Ontario Farm Groundwater Quality Survey

Summer 1992

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ONTARIO FARM GROUNDWATER QUALITY SURVEY

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A critical factor in the successful completion of this survey has been the continued cooperation and enthusiasm of the farming community, and specifically the farm families that directly participated. The survey would not have been possible without their cooperation.

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1.0 Executive Summary

This section summarizes the main results, observations, and conclusions from the Ontario Farm Groundwater Quality Survey: Summer, 1992. This program investigated the same set of drinking water wells and multilevel monitoring wells that were sampled during the initial survey conducted in the winter of 1991-1992. Some reference to results from the winter survey are presented for the purposes of comparison. A complete summary of the winter survey is contained in the report of the Ontario Farm Groundwater Quality Survey Winter 1991/92, available from Agriculture Canada.

Section 1: Water Well Survey

- Approximately 1300 domestic farm wells were re-sampled between June 1992 and August 1992 and the groundwater analyzed for nitrate-N, total and faecal coliform bacteria, and several common herbicides, which are referred to as pesticides.

- The majority of the wells (900) were located in areas of intense agriculture on the most common soil types and on farms involved with the most common agricultural land-use practices. The remainder of the wells were located in less agriculturally intense areas including Northern Ontario.

- The maximum acceptable concentration (MAC) of total coliform bacteria in private drinking water supplies was revised by the Ontario Ministry of Health, in October 1992, from 10 to 5 colonies per 100 mL. The results were analysed relative to both the old and new objectives.

- 40% of all wells tested contained one or more of the target contaminants at concentrations above the previous Provincial drinking water objectives (43% with the updated objectives).

- 32% of wells exceeded the previous maximum acceptable concentration for at least one of the coliform bacteria selected for analysis (36% with the updated MAC).

- 25% had faecal coliform bacteria.

- 15% exceeded the Ontario maximum acceptable concentration for nitrate (7% exceeded the maximum acceptable concentration for both coliform bacteria and nitrate (previous objectives) and 8% exceeded the acceptable concentration for nitrate alone).
- 12% of the wells had detectable levels of pesticides, two wells showed pesticide concentration in exceedence of Ontario interim maximum acceptable concentration (IMAC) values.

! Several trends between the occurrence of groundwater contamination and various physical factors were found in the summer survey:

1.) Dug or bored wells and driven sandpoints were the most frequently contaminated of all well types regardless of depth;

2.) The frequency of contamination of any well type appeared to decrease with depth and increase with age;

3.) No direct correlation was observed between specific land-use practices and the frequency of water wells found in exceedence of the objectives for any of the target contaminants. The incidence of groundwater contamination did not differ significantly between any of the common types of cropping practice;

4.) At sites where manure was spread regularly, levels of coliform bacteria, especially faecal coliforms, tended to be somewhat higher than on farms not using manure. This trend was not observed for nitrate;

5.) Coliform bacteria tended to be less abundant in groundwater under permeable soils than under less permeable soils;

6.) Nitrate-N concentrations tended to be higher in groundwater under the higher permeability soils;

7.) The spatial distribution of wells contaminated with nitrate tended to fall within areas of the Province previously classified by the MOEE as high susceptibility risk to groundwater contamination. Bacteria distribution was somewhat more evenly spread throughout the Province; and,

8.) Coliform bacteria levels tended to increase with decreasing separation distance between the water well and feedlot. No other specific correlations were observed between potential point sources of contamination and groundwater quality in the water wells.

! When the data from the winter and summer surveys are compared, several additional observations can be made.

1.) The frequencies of contamination in the water wells were quite similar in both surveys, which provides further

confidence that the levels of groundwater contamination found in these surveys are representative of actual groundwater quality in the Province;

2.) Both seasonal variation and inherent variabilities in bacteria concentration in groundwater likely contributed to the observation that different sets of wells were found to be contaminated in the surveys. Although different sets were contaminated, the overall frequency of bacterial contamination was similar in the two surveys; and,

3.) The set of wells contaminated with nitrate was similar in both summer and winter samplings and no specific seasonal variability was observed. The mean concentration of nitrate, however, increased by almost 7% between the two samplings.

Section 2: Multilevel Monitoring Well Survey

Resampling of 141 multilevel wells occurred during the summer of 1992. The wells had been installed during the winter survey at 160 farms in Southwestern Ontario. At each of these farms, a multilevel well was located in a cropped field adjacent to the drinking water well. At 16 farms a multilevel well was also installed in a woodlot adjacent to the cropped field. After the winter sampling, the field multilevels were buried below plow depth so they would not interfere with normal field practices but could be located for resampling during the summer survey. Each multilevel provided groundwater samples from various discrete depths. Results were therefore analyzed in terms of either average or maximum contaminant concentration in samples from a multilevel. Results from the summer sampling of the field multilevels were as follows:

- 21% of the multilevels gave an average nitrate-N concentration that exceeded the Ontario drinking water objective.

- 44% of the multilevels gave a maximum nitrate-N concentration that exceeded the drinking water objective.

- 32% of the multilevels indicated groundwater contamination with total coliform bacteria and 10% with faecal coliforms, considering averaged bacterial concentrations.

- 6% of multilevels had detectable concentrations of pesticide residues, and one multilevel showed a pesticide concentration in exceedence of its IMAC value.

! Several additional observations can be made with respect to the summer multilevel data:

1.) At the majority of sites, the concentrations of the target contaminants in the multilevel wells were similar to those observed in the water wells, indicating a clear correlation between the levels of groundwater contamination found in farm wells and those found in adjacent farm fields;

2.) The frequency of groundwater samples found to exceed the Ontario drinking water objectives for any of the target contaminants was fairly consistent under all agricultural land-use practices. A slightly higher frequency of nitrate contamination was seen under "corn systems" (rotations in which corn and/or soybeans occupy more than 30% but less than 90% of the land area);

3.) The application of manure to a given field did not appear to correlate with higher bacteria concentrations in the monitoring wells;

4.) When concentrations of coliform bacteria and nitrate-N from a field multilevel and a corresponding multilevel in a woodlot were compared, levels of bacteria were very similar but nitrate-N tended to be considerably less under the woodlot; and,

5.) Nitrate-N tended to decrease nearly linearly with depth below the water table, whereas coliform bacteria appeared to persist to greater depths before significant decreases in concentration were observed.

! In comparing the multilevel data from the summer and winter surveys, several observations can be made.

1.) Very little seasonal variation in nitrate-N concentration was observed;

2.) The frequency of contamination by coliform bacteria was significantly less during the summer sampling, although the overall trends in the data were very similar; and,

3.) Significant seasonal variations in bacterial concentrations in the shallow groundwater systems appear to occur.

2.0 Introduction

In response to growing concerns related to land-use and development, and the subsequent impacts on groundwater quality, Agriculture Canada initiated a major effort to evaluate the condition of the groundwater resources used by the rural community for drinking water supplies. One of the main motivations for the study was the international awareness of the potential impacts that agricultural activity may have on shallow groundwater quality. Some research work has been completed and more is currently underway in many parts of Canada, the United States, and Europe, to gauge the current and potential impacts of intensive agricultural development on surface and groundwater resources.

An initial survey of approximately 1300 domestic farm wells and about 150 multilevel monitoring wells located in active farm fields was conducted during the winter months of 1991-1992 as the first part of Agriculture Canada's study. The main objectives of this initial survey were to:

- *determine the quality and safety of drinking water for farm families, and*
- *determine the effect of agricultural management on the quality of groundwater.*

Groundwater samples taken from these wells were analyzed for nitrate-N, total and faecal coliforms, and several common herbicides. The results indicated that approximately 37% of all drinking water wells sampled contained concentrations of at least one of the target contaminants at levels above the drinking water objectives specified by the Ontario Ministry of the Environment and Energy (MOEE) and the Ontario Ministry of Health (MOH). Evaluation of data from the multilevel monitoring wells suggested that the quality of the shallow groundwater beneath the active agricultural fields adjacent to the drinking water wells correlated fairly closely with that observed in the water wells themselves. This indicated that the agricultural land-use practice may be directly influencing groundwater quality in the water wells. A detailed report on the results of this survey is contained in the Ontario Farm Groundwater Quality Survey (OFGQS), Winter 1991/92 prepared for Agriculture Canada (September, 1992).

A second complete survey of the same network of water wells and monitoring wells was carried out during the summer months of 1992. The main objectives of the second survey were to:

- verify the conditions and trends observed in the first sampling program and enhance the statistical validity of the data set; and,

- examine the influence of seasonal change, both climatic and related to specific agricultural activity, on the quality of groundwater resources on Ontario farm lands.

As was the case in the first survey, the project involved the collaboration of eight different groups including Agriculture Canada. The overall program was coordinated through the Ontario Soil and Crop Improvement Association (OSCIA) and involved the Waterloo Centre for Groundwater Research (WCGR) at the University of Waterloo, the Centre for Land and Water Stewardship (CLWS) at the University of Guelph, the Resources Management Branch (RMB) and the Pesticide Residue Laboratory (PRL) of the Ontario Ministry of Agriculture and Food (OMAF), the Ministry of the Environment and Energy (MOEE) and the Ministry of Health (MOH).

In this report, the results from the summer sampling are presented and evaluated with respect to spatial distribution, land-use practices, soil characteristics, and several additional factors. Recent surveys published or made available recently and not reviewed in the winter survey report, are included here for background information.

The results from the summer survey are reviewed with respect to the winter survey data and an evaluation and discussion of the combined data sets is presented. Information on sampling protocol, soil and land-use classification systems and statistical analysis procedures are included in the appendices.

The information in this report is not intended to represent an exhaustive study of groundwater quality throughout rural Ontario but is designed to indicate general trends in drinking water quality for farm families in relation to common agricultural land-use practices.

3.0 Recent Groundwater Surveys

Since publication of the report on the Ontario Farm Groundwater Quality Survey (OFGQS, 1992), a number of new surveys of agricultural contaminants in rural groundwater supplies have been conducted throughout North America. A discussion of health concerns, drinking water standards and other rural groundwater quality surveys was included in the first report and will not be repeated here. The following discussion reviews nitrate, bacteria and pesticide surveys that became available since the last report.

3.1 Nitrate Surveys

An extensive survey of nitrate in rural groundwater supplies of Huron County, Ontario, was conducted in the summer of 1991 (Fleming, 1992). Of 301 wells sampled, 15% were over the drinking water limit of 10 mg L^{-1} for nitrate-N. Dug/bored wells (30.5% over the drinking water limit) tended to be much more contaminated than were drilled wells (4%). No significant correlation with linear regression analysis, however, was obvious for well depth vs. nitrate concentration (r^2=0.16). Farms where the nitrogen soil test was used to determine optimum fertilizer use had a significantly lower median nitrate concentration (2.23 mg L^{-1}) than did sites where the soil test was not used (5.12 mg L^{-1}). No significant correlations between the nitrate concentration and factors such as the age of the well, amount of commericial fertilizer used on a farm, the tillage system used, or the distances to the septic system, manure storage or feedlot were found.

Frank et al. (1991) reported the results of groundwater surveys conducted in 1986 and 1987 of 106 and 77 wells respectively. In 1986, 15% of the wells had nitrate-N concentrations in excess of 10 mg L^{-1}. All of these wells were either dug wells or sandpoints less than ten metres deep. The following year, 7% of the wells were over the drinking water objective. Again, the majority of those wells with high nitrate-N levels were shallow dug wells.

A number of new nitrate surveys were conducted in the United States. In a study of drinking water wells in two counties of New Jersey, 6% of 343 wells sampled during the spring of 1990 were contaminated with nitrate (Murphy, 1992). Wells deeper than 30 m were found to contain significantly lower nitrate concentrations than water from wells less than 30 m. A significantly larger percentage of wells located near a septic system (<15 m) had elevated nitrate concentrations (13%) compared to wells on farms where there was no septic system (1%). The application of

fertilizer or manure was also correlated with higher nitrate concentrations.

A survey of 201 rural wells in Missouri was conducted between 1987 and 1989 (Sievers and Fulhage, 1992). Counties that were considered more vulnerable to groundwater contamination according to their principal land-uses and soil types were chosen. Twenty-two percent (22%) of the wells exceeded the nitrate drinking water limit. The depth of wells and the nitrate concentration were not significantly correlated. A significant correlation, however, was found between the amount of nitrogen fertilizer shipped to a county and the number of wells exceeding the nitrate drinking water limit.

Another survey conducted in the Fall of 1990 in counties with predominantly permeable soil types in Southwestern Michigan found that 21% of 121 wells sampled exceeded the nitrate drinking water limit (Ervin and Lusch, 1992). Deep wells (>30 ft) were less often contaminated over the drinking water limit (7.9%) than were shallow wells (26.5%). A random survey (farmers were offered free sampling of their well) conducted across Michigan (Ervin and Lusch, 1992), found a much smaller percentage of wells (12% of 879 wells sampled) were contaminated over the drinking water limit for nitrate. In general, for the case of nitrate-N, the most common positive correlations that have been found in the majority of these surveys have either been related to the depth of the well or the type of well construction.

3.2 Bacteria Surveys

Bacterial contamination of rural groundwater in Ontario was assessed in the Huron County Survey in the summer of 1991 (Fleming, 1992). Of 301 wells sampled, 34% exceeded the total coliform drinking water limit, and 26% exceeded the faecal coliform drinking water limit. The number of dug/bored wells that had either a total or faecal coliform concentration in excess of the drinking water limits was significantly higher than the number of drilled wells in excess of these limits. Bacteria concentrations were not significantly correlated with permeable soil types, deeper or older wells, drainage toward wellhead, presence of animals on the farm, or the proximity of septic systems, manure storage areas or feedlots.

3.3 Pesticide Surveys

The Huron County Survey also sampled 294 wells for triazine and acetanilide herbicides (Fleming, 1992). Atrazine, d-ethyl

atrazine, simazine, and metribuzin were detected, while alachlor, metolachlor, and cyanazine were not. More dug/bored wells were contaminated with atrazine concentrations over 1 mg L^{-1} (9%) than were drilled wells (1%), although the correlation between atrazine concentration and type of well was not statistically significant. No significant correlations were found between atrazine detections and the type of farm operation, the use of inorganic fertilizers, the tillage system, the distance to cropped land or the use of wells to fill pesticide sprayers.

In new surveys of pesticide residues in groundwater in the United States, atrazine was again the most common pesticide encountered. In the Missouri groundwater quality survey, 201 wells sampled four times (804 samples) over the year revealed a total of 189 pesticide detections (23% of the samples) (Sievers and Fulhage, 1992). Fifty-three percent of these detections were for atrazine. Thirteen percent (13%) of the wells in the survey exceeded 1 ppb at some point during the year, 8% during the December sampling and 2-3% during the March, May, and September samplings. Well depth was significanltly correlated with pesticide detection with the shallower wells having the highest occurrences of pesticide residue. The groundwater survey conducted in Southwestern Michigan, in which well water was analyzed for triazine and acetanilide pesticides (Ervin and Lusch, 1992), found that 20% of the wells had detectable pesticide residues.

A survey completed in Iowa (discussed in the first report) found detectable levels of at least one pesticide residue in 14% of 686 wells (Kross et al., 1992). Atrazine or one of two of its degradation products, d-ethyl and d-isopropyl atrazine was found in 8% of the wells. The U.S. drinking water limit for atrazine (3 µg L^{-1}) was exceeded in 1.2% of the rural wells. Twenty-five percent (25%) of the pesticide occurrences appeared to be caused by point sources, such as spills near the wellhead or back-siphoning while filling sprayers, and 62.5% of the occurrences appeared to be nonpoint sources related to normal agricultural practices. Pesticide concentrations were negatively correlated with well depth.

