THE EFFECT OF SOIL QUALITY ON FIELD SCALE RUNOFF UNDER CONVENTIONAL AND CONSERVATION TILLAGE SYSTEMS

A Report for:

The National Soil Conservation Program

Presented to:

Agriculture Canada
Research Branch
Research Station
Harrow, Ontario

Prepared by:

BEAK CONSULTANTS LIMITED
42 Arrow Road
Guelph, Ontario
N1K 1S6

March 1994
BEAK Ref.: 4282.1

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The National Soil Conservation Program (NSCP) is a research program managed and funded by Agriculture Canada. The program focuses on the improvement of agricultural soil and water quality through education and implementation of farm conservation practices. The program is multi-faceted in design and approach and includes several topics of study primarily in the soil quality and soil conservation areas.

As part of the NSCP, Beak Consultants Limited (BEAK) conducted a study examining soil quality, agricultural runoff quality and groundwater quality, under conventional and conservation tillage systems. This research study focused upon field scale processes and encompasses two growing seasons. The study's primary objective was to examine the transport and fate of nutrients (primarily nitrate-N and phosphorus) and metolachlor, a commonly used pesticide in Southern Ontario, under two differing tillage management systems.

This final report includes sections on literature review, study methods, study sites description and design, meteorology, soil quality assessment, surface water and groundwater monitoring and the effects of conservation and conventional tillage on soil and water quality within the study sites.

1.1 Background and Literature Review

Soil and Water Quality

Research over the past forty years in North America has produced conflicting evidence with respect to the effect of no-till farm production upon soil quality, surface runoff quality and groundwater quality. It is well recognized that certain agricultural chemical inputs, primarily nitrogen, (Keeney, 1986), phosphorus (Wall *et al.*, 1982; Logan, 1982; Miller *et al.*, 1978) and pesticides (Agriculture Canada, 1991) are found outside their target soil and plant zones - and some, such as nitrate nitrogen contamination, has been called ubiquitous (Gillham, 1991). Researchers have suggested that the means to controlling the reduction of nitrate transport in surface water, tile flow and groundwater is to examine carbon-nitrogen cycling and increase

carbon contents in soils to promote better soil quality and associated reduced nitrate transport (Shirmohammadi, *et al.*; 1991, Gillham, 1988). Current research conducted by the Waterloo Centre for Groundwater Research has found that nitrate contamination of the shallow aquifers is widespread and that most deep aquifers generally have low nitrate concentrations (Russell *et al.*, 1992).

Other studies have examined means to quantify pesticide leaching through modelling techniques (Carsel and Jones, 1990; Sjoerd and Zee, 1990). These modelling techniques take into account adsorption/desorption processes and leaching potential and provide a framework for evaluation of agricultural management systems such as no-till. However, the data used in these studies are representative of United States climatic conditions and therefore the modelling evaluations are not directly applicable to Southern Ontario. Sjoerd and Zee (1990) identified a stochastic technique for evaluating pesticide transport which accounted for spatial variability with relatively little data. The model accounts for spatial variability through the use of an approximation of apparent residence time variance.

Researchers in the United States have examined surface runoff volumes between conventional systems (usually mouldboard plow followed by discing) and conservation systems which included no-till and minimal tillage systems. During an eight year study, Laflen *et al.* (1990) found that less than half as much runoff was generated from a ridge till fields on steep loess slopes compared to a conventionally tilled fields (30-60 hectares) . Similarly, Laflen *et al.* (1990) reported a 90% reduction (compared to conventional tillage) in surface runoff in a maize-cowpea rotation with no till on slopes ranging from 1 to 15%. In these studies, soil loss was drastically reduced with no-till.

Long-term research in Coshocton USDA Hydrologic Station in Ohio found that no-till fields, on steep silt loam slopes (10-15%), generated less surface runoff during the critical summer thunderstorm period than did plowed fields (Edwards, 1991). Annual erosion was also much less. These results were consistent between well drained fields and fields with poorly drained subsurface soils.

Other U.S. experiences confirm these results (Berg *et al.* 1988; Blevens *et al.* 1983). Explanations for reduced surface runoff in conservation systems include reduced surface flow velocities due to mulch (Edwards, 1991) and higher macroporosity and infiltration rates due to earthworm tunnels (Hendrix *et al*, 1988).

In Ontario, similar studies conducted by Vyn *et al*. (1979) over a six year period (1971-76) were in general agreement with the U.S. results. No-till in Guelph loam had 35% less runoff than conventionally tilled fields. In these studies, benefits were credited to reduced soil sealing and crusting and impeded runoff which provide for more infiltration. However, recent Tillage 2000 studies and TED research has contradicted these observations (O'Neill *et al.* 1990). This study found that plots with a nine year history of no-till management had higher bulk density, lower total porosity, lower micro-porosity, lower saturated hydraulic conductivity, lower matric flux potential and lower infiltration rates than similar plots in which the moldboard plow was used. Study site soils ranged from fine sandy loam to clay loam. Sites with minimum till were not significantly different than the mouldboard sites. These studies indicated that no till systems may result in higher surface runoff due to reduced soil infiltration and hydraulic conductivity as a result of altered soil structure. It was felt, however, that soil loss and adsorbed chemical loss (i.e. phosphorus and pesticides) were reduced in no till due to the higher surface protection and reduced particle detachment inherent to no till. Increased groundwater contamination in no till was felt to be unlikely since water movement through soils may be reduced in no till. It was also suggested that surface runoff of soluble chemicals may be increased in a no till system.

It is well accepted that conservation tillage reduces soil loss and losses of soil adsorbed chemicals from tilled fields as well as resulting in soil quality improvements. The reasons for the soil quality improvements and reduced soil loss under these soil conservation systems is generally credited to the effect of plant residue sheltering soil particles against raindrop impact and impeding surface runoff velocity (Agriculture Canada, 1983).

Immunoassays for Pesticides Analysis

Immunoassays are analytical procedures based upon the specific binding of animal-derived antibodies to a target molecule. When coupled with a visualization method, immunoassays provide simple, specific, sensitive and rapid detection at low cost. The most common use of immunoassays is in clinical laboratories to identify drugs, hormones, viruses and bacteria. Within the past 15 years there has been a heightened interest in generating antibodies for residue analysis of pesticides. Recent work was reviewed by Hammock *et al.* (1987), Lankow *et al.* (1987), and Vanderlaan *et al.* (1988). Immunoassays for triazine and phenoxy herbicide detection and measurement in the

environment have only recently been established. Bushway *et al.* 1988; Fleeker, 1987; Hall *et al.*, 1987; Schlaeppi *et al.*, 1989; Vanderlaan *et al.* 1988; Hall *et al.*, 1989). Laboratory and initial field data generally show excellent correlation with conventional analytical tests. For example, Schlaeppi *et al.* (1989) could detect atrazine in water samples as low as 0.05 µg/L. For 25 samples containing atrazine (>0.05 µg/L), the correlation between immunoassay and conventional chemistry measurements, calculated by regression analysis, was excellent ($r=0.91$, $p<0.0005$).

More recently, Thurman *et al.* (1990) compared ELISA immunoassay to GC procedure for the analysis of triazine herbicides in surface water and groundwater in Kansas, U.S.A. Apparent recoveries from natural water and spiked water by both methods were comparable at 0.2 - 2 µg/L. The authors of this study concluded that the combination of screening analysis by ELISA, which requires no sample preparation, and confirmation by GC was designed for rapid, inexpensive analysis of triazine herbicides in water.

Clearly, immunoassays may provide for the analysis of a large number of samples without extraction (hence, low cost), rapidly and accurately. Among other potential benefits, immunoassays may provide an opportunity to greatly increase the scope of water monitoring programs, or to increase the frequency of tests, without added costs.

Pesticide Monitoring and Interpretation

Pesticide monitoring at the mouth of major watersheds in Ontario has been ongoing since the mid 1970's (Frank and Logan, 1988) and continues today as part of the enhanced effort (60 samples/year) at the mouth of the Grand, Thames and Saugeen Rivers and at 85 other sites in Ontario on a less frequent basis (pers. comm. L. Logan). Pesticide monitoring has also been conducted at the mouths of smaller agricultural watersheds as part of PLUARG (PLUARG, 1978a, Frank *et al.*, 1982) and more recent specialized studies in the Nissouri Watershed (BEAK, 1989) and the Kintore Watershed presently monitored by Environment Canada, Inland Waters (pers. comm. D. Draper). The PLUARG study was conducted on 11 selected small agricultural watersheds in Southern Ontario. On average, atrazine was consistently found in runoff samples with an average load of 0.2 g/ha/yr. The Nissouri Creek study reported atrazine concentrations as high as 350 µg/L in surface waters and estimated that 0.84 to 3.3% of the atrazine which was applied in 1985-

1986 was detected in runoff. This corresponded to a loading rate of 0.06 to 0.31 ha/yr. A crude extrapolation of these results to all of Southern Ontario indicates that loadings of atrazine to Lake Erie, the primary basin for Southern Ontario class 1 agricultural land, could approach 1 tonne/year.

There are no studies which have been specifically aimed at identifying empirical relationships between pesticide runoff and spatial factors such as watershed size, treated areas and other physical factors in Ontario or elsewhere. The frequency of sampling is usually insufficient to provide reliable estimates, better than an order of magnitude for watershed loadings. The Nissouri Creek study of atrazine runoff (BEAK, 1989) did provide a high level of atrazine runoff loading information which in turn was useful in examining event based, seasonal and annual runoff loadings. Baker (1987) monitored atrazine and nine other pesticides in three Ohio watersheds ranging in size from 386 km^2 to 16,359 km^2. While this study did not focus upon watershed scale, results did indicate that the time weighted mean concentration of atrazine (April to August, 1983-85) was inversely proportional to watershed size. All watersheds had similar agricultural use.

Numerous studies have reported the observed relationship between runoff hydrology and conventional water quality parameters such as suspended solids and phosphorus (Bodo and Unny, 1983; PLUARG, 1978b). These relationships are relatively well understood in the context of small headwater areas as well as at the mouth of large watersheds where flow and water quality attenuation effects are significant. No studies have attempted to relate pesticide runoff timing and impact (concentrations and durations) to the hydrologic response of various catchment sizes on a seasonal basis, recognizing that the runoff behaviour of these materials differs from that of conventional parameters.

In the past, these types of investigations have been prohibitively expensive due to analytical costs. Yet detailed information of this nature is required in order to design herbicide monitoring programs, identify stream courses at risk in terms of herbicide contamination, and evaluate the effects and benefits of alternative land and pesticide management alternatives.

Loading Estimation

Hydrologic flow data from streams, rivers and channels is very rarely normally distributed over time. In most single flow event cases, the rising limb of a flow hydrograph is more

abrupt and rises faster than does the falling or recessional limb of the hydrograph. This type of data is said to be skewed, (i.e., not normally distributed) (Snedecor and Cochran, 1982). Special care must be taken when analyzing flow quantity and water quality data because most standard statistical methods require data to be distributed normally - particularly when determining yearly water quality mass loadings.

Often water quality parameters such as phosphorus, suspended solids and several organic compounds are highly skewed with respect to time and flow. Furthermore, generalities regarding the shape of the runoff curves for various pollutants cannot be made. Even persistent pesticides have seasonal peak periods corresponding to periods of application. Therefore, the whole year's runoff data cannot be lumped to estimate relationships between flow rate and concentration.

Past studies on pesticide residues in surface water generally centred around a single representative flow event and did not take into consideration the analysis of several flow events spaced over a season or year for the purpose of estimating seasonal or annual loads or parameter mass totals. To estimate yearly mass loadings from data that has been collected from selected rainfall-flow events requires special analysis of the data in order to accurately estimate water quality mass loadings for other non-sampled flow events. Traditionally, mass loads have been calculated using the sum of the product of flow and concentration. However, this can lead to biased estimates of mean loads, particularly if the flows and parameter concentrations vary by orders of magnitude. Bodo and Unny (1983), developed a method in which the data is broken into homogeneous, near normally distributed strata. In this method data segments which are similar in character are analyzed using standard techniques developed during PLUARG (IJC, 1977 and Tin, 1977). The result is a better estimate of means of water quality parameters for the determination of water quality mass loads.

1.2 Objectives

Overall, our objective is to contribute to the understanding of runoff processes as affected by land management systems (both conventional and conservation) within the Ontario setting. Our proposed approach focuses upon:

- the relationship between soil quality and tillage practices, and
- the relationship between tillage practices and environmental impact.

It is believed that the study results will contribute to a greater understanding of conservation farm practices, soil and water quality, and to extension programs. Specifically this study will aid educating producers in:

- developing soil management systems that protect fragile land and improve the quality of the environment;

- improving surface and groundwater quality through the use of environmentally sustainable production systems;

- managing on a sustainable basis the available soil resources; and

- reducing the impact of pollution on soil and water resources used by the agri-food sector.

NSCP was initiated to develop and conduct on-farm research to determine and subsequently demonstrate the most environmentally sustainable field agricultural practices. This study evaluates these agricultural practices through monitoring of soil and water quality associated with conventional and conservation farm management systems. This NSCP study addresses soil quality as well as surface and groundwater quality resulting from the implementation of different tillage systems on operational farms at a field scale.

We hypothesize that:

- Conservation tillage systems that minimize surface soil disturbance and increase plant residue cover, such as no-till, result in altered runoff distributions (surface flow versus subsurface flow) compared to conventionally tilled land.

- Changes in runoff distribution can be accounted for in terms of changes in soil quality indicators such as bulk density, hydraulic conductivity, pore size distribution, organic matter and infiltration rate.

- In Ontario, no-till systems result in higher surface runoff volumes over an annual period with lower soil and absorbed chemical concentrations than runoff from conventional tillage.

- Since conservation tillage tends to reduce soil and chemical concentration in runoff and groundwater flow, the water quality in agricultural drains is improved. Improved water quality can be related to changes in soil quality.

This research project was designed to test these hypotheses with the following objectives.

1. Demonstrate the positive relationship between improved soil quality and runoff water quality that results from the implementation of conservation tillage in Ontario.

2. Identify the relationship between runoff distribution (i.e. surface flow versus subsurface flow) and soil quality by comparison of two different tillage systems on two differing landscapes and soil types.

3. Identify the benefits of conservation tillage in terms of reduced soil and agrochemical losses.

4. Provide evidence to the farming community to support the adoption of conservation tillage systems.

2.0 STUDY BACKGROUND AND STUDY LOCATIONS

This section presents a description of the study sites used in the program, and the field and analytical methods used to collect, store and analyze soil and water samples.

2.1 Study Sites

Four discrete watershed study sites (microbasins) were utilized in this NSCP project. Microbasins are field-sized, hydrologically distinct drainage areas originally installed for the SWEEP Pilot Water Study (PWS). The SWEEP PWS microbasins in the Kettle Creek watershed were selected for this study because of the extensive listing of information and an existing level of cooperation with landowners. These microbasins are characterized by similar soils and land use patterns. Two of the microbasins are located in the Kettle Creek **test** watershed and therefore have a history of conservation farming. The other two microbasins are located in the Kettle Creek **control** watershed which has been under conventional farming systems during the entire PWS. The microbasins were selected based upon the following criteria:

- Two microbasins (**test** microbasins) had at least two years of effective conservation farming practice in place prior to the initiation of this study.
- Two microbasins have had a long history of conventional farming practice (**control** microbasins).
- Each pair of microbasins is similar in hydrologic characteristics, soils, and farming operation. One **test** and **control** pair represents a flat terrain and the other pair represents a rolling terrain.
- Microbasins are characteristic of typical soils, topography, and farm systems within the Southwestern Ontario setting.
- The fields within the microbasins are owned by farmers who are committed to continue to cooperate with the study team through the course of the study.

- The physical configuration of the microbasins facilitate surface and groundwater flow monitoring and water sampling.

- Microbasins do not include confounding factors such as point source discharges, livestock or non-representative land uses.

Soils and landscape found in the Kettle Creek Watershed are representative of significant portions of Southwestern Ontario. Farming in the area centres around corn/soybean production also representative of much of Southern Ontario agricultural production.

Soils found in the Kettle Creek microbasins are loam to clay loams developed on clay loam to clay till and glaciolacustrine deposits. Dominant soil types found in the Kettle Creek microbasins include Tavistock silty clay loams and Muriel silt loams which are imperfectly drained (Ecological Services for Planning, 1990). Slopes range from near level to greater than 15% and average about 6%. Figure 2.1 shows the location of the Kettle Creek study area; while Figures 2.2 and 2.3 show the location of microbasins within the study area. The two microbasins located in the **control** sub-watershed are identified as KCB1 and KCB2 while the **test** microbasins are identified as KTB1 and KTB2. All four microbasins have been surveyed to obtain accurate area measurements required for unit area loading calculations. KCB1 and KCB2 measure 8.5 and 4.1 ha respectively. KTB1 measures 6.5 ha and KTB2 is 5.1 ha in area.

2.2 Study Methods

This NSCP study was designed to focus on a specific set of environmental concerns; namely pesticide and nutrient fate and transport. Additionally, the NSCP project was co-located with the SWEEP PWS not only to take advantage of the history of conservation farming, but also the extensive monitoring network (meteorological, etc.) that already existed. Wherever possible, information from the SWEEP PWS project is provided to the NSCP project to avoid the duplication of data collection programs, instrumentation and information.

A special agreement was made between BEAK and the microbasin landowners to grow an identical crop (corn) in all the study areas during the 1992 growing season. The agreement also stipulated that conventional management (mouldboard ploughing) would occur on both the **control** sites and no-till management would occur on both the **test** sites. Fertilizer was applied based on soil **test** results and the herbicide DUAL (metolachlor) was used at recommended rates to facilitate the comparison of soil quality data.

Routine soil and groundwater monitoring programs were established to track the fate of nutrient and pesticide inputs on the study fields. Monitoring of soil and groundwater was conducted on a bi-monthly to seasonal basis. The surface water monitoring program consisted of the monitoring of runoff events within each of the four study areas. In all cases a mass balance approach has been used in order to track nutrients and metolachlor through the various pathways and to determine mass loading of parameters to receiving water bodies. The following is a brief description of the monitoring installations associated with soil, surface water and groundwater sampling.

2.2.1 Crop and Field Measurements

A number of crop production parameters were monitored during the course of the study. These include the type of crop grown, tillage practice, quantity and types of fertilizers and pesticides applied, crop yield and soil surface crop residue coverage.

Field crops in the microbasin study areas were monitored for crop productivity and measured for grain yield. Farm co-operator crop input records provided the fertilizer and pesticide information required by the study. Grain yields were determined by various means including field weighwagon yield checks, or grain elevator weigh scale tickets. When neither of these methods were available, the farm co-operator's estimate of crop yield was used. All yields were determined on a dry weight basis e.g. 15.5% moisture content for corn; 14% moisture content for soybeans.

