pesticide use increased gradually over the monitoring period. MCPA, 2,4-D, and glyphosate were the active ingredients most commonly used. MCPA and 2,4-D use (growth regulators) corresponded with cereal production. Annual substitution between the two might have been due to price and the choice of other active ingredients in the tank mix, as well as their specificity to certain weed populations. Glyphosate (Round-Up) use generally increased over time and may be correlated with canola production and reduced glyphosate costs near the end of the monitoring period. Glyphosate and 2,4-D use appeared to be inversely related. They are generally not substitutable for in-crop use and the relationship may simply be a reflection of annual crop rotation and associated pesticide preferences. But an increase in glyphosate use for pre-seeding burn-off could decrease subsequent 2,4-D in-crop use. Use of the other six active ingredients monitored in this study was small in comparison, and varied widely between years.

5.1.4 Straw Management

Straw management trends were of particular concern given their potential to influence soil erosion. Straw chopping was the most prevalent form of straw management, while baled hectares increased more than four-fold by the end of the monitoring period. Burning of straw declined to minimal amounts by the mid 1990's. Acknowledging the consistently higher hectares of chopped straw, chopping and baling trends appeared to be inversely related. The rise in baled hectares were accounted for through a three-fold increase for each of flax and barley hectares over the study period. Canola and wheat production strongly influenced the straw chopping trend, with the straw being chopped and spread for incorporation into the soil.

5.1.5 Tillage Practices

Tillage practices were relatively constant and do not indicate a shift toward zero tillage in the watershed. The principal means of tillage on wheat and canola hectares was heavy duty cultivation in the fall (greater than 80 percent) and light duty cultivation in the spring (greater than 75 percent). On average, only modest amounts (less than 15 percent) of wheat and canola stubble received no tillage in the spring or fall, and very few such fields were consistent between years.

5.2 Correlating Land Use and Water Quality

Strategic windows of opportunity for assessing water quality likely occur when canola production is on the increase or at its apex relative to cereal grains. This is because canola production typically demands higher nutrient and pesticide inputs, while often requiring more seedbed preparation and producing less crop residue in the fall—all hazards for increased leaching, runoff and soil erosion.

Cursory attempts at correlating annual N and P loadings to South Tobacco Creek with basin fertilizer applications have been inconclusive. Evidence suggests that hydrologic variability due to run-off and storm events may be a more powerful influence on stream loadings. Work is underway to look more closely at seasonal variations of stream nutrient loading.

Past water quality investigations have indicated that pesticide concentrations in South Tobacco Creek are highest during local crop application periods, although levels were always well below Canadian guidelines for aquatic organisms. Relationships between individual pesticides and water quality will likely best be evaluated on an event basis.

Although total straw burning declined over the monitoring period, the benefits to soil erosion may have been offset to a small degree by an increase in baled area and an associated decrease in soil cover. Identifying the impacts of baling on water quality may be possible through a comparison of spring sediment loading at specific creek locations and the known amount of baling on nearby fields.

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