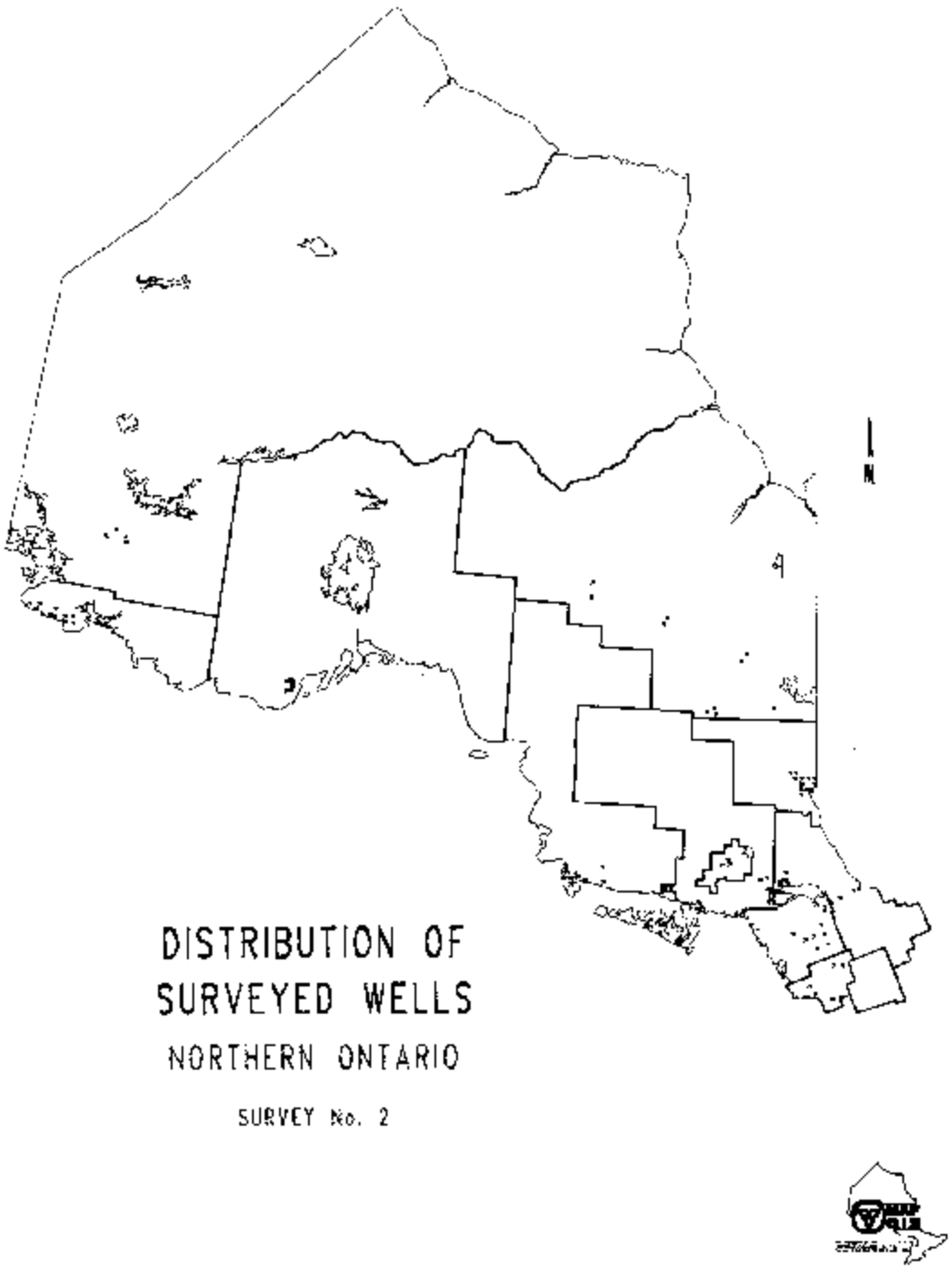
4.0 Survey Site Selection Criteria

4.1 Water Well Selection Criteria

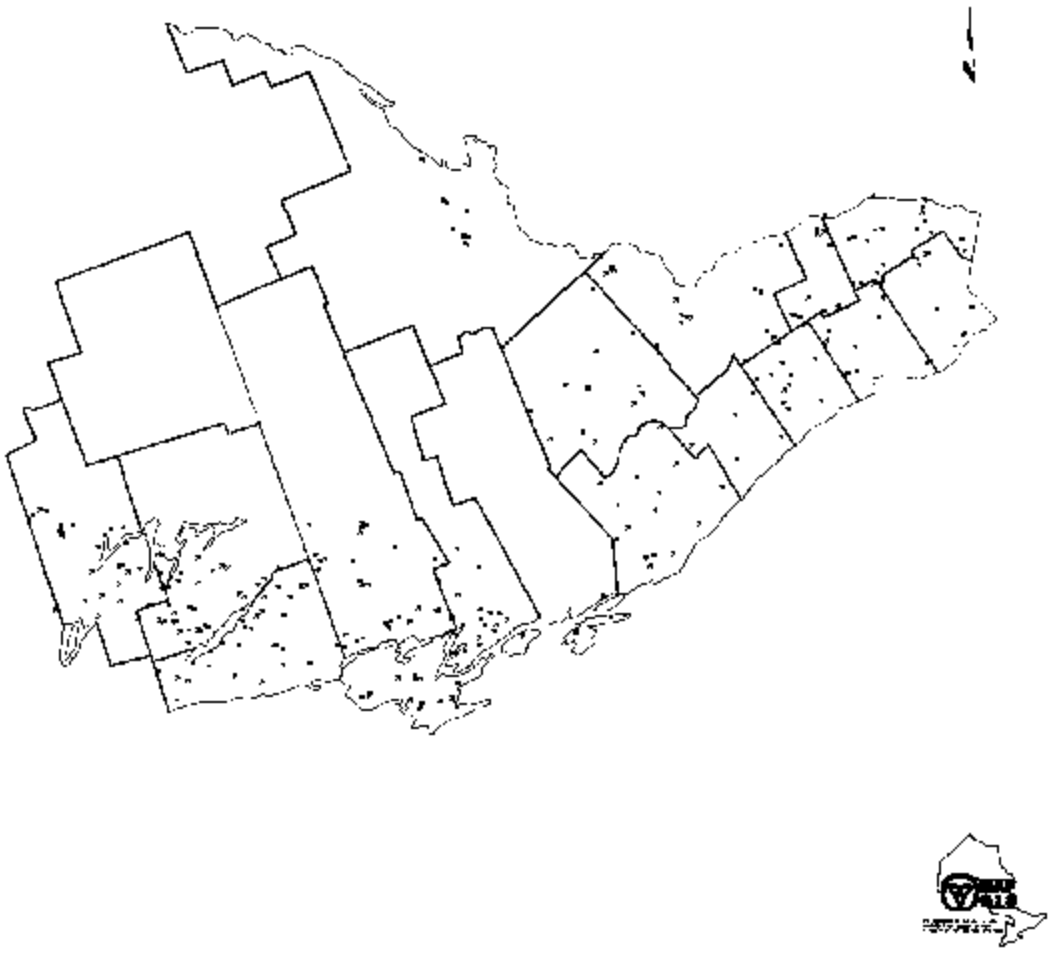
A full account of how farm wells in Ontario were selected for sampling was given in the report on the original survey (Ontario Farm Groundwater Quality Survey, Winter 1991/92). In brief, the original selection of water wells for investigation in the first sampling programme was based on three criteria, the proportion of a township under agricultural management, the primary and secondary soil type within the township, and the most frequent agricultural land management practices adopted in the township. The township was therefore considered as the primary scale unit for the survey. A total of 1157 wells were selected across the province using this scheme, although the criteria were modified slightly when considering wells in Northern Ontario because of the lack of land-use information. An additional 135 wells were selected by pairing a multilevel well with a farm well. The final total of wells sampled in the first round of sampling (the winter programme) was 1292.

All participating farm families from the winter sampling were contacted to obtain their agreement for inclusion in round 2 (summer programme) of well sampling. A small number declined to participate, and some became ineligible because of changes to their water supply system. However, a total of 1237 wells were finally sampled.

A master list of detailed location information (county, township, concession and lot numbers) compiled in 1992 was revised. Easting and northing coordinates of sites were revised by OMAF personnel and a new GIS database was set up. For ease of presentation, the Province of Ontario map was subdivided into maps for South-eastern, South-western and Northern Ontario. The locations of all sampling points in Northern Ontario are shown on Map 1, South-eastern Ontario on Map 2, and in South-western Ontario on Map 3.



Map 1. *Location of surveyed water wells - Northern Ontario.*



Map 2. *Location of surveyed water wells - South-Eastern Ontario.*

Map 3. *Location of surveyed water wells - South-Western Ontario.*

4.2 Multilevel Monitoring Well Site Selection Criteria

The criteria used to select farms for multilevel installation were described fully in the first report (OFGQS, 1992). One of the main purposes of the multilevel installations was to try to differentiate contamination in the farm water well resulting from local point sources, such as septic fields or feedlots, and contamination resulting from agricultural activity on adjacent fields. The areas that were anticipated to be the most susceptible to contamination were farms on sandy soils where shallow dug wells were being used. The OMAF soil maps were consulted to locate areas of coarse-textured soils and the ARI agricultural land-use information was used to focus site selection in active and varied agricultural areas. Multilevel monitoring wells were located in 11 different counties throughout Southern Ontario.

Potential sites were selected by the Working Committee and this information was forwarded to the OSCIA field inspectors in each county. With the assistance of field personnel from OMAF, Resources Management Branch (RMB), suitable sites were located in areas where the dominant agricultural activity was represented and where the farm operator was willing to cooperate. At each selected farm, a multilevel well was installed in a field adjacent to the barnyard, so as to remain fairly close to the water well used by the farm, but away from the influence of barnyard activities. The monitoring wells were primarily located near depressional areas within a field, where the watertable was expected to be closest to ground surface.

A total of 144 farms were ultimately selected for the multilevel monitoring well installation program. Approximately 40% of the sites were located on sandy and gravelly materials and about 20% were in fine-textured clays and silts. The remaining 40% of the wells were placed in combinations of different materials as will be discussed later in the text.

Multilevel monitoring wells were also installed in 16 woodlot areas adjacent to the field where the other multilevel device had been installed. These sites were selected at random by OMAF and OSCIA personnel in the field. The main objective of the monitoring wells in the woodlot areas was to compare the nature of groundwater contamination under cultivated and non-cultivated conditions. Overall, 160 multilevel monitoring wells were installed.

5.0 Results

5.1 Data Compilation

The methodologies used to construct the multilevel monitoring wells during the winter sampling, sample the groundwater, carry out the water chemistry analysis and statistically evaluate the data were the same as adopted for the first sampling programme. The specific details are summarized in Appendices A, B and C.

To improve the quality and reliability of information held in the data base developed in the first sampling programme, a second questionnaire was formulated. It was completed, with the assistance of the farm operator, at each of the 1237 farms visited for either a water well sample or a multilevel installation. A copy of the questionnaire is contained in Appendix D.

The data from the questionnaires were used to correct and amplify the data base, which was updated with results of all the geochemical analyses from the various laboratories. The completed data base was again submitted to the OMAF Resources Management Branch where a GIS system was used to prepare the various maps demonstrating the spatial distributions of the various parameters and parameter correlations.

The soil classification system developed by OMAF was again selected to categorize conditions at each site. This classification system is based on drainage characteristics, material texture and mineralogy (Appendix E.1). The predominant agricultural practice being conducted at each farm was re-classified, taking account of information on the second questionnaire, using the general ARI system of OMAF and drawing on the experience of Agriculture Canada staff (Appendix E.2).

In an attempt to simplify and group similar soil types into a smaller subset of categories, a system developed by the Soil Conservation Service of the United States Department of Agriculture (USDA) was adopted. This classification is based mainly on infiltration capacity and permeability, and places soils into one of four hydrologic groups (Appendix E.3). A hydrologic group was assigned to each soil type encountered in this survey, except for those unique to Northern Ontario, where there was insufficient soils information available in GIS (Appendix E.1).

The results of the groundwater chemistry analyses for each water well and multilevel well are contained in a separate document submitted to Agriculture Canada.

5.2 Distribution of Water Wells and Multilevel Monitoring Wells

As described earlier, an effort was made to select water wells primarily in the intensely-developed agricultural areas throughout the Province. The wells included in the survey were again tabulated on a county basis (Table 1). The well distribution was also mapped (Maps 1,2 and 3).

The distribution of the complete network of multilevel monitoring wells remained the same as given in Table 2 and Map 3 from the report of the first survey. The distribution of multilevels sampled during the summer survey is shown in Table A1 in Appendix A.

Table 1. *Number of farm drinking water wells included in the summer sampling programme in counties of Ontario.*

County	Wells	County	Wells
ALGOMA	9	NIAGARA N.	16
BRANT	14	NIAGARA S.	11
BRUCE	48	NIPISSING	10
CARLETON	15	NORFOLK	48
COCHRANE S.	10	NORTHUMBERLAND	29
DUFFERIN	22	OXFORD	32
DUNDAS	13	PARRY SOUND	10
DURHAM	24	PEEL	8
ELGIN	38	PERTH	51
ESSEX	49	PETERBOROUGH	36
FRONTENAC	6	PRESCOTT	22
GLENGARRY	13	PRINCE EDWARD	15
GRENVILLE	5	RAINY RIVER	13
GREY	56	RENFREW	11
HALDIMAND	9	RUSSELL	13
HALTON	8	SIMCOE N.	18
HASTINGS	28	SIMCOE S.	37
HURON	78	STORMONT	7
KENORA	3	SUDBURY	10
KENT	51	TEMISKAMING	14
LAMBTON	45	THUNDER BAY	8
LANARK	9	VICTORIA	22
LEEDS	17	WATERLOO	22
LENNOX & ADDINGTON	21	WELLINGTON	47
MANITOULIN	13	WENTWORTH	17
MIDDLESEX	82	YORK	19
MUSKOKA	5	Total	1237

5.3 Water Well Survey Results

The groundwater quality survey compiled information from the testing of water samples, and from the two questionnaires completed by the co-operating farmers and the OSCIA personnel. One of the aims of this sampling programme was to assess further the risk of contamination associated with the wells or their construction. In this part of the report, revised information on well age, depth and type is given, followed by information on the general distribution of contamination. The 95% confidence limits are provided on all percentage calculations in tables and on figures where possible, to indicate the variability expected due to the size of the survey population.

5.3.1 Water Well Type, Depth, and Age

The age of wells sampled in the survey ranged between very recent and greater than 100 years. Half the wells sampled were less than 30 years old, but 4% were more than 100 years old (Fig. 1). A wide variation in depth was also encountered with wells ranging from 3 ft to 550 ft (1 m to 169 m). The wells basically fell into three main categories of well type or construction. These were dug or bored wells, sandpoints, and drilled wells. There was a strong, but not exclusive, link between the depth and type of well (Fig. 2). Most wells 40 ft (12.3 m) or less in depth were dug or bored, the majority of deeper wells were drilled wells. Sandpoints were fewest in number but the majority were shallow (<12.3 m).

Of all wells surveyed, 34% were dug or bored, 6% were sandpoints, 58% were drilled, and 2% were springs or combinations of the three main well construction types. The complete distribution of all wells in the survey in terms of well type and depth is shown in Appendix F in the form of tables.

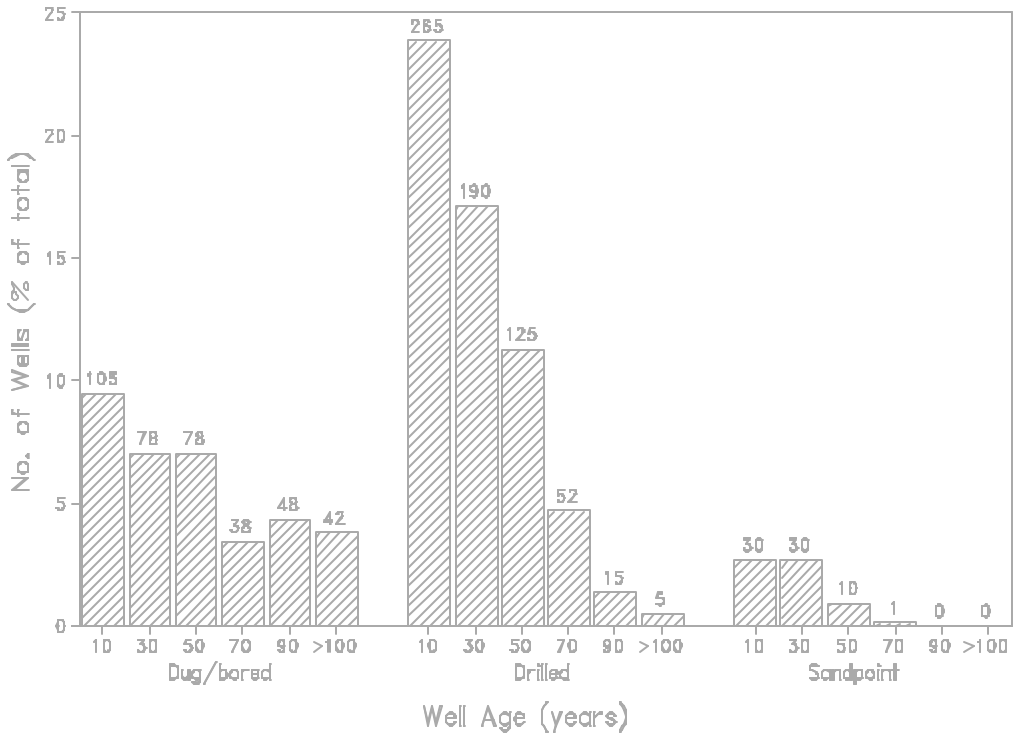


Fig. 1. *Frequency distribution by well type, showing the percentage of wells in each 20 year age class. The number at the head of each column indicates the total number of wells in that category.*