Crop residue counts were conducted at intervals during the study period within the microbasin areas to determine the amount of soil surface residue coverage. The residue count data was collected using a 25 ft nylon rope, knotted every six inches for a total of 50

knots. Upon stretching the rope across random sections of the microbasin area, each piece of crop residue intercepting or touching a knot represented a 2 % level of crop residue cover (e.g. 25 intercepts represented a 50 % crop residue cover). A minimum of 3 counts were taken in each microbasin area and averaged at each sampling period. The residue counts were taken during the fall (after harvest, before tillage), early spring (after spring runoff but before spring field work) and in late spring (after planting).

2.2.2 Soil Monitoring

Soil benchmarks sites were established in each of the four study microbasins (KCB1, KCB2, KTB1 and KTB2). These benchmark sites are representative of their respective microbasins. Each benchmark site has been mapped and referenced to physical benchmark points (stakes, road benchmarks, buildings and structures, etc.).

Soil sampling was conducted on a seasonal basis to coincide with critical times of the farming schedule including pre-spring tillage (April-May), post planting (June-July), full crop canopy (August-September), and post harvest - fall tillage (November-December). A total of six (6) sampling rounds were conducted over the study period; September and December of 1991, May, July, September, and December of 1992. Soil sampling protocol is found in Appendix A.

At each of the soil benchmark sites, soil physical and chemical properties were monitored over the study to account for temporal variation in properties and also to track the fate of various nutrients and metolachlor. Soils for each microbasin were collected for both physical property determination for the following parameters: surface texture, % organic matter, dry bulk density, volumetric soil moisture content and water stable aggregates using the Podjasok and Kay 1990 method. Additional soil samples were collected to characterize soil phosphorus, potassium, magnesium, pH, calcium and metolachlor. Refer to section 3.3 for a complete list of soil benchmark monitoring parameters.

All soil samples were submitted to the appropriate laboratories (University of Guelph Analytical Services and Beak Analytical Services) for analysis.

2.2.3 Surface Water Monitoring

Surface water monitoring was designed to specifically collect samples and flow information on storm/runoff event flow basis. In all SWEEP Pilot Watersheds, microbasins were instrumented with monitoring stations for collecting surface-overland runoff volumes and associated water quality samples. Each monitoring station in Kettle Creek was instrumented with a Stevens F-type flow recorder and a Stevens Electronic Water Level logger. With this flow recording instrumentation, instantaneous and total event flows were determined for each runoff event at each microbasin site. **Control** structures consisting of culverts fitted with V-notch weirs (KCB1 and KTB2), a V-notch weir box (KCB2) or a berm and a weir (KTB1) were installed at each monitoring site as part of the SWEEP PWS. Water levels were recorded continuously, throughout the non-winter months (April - November). Discharge curves have been determined for each microbasin for each year of monitoring.

Surface water quality samples were collected during flow events over the study period. Due to the ephemeral nature (intermittent flow) of the microbasins, only 9 flow events were monitored and sampled over the period of the NSCP study. Spring is a very critical time of year for event monitoring and three events were monitored and sampled during this period in 1992. The remaining flow events were collected during the summer and fall seasons. Water quality samples were collected manually by field staff or with automated ISCO water quality samplers. Manually collected water samples were collected using the depth integration technique which provides for the most representative surface water quality sample.

Water quality samples were collected during the course of the entire flow event at each microbasin. From approximately 6-8 samples collected during a given flow event, 3 to 5 samples were selected for chemical analysis. Collected samples were placed in coolers for shipment to BAS Laboratories of Brampton, Ontario for analysis.

All samples were filtered for SRP aliquots and handled according to MOE protocols. Samples were kept cool on ice and were delivered to the BAS laboratory within 72 hours of collection.

Surface water quality samples were analysed for total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate-nitrogen (NO_3), total Kjeldahl nitrogen (TKN), total suspended solids (TSS), and metolachlor.

A second aliquot was delivered to BEAK's Biodetection Laboratory in Brampton, Ontario for metolachlor analysis by ELISA.

2.2.4 Groundwater Monitoring

The study focused on determining if chemicals were present in the groundwater and the direction and rate of shallow groundwater flow. To meet the data requirements the following tasks were performed:

- drilling of eleven soil borings in four Kettle Creek microbasins (Figures 2.2 and 2.3),
- collection and description of geologic materials encountered in each of the eleven new soil borings,
- installation of monitoring wells in each of the eleven new soil borings,
- development and response testing of five of the new wells,
- collection of groundwater samples from all wells for field and laboratory analysis,
- performance of an elevation survey on the top of the casing of each of the new wells, and
- collection of static water levels in all new and previously existing wells.

The monitoring wells were installed to provide information concerning groundwater flow and water quality. The locations of each of the wells are shown in Figure 2.2 and 2.3. The methods and materials used to drill the borings, install monitoring wells, develop the wells

and perform response tests, collect groundwater samples, and measure water levels are outlined briefly in the following sections and in greater detail in Appendix A.

Soil Borings

The soil borings were drilled by London Soil Test Limited of London, Ontario using a Canterra™ track-mounted drill rig. The soil borings were drilled using 3 1/2-inch outside diameter (OD) solid stem augers. Samples of geologic materials were collected from the auger flights during drilling. A BEAK hydrogeologist continuously attended the drilling activities to specify the rate of drill penetration, and the total depth of the boring. The total depth of the shallow borings ranged from 3.0 to 9.1 metres below ground surface (mbgs). A detailed description of the soil boring procedures is presented in Protocol No. 1 (Appendix A).

Sample Logging

Soil samples were collected off the flights of the solid stem augers and were geologically logged according to the procedures presented in Protocol No. 1. The geologic samples were visually classified according to the Agriculture Canada (Agriculture Canada, 1984) soil classification system. A detailed boring log containing geologic descriptions of the materials encountered in each boring was prepared. The boring logs include descriptions of soil name, type and moisture content for each boring. The boring logs are presented in Appendix B.

Monitoring Well Installation and Development

Five monitoring wells (KCB1-3S, KCB2-3S, KTB1-2, KTB1-3S, KTB2-2S) were initially installed in 1988 as part of the SWEEP pilot water study. Eleven additional monitoring wells were installed in September 1991 during the subject study (KCB1-1, KCB1-2, KCB1-3D, KCB2-1, KCB2-2, KCB2-3D, KTB1-1, KTB1-3D, KTB2-1, KTB2-2D, and KTB2-3). The new monitoring wells were specifically designed to provide additional

information concerning groundwater chemistry and groundwater flow. The wells were constructed of 2-inch inside diameter (ID), flush-threaded, schedule 40, polyvinyl chloride (PVC) pipe. Each well screen consisted of either one or two five-foot sections of PVC pipe that were factory perforated with 0.010-inch slots to permit the entry of water into the well. To minimize the risk of groundwater contamination by well materials, the factory-cleaned well screens and piping were not removed from their plastic sleeves until the time of installation in the boring. No lubricants or adhesives were used in the construction of the wells.

The total depth of each boring was measured with a weighted tape after the augers were removed. This measurement was performed as a final verification that the drilling depths were accurate. The PVC pipe and screen were then positioned inside the borehole. The annular space around the screen was packed with size No. 3M silica sand to a level above the top of the screen. A seal comprised of bentonite was poured above the sand pack. Each bentonite seal was a minimum of 0.6 m thick. If the bentonite seal did not reach the ground surface, the remainder of the annular space was backfilled with drill cuttings. Approximately 4 to 8 L of distilled water was poured onto the bentonite to cause it to expand to form the seal. A detailed description of the monitoring well installation procedures is presented in Protocol No. 2 (Appendix A). Scaled diagrams of the wells constructed in the borings are included with the boring logs in Appendix B.

The monitoring wells were developed after the bentonite seal had been allowed to set a minimum of 24 hours. All wells were pumped dry to remove drill water according to Protocol No. 3. As each casing volume was purged from each well, a clean glass beaker was filled with a groundwater sample to measure pH, temperature and specific conductance.

Depth to Water Measurements

The depth to water was measured in all new and previously existing wells using an electronic water level tape. A detailed description of the depth to water measurement procedure is presented in Protocol No. 5 (Appendix A). Depth to water measurements were collected in December 1991 and approximately monthly from May through November 1992. The water level data are presented and discussed in Section 3.5.

The elevation of the top of each new monitoring well casing (reference elevation) and the ground surface of each new soil boring were surveyed by BEAK personnel relative to an off-site benchmark. An elevation reference was permanently located and clearly marked on the top of the casing of each new well.

Groundwater Sampling

The following sections briefly describe the sample collection and handling procedures, field measurements, and laboratory analyses for samples collected during the study. Detailed descriptions of these procedures, measurements, and analyses are presented in Protocol Nos. 6, 7, and 8 (Appendix A).

Well Evacuation

Prior to collecting groundwater samples for chemical analysis, the stagnant water in the well bore was evacuated to allow replacement by "representative" groundwater from the subsurface. In general, a minimum of three casing volumes of groundwater are removed ("purged") from wells immediately prior to sampling. However, because these wells could not sustain sufficient yield, they were purged to dryness. Samples were collected the next day following the procedure presented in Protocol No. 5. The pH, temperature, specific conductance and total volume of water removed from each well were measured after each casing volume was removed during well purging activities. These values were recorded in the field book. The well evacuation data are presented in Appendix B.

Groundwater Sample Collection and Laboratory Analysis

Water samples from all of the wells were analyzed for metolachlor, total or soluble reactive phosphorous, nitrate-nitrogen, and total dissolved solids (TDS). Groundwater sampling protocols including sample bottle selection, preservatives, sample labels and chain of custody procedures are presented in Protocol No 5 in Appendix A.

Laboratory and field quality control checks were utilized to assist in the provision of accurate and reliable analytical data. Field QA/QC samples included field duplicate samples. Additional QA/QC control procedures were implemented within the laboratory by incorporation of duplicate samples, laboratory blanks and laboratory references or standards. A brief description of the quality control samples is presented in Protocol No. 5 in Appendix A.

Field Water Quality Measurements

The pH, temperature, and specific conductance of the groundwater was determined in the field after the sample for laboratory analysis had been collected. The pH of the sample was measured with a pH meter calibrated to the temperature of the well fluid. The pH probe was lowered into the sample and gently stirred to allow equilibration before the reading was taken. Specific conductance was measured by placing the probe into the sample and taking readings immediately. Temperature was measured with an alcohol filled thermometer. All measurements were recorded in the field book. Each probe was rinsed initially and between use with a stream of distilled water. At the beginning of the day, prior to entering the field, the pH and specific conductance meters were calibrated according to the manufacturer's instruction. Notes concerning the calibration procedure were recorded in the field book.

Response Testing

Hydraulic response tests were conducted on five selected wells according to Protocol 6 (Appendix A). The wells were selected on the basis of expected speed of recovery. The response **test** data were analysed and interpreted using the Bouwer and Rice method (1976) to determine the hydraulic conductivity of the materials surrounding the well screen.

2.3 Analytical Methods for Metolachlor

2.3.1 ELISA Description

Enzyme-linked immunosorbent assay (ELISA) is an enzyme immunoassay in which one of the reactants is absorbed on to the wells of a microtiter plate. ELISA analyses for this study were performed using the Metolachlor 2.0 kit (Agri-Diagnostics Associates). This ELISA kit is an economical immunoassay which detects a range of key herbicides in water, based on a monoclonal antibody optimized to detect concentrations as low as 0.25 µg/L. The ELISA kit contains a pre-coated 96-well microtiter plate and reagents which enable for simple and rapid analysis. The kit is particularly useful as a tool for quantitative and qualitative screening where metolachlor levels are determined with the use of appropriate standards.

2.3.2 ELISA Procedure

The basic steps of ELISA are:

1. Pipette blanks, standards and samples into assay wells.
2. Pipette enzyme conjugate into each well, incubate.
3. Wash plates with wash solution.
4. Add substrate solution, incubate.
5. Dispense stop solution.
6. Measure absorbency at 650 nm plate reader.

The approximate total time for assay is 30 minutes.

2.3.3 ELISA Sample Handling and Controls

All samples were analyzed directly with the kit without any extraction processing. Each sample was run in duplicate wells. A set of standards of six known concentrations (0.05, 0.1, 0.2, 0.4, 0.8, and 1.6 µg/L), a negative control (0 µg/L), and a blanking standard were used with each kit.

2.4 Water Quality Parameter Loading Estimation

During the NSCP study, both water quality and streamflow data were collected for the purpose of computing water quality loadings from the microbasins. Flow was monitored on a continuous basis, while water quality samples were collected during critical periods such as event and baseflow periods. This type of flow and water sampling scheme has been used extensively for water quality monitoring studies similar to this study (BEAK, 1989). Due to these sampling methods, a continuous record of observed water quality parameter chemistry is not possible or practical. The water quality parameter loadings have been estimated using statistical correlations between the continuous flow and discontinuous water chemistry data.

In the absence of a continuous record of water quality chemistry, a water quality predictive loading model was developed to facilitate the computation of continuous water quality loadings. The model is known as the Sweep Loads Model (SLM) (developed for the SWEEP PWS).

A least squares technique was used to determine the best fit or best relationship between water quality parameters and streamflow. This approach is similar to the rating curve procedure to estimate transport or loading rates (Linsley and Franzini, 1979; Overton and Meadows, 1976; Walling, 1977; Schroeter and Watt, 1989). The rating curve consists of a graph or equation, relating mass discharge or concentration to discharge, which can be used to estimate water quality parameter loads from the continuous streamflow record. This approach is analogous to the stage-discharge curves used to establish streamflows at gauging stations by Water Survey of Canada.

Discrete values of the loads were computed using:

$$L_i = C_i \, Q_i \qquad [2.1]$$

where L_i is the instantaneous load or transport rate (M/T) for water quality sample i, C_i is the measured concentration (M/L^3) and Q_i is the observed instantaneous flow (L^3/T)

corresponding to sample i. The equation used for the computation of water quality loadings was in the form of the power equation below:

$$L_p, C_p = aQ^b \qquad [2.2]$$

where: L_p = Load of a water quality parameter p, (M/T);
C_p = concentration of a water quality parameter p, (M/L^3);
Q = flow discharge at the water quality sampling station, (L^3/T);
a and b are regression determined coefficients.

Water quality and streamflow information are rarely normally distributed due to the frequency at which flow events occur (i.e. high flows are rare while low flows are common). Statistical procedures such as least squares regression are based on the fundamental premise that the data are normally distributed about the mean. Logarithmic transformations were applied to the discrete values of L and Q, to normalize the data set and then a standard linear regression technique (Draper and Smith, 1981) was performed to estimate values for **a** and **b** in Eq. [2.1]. When sediment loads are being considered, some workers have referred to the coefficient **a** as an **erodibility** factor (Linsley and Franzini, 1979; Overton and Meadows, 1976). In general, the rating curve approach has seen wide application for estimating sediment discharge (Walling, 1977), although Betson and McMaster (1975) demonstrate its use for dissolved mineral constituents, and Verhoff *et al.* (1980) for nutrient transport rates.

This type of water quality loading estimation results in a separate and discrete regression equation for each year or portion of year. Furthermore, through this type of analysis, yearly or seasonal coefficients can be compared to evaluate or to correlate with other variables (i.e., rainfall, effectiveness of cover plant residue, etc.). Coefficients from Equation 2.2 were estimated for seasons, defined as follows: January to April (non-growing season), May to August (growing season) and September to December (non-growing season) to produce water quality loads and concentrations for the following parameters:

- Total Suspended Solids (TSS),
- Total Phosphorus (TP),
- Soluble Reactive Phosphorus (SRP).
- Total Kjeldahl Nitrogen (TKN),

- Nitrate-Nitrogen (NO_3), and
- Metolachlor (MET).

The result is a continuous time series record of water quality loadings for each of the above mentioned parameters. Water quality loadings were computed on an hourly basis and can be summarized into various standard periods such as daily, monthly and yearly summaries. The three seasonal periods used respect differences in live cover, soil moisture, and freezing conditions over the year.

3.0 RESULTS AND DISCUSSION

The following section presents the results of the monitoring and sampling (meteorology, soils, soil residues, groundwater, and surface water), and includes a discussion regarding crop yields, soil quality, surface water and groundwater quality under the two tillage management systems.

3.1 Crop Yields and Soil Residues

3.1.1 Field Management and Crop Yields

The field crops grown within the microbasin areas are representative of the major crops of Ontario, namely grain corn, silage corn, soybeans and winter wheat. The crops grown are listed by microbasin in Table 3.1. Often, more than one field and occasionally, more than one crop type are found within each microbasin.

It can be noted that all crops within the **test** microbasin areas were planted using no-till technology, while the crops within the **control** microbasins involved various means of conventional tillage such as fall moldboard ploughing or spring cultivation. Spring cultivation was the primary tillage method within the **control** areas following a soybean crop, a practice which is common, even in conventional tillage systems. Within the **control** area, a number of cultivating passes were made following the primary tillage operation in order to incorporate herbicides and prepare the ground for planting.

While it is useful to compare crop yields of no-till fields against the conventional fields, not enough yield data has been generated within the scope of this study for suitable analysis. Furthermore, both years within the study saw quite abnormal weather (1991 was warm and dry, leading to one of the earliest harvests on record while 1992 was cool and wet, contributing to one of the latest harvests on record). Crop variety and planting date probably had greater effects on crop yields than did the tillage systems during these dramatic weather conditions.

Crop inputs such as herbicides and fertilizers were recorded by the farm co-operators and are listed in Table 3.2. A number of fields did not receive applications of metolachlor (DUAL) in 1991, as the study commenced sometime after planting with no opportunity available to
carry out additional metolachlor spray applications. Even so, all four microbasins received an amount of DUAL herbicide on at least one field in 1991. In 1992, a majority of the microbasin fields received DUAL herbicide applications.

There was no significant difference in Nitrogen use within the **test** and **control** microbasins. However, there was a significant increase in the use of Phosphate and Potash fertilizers within in the **control** microbasin areas, as a whole, as compared to the **test** microbasins, as seen in Table 3.2. However, no individual microbasin received notably higher or lower amounts of fertilizer over the two year period as to characterize them apart from the others.

3.1.2 Crop Residue

Surface crop residue counts were taken over the two-year study. Since more than one field and crop residue type could be encountered within each microbasin, a weighted average of percent residue cover was determined for each microbasin, as shown in Table 3.3.

As expected, pre-plant and post-plant residue counts were significantly higher within the **test** microbasins where no-till practices had been implemented as compared to the **control** microbasins where conventional tillage practices were utilized. The exception to this was microbasin KCB1, where 1991 pre-plant residue levels were found to be comparable to the **test** microbasin levels. This is due to the farm co-operator spring cultivating soybean residue, rather than mouldboard ploughing the previous fall. Residue levels at the 1991 post harvest stage were observed to be similar at all four microbasins.

3.2 Meteorology

The meteorological program consists of the monitoring of rate of rainfall, total precipitation, temperature (air, water and soil). Rate of rainfall, total precipitation and soil temperature are the most important meteorological parameters for this study and the discussion herein is limited to these parameters. Precipitation, which results in surface runoff and percolation through the soil column to the sub-surface drains and the groundwater table, is the primary driving force behind soil particle and agrochemical migration. Temperature, more specifically soil temperature, directly influences soil biochemical degradation rates and also crop development, which affects infiltration rates.