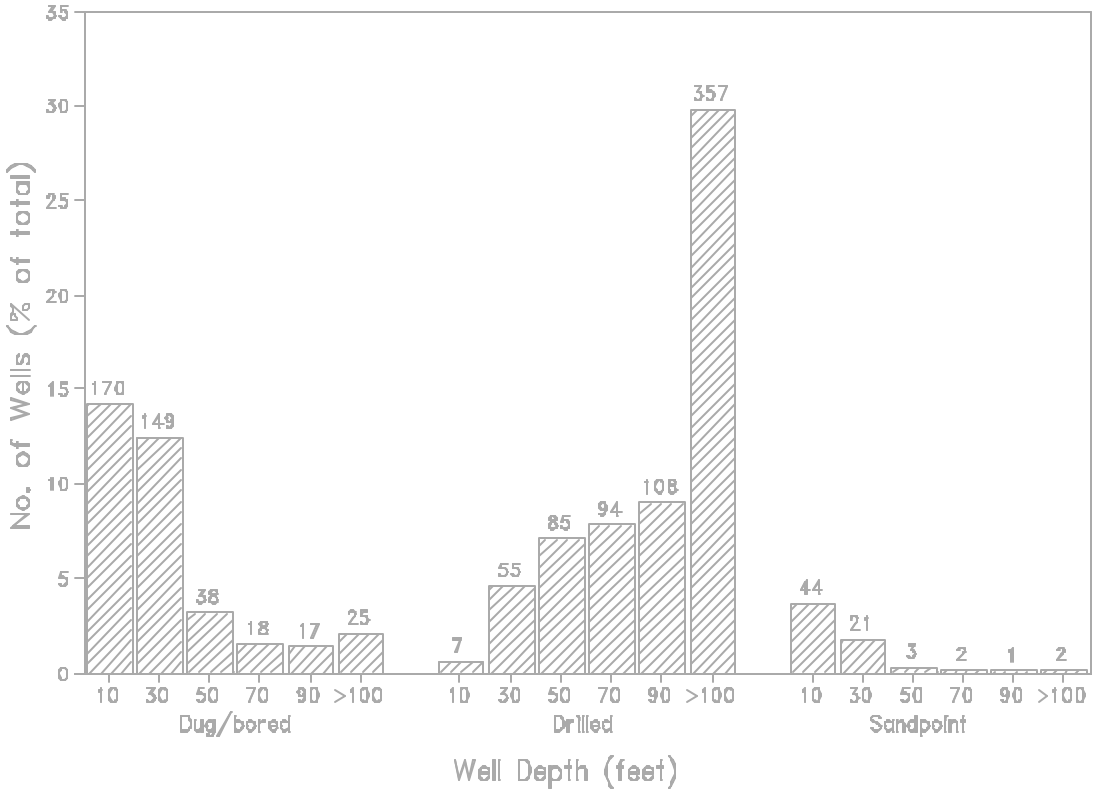


Fig. 2. *Frequency distribution by well type, showing the percentage of wells in each 20 foot depth class. The number at the head of each column indicates the total number of wells in that category.*

5.3.2 General Distribution of Contaminants

To evaluate the general level of contamination in water samples collected in the survey, observed concentrations were compared with the Ontario drinking water objectives as applied to private well supplies. The maximum acceptable concentration (MAC) of total coliform bacteria in private drinking water supplies was revised by the Ontario Ministry of Health, in October 1992, from 10 to 5 colonies per 100 mL. As this change took place after the sampling was completed, results were analysed relative to both the old and new objectives. However, unless indicated otherwise, the results presented are those based on objectives current during the sampling programme. Maximum acceptable concentrations of contaminants considered in this survey are listed in Table 2. For several specific groups of bacteria analyzed by MOH, no current objective was available, so concentration limits suggested by the MOH were adopted. These limits are somewhat arbitrary, as no epidemiological studies have been done to evaluate the health risks associated with them. Also, the new MOH guideline value of 5 total coliform was based on what is normally expected in water of good quality where there are no known sewage sources. The epidemiological basis for the value is tenuous.

A series of five herbicides and one metabolite (degraded form) of one of the herbicides was selected for analysis. Drinking water objectives for these compounds (Table 2) were taken as the maximum acceptable concentration (MAC) or interim MAC (IMAC) given in Ontario Drinking Water Objectives (MOE, 1992). The herbicides have been classified under the general category of agricultural pesticides and will be referred to as pesticides throughout this report.

About 40% of the nearly 1300 wells tested contained one or more of the target contaminants above the maximum acceptable concentration (Table 3). This number increased to 43% when the revised maximum permissible colony count for coliform bacteria was used. Bacteria were the most widespread form of contamination with about 32% of wells having more than the maximum number of faecal or total coliform bacteria permissible in drinking water. Enterococcal bacteria were found in more than 44% of the 113 wells that were tested. Some 14.5% of the wells contained nitrate-N concentrations above the 10 mg L^{-1} limit and about 7% of the wells were contaminated both with bacteria and nitrate.

Almost 68% of wells tested contained 5 or fewer than 5 total coliform bacteria per 100 mL, the maximum number acceptable. It should be noted, however, that about 10% of wells had between 1

and 4 total coliforms per 100 mL. Of the wells having more than 10 per 100 mL, about 40% had 80 or more. Seventy five per cent of wells contained no faecal coliforms, and a further 4% contained only 1 colony per 100 mL.

Approximately 85% of wells tested had less than 10 mg nitrate-N L^{-1}, but 11% had nitrate-N concentrations from 5-10 mg L^{-1}. A cumulative frequency plot of concentrations of nitrate-N and bacterial contaminants is shown in Appendix F (Fig. F1).

The pesticides alachlor, atrazine, cyanazine, metribuzin, metolachlor, and the atrazine metabolite, d-ethyl atrazine, were again chosen for study in the summer survey. They were selected in the first survey because of their extensive past or present use in the Province and their persistence in the environment. In this summer sampling, 11.5% of the wells had detectable concentrations of pesticides. Two wells contained pesticide residues above the interim maximum acceptable concentration (IMAC). One contained alachlor and the other contained metolachlor. The latter well was also contaminated in the first sampling programme and it was known that a spill had occurred.

The survey results have been subdivided into those for Northern and those for Southern Ontario (Tables 4 and 5). The two parts of the Province did not differ significantly in the proportions of types or depths of wells, but most farms in Northern Ontario carried livestock. In Northern Ontario, 35% of 105 wells tested contained levels of at least one of the target contaminants above the specified limits (Table 4). In Southern Ontario (1122 wells tested), 41% of wells were contaminated (Table 5). This difference was not statistically significant. In this sampling programme the proportion of wells with total coliform counts above the drinking water objective (10 colonies per 100 mL) was similar in both parts of the province (29% in Northern Ontario, and 27% in Southern Ontario). The result differs markedly from that obtained in the winter sampling programme, and will be discussed in a further section. The proportion of wells contaminated with bacteria (total or faecal) was significantly greater ($p<0.01$) in Northern Ontario (57%) than in Southern Ontario (32%), but twenty-times more wells were tested in the south (Tables 4 and 5). Overall, the levels of contamination in both areas were very similar.

The general distribution of nitrate contamination in Ontario was mapped. Results for Northern Ontario are shown on Map 4. For clarity of presentation, Southern Ontario was subdivided into south-eastern (Map 5) and south-western regions (Map 6). The distributions of combined total and/or faecal coliform

contamination were also mapped for Northern Ontario (Map 7) and the south-eastern (Map 8) and south-western regions (Map 9).

Table 2. *Recommended maximum concentrations identified in Ontario Drinking Water Objectives (MOEE, 1992) as applied to private supplies by MOH.*

Contaminant	Recommended Maximum
Bacteria	
Faecal Streptococcus	10 colonies† (100 mL)$^{-1}$
Enterococcus	10 colonies† (100 mL)$^{-1}$
Escherichia coli	0 colonies† (100 mL)$^{-1}$
Total coliforms	5 colonies‡(100 mL)$^{-1}$
Faecal coliforms	0 colonies (100 mL)$^{-1}$
Nitrate-Nitrogen	10.0 mg L^{-1}
Pesticides (common name and trade name)	
Alachlor (Lasso)	5 µg L^{-1}
Metolachlor (Dual)	50 µg L^{-1}
Atrazine (Aatrex)	60 µg L^{-1}
d-ethyl atrazine§	#
Metribuzin (Sencor)	80 µg L^{-1}
Cyanazine (Bladex)	10 µg L^{-1}

† Value suggested by the Ontario Ministry of Health.
‡ Value current during the sampling programme was 10 colonies (100 mL)$^{-1}$.
§ An atrazine metabolite.
# Included with total for atrazine.
Note: Values for pesticides are Maximum Acceptable Concentration (MAC) values or Interim MAC's established and recommended by MOEE or Health and Welfare Canada.

Table 3. *General distribution of contaminants in farm drinking water wells sampled during the summer programme.*

Contaminant	Wells Tested	Exceeds Objectives	
	no.	no.	%
Bacteria			
Total coliform >10	1227	332	27.1±2.5[†]
Total coliform >5	1227	395	32.2±2.7
Faecal coliform >0	613	156	25.4±3.5
E. coli >0	812	165	20.3±2.8
F. strep >0	826	224	27.1±3.1
Enterococci >0	113	50	44.2±9.3
F.strep or entero >10	826	148	17.9±2.7
Total >10 or faecal >0	611	205	33.6±3.8
Total >5 or faecal >0	611	223	36.5±3.9
Total >10 or faecal colif. or *E. coli* >0	1227	396	32.3±2.7
Total >5 or faecal or *E. coli* >0	1227	436	35.5±2.7
Nitrate >10	1237	179	14.5±2.0
Mixed contamination			
Bacteria[‡] or nitrate	1227	493	40.2±2.8
Bacteria[†§] or nitrate	1227	524	42.7±2.8
Bacteria & nitrate	1227	80	6.5±1.4
Bacteria[§] & nitrate	1227	89	7.3±1.5
Pesticides (common name and trade name)			
Alachlor (Lasso)	1204	1	0.08±0.2
Metolachlor (Dual)	1204	1	0.08±0.2
Atrazine (Aatrex)	1204	0	0
d-ethyl atrazine	1204	0	0
Metribuzin (Sencor)	1204	0	0
Cyanazine (Bladex)	1204	0	0

[†] ±95% confidence interval.

[‡] Bacteria include total coliforms, and faecal coliforms or *E. coli*.

[§] Maximum permissible level of coliform bacteria taken as 5 colonies $(100\ mL)^{-1}$

Table 4. *General distribution of contaminants in farm wells of Northern Ontario.*

Contaminant	Wells Tested	Exceeds Objectives	
	no.	no.	%
Bacteria			
Total coliform >10	105	30	28.6±8.8[†]
Total coliform >5	105	35	33.3±9.2
Faecal coliform >0	28	10	35.7±18.1
E. coli >0	77	9	11.7±7.3
F. strep >0	99	35	35.4±9.6
Enterococci >0	0	-	-
F.strep or entero >10	99	23	23.2±8.5
Total >10 or faecal >0	28	16	57.1±18.7
Total >10 or faecal or *E. coli* >0	105	35	33.3±9.2
Nitrate >10	105	10	9.5±5.7
Mixed contamination			
Bacteria[‡] or nitrate	105	37	35.2±9.3
Bacteria & nitrate	105	8	7.6±5.2
Pesticides (common name and trade name)			
Alachlor (Lasso)	101	0	0
Metolachlor (Dual)	101	0	0
Atrazine (Aatrex)	101	0	0
d-ethyl atrazine	101	0	0
Metribuzin (Sencor)	101	0	0
Cyanazine (Bladex)	101	0	0

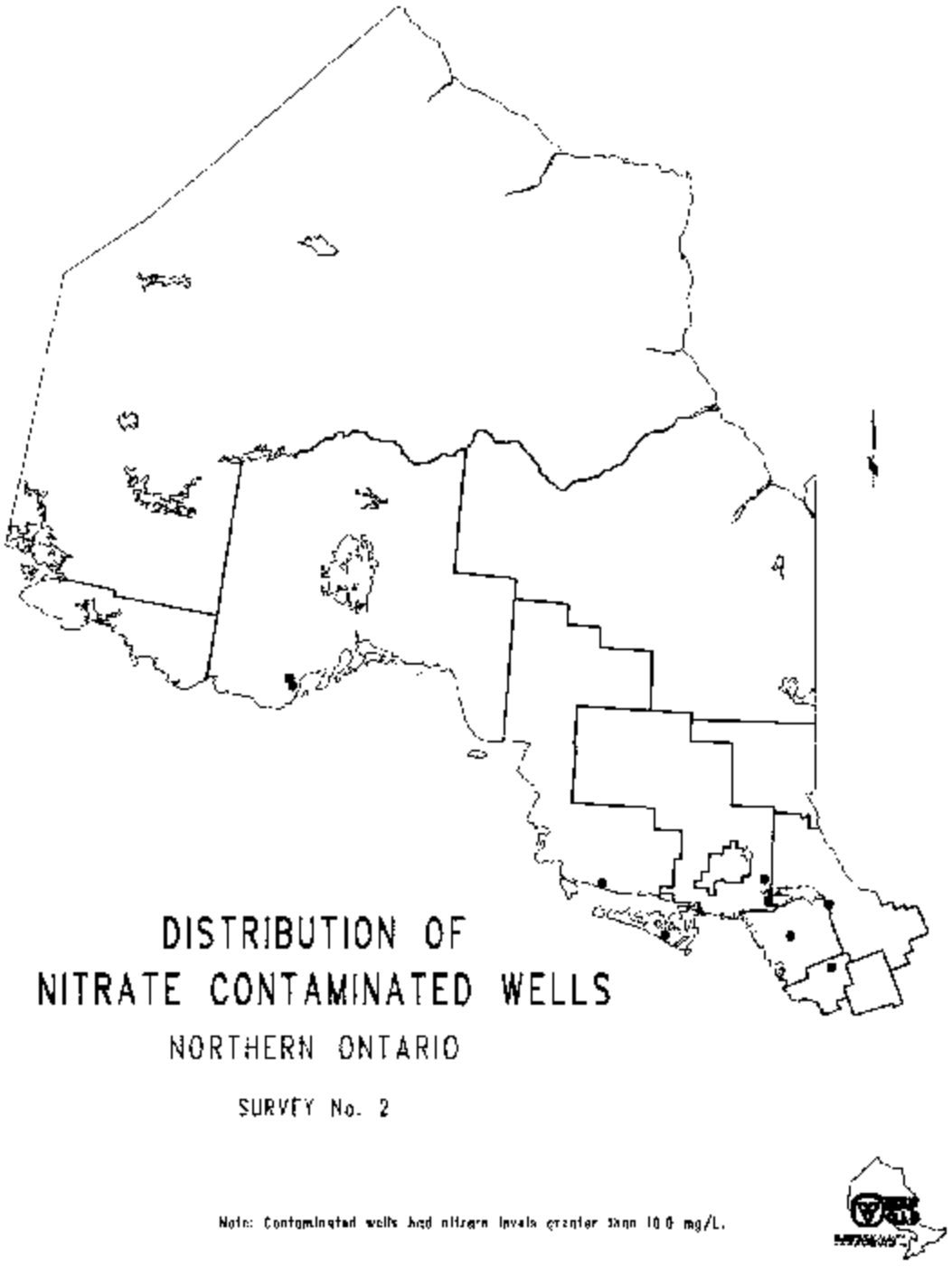
[†] ±95% confidence interval.

[‡] Bacteria include total coliforms, and faecal coliforms or *E. coli*.