The meteorological stations have all performed well with very little data being lost to date. Where data losses have occurred (due to power outages or data logger failures), data has been obtained from nearby weather stations to augment records.

The following sections summarize the relevant meteorological data (temperature and precipitation) recorded over the period of study (July, 1991 to December, 1992). The long term normal values used for comparison with the data collected during the NSCP study are from the AES station closest to the Kettle Creek watershed (i.e London Airport). Complete daily summaries of the collected data are presented in Appendix B.

3.2.1 Temperature Summary

Air Temperature

Table 3.4 summarizes the average monthly air temperatures for the period of January 1991 to December 1992. Graphical representation of the temperature data is presented in Figure 3.1. For the purpose of comparison with long term normal temperatures, the 1951-1980 normal values for the London Airport AES are also presented in Table 3.4.

In comparison to the long-term normal monthly average temperatures, the Kettle Creek watershed experienced temperatures close to normal for the majority of the study period

(July, 1991 to December, 1992), except for the latter half of 1992 which was cooler than normal.

In 1991, each month prior to the period of study exhibited temperatures considerably higher than normal (2.7°C above normal on average). Each month in the latter half of 1991 had temperatures within one Celsius degree of normal except November and December which were 1.3°C below and 1.2°C above normal, respectively. While temperatures for January and February of 1992 were well above normal, temperatures for the balance of the year were below normal, especially during the growing season (see Table 3.4). The period of June through November of 1992 experienced monthly temperatures an average of 1.8°C below normal. Lower than normal temperature results in lower than normal microbial activity, including biodegradation of agricultural chemicals. Accordingly, rates of metolachlor degradation in the soil of the Kettle Creek study area during the growing season of 1992 were likely somewhat lower than normal and also lower than in the previous year.

Soil Temperature

Soil temperatures at three depths (5 cm, 50 cm, 150 cm) in the Kettle Creek watershed are given in Appendix B and are graphically represented in Figures 3.2 and 3.3. While these soil temperatures were recorded near the watershed outlet rather than within the microbasins themselves, they are still representative of soil temperatures throughout the watershed, including the microbasins of interest to this study.

Figures 3.2 and 3.3 illustrate that the temperature of the surface soil (0-5 cm) follows ambient air temperature very closely. As depth increases, temperature vacillations are dampened resulting in flatter temperature curves. Any affects of temperature variation on microbial activity (i.e. decreased rates of activity with decreased temperatures) would be greatest near the soil surface where temperature fluctuations are greatest. However, based on temperature alone, general rates of microbial activity will be lower at depth than at the surface during the growing season and higher at depth during the colder months.

Table 3.5 summarizes the monthly precipitation totals for the Kettle Creek watershed for the years 1991 and 1992. Long term normals from AES are also provided for comparisons in Table 3.5. Kettle Creek data are compared to London Airport (approximately 20 km to the north of Kettle Creek) AES normals for 1961 to 1990.

Graphical representation of precipitation totals for the Kettle Creek watershed are provided in Figure 3.4.

During 1991, the Kettle Creek study area received less than normal total precipitation in every month except February, March and October. Since the initiation of the project in July, total monthly rainfall throughout the duration of 1991 was well below normal (see Table 3.5). The only month of 1991 experiencing greater than normal precipitation during the study was October (29.5 % above normal). Overall, total precipitation for the months of July to December was 176.9 mm (34 %) below normal. As a result of the much lower than normal precipitation over the first six months of the study, little surface runoff occurred, the groundwater table dropped substantially and very few surface water samples were collected.

The Kettle Creek study area continued to receive slightly less than normal precipitation during the first six months of 1992. While January, February and April experienced wetter conditions than normal, March, May and June were very dry compared to normal (see Table 3.5 and Fig 3.4). Overall, the period of January to June received 38.2 mm (8.8 %) less precipitation than normal. The latter half of 1992 was contrastingly wet. Each month from July to December received greater than normal precipitation, especially July, September and November which averaged 77.8% more precipitation than normal (see Table 3.5). Overall, total precipitation over the last six months of 1992 was 243.4 mm (47.0 %) above normal. This heavy precipitation enhanced the processes of erosion and agrochemical migration in the Kettle Creek microbasins and also increased the frequency and duration of microbasin events. Heavy precipitation coupled with lower temperatures, and subsequently lower rates of microbial degradation, could result in a greater than normal proportion of applied metolachlor being delivered to the microbasin outlets via surface water runoff.

3.3 Soils

Soil Physical Properties

Table 3.6 contains the results of soil physical properties, analyses including particle size distribution (texture) of the soil in the microbasins. All but KTB1 soils are silt loam in texture. KTB1 soils are classified as loam due to a slightly greater sand content and a slightly lower silt content. However, the slight differences in texture are not significant and should not effect soil bioactivity, infiltration, or chemical adsorption.

Organic matter levels, both surface and subsurface, were much higher in the **test** microbasins than in the **control** microbasins throughout the period of study (see Table 3.6 and Figure 3.5). The only exception are the subsurface samples obtained during May of 1992. The average organic matter content for the two **test** microbasins over the study period was 4.4 % (surface, 0-5 cm) and 3.6 % (subsurface, 25-30 cm) compared to 2.2 % (surface) and 1.6 % (subsurface) for the **control**. The major contributing factor to the higher **test** organic matter content is the history of no-till management in the **test** area. No-till practices simply leave more surface residue which becomes incorporated into the soil. In both the **test** and **control** microbasins, subsurface organic matter content was lower than that at the surface, as expected.

Details of the surface and subsurface soil bulk density analyses are also provided in Table 3.6. The values ranged from 0.89 to 1.85 g/cm^3 and averaged 1.40 g/cm^3. Generally, both surface and subsurface soil bulk densities tended to be greater in the **control** microbasins than in the **test**. The only notable exception to this trend occurred in May, 1992, when bulk density measurements peaked in the **test** microbasins to equal or exceed those for the **control**. The bulk density readings for May were obtained using soil cores taken during very wet conditions which tends to reduce the reliability of core samples. In addition, the processes of freezing and thawing during the winter tend to create soil instability which would be reflected in soil samples (particularly from the **control** basin), especially from the surface, obtained during the spring.

Soil moisture readings for surface samples are also presented in Table 3.6. As is the case for organic matter, soil moisture is higher in the **test** microbasins than in the **control**.

Test soil moisture readings were consistently higher than those of the **control**, despite the expected seasonal fluctuations experienced in both microbasins. Higher organic matter content and generally lower bulk densities allow **test** soils to retain more of the available moisture.

Water aggregate stability (WAS) readings (Podjasok and Kay Method, 1990) show no consistent trends with respect to conservation (**test**) or conventional (**control**) tillage (Table 3.6). The sharp drop in water stable aggregates experienced in both **test** and **control** microbasins in May of 1992 is again likely a reflection of the structural instability induced by the freeze/thaw process during winter. In September of 1991, and December of 1992, soils from the **test** microbasins have a noticeably higher percentage of water stable aggregates than **control** soils. Stable aggregates mean that the soil is less likely to be detached by raindrop impact and therefore less likely to erode. The higher values in the **test** microbasins are likely a result of the increased organic matter content, acting to bind the soil.

Moisture retention values for each site are listed in Table 3.7. This information provides details on the size of pores within the soil. Larger pores will drain at lower tensions so a significant drop between saturated moisture contents and those at 10 cm (H_2O) indicate the presence of large macropores. Less drastic decreases in soil moisture content indicate small pores which require increased hydraulic retention before they will drain. Most of the soils sampled exhibit generally similar characteristics (see Figures 3.6 and 3.7). The shapes of the moisture retention curves are very similar for the **test** and **control** soils. The moisture retention curves are almost linear suggesting a fairly even pore size distribution in both test and control microbasins. The most notable difference is that the curves for the **control** have a lower volumetric moisture content (at all pressure points) compared to the test. Results suggest that the test soils have a greater moisture retention capacity.

Soil Chemical Properties

A summary of the chemical properties of the soils of the Kettle Creek microbasins is presented in Table 3.8. Total phosphorus content of the microbasin soils was quite variable over the duration of the study. No clear difference exists between the **test** soils and the **control** soils with respect to phosphorous. Accordingly, phosphorus levels are not expected to result in any difference in soil chemical or biochemical activity between **test** and **control** microbasins that may effect rates of agrochemical degradation.

Potassium content of sub-surface soils is similar to phosphorous in that it is quite variable in time and it does not clearly differ between **test** and **control** soils (see Table 3.8). At the soil surface, however, potassium tends to reach greater concentrations in the **test** soils (especially in KTB2) than those of the **control**. The reason for this disparity may be that potassium applied as fertilizer remains concentrated at the soil surface in a no-till (**test**) field while conventional tillage (**control**) tends to incorporate the potassium throughout the soil profile, leaving a relatively small amount in the surface soil.

Concentrations of magnesium in the soils of the Kettle Creek microbasins follow a similar pattern to potassium. The subsurface soils show no distinct difference whereas the surface soils of the **test** microbasins have noticeably higher levels of magnesium than the **control** soils (refer to Table 3.8).

With respect to calcium (as calcium carbonate), the limited analysis (June and September, 1992 only) indicates that **control** soils have significantly higher concentrations than the soils of the **test** microbasins (refer to Table 3.8). Calcium in the **control** was approximately twice the concentration of calcium in the **test** soils. Part of the explanation is that conventional tillage practices tend to bring elements associated with deeper soils to the surface, due to the continued mixing of soil. More importantly, the higher pH of the **control** soils causes a greater proportion of the soil calcium to take the form of calcium carbonate and accordingly prevents calcium leaching through the upper profile soil. Average pH of the **control** microbasin soils was 7.4 (surface) and 7.5 (sub-surface) compared to 6.5 (surface) and 6.7 (sub-surface) for the **test** soils during the times of soil sampling for calcium analysis (refer to Table 3.8).

Soil pH, as mentioned above, tended to be higher for the **control** than the **test**, especially in the latter half of the study period (see Table 3.8 and Figure 3.8). The pH of soils of the **control** microbasins averaged 7.4 (surface) and 7.2 (sub-surface) over the entire study period compared to 6.9 (surface) and 7.0 (sub-surface) for the **test**. Soil pH affects soil mineral contents as well as soil bioactivity. However, the pH values measured for the soils in this study fall within the expected range for most agricultural soils. Soil pH is therefore not likely to have any significant impact on the organisms responsible for degradation of agrochemicals such as metolachlor.

Metolachlor

A summary of the metolachlor analysis for soil samples collected throughout the period of study is provided in Table 3.8. The metolachlor readings are graphically represented in Figures 3.9 and 3.10.

In September of 1991, extremely high concentrations were found in the surface soils of the **control** microbasins (2288 ng/g in KCB1 and 1434 ng/g in KCB2). Concentrations of 36 and 40 ng/g were found in the **control** sites subsurface soils. Much lower values were found in the surface soils of the **test** microbasins (26 ng/g for KTB1 and 28 ng/g for KTB2). Metolachlor was not detected in the subsurface soils of the **test** sites.

Analyses of samples collected in November, 1991, show a dramatic decrease in concentrations with no metolachlor being detected in any samples except low concentrations at both KCB1 (surface) and KTB2 (surface). Surprisingly, no metolachlor was detected in KTB2 in September yet it is detected in November, although at extremely low concentrations. This may simply be due to sample variability.

Samples collected on May 04, 1992, showed very low levels of metolachlor in the **control** soils and no detectable metolachlor in **test** soils. At this point, no applications of metolachlor had taken place since 1991. Accordingly, low levels of metolachlor were expected.

The analyses of samples collected in June of 1992 show the highest levels of metolachlor observed during the study (refer to Table 3.8). These samples were collected shortly after the time of metolachlor application. In the surface soils, June metolachlor levels were much higher (two to five times higher) in the **control** relative to the **test** microbasins (refer to Figure 3.10). Metolachlor levels in sub-surface soils were much lower than surface levels, but the highest sub-surface concentration was again found in the **control (KCB1)**. Surprisingly, metolachlor was not detected in the sub-surface soil sample from KTB2. This may again be a result of spatial variability at the sampling location.

Samples collected during September of 1992 show a sharp decline in metolachlor levels (refer to Table 3.8, Figures 3.9 and 3.10). In the surface soil, the highest soil metolachlor concentration is again seen in the **control** (KCB1). None of the sub-surface soil samples showed detectable levels of metolachlor. Metolachlor has a half-life of approximately 30 to 51 days (in Northern U.S.) and the drop in concentrations is not unexpected.

Analyses of soil samples, both surface and sub-surface, collected in December, 1992, show no detectable metolachlor in either the **test** or **control** microbasins.

The overall trend for soil metolachlor concentration is that the **control** tends to have higher concentrations compared to **test** soils, particularly in the period just after application. The soils of the **control** have also been found to have lower organic matter content than the **test** soils. Accordingly, **test** soils are likely to have higher populations of soil microbes that utilize the organic matter as a nutrient substrate. Some of these same microorganisms also utilize agrochemicals, such as metolachlor, as substrates. This ultimately results in the degradation of these chemicals. Higher ambient levels of these microorganisms likely result in greater rates of degradation of metolachlor and other agrochemicals. In the **control** soils, lower populations and lower activities of microorganisms may well mean slower breakdown of metolachlor and subsequently higher levels of metolachlor than in **test** soils.

3.4 Surface Water

3.4.1 Hydrology

Surface water runoff in the Kettle Creek microbasins has proven to be quite variable during the NSCP study period. Monitoring of water quantity and quality began with the installation of the microbasin instrumentation during the SWEEP study in 1989. Therefore water quantity monitoring was immediately initiated for this study at project award in June 1991. Precipitation was well below normal in the Kettle Creek area for much of 1991 and as a result no flow was recorded in any of the microbasins until November of 1991. Overland flow occurred only in the two **control** microbasins (KCB1 and KCB2) and therefore the 1991 flow data is not useful for comparative purposes between conventional and conservation tillage systems.

Precipitation during 1992 proved to be much greater compared to 1991. The 1992 precipitation resulted in substantial flows in all microbasins, particulary in the latter part of the year. Monthly total microbasin unit area flows (normalized for microbasin area differences) are presented in Table 3.9 while daily total flows are presented in Appendix B. Runoff patterns for all microbasins were similar during 1992 as shown in Figure 3.11.

High microbasin total flows occurred in March, April August, September and November. Lesser amounts occurred in February, July and October. Although patterns of runoff were similar for all microbasins, monthly runoff totals differed substantially between microbasins. The two **control** microbasins produced similar total flows month-to-month while the **test** microbasins had drastically different monthly totals. KTB1 consistently produced the lowest monthly unit area flows of all microbasins. Contrastingly, KTB2 usually produced the greatest monthly unit area flows. The latter microbasin's results are consistent with that of the Tillage 2000 results. Although the microbasin flow analysis is based on only one data year, the comparative flow patterns between microbasins and the temporal flow patterns do seem consistent over the study period. However, to describe these results as trends would be premature. At least two more years of study with similar or greater total flow would be required to fully examine microbasin flow dynamics.

KCB2 is a unique microbasin in that it is the only area which has extensive tile drainage. Flow monitoring at this station does not distinguish between surface flow and tile flow and a complete examination of tile flow was not feasible in the Kettle Creek Area. However, periodically, flow rates from the tiles were determined through the use of volume measurements. Flow rates were measured to range between approximately 0.5 to 9.0 litres/s. Although flow rates associated with the tiles are small compared to event surface flow rates, the tile drains generally flow for a much longer duration and therefore can contribute significantly to KCB2 total flow.

3.4.2 Surface Water Quality

Summary statistics were generated for all water quality parameters (Table 3.10). The purpose of examining the water quality concentration statistics is to determine if parameter concentrations are reduced in the **test** microbasins compared to the **control**. As shown in Table 3.10, certain average parameter concentrations such as nitrate-nitrogen and metolachlor are lower in the **test** areas. For example in KTB1 and KTB2 average nitrate concentrations were 3.4 mg/L and 2.8 mg/L respectively. Both **control** microbasins had higher average nitrate concentrations (KCB1 - 4.1 mg/L and KCB2 - 8.8 mg/L). Similar results were found with metolachlor where KTB1 and KTB2 had average concentrations of 5.59 µg/L and 3.39 µg/L while KCB1 (10.09 µg/L) and KCB2 (7.10 µg/L) both had higher average concentrations.

Analysis of other water quality parameters is less conclusive. For example, the greatest average TSS concentration was highest in KCB1 while the lowest was found in KCB2. The two **test** microbasins were the intermediates. The reason for the low average TSS concentrations in KCB2 is probably the fact that KCB2 is extensively tile drained. Therefore, a large amount of the total flow from this microbasin is routed through the tiles. As a result, TSS and also TP and TKN concentrations will be lower compared to other microbasins without extensive tile drainage. The exact impact the tiles have on the partitioning of flow and water quality was beyond the scope of this study.

Average TP concentrations followed the same pattern as TSS with the two **test** microbasins being intermediate in concentrations. The tile drainage in KCB2 would also explain this phenomenon since TP is usually transported with soil in the sorbed form.

Average soluble phosphorus (SRP) was found to be highest in KTB1 at 0.228 mg/L. KCB1 and KCB2 had very similar average SRP concentrations at 0.158 and 0.160 mg/L respectively. KTB2 had the lowest average SRP concentrations at 0.125 mg/L. The latter was expected because KTB2 produced the greatest surface runoff and thus SRP concentrations were diluted. Similarly, KTB1 which had the lowest overall surface runoff, produced the greatest average SRP concentrations.

It is hypothesized that the superior soil quality and overall soil health of the **test** microbasins has resulted in reduced nitrate and metolachlor concentrations and transport. The two **test** microbasins have enriched soil organic matter contents from residue at the surface - probably in various forms of degradation. The greater organic matter contents produce a large number of beneficial effects and improved soil quality. It is hypothesized that the surface soils in the test microbasins have an associated greater bioactivity (soil microorganisms). It is the greater bioactivity that is responsible the utilization of nitrate-nitrogen and the biodegradation of metolachlor.

3.4.3 Surface Water Quality Loads

Water quality loads for 1992 have been computed for the six primary water quality parameters and are found in Table 3.11. Water quality loads were calculated using the SWEEP loads model described in Section 2.0. For comparative purposes the water quality loads have been grouped into three seasons (January-April, May-August, and September-December).

Of the water quality parameters tested during this study, three fall into the soil sorbed category (total suspended solids, total phosphorus, and total kjedahl nitrogen) and three are dissolved constituents (nitrate, soluble phosphorus, and metolachlor). The sorbed chemicals will tend to be transported with soil particles during erosion processes. Therefore the most effective management of these constituents is to minimize soil losses.