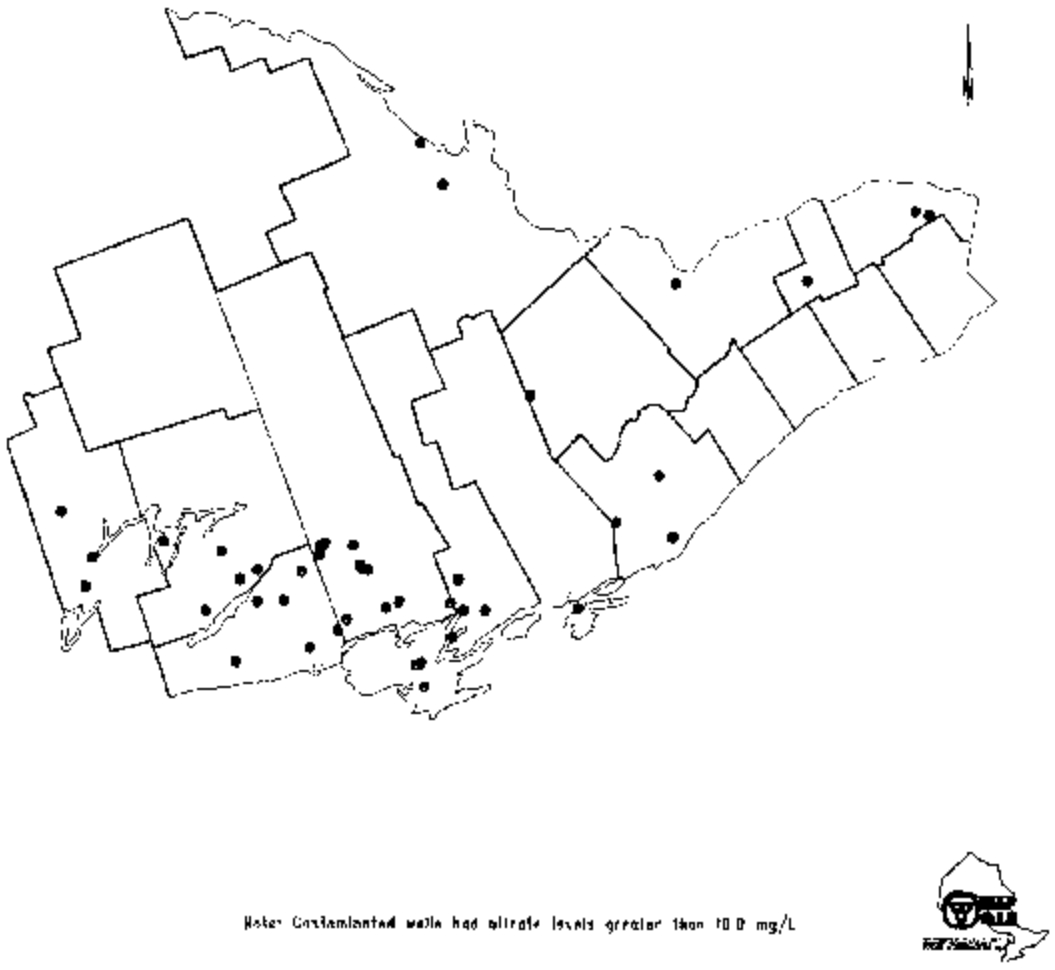
Table 5. *General distribution of contaminants in farm wells of Southern Ontario.*

Contaminant	Wells Tested	Exceeds Objectives	
	no.	no.	%
Bacteria			
Total coliform >10	1122	302	26.9±2.6[†]
Total coliform >5	1122	360	32.1±2.8
Faecal coliform >0	585	146	25.0±3.6
E. coli >0	735	156	21.2±3.0
F. strep >0	727	189	26.0±3.3
Enterococci >0	113	50	44.2±9.3
F.strep or entero >10	727	125	17.2±2.8
Total >10 or faecal >0	583	189	32.4±3.9
Total >10 or faecal or *E. coli* >0	1122	361	32.2±2.8
Nitrate >10	1132	169	14.9±2.1
Mixed contamination			
Bacteria[‡] or nitrate	1122	456	40.6±2.9
Bacteria & nitrate	1122	72	6.4±1.5
Pesticides (common name and trade name)			
Alachlor (Lasso)	1103	1	0.09±0.18
Metolachlor (Dual)	1103	1	0.09±0.18
Atrazine (Aatrex)	1103	0	0
d-ethyl atrazine	1103	0	0
Metribuzin (Sencor)	1103	0	0
Cyanazine (Bladex)	1103	0	0

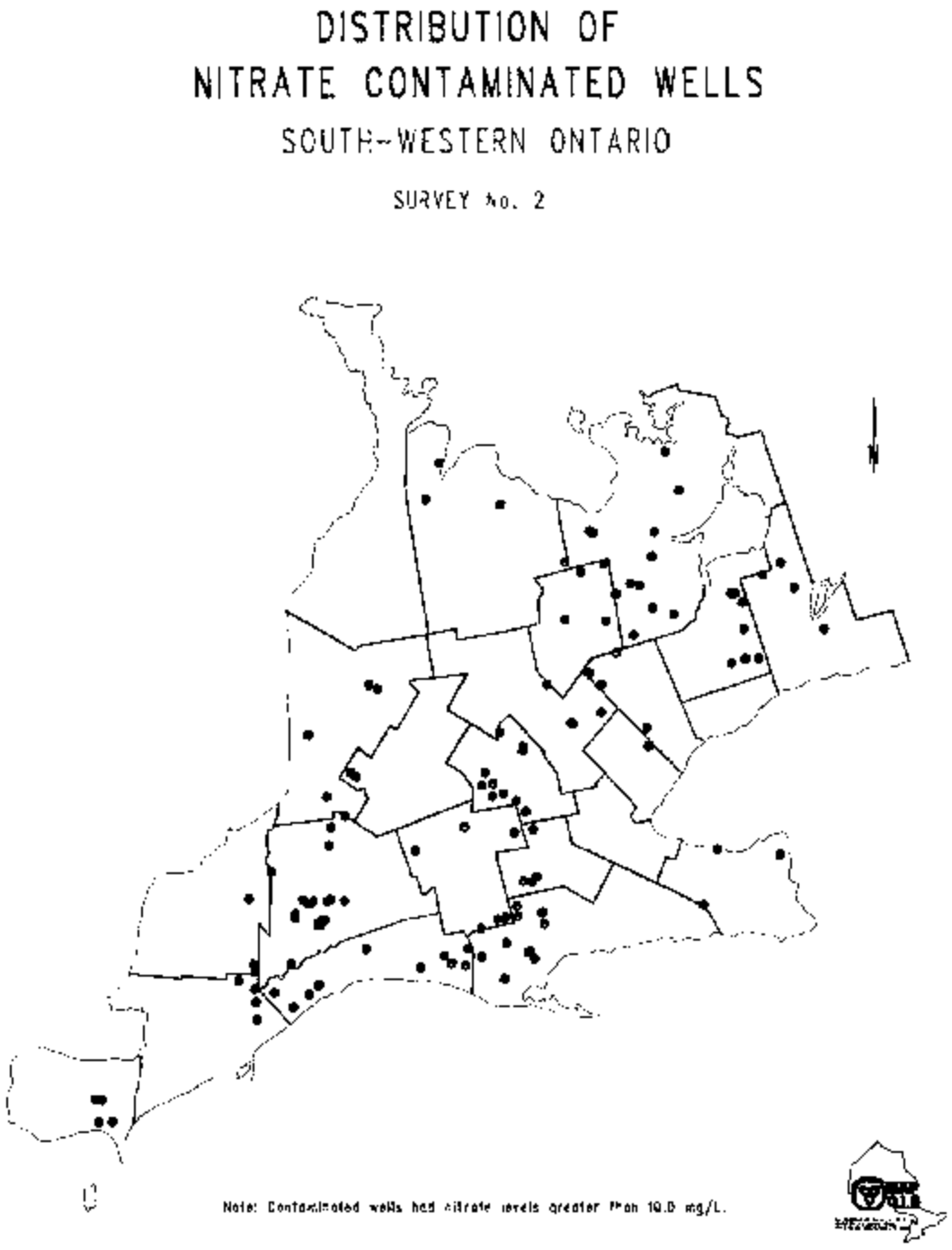
[†] ±95% confidence interval.
[‡] Bacteria include total coliforms, and faecal coliforms or *E. coli*.



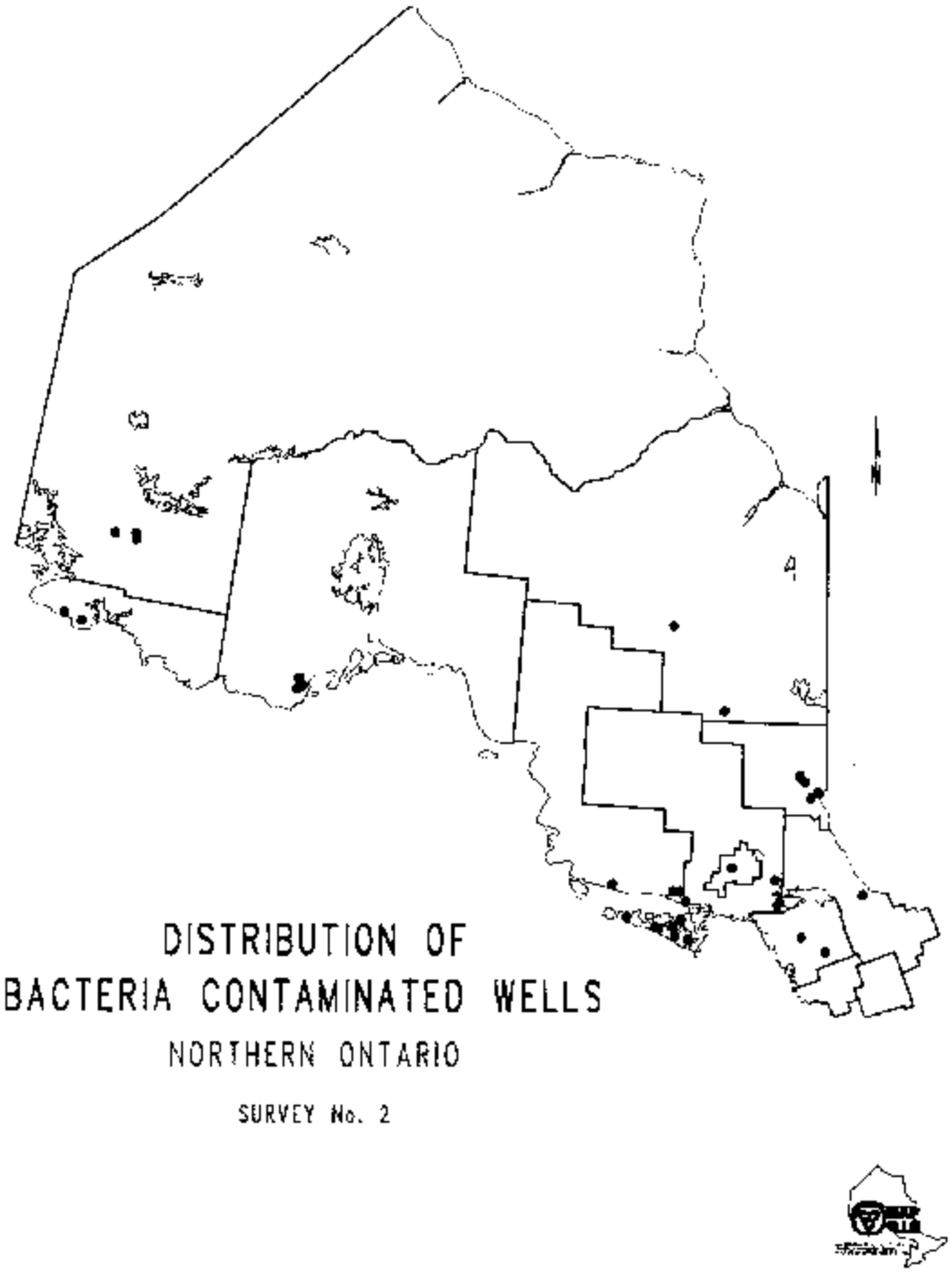
Map 4. *Distribution of wells containing nitrate concentrations in excess of drinking water objectives - Northern Ontario.*



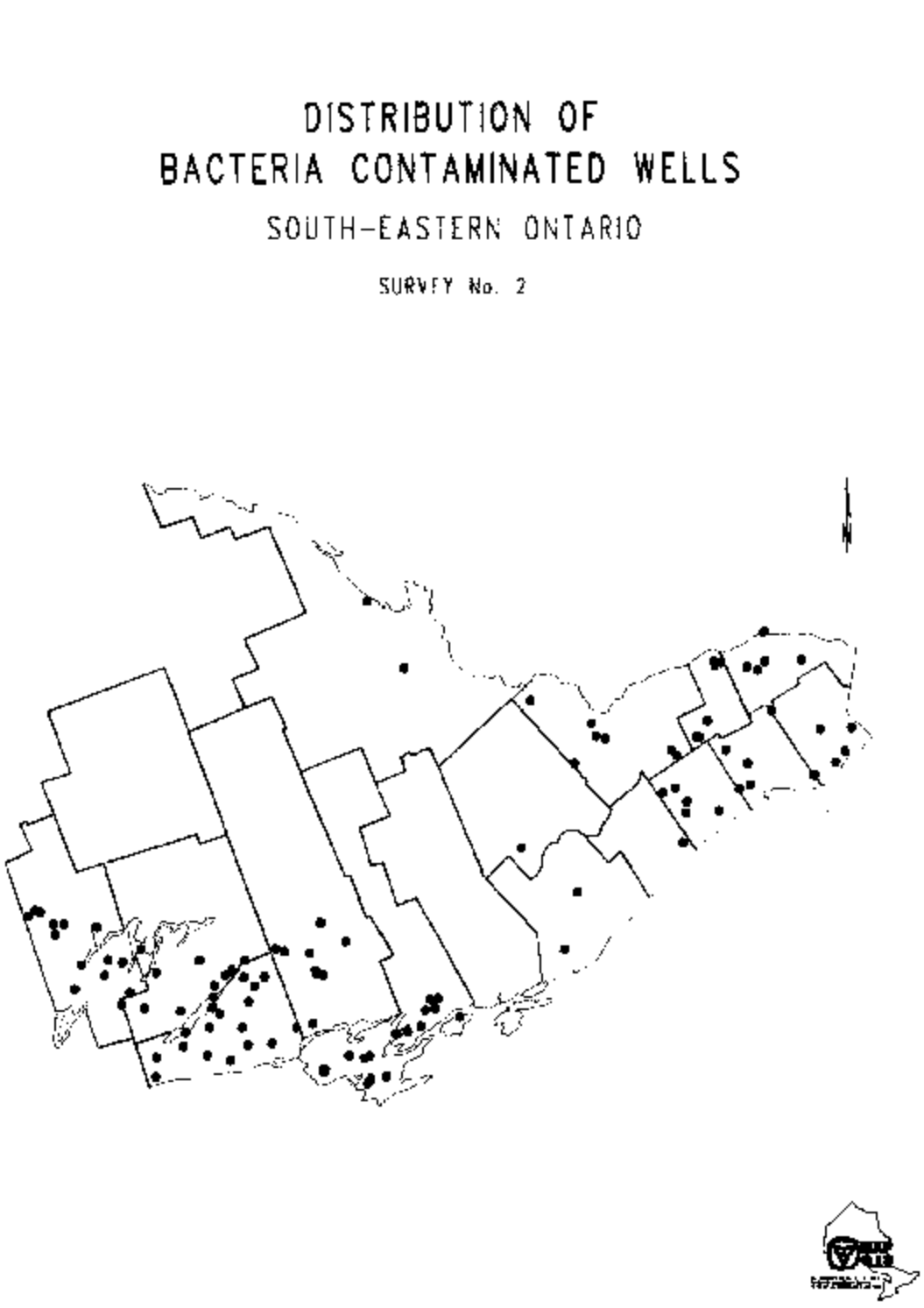
Map 5. *Distribution of wells containing nitrate concentrations in excess of drinking water objectives - South-Eastern Ontario.*



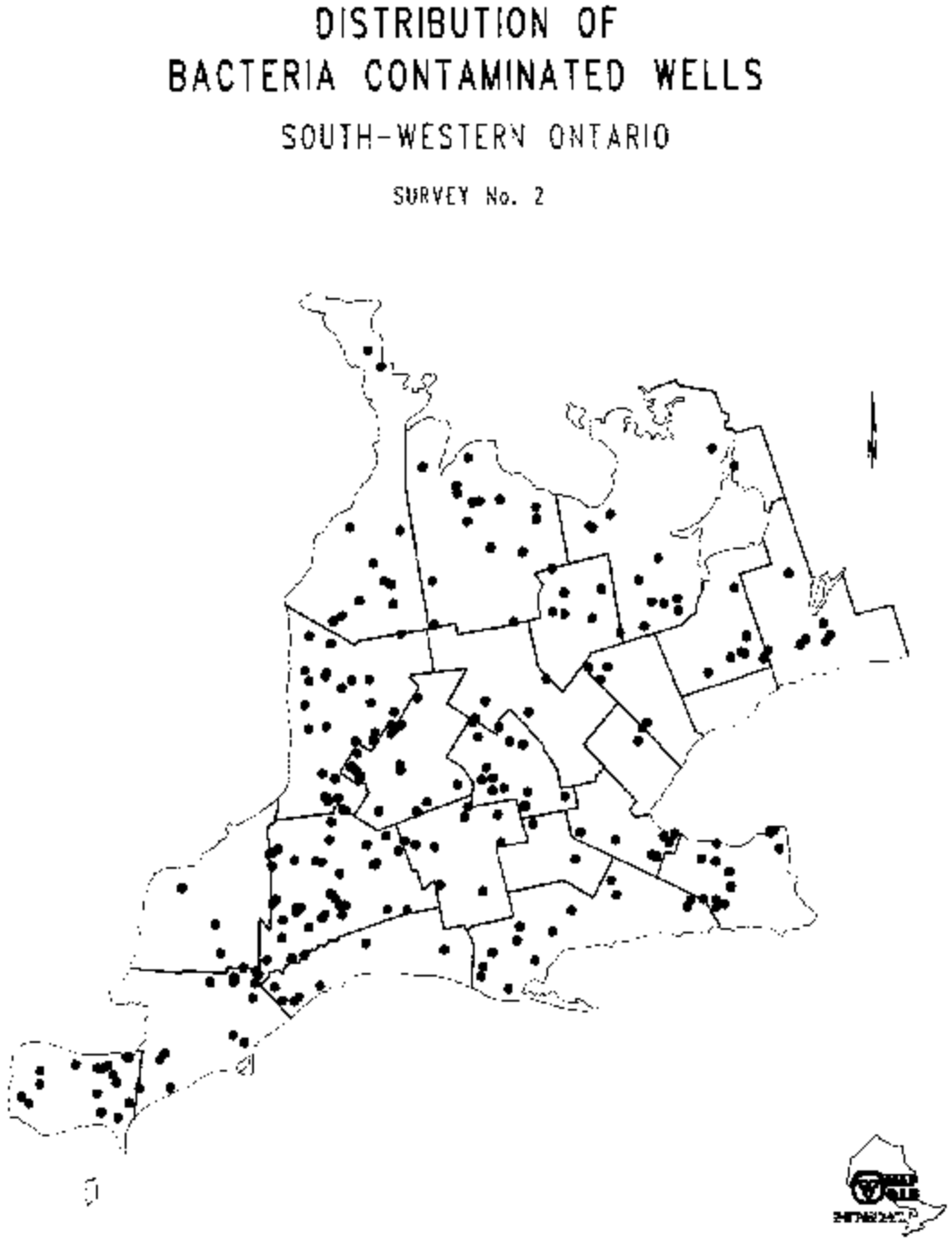
Map 6. *Distribution of wells containing nitrate concentrations in excess of drinking water objectives - South-Western Ontario.*



Map 7. *Distribution of wells containing coliform bacteria in excess of drinking water objectives - Northern Ontario.*



Map 8. *Distribution of wells containing coliform bacteria in excess of drinking water objectives - South-Eastern Ontario.*



Map 9. *Distribution of wells containing coliform bacteria in excess of drinking water objectives - South-Western Ontario.*

5.3.3 Frequency Distribution of Contaminants

In this section, the occurrence of groundwater contamination on the surveyed farms will be examined in relation to well age and construction, soil type and agricultural land-use.

5.3.3.1 Influence of Well Age and Construction

The level of contamination was investigated as a function of the depth and type of well together with the age of the well (Tables 6 and 7). Logistic regression analysis showed that for contamination with bacteria and nitrate, well depth was particularly important, and the interaction between well type and depth accounted for the largest proportion of the variance. After taking account of effects of well type, there was a strong interaction between well depth and age that also accounted for much of the remaining variance in the contamination. It was shown by multiple regression analysis that for dug wells only, there was a statistically significant increase in the *concentration* of nitrate, and the *number* of bacteria with well age (Tables 8 and 9).

Contamination with atrazine and its breakdown product d-ethyl atrazine, depended on the type of well and well depth, but not on the age of wells (Tables 8 and 9).

The relationships between well depth, construction, and the occurrence of nitrate and bacterial contamination is illustrated in Fig. 3, 4, and 5. Sandpoints and dug or bored wells showed a similar frequency of nitrate contamination in wells less than 40 ft (12.3 m) deep, and both were more frequently contaminated than were drilled wells (Fig. 3). Dug or bored wells between 60 ft and 100 ft deep (18 m to 30 m) showed a greater incidence of contamination than did drilled wells of the same depth.

Generally, the level of contamination decreased significantly with depth. Shallow wells (dug or bored, or drilled) showed a greater frequency of contamination with coliform (total or faecal) bacteria than did deeper wells, with dug or bored wells less than 60 ft deep having the greatest contamination (Fig. 4). In contrast, the incidence of bacterial contamination in sandpoints increased with the depth of the well. It was noteworthy that about 20% of deep drilled wells were contaminated with either nitrate or bacteria (Fig. 5).

Table 6. *Parameter estimates from logistic regression of incidence of nitrate or bacterial contamination in the summer sampling on well depth, well age, and depth x age interaction, for the three main well types.*

Independent Variable	Type of Well		
	Dug or Bored	Drilled	Sandpoint
Dependent variable = incidence of nitrate contamination			
Intercept	ns[†]	3.5011[***]	2.4219[*]
Depth	0.0307[**]	ns	ns
Age	ns	-0.0421[**]	-0.0987[*]
Depth x Age	ns	0.000337[*]	ns
Dependent variable = incidence of bacterial contamination			
Intercept	-0.7384[*]	1.5573[***]	ns
Depth	0.0292[***]	ns	ns
Age	ns	-0.0215[*]	ns
Depth x Age	-0.00026[*]	0.000164[*]	ns

[†] ns indicates the parameter estimate was not significantly different ($p<0.05$) from 0.
[*] = $p<0.05$, [**] = $p<0.01$, and [***] = $p<0.001$, where p is the probability that the parameter estimate differs from 0 by chance.

Table 7. *Parameter estimates from stepwise logistic regression of incidence of nitrate or bacterial contamination in the summer sampling on depth, age, and type of well.*

Independent Variable	Contaminant	
	Nitrate	Bacteria
Intercept	0.6141***	-1.6826***
Well type	ns†	1.3756***
Well depth	ns	0.0255***
Well age	ns	-0.00671**
Type x depth	0.0111***	-0.0108**
Type x age	ns	ns

* = $p<0.05$, ** = $p<0.01$, and *** = $p<0.001$, where p is the probability that the parameter estimate differs from 0 by chance.
† ns indicates the parameter estimate was not significantly different ($p<0.05$) from 0.
Note: Independent variables included in the model statement were well depth, well age, well type, and interaction terms for type x depth and type x age.

Table 8. *Summary of multiple linear regression forward selection procedure for dependent variables nitrate, total coliform, and atrazine in well water from the summer sampling*

Step	Variable Entered†	Number In	Partial R**2	Model R**2	F	Prob>F
			Dependent variable = $\log_{10}$(nitrate-N + 1)			
1	TxD	1	0.1801	0.1801	241.6635	0.0001
2	WAGE	2	0.0056	0.1857	7.5757	0.0060
3	TxA	3	0.0093	0.1950	12.6619	0.0004
4	WDEPTH	4	0.0127	0.2078	17.6326	0.0001
			Dependent variable = $\log_{10}$(total coliform count + 1)			
1	WTYPE	1	0.1232	0.1232	153.6366	0.0001
2	WDEPTH	2	0.0239	0.1472	30.6474	0.0001
3	TxD	3	0.0089	0.1561	11.4911	0.0007
4	WAGE	4	0.0070	0.1630	9.0603	0.0027
5	TxA	5	0.0029	0.1660	3.8382	0.0504
			Dependent variable = $\log_{10}$(atrazine + d-atrazine + 1)			
1	TxD	1	0.0331	0.0331	36.6163	0.0001
2	WTYPE	2	0.0063	0.0393	6.9841	0.0083
3	WDEPTH	3	0.0024	0.0417	2.6846	0.1016
4	WAGE	4	0.0013	0.0431	1.4853	0.2232
5	TxA	5	0.0033	0.0464	3.6747	0.0555

†Independent variables are: well type (wtype= dug or bored, drilled, sandpoint), depth (wdepth=feet), age (wage=years), and terms for the interaction of well type with depth (TxD) and type with age (TxA).

Table 9. *Summary of multiple linear regression forward selection procedure, by well type, for dependent variables nitrate, total coliforms, and atrazine in well water from the summer sampling.*

Step	Variable Entered	Number In	Partial R**2	Model R**2	F	Prob>F
			Dependent variable = $\log_{10}$(nitrate-N + 1)			
			Well type = dug or bored			
1	WDEPTH	1	0.0934	0.0934	39.4473	0.0001
2	WAGE	2	0.0133	0.1066	5.6687	0.0178
			Well type = drilled			
1	WDEPTH	1	0.0475	0.0475	32.2375	0.0001
			Well type = sandpoint			
1	WDEPTH	1	0.1342	0.1342	10.2282	0.0021
2	WAGE	2	0.0124	0.1466	0.9450	0.3346
			Dependent variable = $\log_{10}$(total coliform count + 1)			
			Well type = dug or bored			
1	WDEPTH	1	0.0521	0.0521	20.8416	0.0001
2	WAGE	2	0.0212	0.0733	8.6415	0.0035
			Well type = drilled			
1	WDEPTH	1	0.0104	0.0104	6.7667	0.0095
2	WAGE	2	0.0008	0.0111	0.4966	0.4812
			Well type = sandpoint			
1	WDEPTH	1	0.0170	0.0170	1.1222	0.2934
			Dependent variable = $\log_{10}$(atrazine + d-atrazine + 1)			
			Well type = dug or bored			
1	WDEPTH	1	0.0099	0.0099	3.7452	0.0537
2	WAGE	2	0.0040	0.0139	1.5132	0.2194
			Well type = drilled			
1	WDEPTH	1	0.0118	0.0118	7.4819	0.0064
			Well type = sandpoint			
No variable met the 0.5000 significance level for entry into the model.						

[†]Independent variables are: well depth (wdepth=feet), and well age (wage=years).

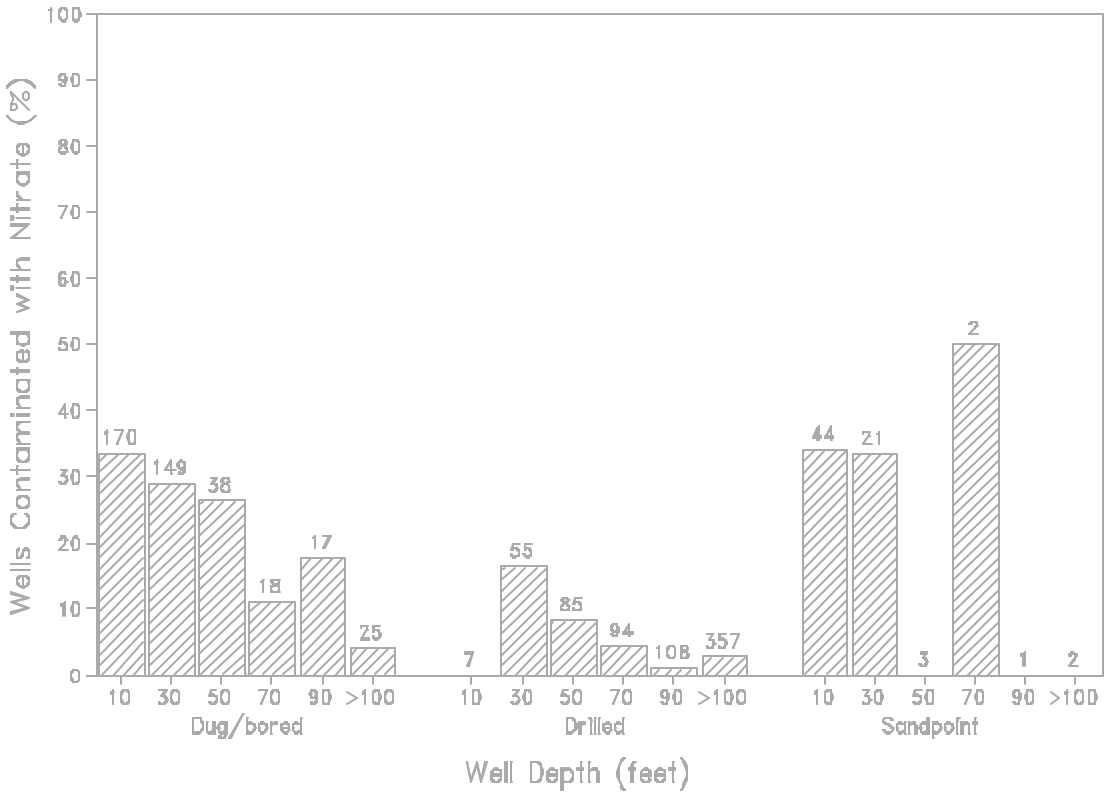


Fig. 3. *Frequency distribution showing, for each well depth increment, the proportion of wells of each construction type that were contaminated with nitrate. The number at the head of each column indicates the total number of wells in that category.*

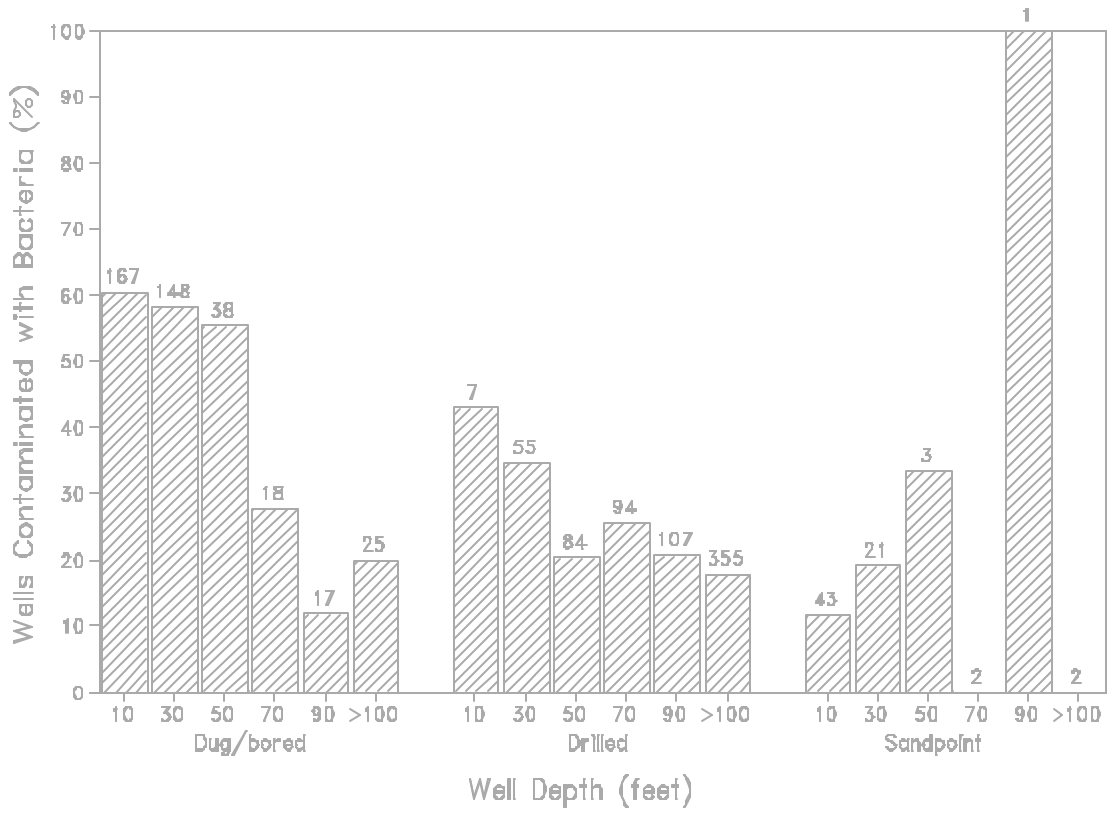


Fig. 4. *Frequency distribution showing, for each well depth increment, the proportion of wells of each construction type that were contaminated with coliform bacteria. The number at the head of each column indicates the total number of wells in that category.*

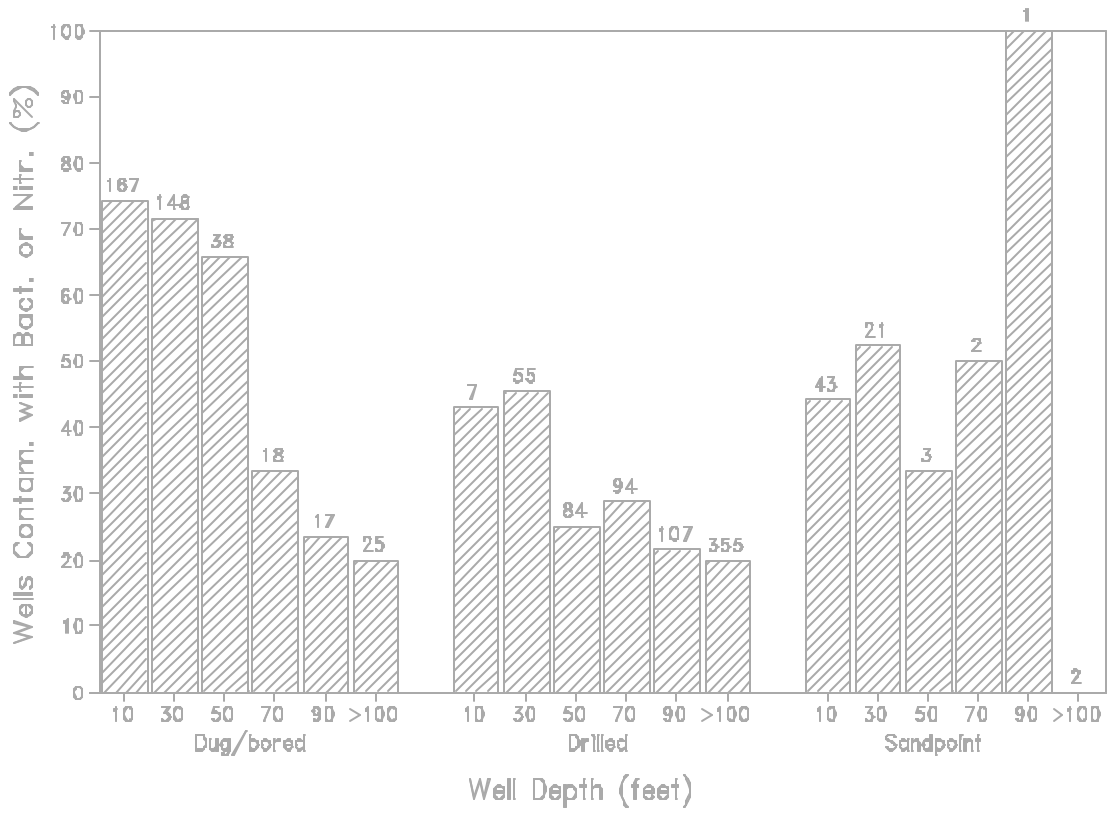


Fig. 5. *Frequency distribution showing for each well depth increment the proportion of wells of each construction type that were contaminated (bacteria or nitrate). The number at the head of each column indicates the total number of wells in that category.*

5.3.3.2 Influence of Soil Type

Wells were located on a total of 154 different soil series identified by OMAF. A complete list of the soil series is given in Appendix E.1. Table 10 lists those soil series on which at least 10 wells were located, and gives the percentage of the wells for each series that were contaminated with nitrate and bacteria. Soil series that had coarser textured topsoils (gravelly soils , sands, loams) tended to have a greater frequency of nitrate contamination than did those with finer textured topsoils (silty loams, clay loams).