Total suspended solids (TSS) annual loads were quite low for all microbasins (KTB1 - 0.15 tonnes/ha; KTB2 - 1.51 tonnes/ha; KCB2 0.49 tonnes/ha) with the exception of KCB1 which produced 10.15 tonnes/ha during 1992 (see Figure 3.12). As discussed previously, KCB2 has extensive tile drainage and as a result TSS concentrations and subsequent loads and therefore quite low for a conventional tillage system. TSS loads varied

seasonally from microbasin to microbasin but were generally greatest during the January to April and September to December periods. Similar unit area TSS load distributions between microbasins were found in each of the seasons examined (i.e., KCB1 consistently had the greatest TSS load etc.)

Patterns and trends in total phosphorus loads (TP) and to some extent total Kjeldahl nitrogen (TKN) were similar to those found with TSS. This is not unexpected as both TP and TKN are associated with eroded soil particles in surface waters. Therefore, TSS, TP and TKN load patterns will be similar and will differ only due to normal variability.

Annual TP loads were greatest in KTB2 (4.60 kg/ha) followed by KCB1 (2.71 kg/ha), KCB2 (1.93 kg/ha) and KTB1 (0.59 kg/ha). The period of September to December experienced the largest seasonal share of the total annual TP loads in all microbasins except KTB1 where January to April and September to December were approximately equal with respect to TP load.

Dissolved parameter loads such as nitrate-nitrogen (NO_3), soluble reactive phosphorus (SRP) and metolachlor exhibited a very different pattern when compared to the soil sorbed parameters. The greatest nitrate loads were generated from KCB2 with a total unit area yearly load of 19.05 kg/ha. KTB2 produced the second greatest yearly unit area nitrate load of 7.52 kg/ha (Figure 3.13). The unit area nitrate loads were relatively high for a **test** basin. This was due mainly to the surface water flows of KTB2. KTB1 (3.87 kg/ha) and KCB1 (4.09 kg/ha) produced similar total yearly unit area nitrate loads. On a seasonal basis, unit area nitrate loads were greatest during the January-April period and lowest during the summer when flows were very low.

When averaged the **control** microbasins yielded a higher unit area nitrate load compared to the **test**, however this cannot be considered significant based on one year of monitoring.

No consistent trends in yearly unit area SRP loads were determined. In most cases, the greatest loads came in the September to December period (Table 3.11). KTB1 produced the greatest unit area load (601.45 g/ha) while KTB1 produced the lowest (80.31 g/ha). The two **control** microbasins were intermediate. This pattern is the same as the pattern associated with the surface water flows and therefore flow seems to govern SRP loads.

Metolachlor unit area loads are found in Table 3.11. In all cases, both seasonally and yearly, the **test** microbasins produced the lowest unit area loads (Figure 3.14 and Table 3.11). Unit area metolachlor loads were lowest in the January-April season and generally similar for the remaining two seasons examined. Given the fact that metolachlor application rates were identical for all microbasins, there does seem to be an improvement in runoff quality associated with the no-till **test** microbasins. **Test** microbasin unit area metolachlor loads ranged from 0.13 to 0.51 g/ha during January to April, 2.27 to 2.39 g/ha during May to August (during the period of most active decay) and from 0.24 to 2.66 g/ha during the September to December 1992 period. In contrast, **control** microbasin unit area metolachlor loads ranged from 0.72 to 4.07 g/ha during January to April, 2.28 to 8.67 g/ha during May to August and from 8.24 to 9.88 g/ha during the September to December period.

As mentioned previously, the lower metolachlor loads are thought to be due to the enrichment of plant residue organic matter in the surface soils of the **test** microbasins. It is well documented that no-till systems soils have greater organic carbon contents compared with conventionally tilled soils. Therefore, as a result of the organic matter enrichment in the conservation tilled microbasins, the soil quality is improved and subsequently these areas are more biologically active and can therefore breakdown metolachlor at greater rates when compared to conventionally tilled soils.

3.5 Hydrogeology

3.5.1 Geology

The Kettle Creek watershed is located within the Mount Elgin Ridges physiographic region. This region contains the Westminster moraine which is characterized by well to imperfectly drained clay loam to clay till ridges. Alluvial derived soils are found in poorly drained, low lying areas (Department of Supply and Services, 1990). The dominant soils in the watershed are derived from shallow water lacustrine deposits overlying till (Bennington soils), till derived soils (Muriel) and deep, lacustrine deposits (Brant soils).

The unconsolidated geologic materials in the microbasins in general are comprised of silt loam to silty clay/clayey silt underlain by silt or clay loam. In boring KTB2-3, a silty sand till

is present in place of the silt or clay loam. Complete descriptions of these materials are provided in the boring logs presented in Appendix A.

3.5.2 Groundwater Flow

Water levels measured in the monitoring wells in 1991 to 1992 are presented in Table 3.12. Water levels show considerable temporal variation. This is assumed to be caused by a seasonal variation in precipitation. Groundwater elevations were generally lowest in June-July and highest in November. The watertable generally ranges in elevation from approximately 263.62 to 283.31 m above mean sea level (amsl) in the monitoring wells.

In general, groundwater flows from areas of high hydraulic head (more elevated watertable) to areas of low hydraulic head. The groundwater in KTB2 flows from the north-northwest toward the south-southeast. Groundwater in Kettle KCB2 flows from the north-northeast to the south-southwest. The groundwater flow direction in KCB1 and Kettle KTB1 could not be determined with the existing information.

The shallow horizontal hydraulic gradient in KTB2 ranges from 0.027 to 0.038 while the shallow horizontal hydraulic gradient in KCB2 ranges from 0.021 to 0.025 during the time period May-November 1992. The shallow hydraulic gradient in KCB1 and KTB1 could not be determined with the existing information.

3.5.3 Hydraulic Conductivity Determinations

The hydraulic conductivity of the till unit was determined by conducting single well recovery tests on new wells KTB1-2, KTB2-1, KCB1-3D KCB2-3S and KCB2-3D. The data were interpreted using the Bouwer and Rice (1976) method for analysis of rising head response tests. The method used to conduct the test and analyze the data is presented in Section 2.2.4 and Protocol No. 9 (Appendix A). The graphs of water level recovery versus time, and the input parameters for each of the hydraulic conductivity calculations are presented in Appendix B. Hydraulic conductivity values for the wells ranged from 2.21×10^{-9} m/s to 1.24×10^{-7} m/s for an average (geometric mean) hydraulic conductivity of 9.7×10^{-9} m/s.

3.5.4 Groundwater Velocities

The velocity with which water moves through a geologic medium is proportional to the hydraulic conductivity of the medium and the hydraulic gradient at that location. The approximate average linear groundwater velocity may be calculated using the following equation:

$$v = \frac{K\,i}{n}$$

where: v = average linear groundwater velocity (L/T)
K = hydraulic conductivity of the geologic material (L/T)
i = hydraulic gradient (L/L)
n = porosity of geologic material (dimensionless)

Assuming an average geometric mean hydraulic conductivity of 9.7×10^{-7} cm/sec, a porosity of 40% (typical of clay deposits as indicated by Freeze and Cherry, 1979), and an average horizontal hydraulic gradient of 0.027 (arithmetic mean), then the average horizontal groundwater velocity can be calculated. Using these assumptions, the calculated average horizontal groundwater linear velocity is very slow and is estimated to be approximately 0.02 m/yr.

3.5.5 Subsurface Chemistry

The results of the analyses performed on groundwater samples collected from monitoring wells within the **test** and **control** basins are presented in this section. The groundwater samples were analyzed for nitrate-nitrogen, soluble-reactive phosphorus, total phosphorus, total dissolved solids and metolachlor. The pH, temperature and specific conductance of the groundwater was measured in the field after samples had been procured for laboratory analysis.

The groundwater chemistry analytical results are summarized in Table 3.13. Field water quality measurements are presented in Table 3.14. The groundwater chemistry data were compared to applicable Guidelines for Canadian Water Quality (CWQGs) (CCME, 1992).

Nitrate-Nitrogen

The concentrations of nitrate-nitrogen in groundwater ranged from <0.01 to 9.8 mg/L with the highest concentration detected in a groundwater sample collected from monitoring well KTB2-1 on 5 May 1992. A higher nitrate concentration was detected in a groundwater sample collected from monitoring well KTB1-2 but the integrity of the well is questionable. With the exception of groundwater samples collected from monitoring well KTB1-2, the nitrate concentration in groundwater samples is less than the CWQG.

Soluble Reactive Phosphorus

The concentration of soluble-reactive phosphorus in groundwater ranged from <0.001 to 0.04 mg/L with the highest concentration detected in a groundwater sample collected from monitoring well KTB1-2 on 5 November 1992. Soluble-reactive phosphorous concentrations in groundwater are not addressed in the CWQG.

Total Phosphorus

The concentration of total phosphorus in groundwater ranged from 0.002 to 0.26 mg/L with the highest concentration detected in a groundwater sample collected from monitoring well KTB1-2 on 5 May 1992. Total phosphorous concentrations in groundwater are not addressed in the CWQG

Total Dissolved Solids (TDS)

The TDS was only measured for four wells in the **control** basins (KCB1-3S, KCB1-3D, KCB2-3S and KCB2-3D) and two wells in the **test** basins (KTB2-2S and KTB2-2D) at different times of the year. The concentration of TDS ranged from 310 to 970 mg/L. The highest TDS concentration was detected in a groundwater sample collected from monitoring well KCB1-3D on 10 July 1992. The CWQG of 500 mg/L for TDS is exceeded in five of the eight groundwater samples collected for TDS analysis.

Metolachlor

The concentration of metolachlor in groundwater ranged from <0.25 to 1.38 µg/L. The highest metolachlor concentration was detected in a groundwater sample collected from monitoring well KTB1-1 on 5 November 1993. Metolachlor concentrations in groundwater are not addressed in the CWQG

pH

The pH of the groundwater ranged from 7.12 to 8.20 with the highest pH measured in a groundwater sample collected from monitoring well KTB2-2D. The pH values indicate that the groundwater is neutral to slightly alkaline. The temperature of the groundwater ranged from 2°C to 17.5°C with the range in values due to seasonal variation. The specific conductance of the groundwater ranges from 510 µmhos/cm to 1,723 µmhos/cm. The highest specific conductance was measured in a groundwater sample collected from monitoring well KCB2-3S.

3.5.6 Discussion of Groundwater Chemistry

Nitrate-nitrogen and phosphorus were detected in groundwater samples from all wells at least once during the 1992 groundwater monitoring program. This is to be expected in areas where nitrogen and phosphorus based fertilizers are utilized. The highest concentrations of nitrate-nitrogen, soluble reactive phosphorus, total phosphorus, and metolachlor were detected in groundwater samples collected from **test** basin KTB1. However, the integrity of the surface seals in monitoring well KTB1-2 and KTB1-3S are suspect and it is likely that hydraulic communication exists between the ground surface and the sand pack surrounding the well screens. Surface water runoff carrying high concentrations of nitrate and phosphorous has likely flowed down the annulus of the wells into the groundwater resulting in elevated concentrations of these parameters in water samples collected from these monitoring wells. Discounting these wells, no significant differences in groundwater chemistry were observed between microbasins. The chemical

parameters do not show significant temporal or spatial trends within individual microbasins. These results indicate that fate and nitrate-nitrogen and metolachlor are usually through transport of surface and near-surface pathways (i.e., surface runoff, tiles, etc.). It has been noted that the **test** microbasins have resulted in lower transport of aquichemicals (primarily nitrate and metolachlor). Furthermore, these chemicals are not transported to the subsurface pathways and therefore it is expected that these chemicals are utilized or degraded in greater quantities in the surface soils of the test microbasins.

4.0 SUMMARY AND CONCLUSIONS

A summary of the main results of monitoring and analyses conducted for the NSCP study are presented below. Conclusions are based on interpretation of significant trends and differences in the aforementioned data sets.

Agronomy

No significant differences were noted for crop type or yield when comparing **test** microbasins to **control**. There were also no significant differences observed with respect to applications of fertilizers and pesticides, including metolachlor. The only difference between **test and control** microbasins involved surface crop residue. As expected, pre-plant and post-harvest residue counts in the **test** (no-till) microbasins were significantly higher than in the **control** (conventional tillage). The higher surface residues are incorporated into the soil surface resulting in an overall improvement of soil quality (higher organic matter content, moisture retention capacity, etc.). In theory, this affects soil microbial populations and subsequently affects microbial degradation of agrochemicals such as metolachlor, however, these hypotheses would require testing under field conditions to verify these trends.

Soil Monitoring

The physical and chemical properties of the soils of the **test** and **control** microbasins differed in a number of respects. The soils of the **test** microbasins (KTB1 and KTB2) exhibited the expected characteristics of soil under conservation management (no-till) when examined in comparison to the soils from the **control** microbasins (KCB1 and KCB2). These characteristics of the test microbasins include:

- higher organic matter, both at the surface (0-5 cm) and at depth (25-30 cm),
- greater soil moisture content throughout all seasons,
- lower bulk density at surface and at depth, and

- generally lower soil pH (surface and sub-surface).

There were further differences evident in the chemistries of **test** and **control** soils, including lower levels of calcium in the **test** soils, which is also expected for no-till soils.

These general soil conditions for the **test** areas, especially elevated organic matter, provide an environment with a higher capacity for supporting soil micro-organisms than do the soil conditions found in the **control** areas. The **test** soils are therefore likely to have higher populations and activity levels of microbes. These micro-organisms, acting as decomposers, can in turn enhance the rate of degradation of agrochemicals such as metolachlor. Analyses of the soils from the Kettle Creek study area support the contention that metolachlor is degraded more readily in the **test** soils. Levels of metolachlor in soil samples from the **test** microbasins were much lower than those for **control** soil samples for almost every period of sampling. The difference in soil metolachlor concentration is most prominent during the periods closely following the application of the herbicide.

Groundwater

The main results from groundwater monitoring are as follows:

- average linear velocity of groundwater in the Kettle Creek microbasins is very slow,

- nitrate and phosphorous were detected in groundwater samples from all microbasins, as expected for an agricultural area,

- levels of nitrate, SRP, and metolachlor are much lower in groundwater than in surface water,

- the chemical parameters addressed herein show no significant temporal or spatial trends within individual microbasins, and

- no significant differences in groundwater chemistry, including metolachlor concentration, exist between **test** and **control** microbasins.

Surface Water

Surface water flow in the four study microbasins was quite variable over the NSCP study period. General findings concerning flow include the following:

- KTB1 consistently produced the lowest flow of all four microbasins,
- KTB2 usually produced the highest flow of all four microbasins, and
- KCB1 and KCB2 produced similar flows throughout the period of study.

Overall, further examination of flow data during periods of adequate precipitation is required to accurately assess any differences between **test** and **control** microbasins with respect to flow. Flow during the NSCP study was too infrequent for a thorough assessment.

Analyses of surface runoff samples collected from the four Kettle Creek microbasins during the study period reveal several differences in water quality between the **test** and **control** microbasins. The two main conclusions with respect to concentrations of water quality parameters are;

- surface runoff nitrate concentrations were lower in the **test** microbasins, and
- surface runoff metolachlor concentrations were also lower in the **test** microbasins.

Microbasin water quality loads were also computed for six primary water quality parameters. The main findings are as follows:

- soil sorbed water quality indicators (TSS, TP, and TKN) showed no consistent differences between **test** and **control** microbasin,

- SRP and Nitrate (dissolved water quality indicators) showed no clear differences between **test** and **control** (although indications are that nitrate may tend to be lower in the **test** microbasins), and

- in all cases, unit area metolachlor loads were lower in the **test** microbasin.

Overall, both soil and water quality analysis appears to indicate that the conservation tillage implemented in the **test** microbasins is having a positive effect on environmental quality with respect to residues of the herbicide metolachlor. The main reason for the improvement is theorized to be the enrichment of soil organic matter and subsequent increase in populations of microorganisms (relying on organic matter to thrive) that act to degrade metolachlor and other compounds in the soil. Lower levels of soil metolachlor translate to lower water borne metolachlor delivered by runoff.

Recommendations for further study include;

- continuation of current studies to provide a larger and more conclusive data base with respect to surface water flow, and

- monitoring for degradation products of metolachlor in soil and water to better understand the fate of the herbicide in agricultural systems.

5.0 REFERENCES

Agriculture Canada. 1983. Agricultural Management Practices for Improved Water Quality in the Canadian Great Lakes Basin. Research Branch. LRRT Contribution no. 82-10.

Agriculture Canada. 1984. A Soil Mapping System for Canada: Revised. Expert Committee on Soil Survey, Land Resource Research Institute, Ottawa, LRRI Contribution No. 142

Agriculture Canada. 1989. The characterization and identification of potentially leachable pesticides and areas vulnerable in groundwater contamination by pesticides in Canada. Rept. No. 89-01.

Agriculture Canada (Food Production and Inspection Branch). 1991. Memorandum: Revision of Chapter 2: Pesticide Rating Scheme of Backgrounder 89-01.

Beak Consultants Limited. 1993. The Effects of Soil Quality on Field Scale Runoff Under Conventional and Conservation Tillage Systems (in preparation). Guelph, Ontario.

Beak Consultants Limited. 1993. The Pilot Watershed Study Soil and Water Environmental Enhancement Program: Reports #5 and #6 Evaluation of Conservation Systems, Water Quality. Guelph, Ontario.

Beak Consultants Limited. 1993. Herbicide Residue Occurrence at Three Watershed Scales in Southwestern Ontario. Guelph, Ontario.

Beak Consultants Ltd. March 1992. The Effect of Soil Quality on Field Scale Runoff Under Conventional and Conservation Tillage Systems. Interim Progress Report

Beak Consultants Limited. 1991. Evaluation of immunoassays for the detection and measurement of atrazine residues in water (Submitted to the MOE).

Beak Consultants Limited. 1989. Modelling the Loss of Soils, Atrazine and Phosphorus in a Southwestern Ontario Agricultural Watershed. Guelph, Ontario.

Beak Consultants Limited, 1989. Modelling the Loss of Soils, Atrazine and Phosphorus in a Southwestern Ontario Agricultural Watershed. A report to the Ontario Ministry of the Environment.

Berg, W.A., S.J. Smith, and G.A. Coleman. 1988. Management Effects on Runoff, Soil and Nutrient Losses from Highly Erodible Soils in the Southern Plains. J. Soil Water Cons. 43: No. 5, 407-415.

Betson, R.P. and W.M. McMaster. 1975. Nonpoint source mineral water quality model. Journal of the Water Pollution Control Federation, 47(10):2461-2473.

Blevins, R.L., M.S. Smith, G.W. Thomas and W.W. Frye. 1983. Influence of Conservation Tillage on Soil Properties. J. Soil Water Cons. 38: 301-305.

Bodo, B. and T.E. Unny. 1983. Sampling Strategies for Mass-Discharge Estimation. J. of Env. Eng. 109: 812-829.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells. Water Resources Research V. 12, No. 3.

Bushway, R.J., B. Perkins, S.A. Savage, S.J. Lekous and B.S. Ferguson. 1988. Determination of atrazine residues in water and soil by enzyme immunoassay. Bull. Environ. Contam. Toxicol. 40:647-654.