The percentage of wells contaminated with coliform bacteria in most soil series encountered was greater than that for nitrate (Table 10). Loamy soils generally showed the greatest contamination with bacteria. In contrast with the results for nitrate, bacterial contamination tended to be less under coarse textured soils compared to finer textured soils.

The Soil Conservation Service of USDA has described four hydrologic soil groups, based on the infiltration and groundwater transmission rates (Appendix E.3). As part of the study associated with the first sampling programme, the GIS/Data Management Unit of the Resources Management Branch, OMAF classified each well location in Southern Ontario into one of these hydrologic soil groups.

The general characteristics of the four hydrologic soil groups are as follows:

- Group A - high infiltration capacity, highly permeable (sand and gravel)
- Group B - moderate infiltration capacity, medium permeability (sandy loam)
- Group C - low infiltration capacity, low permeability (silt and silty loam)
- Group D - very low infiltration capacity, low permeability (clay)

In the permeable soils of Group A, about 27% of the wells were contaminated with nitrate (Fig. 6). This percentage decreased steadily to around 7% in Group D. On the other hand, bacterial contamination was least in the most permeable soils, but the moderately permeable soils showed the highest occurrence of contamination, about 35%. Even the less permeable soils showed fairly high occurrences of bacterial contamination, around 32%.

Table 10. *Number of wells in which nitrate or bacteria exceeded Ontario drinking water objectives, for soil series in which at least ten water wells were located.*

Soil Series	Texture[†]	Wells Tested	Exceeds Objectives	
			Nitrate	Bacteria[‡]
		no.	%	%
Watrin	S	10	40.0±31.0[§]	20.0±25.3
Brady	S,SL	11	27.3±26.9	9.1±17.3
Berrien	SL,S	52	21.2±11.3	28.8±12.6
Plainfield	S	16	25.0±21.7	25.0±21.7
Fox	SL,LS	40	39.0±15.2	15.0±11.3
Dundonald	SL	10	10.0±19.0	40.0±31.0
Bondhead	SL,L	54	20.4±11.0	38.9±13.3
Wendigo	SL	10	10.0±19.0	10.0±19.0
Donnybrook	SL	10	0.0±0.0	10.0±19.0
Dumfries	L	10	20.0±25.3	20.0±25.3
Guelph	L	25	24.0±17.1	12.0±13.0
Otonabee	L	38	25.6±14.0	42.1±16.0
Burford	L	14	28.6±24.1	28.6±24.1
Harriston	L,ZL	67	7.5±6.4	29.9±11.2
Osprey	L	12	0.0±0.0	33.3±27.2
Grenville	L	17	11.8±15.6	47.1±24.2
Harkaway	ZL,L	10	20.0±25.3	30.0±29.0
Perth	CL,C,ZL	69	8.7±6.8	31.9±11.2
Listowel	ZL,L	14	0.0±0.0	14.3±18.7
Huron	CL	77	7.8±6.1	35.1±10.9
Brookston	C,CL,SL,ZL	110	4.5±3.9	31.8±8.9
North Gower	CL	21	0.0±0.0	38.1±21.2
Napanee	C	12	23.1±23.4	25.0±25.0
Haldimand	C,CL	20	5.0±9.7	35.0±21.3
Bearbrook	C	20	0.0±0.0	25.0±19.4

[†] C=clay, L=loam(y), S=sand(y), Z=silt

[‡]Objectives were total coliform #10, faecal coliform or *e. coli* = 0 colonies $(100\ mL)^{-1}$

[§] ±95% confidence interval

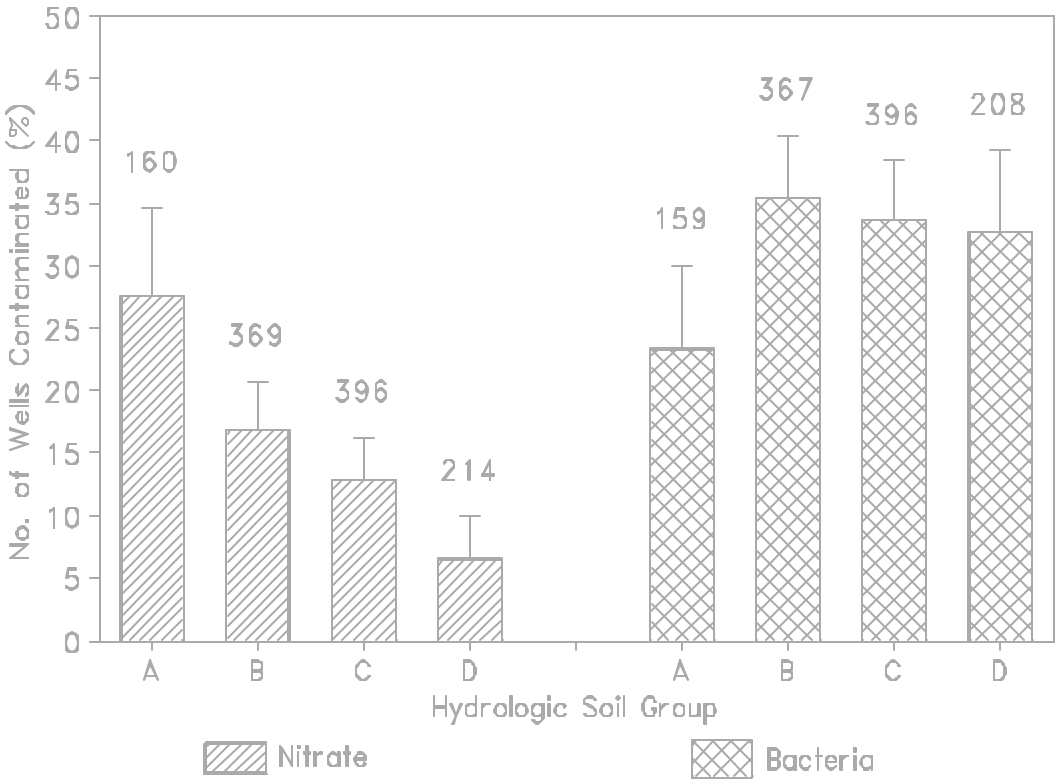


Fig. 6. *Frequency distribution showing the percentage of wells from soils of different hydrologic groupings contaminated with nitrate and with coliform bacteria. The number at the head of each column indicates the total number of wells for which results were obtained in that hydrologic class. The error bars indicate the upper bound of the 95% confidence interval.*

5.3.3.3 Influence of Agricultural Land-Use

The first sampling programme indicated that the occurrence of contaminant species in farm wells was related to different agricultural land-use practices. One of the main objectives of the summer survey was to verify these relationships. The `Agricultural Resource Inventory (ARI) - land-use system' devised by the Ontario Ministry of Agriculture and Food was used to define the land-use class for each farm. Additional information was obtained during the summer sampling programme to improve the classification of land-use of the farms. The OMAF agricultural land-use classification is given in Appendix E.2. The majority of the wells fell into a subset of 15 different land-uses.

Mixed contamination:

The occurrence of mixed contamination (nitrate and/or bacteria) in each of the different land-use practices encountered during the survey is shown in Fig. 7. No significant differences in contamination were found between the various agricultural land-use systems (Fig. 7).

Nitrate contamination:

When nitrate contamination was considered separately, no land-use class showed significantly more contamination than any other (Fig. 8). However, the average level of contamination was greatest in some of the minor land-use systems such as orchards and tobacco. Unlike the results for the first sampling programme, corn systems (rotations in which corn and/or soybeans occupy more than 30% but less than 90% of the land area) did not show greater frequency of nitrate contamination.

The average percentage of farm wells that were contaminated with nitrate was about one-third less on farms where manure was spread than where it was not, and this difference was statistically significant at $p < 0.01$ (Table 11).

A further approach was made to identify the impact that livestock operations might have on well water quality. The percentage of wells contaminated with nitrate was investigated as a function of distance from a feedlot (Fig. 9). No significant correlations were identified.

Coliform bacterial contamination:

When bacterial contamination was considered separately, no land-use class showed significantly more contamination than any other (Fig. 10).

The percentage of farm wells that were contaminated with bacteria was generally greater for the group where manure was spread compared to where it was not, but only the difference in total bacteria (ie wells contaminated with total or faecal coliforms) was statistically significant (Table 11). This contrasts with the results for nitrate. A possible explanation for the difference is indicated in Fig. 11, which shows the percentage of wells contaminated with bacteria and those contaminated with nitrate for different hydrologic soil groups according to whether or not manure was spread on the land. The increase in bacterial contamination for farms where manure was spread compared to those where it was not spread was greatest with hydrologic soil groups A and B and least or nonexistent for groups C and D. It appeared that as soil permeability decreased, the apparent effect of manure spreading on bacterial contamination also decreased. Only the low permeabilty soils (hydrologic groups B and C) however, showed the decrease in nitrate contamination where manure was spread (Fig. 11). Nitrate contamination was not affected by manure spreading on soils of hydrologic groups A and B, the high and medium permeability soils (Fig. 11). Perhaps the additional organic carbon input from manure spreading promoted denitrification on the low permeability soils compared to the medium and high permeability soils, resulting in less nitrate contamination.

The impact that livestock operations might have on the contamination of well water with bacteria was also investigated by analyzing the level of contamination as a function of well-distance from feedlots. There was a significant decrease in contamination by coliform bacteria with increasing separation of the well from a feedlot (Fig. 12). This decrease in percent contamination was three times greater than the difference in contamination between farms where no manure was spread and farms where it was spread. Livestock systems therefore appeared to contribute most to well water contamination by bacteria when animals were held in feedlots less than 300 ft from the well head, rather than if manure was spread on the farm.

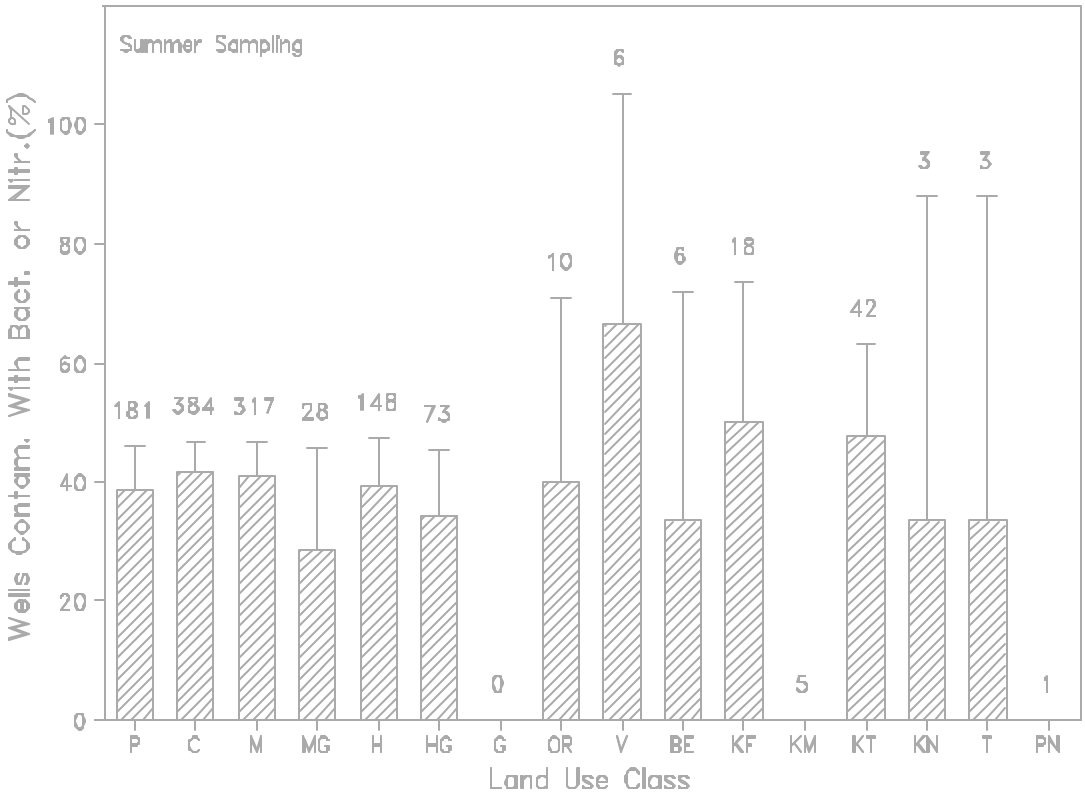


Fig. 7. *Frequency distribution showing the number of wells contaminated with bacteria or nitrate as a percentage of wells located on farms with the given land-use system. The number at the head of each column indicates the total number of wells in that land-use system. The error bars indicate the upper bound of the 95% confidence interval.*

P- Continuous row crops (corn,bean rotation)
C-Corn (corn, beans, grain, (hay))
M-Mixed (grain, corn, soybeans, hay)
MG-Grain (sod and grain, no row crops)
H-Hay (good quality hay production)
HG-Pasture (extensive or unconfined grazing)
G-Grazing (rough grazing)

OR-Orchard (hardy fruits)
V-Vineyard (grapes)
BE-Berries (soft fruit)
KF- Extensive Field Vegetables
KM- Market Gardens
KT-Tobacco
KN-Nursery (trees, shrubs)
T-Sod
PN-Peanut

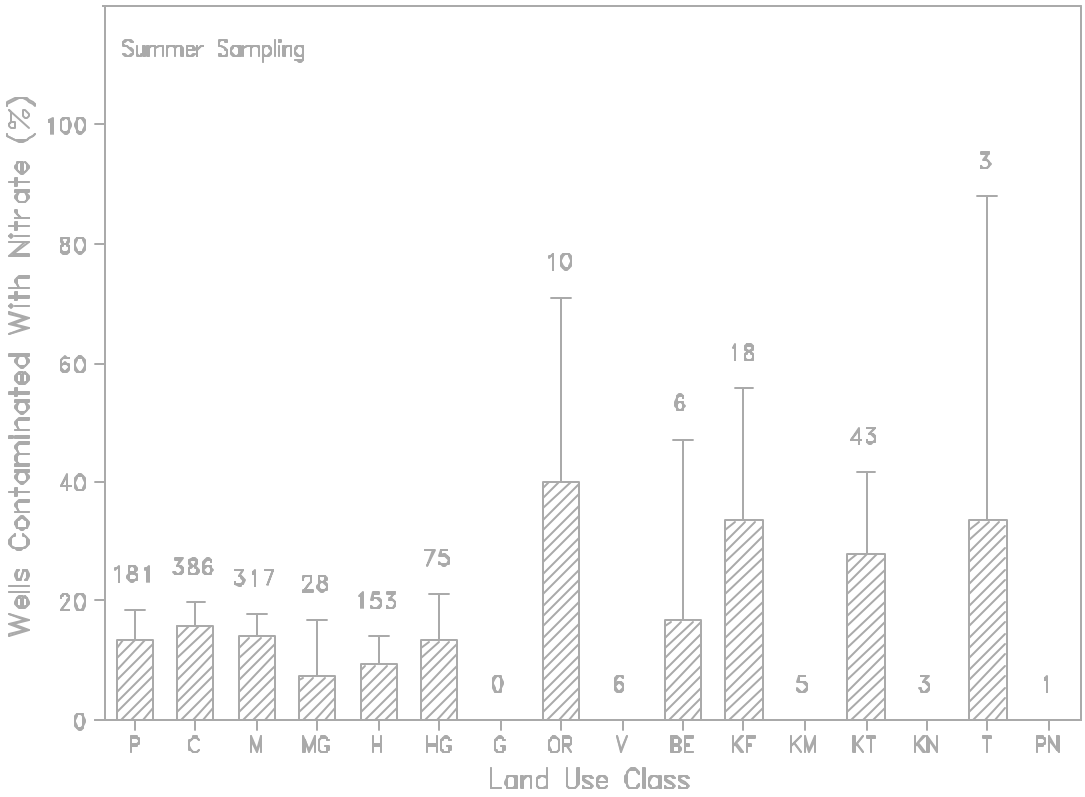


Fig. 8. *Frequency distribution showing the number of wells contaminated with nitrate as a percentage of wells located on farms with the given land-use system. The number at the head of each column indicates the total number of wells in that land-use system. The error bars indicate the upper bound of the 95% confidence interval.*

P- Continuous row crops (corn,bean rotation)
C-Corn (corn, beans, grain, (hay))
M-Mixed (grain, corn, soybeans, hay)
MG-Grain (sod and grain, no row crops)
H-Hay (good quality hay production)
HG-Pasture (extensive or unconfined grazing)
G-Grazing (rough grazing)
OR-Orchard (hardy fruits)
V-Vineyard (grapes)
BE-Berries (soft fruit)
KF- Extensive Field Vegetables
KM- Market Gardens
KT-Tobacco
KN-Nursery (trees, shrubs)
T-Sod
PN-Peanut

Table 11. *Contamination of well water on farms where manure is spread compared to farms where manure is not spread.*

Contaminant	Spread		Not Spread	
	Tested	High	Tested	High
	no.	%	no.	%
Bacteria				
Total coliform >10	901	28.2±3.0[†]	326	23.9±4.7
Total coliform >5	901	33.4±3.1	326	28.8±5.0
Faecal coliform >0	336	28.3±4.9	277	22.0±5.0
E. coli >0	739	20.6±3.0	73	17.8±9.0
F. strep >0	752	27.0±3.2	74	28.4±10.5
Enterococci >0	102	45.1±9.9	11	36.4±29.0
F.strep or entero >10	752	17.7±2.8	74	20.3±9.3
Total >10 or faecal >0	335	37.3±5.3	276	29.0±5.5[*]
Total >10 or (faecal or *E. coli*) >0	901	33.3±3.1	326	29.4±5.0
Nitrate >10	906	12.8±2.2	331	19.0±4.3[**]
Mixed contamination				
Bacteria[‡] or nitrate	901	39.6±3.3	326	41.7±5.5
Bacteria & nitrate	901	6.4±1.6	326	6.7±2.8
Pesticide detects	880	11.6±2.2	324	11.4±3.5

[†] ±95% confidence interval.
[‡] Bacteria include total coliforms, and faecal coliforms or *E. coli*.
[*] Percentages different at p = 0.03
[**] Percentages different at p = 0.007

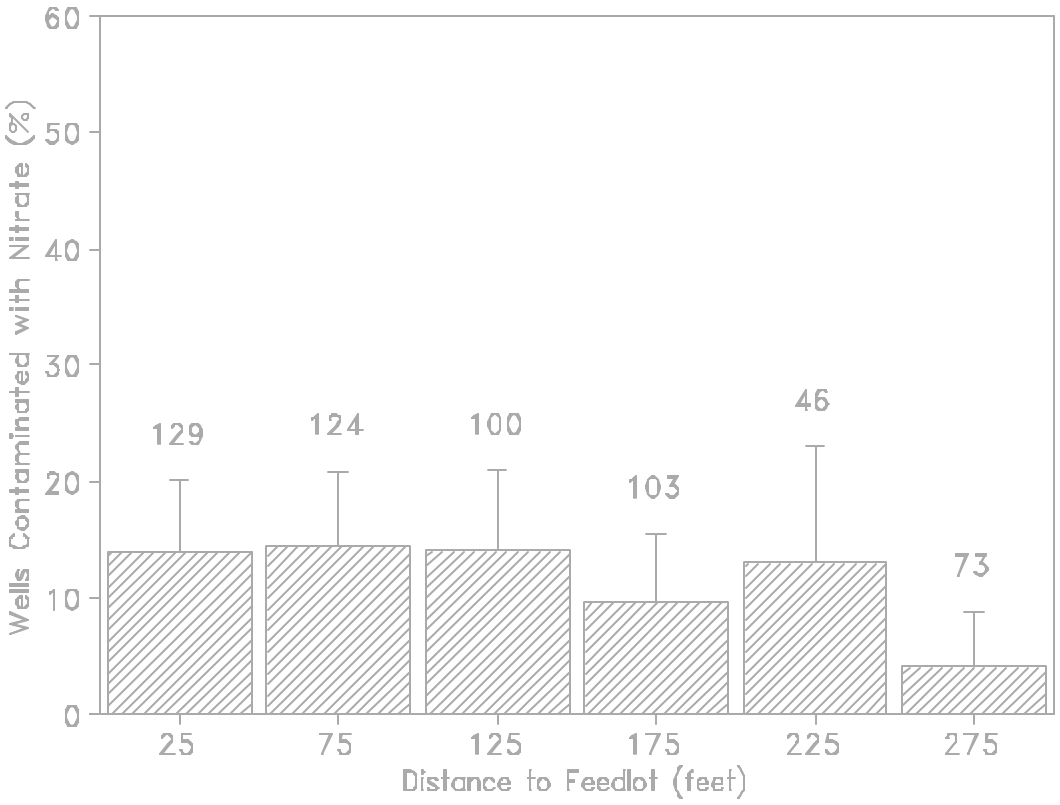


Fig. 9. *Frequency distribution showing the variation with distance from a feedlot of the percentage of wells contaminated with nitrate. The number at the head of each column indicates the total number of wells for which results were obtained at that distance from a feedlot. The error bars indicate the upper bound of the 95% confidence interval.*

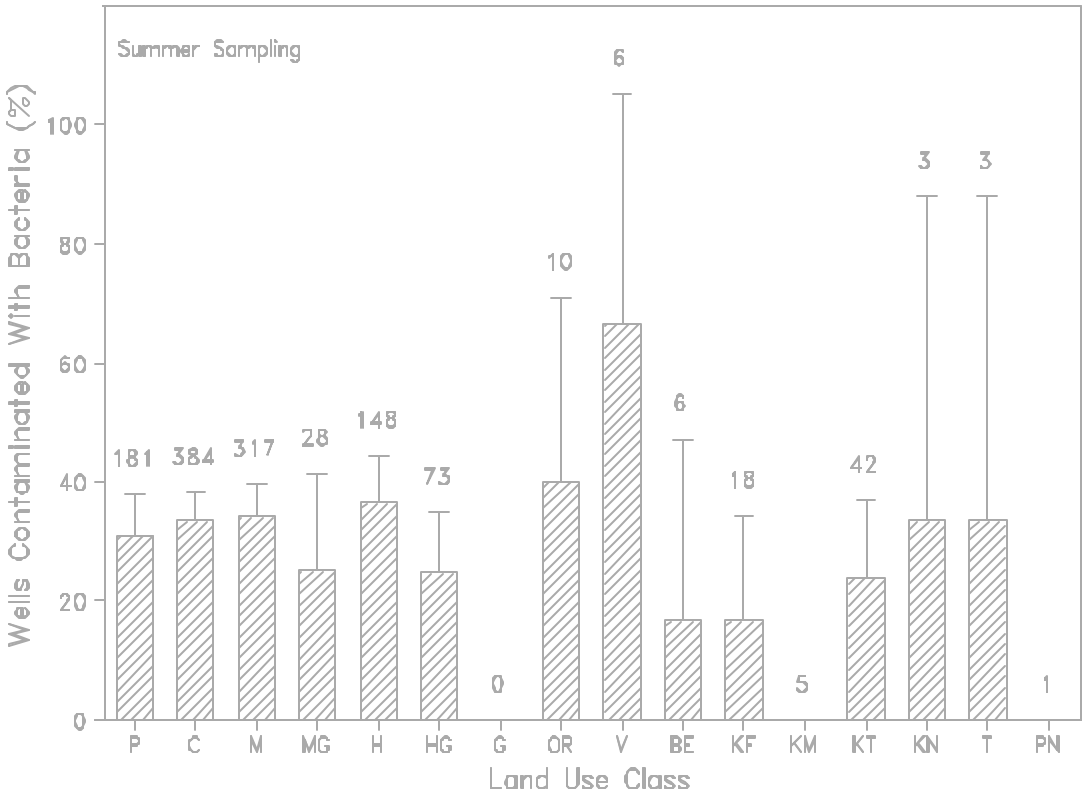


Fig. 10. *Frequency distribution showing the number of wells contaminated with bacteria as a percentage of wells located on farms with the given land-use system. The number at the head of each column indicates the total number of wells in that land-use system. The error bars indicate the upper bound of the 95% confidence interval.*

P- Continuous row crops (corn,bean rotation)
C-Corn (corn, beans, grain, (hay))
M-Mixed (grain, corn, soybeans, hay)
MG-Grain (sod and grain, no row crops)
H-Hay (good quality hay production)
HG-Pasture (extensive or unconfined grazing)
G-Grazing (rough grazing)

OR-Orchard (hardy fruits)
V-Vineyard (grapes)
BE-Berries (soft fruit)
KF- Extensive Field Vegetables
KM- Market Gardens
KT-Tobacco
KN-Nursery (trees, shrubs)
T-Sod
PN-Peanut

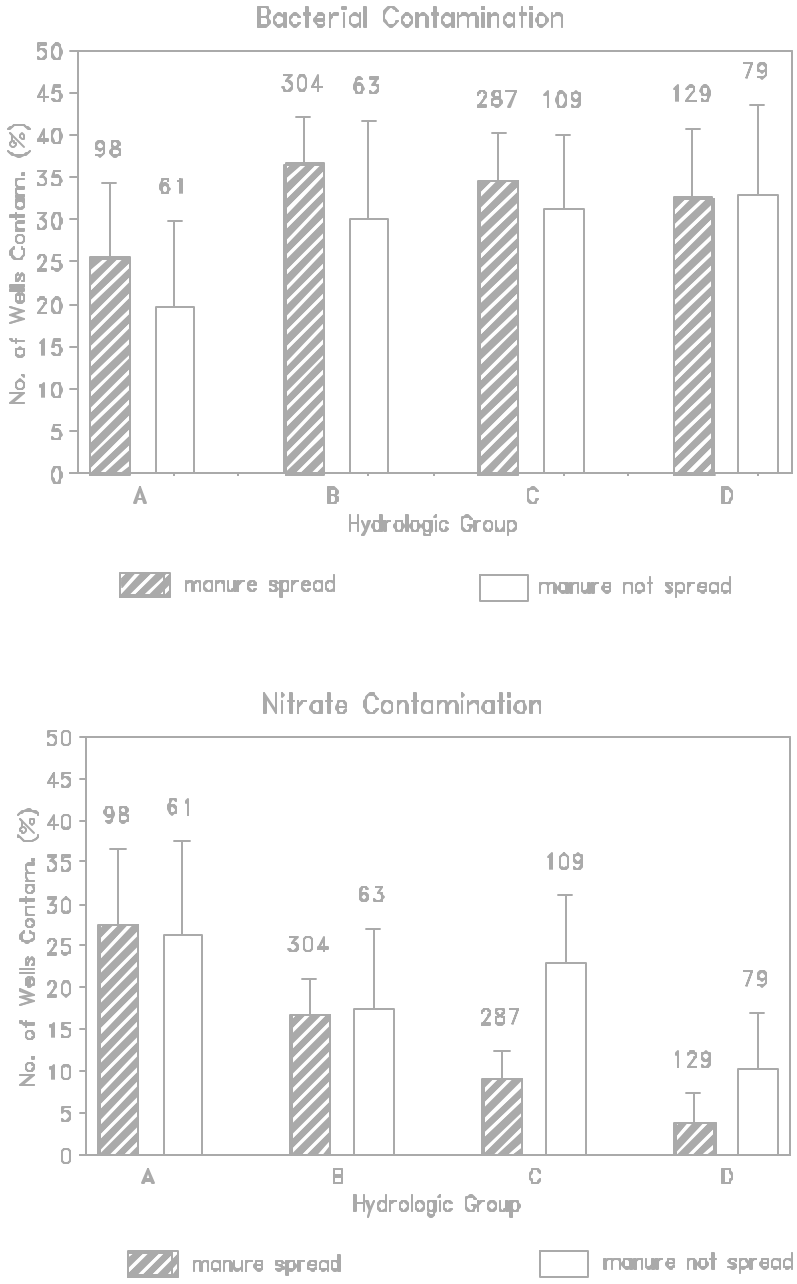


Fig. 11. *Incidence of bacterial (total coliforms, faecal coliforms, or e. coli) and nitrate contamination of well water for different soil hydrologic groups, on farms where manure is spread compared to farms where manure is not spread.* *Data include 818 farms where manure was spread and 312 farms where manure was not spread. Error bars indicate the upper bound of the 95% confidence interval. Numbers at the top of each column are the total number of farms in a hydrologic group where manure was spread or not spread.*

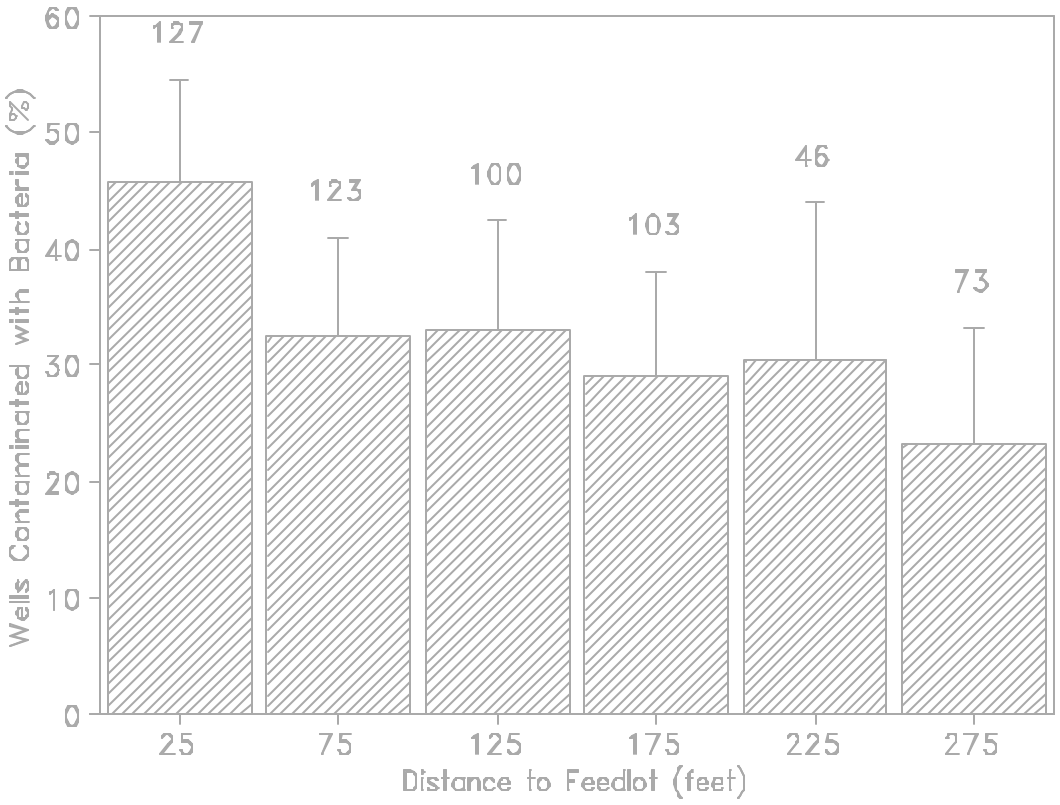


Fig. 12. *Frequency distribution showing the variation with distance from a feedlot of the percentage of wells contaminated with coliform bacteria. The number at the head of each column indicates the total number of wells for which results were obtained at that distance from a feedlot. The error bars indicate the upper bound of the 95% confidence interval.*

5.3.3.4 Influence of Sewage Disposal Systems

Septic or sewage disposal systems were the major point sources common to most farms. As in the first sampling programme no influence of the distance between wellheads and the weeping bed of the septic system on the frequency of contamination with nitrate or bacteria was detected. However, the level of bacterial contamination in wells within 300 ft of a septic tank increased with increasing distance from the tank (Fig. 13). This observation is a somewhat unexpected result and requires additional investigation to evaluate processes that may account for it.

Sewage sludge was used by 27 farmers co-operating in the sampling programme. Nitrate contamination of the well water was found in 19%(±15.4) of their wells, and 31% (±18.2%) of their wells were contaminated with bacteria. However, these values were not significantly different from the average values found in the whole survey (Table 4).