Canadian Council of Ministers of the Environment. 1992. Canadian Water Quality Guidelines Prepared by the Task Force on Water Quality Guidelines.

Carsel, R.F. and R.L. Jones. 1990. Using Soil and Meteorologic Data Bases in Unsaturated Zone Modeling of Pesticides. Ground Water Monitoring Review. Fall 1990. 96-101.

Department of Supply and Services, Agriculture Canada. 1990. Soil Survey of the Pilot Watersheds, Southwesten Ontario Soil and Water Environmental Enhancement Program

Draper, N.R. and H. Smith. *Applied Regression Analysis*, 2nd ed. John Wiley, New York. 709 pp.

Ecological Services for Planning. 1990. Soil Survey of the Pilot Watersheds Southwestern Ontario Soil and Water Environmental Enhancement Program. A SWEEP report to Agriculture Canada.

Edwards, W.M. 1991. Why I Like No-Till. Excerpts from Remarks to a Farmers Workshop, Guelph.

R.W. Gillham. 1988. Nitrate Contamination of Groundwater in Southern Ontario: A Hydrogeologic Perspective. In Proceedings, Ontario Water Management and Services Committee Workshops, Kitchener, Ontario. November 17-18, 1988.

Ferris, I.G. and B.M. Haigh. 1987. A rapid and sensitive HPLC procedure for the Ferris, I.G. and B.M. Haigh. 1987. A rapid and sensitive HPLC procedure for the determination of atrazine residues in soil-water extracts. J. Chromatog. Sci. 170-173.

Fleeker, J. 1987. Two enzyme immunoassays to screen for 2,4-Dichlorophenoxyacetate acid in water. J. Ass. Off. Anal. Chem. 70: 874-878.

Frank, R., H.E. Braun, M. Van Hove Holdrinet, G.J. Sirons and B.D. Ripley. 1982. Agriculture and water quality in the Canadian Great Lakes Basin: V. Pesticide use in 11 agricultural watersheds and presence in stream water, 1975-1977. J. Environ. Qual. 11:497-505.

Frank, R., B.S. Clegg, B.D. Ripley and H.E. Braun. 1987. Investigations in pesticide contaminations in rural wells, 1979-1984, Ontario, Canada. Arch. Environ. Contam. Toxicol. 16:9-22.

Frank, R., and L. Logan. 1988. Pesticide and industrial chemical residues at the mouth of the Grand, Saugeen and Thames Rivers, Ontario, Canada., 1981-1985. Arch. Environ. Contam. toxicol. 17:741-754.

Freeze, R.A., and J.C. Cherry. 1979. Groundwater, Prentice Hall, Englewood Cliffs, New Jersey.

R.W. Gillham. 1991. Nitrate Contamination of Ground Water in Southern Ontario and the Evidence for Denitrification. NATO ASI Series, Vol. G 30. Nitrate Contamination. Springer-Verlag Berlin Heidelberg.

Hall, J.C., R.J.A. Deschamps and K.K. Kreig. 1989. Immunoassays for the detection of 2,4-D and picloram in river water and urine. J. Agric. Food Chem. 37:981-984.

Hall, J.C., R.J.A. Deschamps and M.R. McDermott. 1989. Immunoassays for detecting pesticides in the environment. Highlights. 3(12):19-23.

Hammock, B.D. *et al.* 1987. In: Pesticide Sciences and biotechnology. Greenlaigh, R. and T.R. Roberts (eds). Blackwell Scientific. London. pp 341-348.

Harrison, R.O., M.H. Goodrow and B. Hammock. 1991. Competitive inhibition ELISA for the s-triazine herbicides: assay optimization and antibody characterization. J. Agric. Food Chem. 39:122-128.

Hendrix, P.F., D.A. Crossley Jr., J.M. Blair and D.C. Coleman. 1990. Soil Biota as Components of Sustainable Agroecosystems. Sustainable Agriculture Systems. Ed. SWCS.

International Joint Commission - Internal Reference Group on Great Lakes Pollution from Land Use Activities. 1977. Quality Control Handbook for Pilot Watershed Studies. International Joint Commission, Windsor, Ontario.

D. Keeney. 1986. Sources of Nitrate to Ground Water. In CRC Critical Reviews in Environmental Control. 16(3):257-304.

Laflen, J.M., L. Rattan and S.A. EI-Swaify. 1990. Soil Erosion and Sustainable Agriculture. Sustainable Agriculture Systems. Ed. SWCS.

Lankow, R.K., G.D. Gorthaus and S.A. Miller. 1987. Immunoassays for crop management systems and agricultural chemistry. Biotechnology in Agriculture Chemistry. ASC Symposium Series. 334: 227-252.

Linsley, R.K. and J.B. Franzini. 1979. Water Resources Engineering, 2nd Edition. McGraw Hill Book Co., New York.

T.J. Logan. 1982. Mechanisms for release of sediment-bound phosphate to water and the effects of agricultural land management on fluvial transport of particulate and dissolved phosphate. Hydrobiologia 92:519-530. Dr. W. Junk Publishers. The Hague.

Miller, M.H., J.B. robinson, D.R. Coote, A.C. Spires and D.W. Draper. 1982. Agriculture and water quality in the Canadian Great lakes Basin: III Phosphorus. J. Environ. Qual. II: 487-493.

Mutchler, C.K., C.E. Murphee, and K.C. McGregor. 1988. Laboratory and Field Plots for Soil Erosion Studies. Soil Erosion Research Methods. R. Lal Ed. SWCS. Iowa.

O'Neill, B.C., R.G. Kachanoski, and D.E. Elrick. 1990. Effects of Management on Soil Hydraulic Properties. Final Report to SWEEP TED Sub-program, Agriculture Canada.

Ontario Ministry of Agriculture and Food. 1989. Survey of pesticides use in Ontario. 1988. Rept. No. 89-08.

Overton, D.E. and M.E. Meadows. 1976. Stormwater Modelling. Academic Press, New York.

PLUARG, 1978a. Stream Flow Quality - Pesticides in Eleven Agricultural Watersheds in Southern Ontario, Canada, 1974-1977.

PLUARG, 1978b. Agricultural Watershed Studies, Contribution of Phosphorus from Agricultural Land to Streams by Surface Runoff.

Podjasok, T. and B.D. Kay. 1990. Assessment of Combination of Wet Sieving and Turbidimetry to Characterize the Structural Stability of Moist Aggregates. Can. J. Soil Sci. 70:33-42.

Rittenburg, J.H., G.D. Grothaus, D.A. Fitzpatrick, and R.K. Lankow. 1990. Rapid on-site immunoassay systems. Vanderlaan *et al.* (eds.). In: Immunoassays for trace chemical analysis. ACS Symposium 451:28-39.

Russell, B., Robertson, W.D., Gillham, R.W. and J.A. Cherry. 1992. Nitrate Persistence in Slightly Permeable Sediments in Ontario.

Schlaeppi, J.M., W. Fory and K. Ramsteiner. 1989. Hydroxyatrazine and atrazine determination in soil and water by enzyme-linked immunosorbent assay using specific monoclonal antibodies. J. Agric. Food Chem. 37:1532-15388.

Schroeter, H.O. and W.E. Watt. 1989. Practical simulation of sediment transport in urban runoff. Canadian Journal of Civil Engineering. 16(5):704-711.

Shirmohammadi, A., Magette, W.L., and L.L. Shoemaker. 1991. Reduction of Nitrate Loadings to Ground Water. Winter Ground Water Monitoring Review. 112-118.

Snedecor, G.W. and W.G. Chochran, 1982. Statistical Methods. Sixth Edition. IOWA State University Press, Anes, IOWA.

Thurman, E.M., M. Meyer, M. Pomes, C.A. Perry and A.P. Schwab. 1990. Enzyme-linked immunosorbent assay compared with gas chromatography/mass spectrometry for the determination of triazine herbicides in water. Anal. Chem. 62:2043-2048.

Tin, M. 1965. Comparison of Same Ratio Estimators. J. of Amer. Stat. Assoc. 60: 1555 1565.

Vanderlaan, M., B.E. Watkins and L. Stanker. 1988. Environmental monitoring by immunoassay. Environ. Sci. Technolo. 22:247-254.

Van Der Zee, Sjoerd, E.A.T.M. and Jos J.T.I. Boesten. 1990. Effects of Soil Heterogeneity on Pesticide Leaching to Groundwater. Water Resources Research, Vol. 27(12):3051-3063.

Verhoff, F.H., S.M. Yakish, and D.A. Melfi. 1980. River nutrient and chemical transport estimation. Journal of Environmental Engineering Division, ASCE, 106(EE3):591-608.

Vyn, T.J., T.B. Daynard and J.W. Ketcheson. 1979. Tillage Practices for Field Crops in Ontario. Ont. Agricultural College, U. of Guelph; Ont. Min. of Agriculture and Food, and Ont. Ministry of the Environment. Toronto, Ontario.

Wall, G.J., W.T. Dickinson and L.J.P. Van Vliet. 1982. Agriculture and water quality in the Canadian Great Lakes Basin: II Fluvial sediments. J. Environ. Qual. 11:482-486.

Walling, D.E. 1977. Assessing the accuracy of suspended sediment rating curves for a small basin. Water Resources Research. 13(3):531-538.

Water Survey of Canada. 1990. Report on Water Quality Monitoring for Pilot Demonstration Watersheds (1988-89) AWSC report by M. Shaw.

Wilson, M.P., E.P. Savage, D.D. Adrian, M.J. Aaronson, T.J. Keefe, D.H. Hamar and J.T. Tessari. 1987. Groundwater transport of the herbicide, atrazine, Weld County. Colorado Bull. Environ. Contam. Toxicol. 39:807-314.

Wilson, M.P., E.P. Savage, D.D. Adrian, M.J. Aaronson, T.J. Keefe, D.H. Hamar and J.T. Tessari. 1987. Groundwater transport of the herbicide, atrazine, Weld County. Colorado Bull. Environ. Contam. Toxicol. 39:807-314.

APPENDIX B

MONITORING DATA

APPENDIX A

SAMPLING PROTOCOLS

PROTOCOL NO. 1

SUPERVISION OF EXPLORATORY BORINGS

PROTOCOL NO. 1
SUPERVISION OF EXPLORATORY BORINGS

1.1 Introduction

This document describes the procedures followed during the drilling and sampling of exploratory borings for Agriculture Canada at two microbasins monitored during the National Soil Conservation Program (NSCP) at Belmont, Ontario. A total of eleven borings were drilled.

1.2 Drilling Methods

The exploratory borings were drilled by London Soil Test Inc. of London, Ontario using a track mounted Canterra 150 drill rig. The borings were drilled with 4 1/4-inch inside diameter (ID) (8 1/4-inch outside diameter (OD)) hollow stem augers. A BEAK hydrogeologist attended the drilling activities continuously to specify the rate of drill penetration, depth of sample collection, and total depth of boring.

No greases or petroleum-based solvents were used during the drilling procedures.

1.3 Sample Logging

Soil samples were collected from the auger flights during drilling and were visually classified according to the Agriculture Canada Soil mapping system (Agriculture Canada, 1984). A detailed boring log containing the geologic description including descriptions of soil type, colour, moisture content and structure (if any) was constructed for each boring. The boring logs also contained observations noted during the drilling procedure, notes on sample recovery, and well construction details.

PROTOCOL NO. 2

WELL INSTALLATIONS

PROTOCOL NO. 2
WELL INSTALLATIONS

2.1 Introduction

This document describes procedures followed during well installation for Agriculture Canada at two microbasins monitored during the NSCP at Belmont, Ontario.

A single monitoring well was installed in each of the eleven exploratory borings. Each monitoring well was designed to permit the collection of water samples from selected intervals in which the sand pack was positioned. The interval to be intersected by the well screen was based on the assumed depth to the water table.. Monitoring wells were constructed using the procedures outlined in the following sections.

2.1.1 Screen and Riser Pipe

The monitoring wells were constructed using flush threaded schedule 40 polyvinyl chloride (PVC) casing. The inside diameter of the casing was sufficiently large (2-inches) to permit the entry of water level measuring and groundwater sampling devices. The well screens consisted of casing material which was factory slotted (slot width = 0.01 inches) to permit the entry of water into the well. The bottom of the screens were plugged with appropriately sized screw-in end caps. The appropriate number of risers were coupled with the 5-foot screen sections via threaded joints to construct the well. No PVC cements or other solvents were used in the construction of the wells

2.1.2 Setting Screens, Riser Casings and Filter Materials

The total depth of the boring was measured with a weighted tape prior to installing the well. This measurement was performed as a final verification that the drilling depths were accurate.

The hollow stem augers were left in the boring upon completion of the drilling to prevent soil from collapsing into the boring. The necessary well materials were assembled and lowered to the bottom of the borehole. The bottom of the well screen (end cap) was positioned flush with the bottom of the boring and sufficient lengths of riser were added until approximately 1 m of the riser protruded above the ground surface.

After the monitoring well assembly was lowered to the bottom of the boring, coarse grained prewashed silica sand (size 3M) was added through the inside of the boring to fill the annular space created between the outside of the well and the wall of the boring. The top of the sand was constantly plumbed with a weighted measuring tape as the sand was being poured to ensure that the filter material was flowing without obstruction and evenly into the open boring around the well screen. Sand was added until the level of the sand in the annular space around the well was a minimum of 1/3 m above the top of the screened interval.

2.1.3 Setting Seals and Grouting

Once the top of the sand pack was verified to be in the correct position, a layer of bentonite pellets was placed on top of the silica sand to seal the screened interval of the well off from the overlying fluids/geologic materials in all wells. Sufficient bentonite pellets (1/2 cm in diameter) were poured down the boring to produce a seal that was a minimum of 2/3 m thick above the sand. Drill water in the boring interacted with the pellets, causing them to swell, thereby immediately sealing off the well screen/filter pack from any fluids migrating down from above. A minimum of 30 minutes were allowed for bentonite pellet-expansion.

2.1.4 Documentation of Monitoring Well Configuration

Notes concerning the well construction were recorded in the field book.

PROTOCOL NO. 3

DEVELOPMENT OF MONITORING WELLS

PROTOCOL NO. 3
DEVELOPMENT OF MONITORING WELLS

3.1 Introduction

This document describes the well development procedures followed for Agriculture Canada at two microbasins monitored during the NSCP at Belmont, Ontario.

3.2 Well Development

After the monitoring well installations were completed and had been allowed to set for at least 24 hours, the wells were developed using a Waterra™ pump dedicated to each well and stored in the well bore. In general, a minimum of three well volumes would be removed during the development of a well. However, as the wells on this site could not maintain a yield they were purged to dryness.

The pH, specific conductance, temperature, and total volume of water pumped from each well were monitored during development and recorded in the field book.

3.3 Waterra™ Pump Assembly

The Waterra™ pump assembly consists of a Delrin™ foot valve attached to a length of stiff 5/8-inch outside diameter (OD) high density polyethylene tubing equal to the depth of the well. Oscillation of the tubing, together with the action of the foot valve, forces water to the ground surface. The entire pump assembly is stored in each well.

PROTOCOL NO. 4

WATER LEVEL MONITORING

PROTOCOL NO. 4
WATER LEVEL MONITORING

4.1 Introduction

This document describes the procedures followed during water level monitoring activities for Agriculture Canada at two microbasins monitored during the NSCP at Belmont, Ontario.

4.2 Water Level Measurements

Water level measurements were obtained from all wells using a battery operated water level tape. The water level tape is marked at 1 cm intervals for accurate measurements to the nearest 0.5 cm. The probe used to measure water levels consists of a stainless steel electrode with a circuit insulating gap. The circuit is completed when the probe contacts water and a buzzer is activated.

The procedure used for measuring water levels is as follows:

- switch on;
- lower the weighted electric tape slowly into the well until the buzzer indicates a closed circuit;
- note the length of tape which corresponds to the top of the well casing (reference point is marked on casing); and
- record the resultant value as the water level to the nearest 0.5 cm below the top of the casing.

All water level measurements collected by BEAK personnel were recorded in the field book.

4.3 Equipment Cleaning

Care was taken not to immerse the electrode/tape any further into the well than necessary so that only the stainless steel probe came in contact with the water during a water level measurement. The probe and approximately 1 m of the polyethylene tape were decontaminated after each measurement according to the following procedure:

- rinse thoroughly with distilled water, and
- allow apparatus to air dry

PROTOCOL NO. 5

GROUNDWATER SAMPLING

PROTOCOL NO. 5
GROUNDWATER SAMPLING

5.1 Introduction

This document describes the procedures followed during the collection of groundwater samples for Agriculture Canada at two microbasins monitored during the NSCP at Belmont, Ontario.

5.2 Presampling Activities

The depth to water was measured in each monitoring well to the nearest 0.5 cm using an electronic water level indicator following the procedure presented in Protocol 4. These data were used to calculate the volume of water in each well based on the total depth of the particular well and the inside diameter of the well casing. The 2-inch inside diameter of the casing used to construct the monitoring wells has a volume of 2.03 L of fluid per metre of depth.

5.2.1 Well Evacuation

In general, a minimum of three well volumes are removed from a well prior to sampling. However, the wells were purged to dryness as they could not maintain a yield and the samples were collected the following day. The pH, specific conductance, temperature and total volume of water pumped from each well were monitored during well evacuation and recorded in the field book.

The volume of fluid evacuated from each well was measured in a calibrated bucket and recorded in the field book. Field measurements and observations on the physical appearance and odour of the development water were noted and recorded.

5.3 Sample Acquisition

Groundwater samples were collected in the following order, metolachlor, total or soluble reactive phosphorous, nitrate-nitrogen, and total dissolve solids (TDS).

Groundwater samples were collected in the proper container, field filtered (TDS only) and the appropriate preservative added. All bottles were labelled, placed in insulated coolers with ice, and the necessary chain of custody forms filled out.

5.4 Sample Custody and Handling

The primary objective of sample custody procedures was to create an accurate written record which could be used to trace the possession and handling of all samples from the moment of their collection, through analysis, until their final disposition. Custody for samples collected during this assessment were maintained by the field personnel collecting the samples. The field personnel were responsible for documenting each sample transfer and maintaining custody of all samples until they were shipped to the laboratory.

5.4.1 Chain-of-Custody Procedure

The specific handling and shipment procedures are described below.

A self-adhesive sample label was affixed to each container before sample collection to minimize label loss during handling of the container. At a minimum, the sample label contained:

- Project number,
- Field sample number,
- Date collected,
- Analysis required,
- Preservatives, and
- Samplers initials.

In order to further document details regarding the sample identification, the following numbering system was implemented.

1. The first two symbols indicate the sample medium:

   eg. GW - Groundwater

2. The next number indicates the number of the sample collected on that specific day for that medium:

   eg. GW01 then GW02

3. The next symbol, if present, indicates the type of quality control sample (if applicable):

   FB - Field Blank

   eg. GW02FB

4. The last two letters were the initials of the sampler:
   MO - Marc Oudejans
   eg. GW02FBMO

Samples were placed immediately into an insulated cooler for shipment to the laboratory. The samples were properly relinquished on the field chain-of-custody record by the field personnel. The chain of custody record forms were sealed in a ziplock plastic bag to protect them against moisture. Field chain-of-custody records were completed at the time of sample collection, and accompanied the samples inside the cooler for delivery to the laboratory. Each cooler was filled with ice and was packed in a manner to prevent damage to sample containers. All coolers were delivered to BAS Laboratories Ltd. (BAS) in Brampton, Ontario. Upon receiving the samples, the Sample Custodian inspected the condition of the samples, compared the information on the sample labels against the field chain-of-custody records, assigned a control number, and logged the control number into the computer sample inventory system.

5.4.2 Laboratory Sample Handling Procedures

The Sample Custodian noted any damaged sample containers or discrepancies between the sample label and information on the field chain-of-custody record when logging the sample. This information was also communicated to the Field Operations Manager so proper action could be taken.

The Sample Custodian stored the sample in a secure sample storage cooler refrigerated at 4EC and maintained custody until the sample was assigned to an analyst for analysis.

Original samples were held by the laboratory for thirty (30) days after submission of the analysis results and data packages. Extracts prepared from the samples will be held one hundred eighty (180) days after submission of the analysis results and data packages.

5.5 Field Measurements

The pH and specific conductance meters were calibrated according to the specific manufacturers instructions.

After samples are procured for chemical analysis, a clean glass beaker was filled to measure pH, specific conductance and temperature.

The pH of the sample was measured with a pH meter calibrated to the temperature of the well fluid. The pH probe was lowered into the sample and gently stirred to allow equilibration before the reading was taken. Specific conductance was measured by placing the probe into the sample and taking readings immediately. Temperature was measured with an alcohol-filled thermometer. All measurements were recorded in the field book. Each probe was rinsed initially and between use with a stream of distilled water.

5.6 Quality Control Samples

Laboratory and field quality control checks were utilized to assist in the provision of accurate and reliable analytical data quality control samples. An equipment blank were used as a field quality control check.

5.6.1 Field Duplicate Sample

A field duplicate sample was collected by filling a second set of sample containers after collecting the initial water sample. The duplicate sample was given a fictitious identification so that the laboratory personnel would not know that it was a duplicate sample.

PROTOCOL NO. 6

RESPONSE TESTS

PROTOCOL NO. 6
RESPONSE TESTS

6.1 Introduction

This document describes the procedures followed during the performance of response tests on monitoring wells installed for Agriculture Canada at two microbasins monitored during the NSCP at Belmont, Ontario.

To perform the tests the water level in each well was rapidly lowered as much as possible and then observed as it recovered toward equilibrium. If all other factors remain equal, the rate at which the water level in the well recovers is a function of the bulk (average) hydraulic conductivity of the geologic materials intersected by the well screen/sand pack.

6.2 Data Collection

Recovery tests were initiated by pumping each of the new wells until the water level was lowered to the desired depth. The Waterra™ hand pump dedicated to each well was used for this purpose and reversed in the well and drained immediately prior to commencement of data collection. Once maximum drawdown was achieved the water level in the well, the time, and the date were recorded in the field book and the well was loosely recapped and left to recover.

Recovery was monitored by periodically measuring the water level in each of the wells. Since the rate of recovery declines exponentially with time, the bulk of the recovery water level measurements were collected during the first 8 hours of the test. A complete set of recovery data (water level vs. time elapsed since termination of pumping) was collected as the well recovers toward equilibrium. The response test data was analyzed and interpreted using the Bouwer and Rice (1976) method.

FIELD PROTOCOL NO. A1
SOIL SAMPLING

Purpose:

To obtain a sample from which fertility, aggregate stability, soil moisture content, particle size distribution, pH organic matter content can be determined.

Schedule:

4 times per year:
- pre-spring tillage
- post planting
- full crop canopy
- post harvest-fall tillage

Equipment:

- soil probe
- plastic pail
- screwdriver
- prelabelled plastic soil sample bags
- pencil
- map showing soil benchmark and co-ordinates from reference point

Methodology:

1) Locate benchmark according to map.
2) With the soil probe perpendicular to the ground, insert to a depth of 15 cm and twist 90E.
3) Pull the probe straight up, careful not to lose any of the sample.
4) Using the screwdriver, remove the soil from the probe into the plastic pail.
5) Take representative samples from around the benchmark area.
6) Mix the contents of the plastic pail thoroughly until all soil is of a uniform size.
7) Fill the bag with soil from the pail, seal the bag.
8) Repeat 1 thru 7 for 15 - 30 cm depth.
9) Submit sample to Analytical Services Laboratory, U of G.

FIELD PROTOCOL NO. A2
BULK DENSITY SAMPLING

Purpose:

To obtain soil cores to be used in determining bulk density of the soil.

Schedule:

4 times per year:
- pre-spring tillage
- post planting
- full crop canopy
- post harvest-fall tillage

Equipment:

- sampling cores (2 plus one for pressing core in place)
- wooden block
- small sledge hammer
- prelabelled plastic bags
- trowel
- shovel
- soil

Methodology:

1) Locate benchmark according to map.
2) Place core (bevelled edge down) on the soil surface in an area that seems free of stones, residue etc.
3) Gently press core into soil.
4) Place other core on top of first core and using the wooden block, tap the bottom core completely into the soil.

5) Using the trowel or shovel, gently lift core out taking care not to lose any of the soil within the core.

6) Carefully trim soil which extends beyond core ends and remove any soil attached to the outside of the core.
7) Extrude core contents into prelabelled bag ensuring all soil enters bag.
8) Repeat 1 thru 7 to obtain a total of three cores.
9) Using the shovel, dig a pit >30 cm deep exposing a large enough face to permit the retrieval of 3 more bulk density cores from the 15-30 cm depth using the same methods described above.

FIELD PROTOCOL NO. A3
PORE SIZE DISTRIBUTION CORE SAMPLING

Purpose:

To obtain cores which can be analyzed for water retention characteristics.

Schedule:

At beginning and end of study (preferably pre-spring tillage conditions)

Equipment:

- 11 prelabelled sampling cores (approximately 2 cm x 5 cm cylinders)
- shovel and trowel
- plastic bags
- wooden block
- small sledge hammer

Methodology:

1) Carefully insert 10 cores (bevelled edge down) into soil in locations close to the soil benchmark site taking care to chose areas with little obvious disturbance and low surface residue and stones.
2) Using the wooden block and extra core, press the bottom core into the soil completely.
3) Using the trowel and/or shovel, carefully remove soil and core taking care not to lose any soil from the core.
4) Place core and excess soil (to act as protection) in plastic bag. Seal bag (excess soil will be trimmed later).
5) Keep cores refrigerated but DO NOT FREEZE.
6) Submit cores to Analytical Services Laboratory at U of G for water retention characteristic determination.

FIELD PROTOCOL NO. A4
GUELPH PERMEAMETER MEASUREMENT

Purpose:

To determine field saturated hydraulic conductivity (K_{fs}).

Schedule:

4 times per year:
- pre-spring tillage
- post planting
- full crop canopy
- post harvest-fall tillage

Equipment:

- Guelph Permeameter (GP)
- data sheets
- pencil
- stopwatch
- water (approximately 20 litres)
- map showing soil benchmark locations

Methodology:

1) Locate an appropriate **test** location close to the soil benchmark.
2) Using the GP auger, auger a well to a depth of 30 cm.
3) Follow GP manual for well preparation and equipment set-up.
4) Perform a two head well test using 10 and 15 cm heads according to manual.
5) Repeat 1 thru 4 to obtain data from 2 test wells on each microbasin.

FIELD PROTOCOL NO. A5
GUELPH PRESSURE INFILTROMETER MEASUREMENT

Purpose:

To determine the infiltration rate at the soil surface.

Schedule:

4 times per year:
- pre-spring tillage
- post planting
- full crop canopy
- post harvest-fall tillage

Equipment:

- Guelph Permeameter with Pressure Infiltrometer Attachment (GI)
- data sheets
- pencil
- stopwatch
- water (approximately 20 litres)
- map showing soil benchmark locations

Methodology:

1) Locate an appropriate **test** location close to the soil benchmark.
2) Using the instruction manual, prepare the soil surface, assemble apparatus and conduct measurements as indicated.

FIELD PROTOCOL B1
SURFACE WATER SAMPLING PROTOCOLS

Purpose:

To obtain representative surface water quality samples during flow events from microbasins.

Schedule:

Samples to be collected during rainfall/flow event periods.

Equipment:

- sample bottles
- pH specific conductance meter
- mercury thermometer
- log book

Methodology:

Sample Containers Required

Sample bottles and supplies of distilled water are available from the BAS Laboratory. The following sample bottles are required for this program:

For General Chemistry and Sediment (TP, TSS, TKN, NO_3)

- 500 mL Round Clear Plastic Bottle

For Field Filtered Soluble Reactive Phosphorus (SRP)

- 100 mL Glass Bottle

For Pesticide

- 250 mL Amber Bottle with Teflon Cap

Sampling Sites

The following criteria should be applied to the selection of sampling points at the watershed outlets.

1. Select a location accessible to the control structure near the V-notch weir. During very low flow periods it may be necessary to collect the sample just downstream of the V-notch as water cascades through the V-notch.
2. Sample from a vertical panel located at the centre of flow (ie. depth integration technique).

Sampling Protocol

The following procedure should be followed during the collection of a water sample at each site.

As the streams in this program are very small, manual grab samples should be taken by wading in the stream. approach the sampling point from downstream and collect the sample directly in the 1 Litre glass sample bottle. The use of sampling buckets is not recommended.

Bottle Labelling

Prior to collection of the sample, label all containers with the following information:

Name of Sample site
Date of Sample Collection
Time of Sample Collection (Eastern Standard only!)
Field Sample Number

* see attachment for standard names and recommended sampling number structure.

Bottle Filling

1. For General Chemistry and Sediment Sample

    1. Use 500 mL clear plastic bottle.

    2. Label bottle as above.

    3. Rinse the bottle and cap with at least 250 mL of stream water.

This procedure tends to equilibrate the sample with the container walls, and hance any 'container effects' (leaching, absorption, etc.) are minimized.

4. Fill the bottle with a representative sample of stream water.
   Representative samples of suspended sediment and water quality parameters which have a strong affinity for sediment (phosphorus), should be collected using a depth integrating technique.
   Depth integrated samples are collected by raising and lowering the sample container at a constant velocity through the vertical panel of the sampling site.

5. Leave a one-inch air space at the top of the bottle. (This allows lab staff to thoroughly mix the sample before taking aliquots for analysis.)

2. For Field Filtered Sample - Soluble Reactive Phosphorus

   Collect surface water samples in the manner described above using a 500 mL plastic open-ended bottle.

<u>Field Filtration Procedure</u>

List of Equipment:

- cellulose acetate filters, Sartorius 0.45 micron, 47 mm in diameter.
- Swinnex Disc Filter Holder, 47 mm diameter.
- Filter forceps, stainless steel.
- Syringe, 50 mL with luer slip tip.
- Supply of distilled water.

From the water sample collected previously, a 50 mL aliquot should be immediately field filtered using the following procedure.

1. Remove filter paper from storage carton with forceps and place on Swinnex support screen. Install Swinnex top and tighten, taking care that O-rings are properly in place. Position the Swinnex assembly on the top of a 250 mL labelled sample bottle.

2. With the syringe, dispense two 50 mL aliquots of distilled water through the system to wet all surfaces. Discard the distilled water.

3. With the syringe, dispense 50 mL of raw sample water through the filter and into the sample bottle. Shake sample bottle to condition container walls and discard water.

4. Finally, with syringe, dispense a second 50 mL of raw sample water into the sample bottle and cap the bottle for delivery to the lab.

5. Discard the filter paper, wash all equipment with tap water and rinse with distilled water and store in a clean location.

Submission Forms and Field Records

Sample Submission Form

Each time bottles are submitted to the Lab, a Sample Submission Form must be completed.

Blank Submission Forms from BAS will be available including details of reporting addresses and analyses required.

Information previously entered on the Bottle Label must be completed on the Submission Form. Enter the following:

Field Sample Number (Senders Number)
Station Name
Date of Sample collection
Time of Sample Collection (Eastern Standard only!)

Station Record Form

Records of sample collection activity should also be logged on a Station Record Card and this record kept in on-site trailer.

This record is extremely useful in keeping track of sampling numbers used, date of last sample, etc., and may also prove invaluable in the event of sample loss, misnumbering of sample bottles or report sheets, etc.

Sample Storage and Transportation

To minimize any in-bottle chemical changes, store all samples at 4 EC and deliver to the BAS Laboratory in Brampton in a cooler as soon as possible.

FIELD PROTOCOL B2
FLOW MONITORING

Purpose:

To determine flow volumes during events in all microbasins over the entire study period.

Schedule:

Conducted during and flow event in microbasins.

Equipment:

- Stevens F-type recorder and Q-loggers
- chart paper for Stevens F-type recorder
- soft lead pencil
- staff gauge
- log book

Methodology:

1. Prior to expected flow events prepare the flow recording instrumentation to record event flows in all microbasins.

2. On the Stevens - F-type recorder, place a new paper chart on the drum and label with Sample station (ie. KCB1, KTB2, etc.), the Station number (ie. KCB1, KTB2, etc.). Once the flow recorder is turned on and the tracing pen is installed for flow level measurement, make a cross-hatch on the level trace and label the date and time (eastern standard only) and the staff gauge reading and any general comments (eg. low flow through weir, etc.). Allow the recorder to operate for 30 min. to 1 hr and check to ensure that it is functioning properly. Periodically throughout an event (when water samples are collected) record the date, time and staff gauge reading. At the end of the event, record this information again. This will be invaluable in determining if there has been any drift in time or water level over the event monitoring period. As a result of this detailed information on the charts, any time or level drifts can be corrected during digitization.

3. Collect the chart paper after each event. Do not leave the chart paper on the level recorders too long, for they have a tendency to absorb the humidity from the air.

4. Prepare the station for any forthcoming flow events by conducting a check of all recorder operations.

FIELD PROTOCOL NO. C1
WELL SAMPLING

Purpose:

To obtain representative groundwater quality samples.

Schedule:

4 times per year
- pre-spring tillage
- post-planting
- full crop canopy
- post harvest - fall tillage

Equipment:

- dedicated Delrin footvalve pump
- water level tape
- pH, specific conductance meter
- mercury field thermometer

Methodology:

1. All wells will be inspected for integrity and the physical condition of pipe, casing and surface seal. Initial water levels will be recorded. Where necessary and feasible, minor repairs will be made to the wells.

2. The dedicated Delrin footvalve and polyethylene tubing will be used to sample each well. Three bore volumes will be removed prior to sampling with the volume removed and water levels recorded. The removed water is to be disposed of away from the well.

3. Samples will be collected in the following order:

   - pesticide
   - nitrate

- B soluble reactive phosphorus

Colour, degree of siltiness and odours are recorded during sample collection. Field pH, specific conductance and temperature will be recorded with the removal of each bore volume.

4. Samples for analysis of soluble reactive phosphorus will be filtered through a 0.45 micron filter.

PROTOCOL NO. C2
INSTALLATION OF PIEZOMETERS

Purpose:

To install and establish groundwater monitoring wells.

Equipment:

- power auger
- Zinch ID PVC piezometer screening
- Zinch ID PVC piezometer tubing
- piezometer caps
- bentonite
- silica sand
- borehole log sheets

Methodology:

This section describes the procedures to be followed during the installation of the piezometers in the boreholes in microbasins.

A single piezometer will be installed in each exploratory borehole. Four additional piezometers will be constructed in shallower boreholes drilled within 2 m of the deeper exploratory boreholes. The well nests provide information concerning the nature of vertical hydraulic gradients at each nest location and allow discrete sampling in the deeper and shallower zones.

Piezometer Installation

Each piezometer is designed to display the potentiometric surface and permit water sampling of the materials in which the sand pack was positioned. At well nests, separate piezometers are completed in both the shallower unconsolidated materials. The BEAK hydrogeologist (or

geologist) selects the interval to be intersected by the well screen based on observation of the samples collected from each of the boreholes. Construction of the piezometers within the borehole follows the procedures outlined in the following sections.

Screen and Riser Pipe

The piezometers will be constructed from schedule 40 polyvinyl chloride (PVC) casing. The inside diameter of this casing (2 inches) is sufficiently large to permit the entry of water level measuring and water sampling devices. The well screens are composed of casing material which are factory slotted (slot width - 0.01") to permit the entry of water into the well. The bottom of the screens will be plugged with the appropriately sized screw-in cap. The appropriate 2.5-foot sections of screen and 10-foot risers are coupled with flush-threaded joints to construct the well. Suitably-sized O-rings are placed between the two sections at each joint to prevent the entry of water into the well through the threads of the joint. No PVC cements or other solvents are used in the construction of the wells.

Filter Material

Clean, coarse, silica sand will be positioned around the well screen to transmit water from the surrounding geologic materials into the well.

Setting Screens, Riser Casings and Filter Materials

Upon completion of the borehole, the necessary well materials are assembled and lowered down the inside of the augers to the bottom of the borehole. The plugged bottom of the well screen is always positioned flush with the bottom of the borehole and sufficient lengths of riser are added to ensure that approximately 1 m of the riser protruded above the ground surface.

After the piezometer assembly has been lowered to the bottom of the borehole, silica sand is added to fill the annular space created between the outside of the well and the inside of the borehole. The top of the sand in the borehole is constantly plumbed with a weighted measuring tape as the sand is being poured to ensure that the filter material is not being obstructed and is flowing evenly into the open borehole around the well screen. Silica sand

is added until the level of the sand in the borehole is approximately 0.7 m above the top of the screened interval.

Setting Seals and Grouting

Once the depth to the top of the filter pack is verified in the correct position, a layer of bentonite pellets is placed to seal the screened interval of the well off from the overlying fluids/geologic materials. Sufficient bentonite pellets 1/4" in diameter are poured down the inside of the borehole to produce a 0.50 to 0.75 m thick layer above the sand pack. As with the placement of the sand, the bentonite pellets are poured into the borehole to infill the open space above the sand filter pack. After the depth to the final top of the bentonite seal is verified using a weighted measuring tape approximately 2-3 litres of distilled water are poured down the well and onto the pellets. This water interacts with the pellets, causing them to begin to swell, thereby immediately sealing off the well screen/sand pack from any fluids migrating downward from above. If sufficient water flows into the well during the placement

of the well materials to wet the bentonite pellets as they settle onto the top of the sand, no extra water will be added to the borehole.

A bentonite/cement grout seal is placed above the layer of bentonite pellets to the ground surface. The bentonite/cement grout will consist of Portland cement, powdered bentonite and clean water from the municipal water supply. No work, with the exception of the collection of water levels, will be performed on the wells until the grout has set, approximately 48 hours after it has been poured.

Capping the Wells

The tops of the wells will be capped to prevent the entry of foreign material using a suitably-sized PVC cap.

Documentation of the Piezometer Configuration

Scaled diagrams of the wells constructed in each of the boreholes will be provided with the borehole logs.

Cleaning of Equipment

The PVC risers and screen from which the piezometers will be constructed are factory cleaned and individually sealed in plastic sleeves prior to shipment to the site. Immediately prior the construction of the well, all the PVC well materials will be removed from their plastic coverings, connected and installed down the borehole. The PVC pipe will be handled only by persons wearing clean surgical gloves.

FIELD PROTOCOL NO. C3
DEVELOPMENT OF PIEZOMETERS

Development of Piezometers

After the piezometer installation is complete and the grout has been allowed to set for at least 48 hours, the well will be developed by pumping to remove as much silt as possible from the well and enhance the performance of the well screen/sand pack. Each well will be developed using a Waterra pump which is dedicated to the well. Since the geologic materials intercepted by most of the wells will likely not transmit large quantities of water over a short period of time, well development will consist of emptying the wells on two to three separate occasions. The pH, specific conductance, temperature and total volume of water pumped will be monitored during the development pumping. Well development proceeds until the water reaches its maximum clarity and the field water quality parameters stabilize.

Cleaning of Equipment

Any water level measuring equipment that comes into contact with the well and or water will be rinsed with distilled water and wiped with a clean, dry paper towel between measurements to minimize cross contamination between wells.

FIELD PROTOCOL NO. C4
WATER LEVEL MONITORING

Introduction

This section describes the procedures which are to be followed during groundwater level monitoring conducted during the NSCP study.

Water Level Measurements

Water level measurement will be obtained using an electric water level tape. The electric sounder consists of a contact electrode that is suspended down the well with an insulated electric cable which is attached, at the surface, to a reel containing closed circuit indicators, in this case a light and a buzzer. The indicators show a closed circuit (light on, buzzer sounding) when the current flows through the electrode when as it contacts the water surface. The electric sounder used in this project consists of a stainless steel weight containing the electrode which is attached to a fibreglass tape which is marked in 0.5 cm (approximately 1/4") intervals.

The procedure used for measuring water levels is as follows:

1) switch on
2) lower the weighted electric cable into the well until the buzzer or light indicates a closed circuit
3) note the length of the cable corresponds to the top of the outermost well casing
4) record the resultant value as the water level in metres below the top of the casing

All the water level measurements are recorded in the field notebook.

Care is taken to not immerse the electrode/tape any further than necessary into the well, and only the stainless steel weight should come in contact with the water surface during a water level measurement. This portion of the sounder and approximately 1 m of the fibreglass tape

are rinsed with distilled water and wiped dry with a clean paper towel after each measurement is completed.

FIELD PROTOCOL NO. C5
RESPONSE TESTS

Introduction

This document describes the procedures to be followed during the performance of recovery tests on piezometers. To perform the tests, the water level in each well is rapidly lowered as much as possible and then observed as it recovers toward equilibrium. If all other factors remain equal, the rate at which the water level in the well recovers is a function of the bulk (average) hydraulic conductivity of the geologic materials intersected by the well screen/sand pack.

Data Collection

Recovery tests will be initiated by pumping each well until the pump no longer yields water. The Waterra hand pump dedicated to each well is used for this purpose. Once maximum drawdown is achieved, the water level in the well, the time and the date are recorded in the field book and the well is loosely recapped and left to recover.

Recovery is monitored by periodically measuring the water level in each of the wells. Since the rate of recovery declines exponentially with time, the bulk of the recovery water level measurements will be collected during the first 24 hours of the test. A complete set of recovery data (water level vs. time elapsed since termination of pumping) is collected as the well recovered toward equilibrium.

Interpretation

The recovery data are interpreted via the method of Hvorslev (1951) to yield the average saturated hydraulic conductivity of the geologic materials which surround the well screens. Interpretation of the field recovery data is initiated by plotting the log of the relative recovery (H-h/H-ho; where H = equilibrium water level, h = current water level data point during recovery and ho = water level at maximum drawdown immediately after pumping vs. time elapsed since the end of the pumping). The basic time lag of each well, T_o, is measured graphically off each recovery plot (time corresponding to when H-h/H-Ho = 0.37 or ln (H-h/H-Ho) = -1) and used in the following formula to calculate K, the hydraulic conductivity of the geologic materials surrounding the well screen/sand pack.

$$K = \frac{r^2 \ln (L/R)}{2 L T_o}$$

where: K = hydraulic conductivity (ft/hr)
r = radius of casing (ft)
L = length of sand pack (ft)
R = radius of sand pack/well screen (ft)
T_o = basic time lag (hrs)

This simple interpretation of the field recovery data assumes a homogeneous isotropic infinite geologic medium in which the soil and water are incompressible.

FIELD PROTOCOL NO. D1
CROP RESIDUE MEASUREMENT PROTOCOLS

Purpose:

To determine the amount of soil surface residue coverage.

Schedule:

3 times per year:
- pre-spring tillage
- post plant
- post harvest-fall tillage

Equipment:

- nylon rope knotted every six inches (50 knots long)
- 2 screwdrivers
- data collection sheet on clipboard, watershed map with field numbers

Methodology:

Before entering the field, ensure the co-operator has given approval. Clean boots and clothing of mud (and weed seed).

Enter a field at a convenient location and randomly select a sampling area at least 10 m from the field edge. Avoid depressions and headlands.

Attach the screwdrivers to each end of the knotted rope. Insert one screwdriver into the ground and place the other end diagonally across the direction of planting or tillage.

Straddle the rope and walk slowly along its length. Look straight down at the knots on the rope and count the number of times a piece of dead residue intercepts or touches a knot (do not include stones). The general 'rule of thumb' is that a piece of residue must be big enough to intercept a raindrop to be counted. If you have any doubt whether the point intersects residue, don't count it. (***Note:*** *Weeds are not residue*).

Record the number of intercepts on the data sheet and at the approximate location on the co-operator field map.

Repeat the process at various locations throughout the field. By referring to the polygon map, representative samples should be taken from within areas of similar elevation, slope and soil type.

The number of sampling counts is dependent on field acreage:

3 counts on 0-10 acres

1 count for every additional 5 acres

Take the average of the data recorded for each field and multiply by two to get the % residue cover.

FIELD PROTOCOL NO. D2
HAND-SAMPLED CROP YIELD MEASUREMENTS PROTOCOLS

Crop yield is an annual measurement, to be taken at all soil benchmark sites. Yield sample collections must be made at crop maturity, but before the co-operator harvests.

All measurements of crop yields at soil benchmarks are made by hand harvesting representative samples of the crop from known areas. The methods of sample collection and analysis will therefore vary depending upon the crop in question.

Corn

At crop maturity, hand sample and shuck all ears from a 10.0 m length of row. Three such samples are collected at each benchmark sub-site from adjacent rows.

Each sample is weighed (TC), ten average cobs are selected, weighed (FC) and dried to a constant weight in a forced-air dryer at 80EC for about four days. The dried ears are subsequently weighed (DS) and shelled.

The shelled grain is again weighed (G). The final grain weight per sample, adjusted to kilograms per hectare at 15.5 % moisture content, is calculated using the following equation:

$$\text{Yield} = \frac{TC \times G}{FC} \ \frac{kg}{7.62 m^2 *} \times \frac{10^4 m^2}{ha} \times \frac{100}{84.5}$$

* for 30 inch rows

From the same data the % moisture content at harvest was calculated as follows:

$$\%\ \text{Moisture Content} = \frac{FC-DR}{FC} \times 100$$

Soybeans, White Beans and Kidney Beans

At crop maturity, hand harvest all the above-ground plant material within the length of crop row equating to an area of one square metre. Three such samples are collected at each benchmark sub-site; each sample from an adjacent row. Should it be necessary to store the samples prior to threshing, the samples are placed in burlap bags to permit air movement. Should the samples require drying prior to being threshed, they are placed in the forced-air dryer for the required period of time.

Each sample is threshed and the resulting beans are cleaned to remove any debris. The beans from each sample are then weighed and the moisture content measured using a moisture meter. The resulting yield weights adjusted to kilograms per hectare at the standard moisture content (soybean - 14.0%; white bean and kidney bean - 18.0%) are calculated using the following equation:

$$\frac{\text{sample bean weight (kg/m}^2\text{)} \times \left(1 - \frac{\text{bean \% moisture content}}{100}\right)}{1 - \left(\frac{\text{standard \% moisture content}}{100}\right)} \times 10^4 \text{ m}^2\text{/ha}$$

APPENDIX B

HYDRAULIC CONDUCTIVITY DATA

APPENDIX C

BOREHOLE LOGS

METEOROLOGICAL DATA

SURFACE WATER CHEMISTRY

RESPONSE TESTS

BORING LOGS

DAILY LOADINGS

TABLE 3.1: KETTLE CREEK MICROBASIN CROP AND TILLAGE, 1991

Microbasin	Area	Crop	Tillage	Yield (bu/a)
1991				
KTB1	2	soybeans	no-till	32.4
	2	winter wheat	no-till	68.5
	2.5	corn	no-till	59.3
KTB2	3.5	winter wheat	no-till	86.7
	1	silage corn	no-till	n/a
	0.5	forage buffer strip		
KCB1	6.9	grain corn	spring cultivate	111.1
	1	grain corn	fall plough	116.2
	0.2	soybeans	spring cultivate	36.7
KCB2	2.9	grain corn	fall plough	95.9
	1.2	grain corn	fall plough	116.2
1992				
KTB1	6.5	grain corn	no-till	100
KTB2	3.5	grain corn	no-till	112
	1	silage corn	no-till	n/a
	0.5	forage buffer strip		
KCB1	7.9	grain corn	fall plough	154
	0.2	grain corn	fall plough	90
KCB2	2.9	grain corn	fall plough	95
	1.2	soybeans	fall plough	43

TABLE 3.2: KETTLE CREEK MICROBASIN CROP INPUTS, 1991-92

Microbasin	1991 Ha	1991 DUAL (L/ha)	1991 Nitrogen (kg/ha)	1991 Phosphate (kg/ha)	1991 Potash (kg/ha)	1991 Other Herbicides Applied	1992 Ha	1992 DUAL (L/ha)	1992 Nitrogen (kg/ha)	1992 Phosphate (kg/ha)	1992 Potash (kg/ha)	1992 Other Herbicides Applied
KTB1	2	0	0	0	0	Lorox	6.5	2.5	142	20	30	Roundup
	2.5	2.5	150	40	41							
	2	0	86	0	0							
KTB2	3.5	0	40	27	27		4.5	2.5	116	24	27	Roundup/2
	1	1.25	170	34	0	Lorox						Banvel
	0.5	0	0	0	0		0.5	0	0	0	0	
KCB1	7.9	2.5	153	90	108	Banvel	7.1	2.5	135	11	180	Banvel
	0.2	0	6	24	24	Pursuit/Treflan	1	0	0	0	0	Pursuit/Sencor
KCB2	2.9	0	123	51	51	Sutan/Pardner	2.9	2.5	125	47	54	Marksman
	1.2	2.5	153	90	108	Banvel	1.2	2.5	0	0	0	Pursuit/Sencor

TABLE 3.3: KETTLE CREEK MICROBASIN CROP RESIDUE COVER, 1991-92

Microbasin	Area (ha)	Residue Count %	Weighted Average %
KCB1			
pre-plant, 91	6.9	64.8	
	1	8	57.7
	.2	61.5	
post-plant, 91	6.9	18.9	
	1	16.6	18.2
	.2	4	
post-harvest	6.9	86.7	
	1	89.3	87.1
	.2	86.6	
pre-plant, 92	6.9	4.3	
	1	2.9	4.3
	.2	12.2	
post-plant, 92	6.9	7.1	
	1	8	7.1
	.2	1	
KCB2			
pre-plant, 91	2.9	10.7	9.9
	1.2	8	
post-plant, 91	2.9	9	11.2
	1.2	16.6	
post-harvest, 91	2.9	88.3	88.6
	1.2	89.3	
pre-plant, 92	2.9	10.5	11
	1.2	12.2	
post-plant, 92	2.9	5	5.9
	1.2	8	

TABLE 3.3: KETTLE CREEK MICROBASIN CROP RESIDUE COVER, 1991-92

Microbasin	Area (ha)	Residue Count %	Weighted Average %
KTB1			
Pre-plant, 91	2	70.8	
	2.5	70.8	70.3
	2	87	
post-plant, 91	2	56	
	2.5	64.8	64.3
	2	70	
post-harvest, 91	2	99.4	
	2.5	90.5	95.1
	2	96.5	
pre-plant, 92	2	70.7	
	2.5	63.3	68
	2	71.3	
post-plant, 92	2	59.5	
	2.5	62.5	65.2
	2	74.1	
KTB2			
pre-plant, 91	1	17.3	
	1	5.3	37.8
	2.5	59	
post-plant, 91	1	17	
	1	5.3	37.8
	2.5	59	
post-plant, 91	1	17	
	1	5.3	43.8
	2.5	70	
post-harvest, 91	1	91.3	
	1	13	76.1
	2.5	95.3	
pre-plant, 92	1	86.7	
	1	9.3	68
	2.5	84	
post-plant, 92	1	70	
	1	5	55.6
	2.5	70	

TABLE 3.4: KETTLE CREEK AVERAGE AIR TEMPERATURE

Month	1991	1992	Normal*
January	-5.4	-3.8	-6.3
February	-2.1	-3.4	-6.5
March	1.7	-0.6	-0.3
April	8.7	5.3	6.3
May	16.9	13.0	12.6
June	20.2	16.1	17.9
July	21.0	18.2	20.3
August	20.3	17.1	19.8
September	15.0	14.9	15.8
October	10.4	7.2	9.7
November	2.2	2.9	3.5
December	-2.0	-1.2	-3.2
Average	8.9	7.1	7.5

* London Airport AES, 1961 to 1990

TABLE 3.5: KETTLE CREEK MONTHLY PRECIPITATION

Month	1991	1992	Normal*
January	49.4	93.2	67.1
February	104.0	66.3	57.1
March	85.0	53.2	71.5
April	54.3	92.1	76.5
May	58.1	29.9	74.5
June	26.9	60.2	86.4
July	43.4	141.9	82.5
August	49.7	119.0	98.3
September	19.1	150.2	82.8
October	95.8	86.1	74.0
November	60.4	162.3	90.1
December	73.6	101.8	90.2
Annual Total	719.7	1156.2	951.0

* London Airport AES, 1961 to 1990.

TABLE 3.6: KETTLE CREEK MICROBASIN SOIL PHYSICAL PROPERTIES

Site	Date	Texture	Organic Matter (%)		Bulk Density (g/cm3)		Soil Moisture (% gravimetric)		Water Stable+ Aggregates (%)
		Surface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
KCB1	12-Sep-91	Silt Loam	1.8	2.1	1.48	1.30	5.927	NA	38.32
KCB1	28-Nov-91	NA	2.2	2.0	1.43/1.35*	1.44/1.48*	24.73	28.73	NA
KCB1	04-May-92	NA	2.4	1.4	1.54	1.59	24.18	NA	3.76
KCB1	17-Jun-92	NA	2.3	1.0	1.62	1.61	5.16	NA	24.31
KCB1	01-Sep-92	NA	2.1	0.6	1.53	1.51	19.55	NA	16
KCB1	14-Dec-92	NA	1.9	NA	1.21/1.37*	1.56/1.57*	NA	NA	7.53
KCB2	12-Sep-91	Silt Loam	2.8	1.0	1.42	1.46	6.007	NA	44.44
KCB2	28-Nov-91	NA	2.6	2.2	1.30/1.32*	1.39/1.50*	24.43	24.13	NA
KCB2	04-May-92	NA	1.7	2.1	1.53	1.51	15.32	NA	35.67
KCB2	17-Jun-92	NA	1.6	0.8	1.75	1.60	5.17	NA	39.86
KCB2	01-Sep-92	NA	2.1	1.6	1.65	1.64	18.28	NA	22.47
KCB2	14-Dec-92	NA	2.4	NA	1.35/1.17*	1.53/1.55*	NA	NA	8.91
KTB1	12-Sep-91	Loam	4.2	3.4	1.28	1.27	8.201	NA	52.8
KTB1	28-Nov-91	NA	3.8	4.1	1.26/1.24*	1.44/1.44*	32.31	27.66	NA
KTB1	04-May-92	NA	2.9	1.1	NA	1.85	26.81	NA	2.27
KTB1	17-Jun-92	NA	3.7	2.2	1.32	1.45	10.42	NA	37.52
KTB1	01-Sep-92	NA	5.1	4.1	1.17	1.17	26.11	NA	30.05
KTB1	14-Dec-92	NA	4.1	NA	1.16/1.24*	1.41/1.52*	NA	NA	34.29
KTB2	12-Sep-91	Silt Loam	4.7	4.7	1.29	1.36	11.92	NA	65
KTB2	28-Nov-91	NA	4.6	4.3	1.23/1.21*	1.39/1.37*	31.75	28.49	NA
KTB2	04-May-92	NA	5.0	1.4	1.56	1.36	32.86	NA	5.48
KTB2	17-Jun-92	NA	5.1	6.2	1.10	1.19	14.56	NA	49.42
KTB2	01-Sep-92	NA	5.1	4.7	1.17	1.15	34.91	NA	13.78
KTB2	14-Dec-92	NA	4.5	NA	1.34/1.24*	0.93/0.89*	NA	NA	26.8

Notes:

NA - not analyzed

* - denotes field replicates

+ - water stable aggregates determined by Pojasok and Kay (1990) method

TABLE 3.7: KETTLE CREEK SOIL MOISTURE RETENTION

		Volumetric Moisture Content							
Date	**Pressure (cm H2O)**	**KCB1-1**	**KCB1-2**	**KCB2-1**	**KCB2-2**	**KTB1-1**	**KTB1-2**	**KTB2-1**	**KTB2-2**
12-Sep-91	10	40.17	39.09	42.07	43.16	45.28	42.96	47.37	46.53
12-Sep-91	100	38.24	32.21	33.24	34.52	40.25	38.86	42	42.28
12-Sep-91	15,000	36.84	17.93	16.81	18.96	21.46	20.26	26.42	23.44
04-May-92	0	52.08	NA	44.75	48.94	45.99	45.19	63.03	50.68
04-May-92	10	49.77	NA	42.18	42.68	44.74	42	50.35	48.58
04-May-92	100	45.69	NA	36.91	37.84	40.91	39.25	45.41	46.58
04-May-92	15,000	31.72	NA	27.77	22.99	29.38	28.22	25.85	37.2
17-Jun-92	0	48	46.65	61.3	56.39	48.95	47.03	52.46	50.09
17-Jun-92	10	44.91	43.2	42.64	45.08	46.74	44.81	48.91	48.38
17-Jun-92	100	36.14	35.48	31.95	34.18	40.29	39.49	42.54	43.33
17-Jun-92	15,000	27.07	28.5	22.24	22.23	29.43	33.43	33.16	33.87
01-Sep-92	0	45.04	45.09	45.94	45.39	48.44	52.28	51.65	52.16
01-Sep-92	50	34.83	34.43	42.06	33.91	40.27	41.1	44.79	44.01
01-Sep-92	100	33.78	33.13	31.13	33	38.74	39.66	43.79	42.82
01-Sep-92	333	30.93	29.88	40.25	30.78	35.51	36.92	40.55	38.71
01-Sep-92	1,000	28.08	26.62	26.69	28.26	34.14	34.62	38.49	34.83
01-Sep-92	15,000	26.39	23.14	23.08	23.67	34.08	33.33	34.73	33.23
14-Dec-92	0	42.62	44.49	48.85	46.03	52.5	52.36	52.45	52.54
14-Dec-92	50	31.75	34.59	35.49	33.35	38.28	39.7	46.79	43.2
14-Dec-92	150	29.01	32.13	33.19	30.37	35.49	35.82	44.22	40.31
14-Dec-92	333	27.45	30.89	31.88	29.21	34.45	34.26	42.55	38.11
14-Dec-92	15,000	21.03	25.9	26.9	22.67	30.26	29.27	37.2	29.69

NA - not analyzed

TABLE 3.8: KETTLE CREEK MICROBASIN SOIL CHEMICAL PROPERTIES

		Phosphorus (mg/L)		Potassium (mg/L)		Magnesium (mg/L)		pH		Calcium (mg/L)		Metolachlor (ng/g)	
Site	Date	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
KCB1	12-Sep-91	45	12	205.0	60.2	104	93	6.6	6.8	NA	NA	2288	36
KCB1	28-Nov-91	100	NA	176.4	NA	105	NA	7.8	NA	NA	NA	54	<50
KCB1	04-May-92	18	10	155.7	96.1	162	286	6.4	6.8	NA	NA	43	40
KCB1	17-Jun-92	64	15	193.1	131.6	116	246	7.4	7.7	5404	5660	5125	345
KCB1	01-Sep-92	50	3	178.7	111.4	104	125	7.3	6.8	4824	5610	300	<50
KCB1	14-Dec-92	15	NA	269.0	NA	117	NA	7.5	NA	NA	NA	<50	<50
KCB2	12-Sep-91	38	32	171.0	123.0	182	164	6.6	6.7	NA	NA	1434	40
KCB2	28-Nov-91	15	NA	105.3	NA	151	NA	7.8	NA	NA	NA	<50	<50
KCB2	04-May-92	17	4	84.7	52.9	135	182	8.0	7.7	NA	NA	<50	24
KCB2	17-Jun-92	19	6	112.2	83.3	179	240	7.6	7.9	5740	5690	1820	<50
KCB2	01-Sep-92	17	25	110.8	149.2	123	176	7.2	7.4	4980	5420	640	<50
KCB2	14-Dec-92	10	NA	72.0	NA	129	NA	8.1	NA	NA	NA	<50	<50
KTB1	12-Sep-91	41	18	398.0	157.0	260	240	6.7	6.9	NA	NA	26	<50
KTB1	28-Nov-91	34	NA	193.1	NA	201	NA	7.4	NA	NA	NA	<50	<50
KTB1	04-May-92	19	6	150.7	87.2	185	204	7.5	7.9	NA	NA	<50	<50
KTB1	17-Jun-92	47	21	191.7	119.9	221	195	7.1	7.5	2283	2175	820	230
KTB1	01-Sep-92	23	24	168.1	136.0	208	227	5.6	5.7	2055	2262	340	<50
KTB1	14-Dec-92	20	NA	197.0	NA	172	NA	6.8	NA	NA	NA	<50	<50
KTB2	12-Sep-91	45	9	394.0	97.8	272	247	6.8	6.9	NA	NA	28	<50
KTB2	28-Nov-91	35	NA	305.9	NA	176	NA	7.3	NA	NA	NA	25	<50
KTB2	04-May-92	19	4	200.5	99.1	212	232	7.4	7.5	NA	NA	<50	<50
KTB2	17-Jun-92	43	8	388.3	60.1	229	238	6.8	7.1	2896	3470	915	<50
KTB2	01-Sep-92	73	12	322.9	112.7	231	200	6.3	6.4	2167	2290	<50	<50
KTB2	14-Dec-92	13	NA	130.0	NA	211	NA	7.2	NA	NA	NA	<50	<50

NA - not analyzed

TABLE 3.9: TOTAL MONTHLY FLOWS IN KETTLE CREEK MICROBASINS IN 1992

	FLOW (m^3/month)			
Month	KCB1	KCB2	KTB1	KTB2
January	0.00	0.00	0.00	0.00
February	141.88	496.59	5.98	20.46
March	128.24	214.39	27.76	533.66
April	230.82	486.34	173.76	1,175.61
May	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00
July	10.93	71.95	2.04	21.41
August	201.18	208.05	39.53	489.27
September	549.06	847.32	37.76	797.56
October	57.53	7.63	58.82	67.32
November	777.29	703.17	96.00	1,537.80
December	0.00	0.00	0.00	0.00
TOTAL	2,096.93	3,035.44	441.66	4,643.10

TABLE 3.11: UNIT AREA SURFACE WATER QUALITY LOADS - KETTLE CREEK MICROBASINS

	TSS (tonnes/ha)	TP (kg/ha)	TKN (kg/ha)	SRP (g/ha)	Nitrate-N (kg/ha)	Metolachlor (g/ha)
KCB1						
Jan. - Apr.	2.53	0.63	1.48	47.38	2.62	4.07
May - Aug.	1.22	0.26	0.61	27.85	0.34	2.28
Sept. - Dec.	6.40	1.81	4.26	216.14	1.12	8.24
Total	10.15	2.71	6.34	291.36	4.09	14.59
KCB2						
Jan. - Apr.	0.13	0.52	1.54	63.90	13.66	0.72
May - Aug.	0.03	0.11	0.35	40.05	2.52	8.67
Sept. - Dec.	0.33	1.30	2.70	373.11	2.87	9.88
Total	0.49	1.93	4.59	477.06	19.05	19.26
KTB1						
Jan. - Apr.	0.08	0.29	0.68	27.80	3.64	0.13
May - Aug.	0.01	0.05	0.13	11.79	0.06	2.39
Sept. - Dec.	0.06	0.25	0.60	40.73	0.17	0.24
Total	0.15	0.59	1.41	80.31	3.87	2.76
KTB2						
Jan. - Apr.	0.51	1.60	4.00	112.82	5.03	0.51
May - Aug.	0.23	0.66	1.41	139.98	0.55	2.27
Sept. - Dec.	0.77	2.34	5.70	348.66	1.94	2.66
Total	1.51	4.60	11.11	601.45	7.52	5.43

TABLE 3.12: WATER LEVELS

Monitoring Well	Top of Casing Elevation (m amsl)	Water Level Elevation (m masl)										
		05-Dec-91	04-May-92	25-May-92	02-Jun-92	23-Jun-92	09-Jul-92	04-Aug-92	19-Aug-92	24-Sep-92	22-Oct-92	04-Nov-92
KCB 1-1	275.67	270.27	274.53	273.25	273.52	272.68	273.44	273.93	273.97	274.49	274.56	274.64
KCB 1-3S	270.49	269.50	269.72	268.54	268.69	268.65	268.19	269.49	269.49	269.76	269.84	269.96
KCB 1-3D	270.57	269.04	269.46	268.92	268.49	268.15	269.19	269.27	269.26	269.59	269.65	269.72
KCB 2-1	273.12	269.10	272.00	270.92	270.99	270.64	270.93	271.42	271.67	271.99	272.09	272.15
KCB 2-2	273.45	269.22	272.14	271.51	271.43	271.42	271.30	271.73	271.76	272.19	272.32	272.42
KCB 2-3S	270.17	269.37	269.14	268.44	268.67	268.63	268.54	269.18	269.18	269.26	269.35	269.50
KCB 2-3D	270.27	268.86	269.13	268.70	268.47	268.45	268.30	269.12	269.10	269.26	269.27	269.30
KTB 1-1	272.79	NA	271.74	270.87	270.88	270.54	270.79	NA	NA	NA	271.59	271.75
KTB 1-2	270.68	NA	269.49	268.62	268.44	268.56	268.48	268.98	268.81	269.66	269.82	270.00
KTB 1-3D	267.44	NA	263.62	263.84	263.84	263.79	263.81	263.75	263.89	264.39	264.72	265.23
KTB 2-1	283.20	278.82	281.50	279.46	281.07	279.14	279.70	281.00	281.18	281.86	281.80	281.84
KTB 2-2S	280.76	279.84	279.36	278.82	279.06	279.16	279.05	280.21	280.04	280.29	280.37	280.51
KTB 2-2D	280.67	278.27	279.64	279.20	278.62	278.52	278.35	279.57	279.35	279.69	279.73	279.81
KTB 2-3	284.26	NA	282.86	282.06	281.95	281.83	281.63	282.04	281.83	282.79	283.20	283.31

Notes:

NA - not available

m amsl - metres above mean sea level

TABLE 3.13: ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

Monitoring Well	Date	Nitrate-Nitrogen (mg/L)	Soluble Reactive Phosphorous (mg/L)	Total Phosphorous (mg/L)	Total Dissolved Solids (mg/L)	Metolachlor (µg/L)

TABLE 3.13: ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

Monitoring Well	Date	Nitrate-Nitrogen (mg/L)	Soluble Reactive Phosphorous (mg/L)	Total Phosphorous (mg/L)	Total Dissolved Solids (mg/L)	Metolachlor (µg/L)
KTB 1-1	05-May-92	1.68	NA	0.007	NA	0.16
	03-Jun-92	4.5	NA	0.32	NA	0.23
	10-Jul-92	4.9/4.9	0.001	NA	NA	0.34
	20-Aug-92	NA	NA	NA	NA	NA
	05-Nov-92	6.7	0.005	NA	NA	1.38
KTB1-2	05-May-92	27/28	NA	0.026	NA	0.5
	03-Jun-92	56/56	NA	1.69	NA	0.4
	10-Jul-92	57/60	0.001	NA	NA	0.55
	20-Aug-92	59	<0.001	NA	NA	ND
	05-Nov-92	38	0.04	NA	NA	0.56
KTB2-1	06-Dec-91	<0.01	0.004	NA	NA	0.19
	05-May-92	9.8	NA	0.003	NA	0.41
	03-Jun-92	7.7/7.6	NA	0.26	NA	0.33
	10-Jul-92	5.7	0.002	NA	NA	0.44
	20-Aug-92	5.3	<0.001	NA	NA	ND
	05-Nov-92	NA	NA	NA	NA	NA
KTB2-2S	05-May-92	0.54	NA	0.003	450	0.59
	03-Jun-92	0.23	NA	0.59	NA	0.16
	10-Jul-92	0.04	0.001	NA	NA	0.3
	20-Aug-92	<0.001	<0.001	NA	NA	0.35
	05-Nov-92	NA	NA	NA	NA	NA
KTB2-2D	06-Dec-91	0.18	0.003	NA	NA	0.19
	05-May-92	0.45	NA	0.006	NA	0.13
*	05-May-92	0.48	NA	0.006	NA	0.17
	03-Jun-92	0.49	NA	0.97	NA	0.12
*	03-Jun-92	0.34	NA	1.43	NA	0.17
	10-Jul-92	0.43	<0.001	NA	510	0.21
*	10-Jul-92	0.29	<0.001	NA	530	0.24
	20-Aug-92	0.35	0.001	NA	NA	ND
*	20-Aug-92	NA	NA	NA	NA	NA
	05-Nov-92	0.28	0.008	NA	NA	<0.25
KTB2-3	05-May-92	2.5	NA	0.003	NA	0.14
	03-Jun-92	3.2/3.1	NA	0.83	NA	0.11
	10-Jul-92	2.7	0.001	NA	NA	NA
	20-Aug-92	0.30	<0.001	NA	NA	ND
	05-Nov-92	2.90	0.015	NA	NA	<0.25

TABLE 3.13: ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

Monitoring Well		Date	Nitrate-Nitrogen (mg/L)	Soluble Reactive Phosphorous (mg/L)	Total Phosphorous (mg/L)	Total Dissolved Solids (mg/L)	Metolachlor (µg/L)
KCB1-1		06-Dec-91	0.15	0.003	NA	NA	0.19
		05-May-92	0.39	NA	0.006	NA	0.13
		03-Jun-92	1.04	NA	0.4	NA	0.11
		10-Jul-92	1.25/1.33	0.001	NA	NA	0.18
		20-Aug-92	1.72	<0.001	NA	NA	ND
		05-Nov-92	1.44	0.005	NA	NA	<0.25
KCB1-3S		05-May-92	0.01	NA	0.003	310	0.26
	*	05-May-92	0.013	NA	0.013	370/320	0.46
		03-Jun-92	0.01	NA	0.87	NA	0.61
		10-Jul-92	<0.01	0.001	NA	NA	0.40
		20-Aug-92	NA	NA	NA	NA	NA
		05-Nov-92	NA	NA	NA	NA	NA
KCB1-3D		06-Dec-91	0.22	0.003	NA	NA	0.18
		05-May-92	<0.01	NA	0.002	NA	0.26
		03-Jun-92	0.05	NA	0.59	NA	0.16
		10-Jul-92	0.13	0.001	NA	960/970	0.23
		20-Aug-92	0.05	<0.001	NA	NA	ND
		05-Nov-92	0.11	0.006	NA	NA	0.31
KCB2-1		06-Dec-91	2.0	0.003	NA	NA	0.17
		05-May-92	6.6	NA	0.004	NA	0.18
		03-Jun-92	5.1	NA	0.76	NA	0.10
		10-Jul-92	5.4	<0.001	NA	NA	0.21
		20-Aug-92	NA	NA	NA	NA	NA
		05-Nov-92	1.63	0.007	NA	NA	<0.25
KCB2-2		05-May-92	0.18	NA	0.003	NA	0.10
		03-Jun-92	0.14	NA	0.83	NA	ND
	*	03-Jun-92	0.17	NA	0.83	NA	ND
		10-Jul-92	0.23	<0.001	NA	NA	0.26
		20-Aug-92	NA	NA	NA	NA	NA
		05-Nov-92	NA	NA	NA	NA	NA
KCB2-3S		05-May-92	<0.01	NA	0.006	890	0.17
		03-Jun-92	<0.01	NA	1.53	NA	ND
		10-Jul-92	<0.01	0.001	NA	NA	ND
	*	10-Jul-92	0.02	0.001	NA	NA	0.17
		20-Aug-92	<0.01	<0.001	NA	NA	ND
	*	20-Aug-92	<0.01	<0.001	NA	NA	ND
		05-Nov-92	0.09	0.004	NA	NA	<0.25
	*	05-Nov-92	0.09	0.004	NA	NA	<0.25
KCB2-3D		06-Dec-91	<0.01	0.003	NA	NA	0.11
		05-May-92	<0.01	NA	0.003	NA	0.15
		03-Jun-92	0.01/0.01	NA	0.32	NA	0.14
		10-Jul-92	0.10	<0.001	NA	630	0.18
		20-Aug-92	0.04	<0.001	NA	NA	ND
		05-Nov-92	0.13	0.003	NA	NA	<0.25
Equipment Blank		05-May-92	0.034	NA	0.006	NA	0.12
		03-Jun-92	0.02	NA	<0.001	NA	ND
		10-Jul-92	0.2	0.001	NA	NA	0.18
		20-Aug-92	<0.01	<0.001	NA	NA	ND
		05-Nov-92	<0.01	<0.001	NA	NA	<0.25

Notes:
NA - not analyzed
ND - not detected
* - field duplicate

TABLE 3.14: GROUNDWATER QUALITY FIELD MEASUREMENTS

Monitoring Well	Date	Temp (°C)	pH	Specific Conductance (µmhos/cm)

TABLE 3.14: GROUNDWATER QUALITY FIELD MEASUREMENTS

Monitoring Well	Date	Temp (°C)	pH	Specific Conductance (µmhos/cm)
KTB 1-1	05-May-92	10	7.17	1106
	02-Jun-92	13	8.00	629
	10-Jul-92	13	7.50	780
	05-Nov-92	10	8.15	560
KTB1-2	05-May-92	11	7.20	1102
	10-Jul-92	12	7.37	1340
	20-Aug-92	17.5	7.20	1713
	04-Nov-92	10	7.40	790
KTB 1-3D	02-Jun-92	15	7.65	950
	09-Jul-92	16	7.24	1130
	04-Nov-92	11	7.30	620
KTB2-1	06-Dec-91	4	7.20	900
	05-May-92	11	7.50	1469
	02-Jun-92	14	7.45	999
	10-Jul-92	12	7.65	1235
	04-Nov-92	11.5	7.70	990
KTB2-2S	05-May-92	9	7.54	797
	02-Jun-92	14	8.00	587
	10-Jul-92	14	7.76	755
	20-Aug-92	17	7.30	1032
KTB2-2D	06-Dec-91	10	7.52	620
	05-May-92	8	7.62	839
	02-Jun-92	13	7.90	525
	10-Jul-92	13	7.58	700
	20-Aug-92	15	7.33	819
	05-Nov-92	11	8.20	500
KTB2-3	05-May-92	9	7.18	813
	02-Jun-92	13	8.05	544
	10-Jul-92	12	7.91	750
	20-Aug-92	15	7.29	828
	05-Nov-92	11	7.70	510

TABLE 3.14: GROUNDWATER QUALITY FIELD MEASUREMENTS

Monitoring Well	Date	Temp (°C)	pH	Specific Conductance (µmhos/cm)
KCB1-1	06-Dec-91	3	7.77	725
	05-May-92	9	7.56	928
	02-Jun-92	14	8.00	629
	10-Jul-92	15	7.53	745
	20-Aug-92	15	7.47	898
	05-Nov-92	10	8.12	520
KCB1-3S	05-May-92	8	7.59	524
	02-Jun-92	14	7.40	510
	10-Jul-92	13	7.41	640
KCB1-3D	06-Dec-91	7	7.42	655
	05-May-92	8	7.29	888
	02-Jun-92	14	7.50	940
	10-Jul-92	14	7.34	1000
	20-Aug-92	14	7.27	1068
	05-Nov-92	11	7.70	630
KCB2-1	06-Dec-91	2	8.16	640
	05-May-92	6	7.47	867
	02-Jun-92	13	7.45	547
	10-Jul-92	13	7.82	650
	20-Aug-92	14.5	7.49	768
	05-Nov-92	11	8.20	490
KCB2-2S	05-May-92	7	7.29	1209
	02-Jun-92	14	7.25	810
	10-Jul-92	14	7.44	1170
	20-Aug-92	16	7.12	1723
	05-Nov-92	10	7.6	1290
KCB2-2D	06-Dec-91	6	7.75	645
	05-May-92	8	7.36	984
	02-Jun-92	13	7.20	1060
	10-Jul-92	12	7.15	611
	20-Aug-92	15	7.36	1131
	05-Nov-92	10.5	7.95	700

Notes:
- not measured