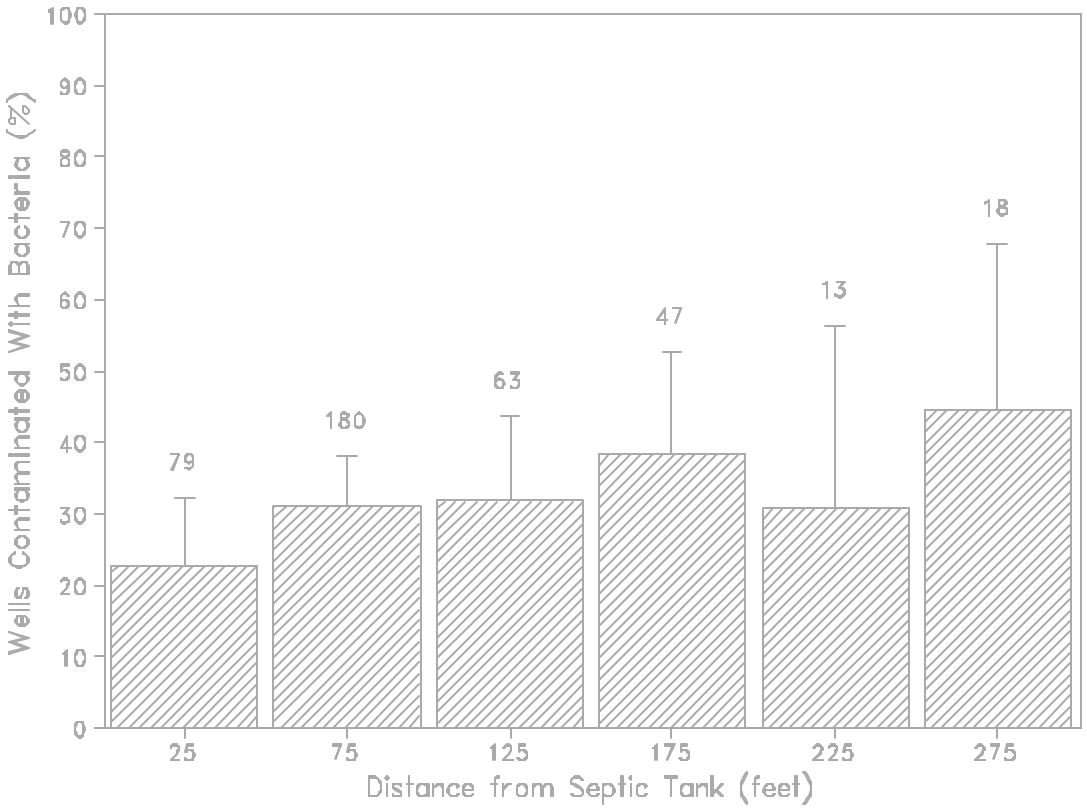


Fig. 13. *Frequency distribution showing the variation in bacterial contamination of water wells with distance from a septic tank, where the separation between the two was up to 300 feet and no feedlot was present. The error bars indicate the upper bound of the 95% confidence interval, and the numbers at the top of the bars indicate the total number of wells in that depth category.*

5.3.4 Pesticides

Detectable levels of pesticides were found in 139 of 1204 wells. This represents 11.5% (±1.8%) of wells (Table 12). The distribution of these detections of pesticide residues in Southern Ontario are shown in Maps 10 and 11. Two wells exceeded the IMAC values, one for alachlor and one for metolachlor. Most wells with detectable pesticide residues had atrazine or its metabolite, d-ethyl atrazine, as a contaminant. Atrazine or d-ethyl atrazine was found in 11.3% (±1.8 %) of wells. The IMAC for total atrazine (atrazine + metabolites) is 60 µg L^{-1} in Ontario. The comparable value for the maximum permissible concentration in drinking water in the U.S. is 3 µg L^{-1}. If the U.S. standard was used, 1% of the wells would not be acceptable.

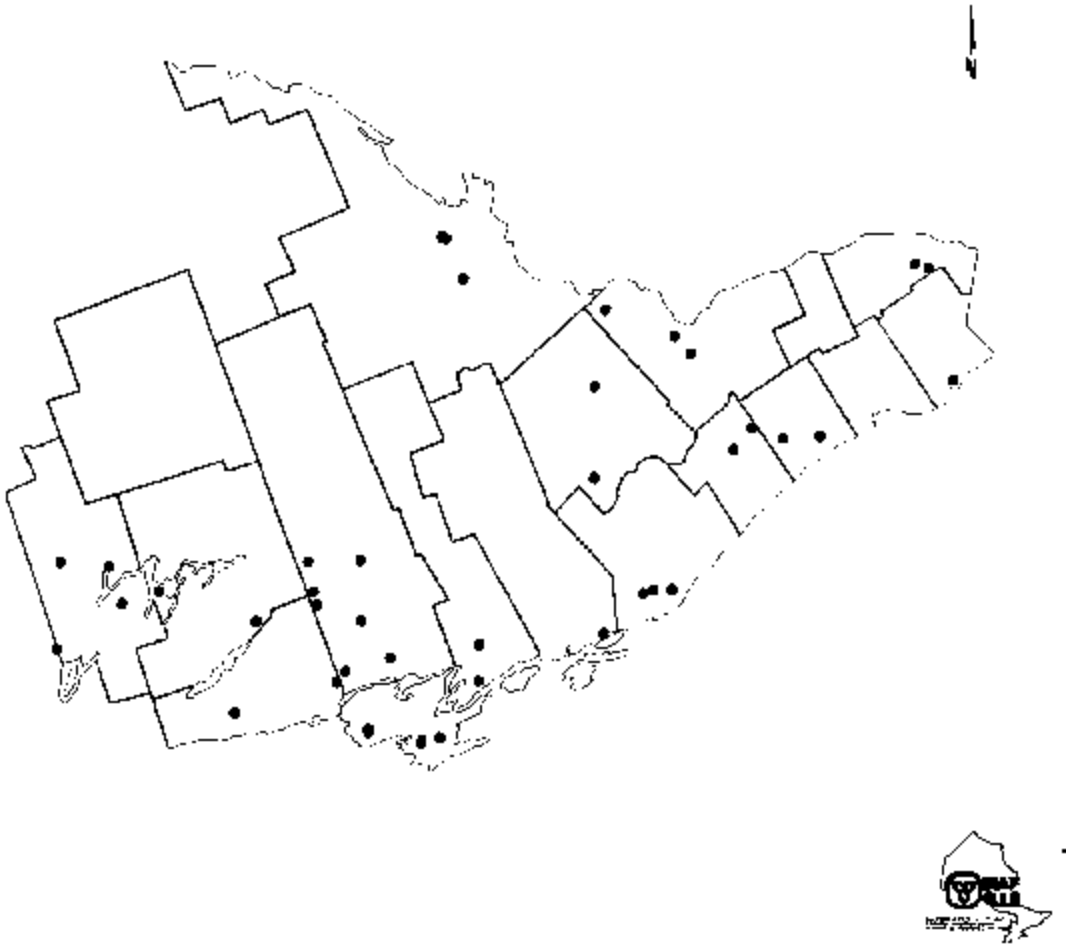
The frequency of detectable levels of pesticides was generally greatest in those wells less than 40 ft deep. Detections of pesticide residues were generally more frequent in dug or bored wells than drilled or sandpoint wells (Fig. 14). Nonetheless, there was a significant number of detections in drilled wells more than 100 ft deep.

The occurrence of detectable levels of pesticides in well water was much more likely when nitrate concentration exceeded the acceptable level. Frequency of occurrence of detectable levels of pesticides in well water was 8.6% (±1.8%) when nitrate-N concentration was less than 10.0 mg L^{-1}, and 29.1% (±6.9%) when nitrate-N concentration was greater than 10.0 mg L^{-1}.

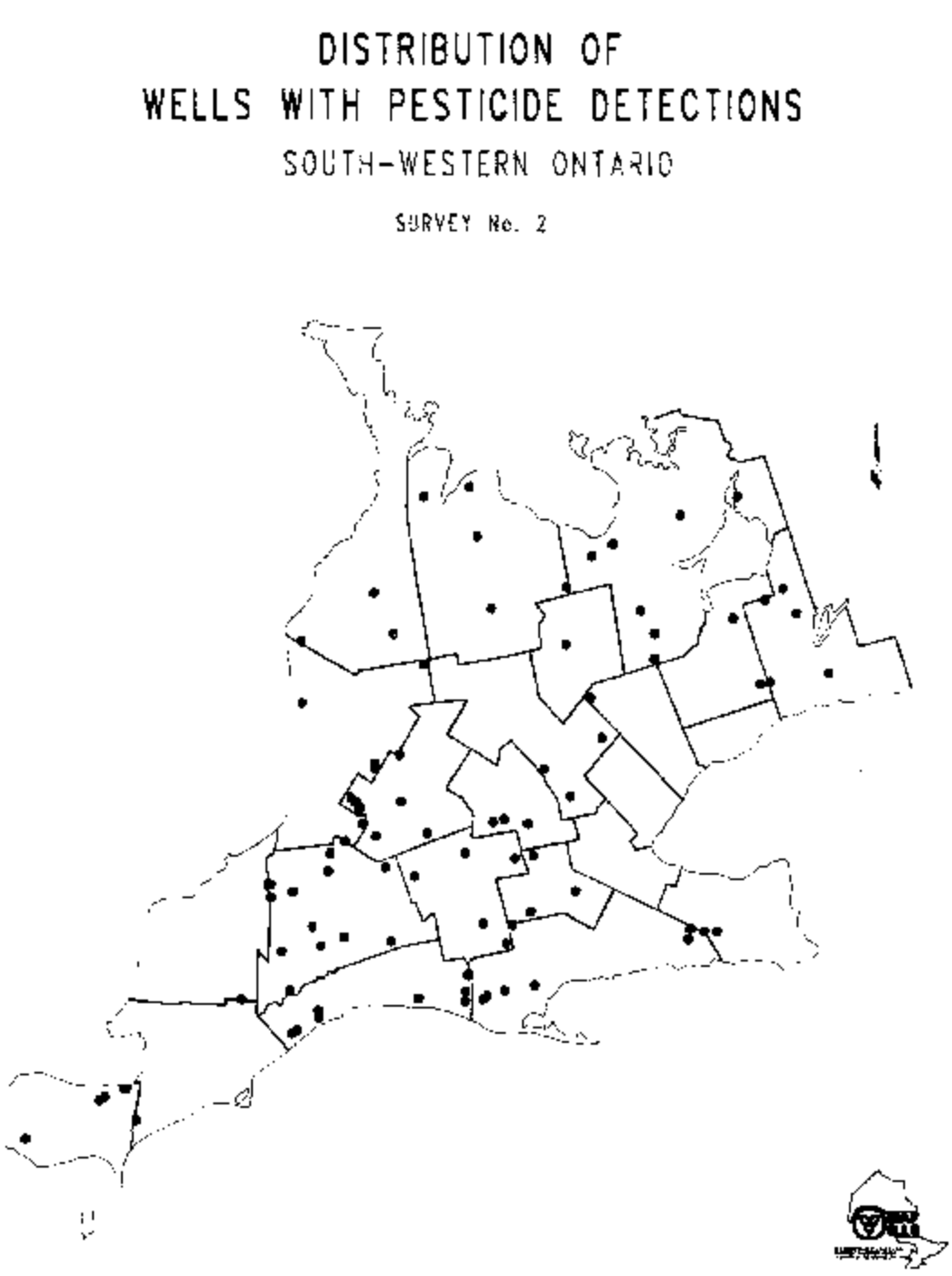
Table 12. *Results of pesticide residue analyses for wells with detectable levels of pesticides in the summer sampling.*

Wells With Detected Residues	ALA[†]	METOL	ATR	DATR	SEN	CNZ
Frequency (no. of wells)	1	9	126	76	3	3
Frequency (% of all wells)	0.08	0.75	10.47	6.31	0.25	0.25
Maximum concentration (µg L^{-1})	15	93	18	8.2	0.69	3.6
Mean concentration (µg L^{-1})	15.0	17.3	0.69	0.98	0.61	1.68
Median concentration (µg L^{-1})	NA	1.7	0.3	0.72	0.63	1.2
Minimum detection limit (µg L^{-1})	0.2	0.2	0.05	0.1	0.05	0.2

[†] ALA=alachlor, METOL=metolachlor, ATR=atrazine, DATR=D-ethyl atrazine (atrazine metabolite), SEN=metribuzin, CNZ=cyanazine.
Note: One or more of the pesticide residues were detected in 139 of 1204 wells.



Map 10. *Distribution of wells containing detectable concentrations of pesticide residues - South-eastern Ontario.*



Map 11. *Distribution of wells containing detectable concentrations of pesticide residues - South-western Ontario.*

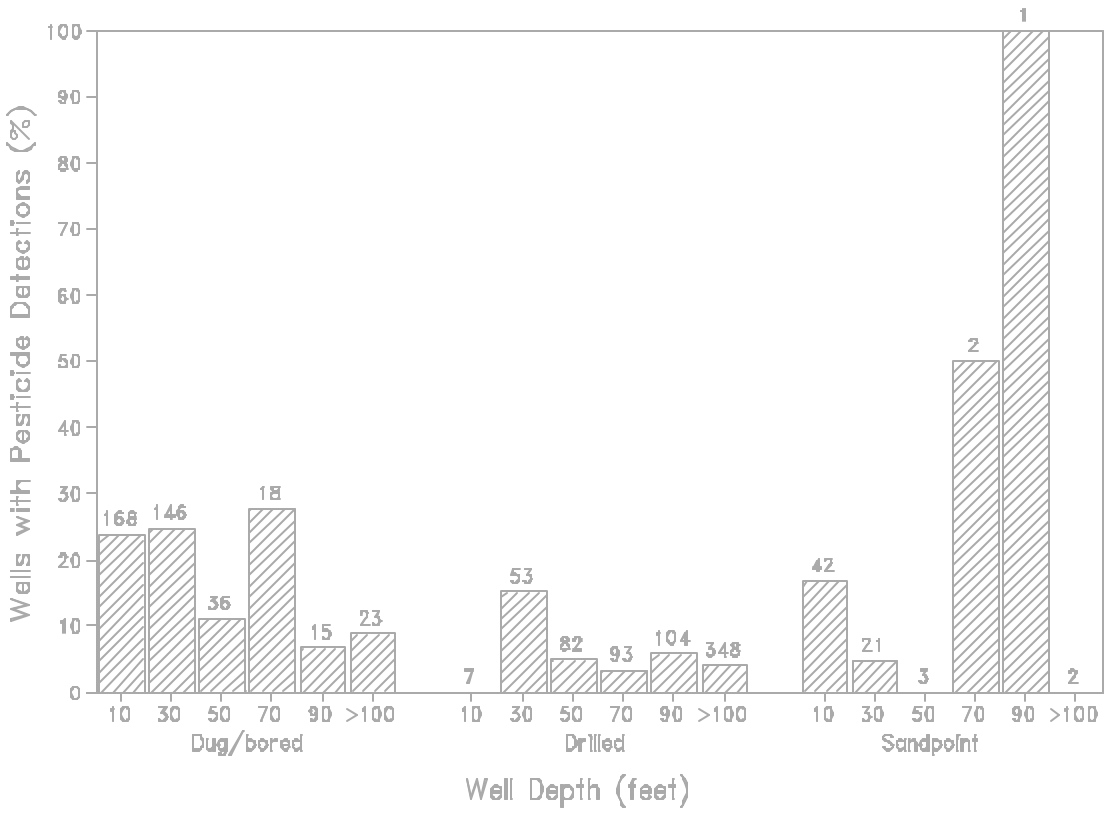


Fig. 14. *Frequency distribution showing for each well depth increment and construction type, the proportion of wells that had detected pesticide residues. The number at the head of each column indicates the total number of wells in that category.*

5.3.5 Comparison of Results from the Summer Sampling with those from the Previous Winter

5.3.5.1 General Distribution of Contaminants

The samples analyzed in this study were all retests of the same wells sampled in winter 1991-92. A direct comparison of the results for the two samples can give information about possible temporal changes, both seasonal and longer-term. Many comparisons of contaminant distribution showed a very similar incidence in the two programmes (Table 13). However, the incidences of contamination with faecal bacteria (faecal coliforms, *E. coli*, faecal streptococci and enterococcus spp were all greater in the summer. In consequence, the total contamination due to bacteria or nitrate was greater in the summer by 4%. The general level of contamination with total coliform bacteria was similar between northern and southern Ontario in the summer. However, there was less contamination with coliform bacteria reported for the north than for the south in the winter sampling. One possible explanation for the difference over winter could be a significant temperature effect, with colder temperatures in Northern Ontario reducing the survival of some groups of bacteria, compared with conditions in Southern Ontario.

The frequency of well contamination due to nitrate alone was not statistically significantly greater in the summer. The maximum concentration observed during the summer sampling, however, was 92 mg L^{-1}, compared with 40.1 mg L^{-1} in the winter programme. Furthermore, the average concentration of nitrate in the wells increased by an average of 7% from 1.4 mg L^{-1} to 1.5 mg L^{-1} between the winter and summer sampling programmes (Fig. 15). Additional analysis showed that there was on average, no significant change between winter and summer samplings in the nitrate concentration of wells that exceeded the drinking water objective concentration at the winter sampling. The mean increase in nitrate-N concentration in wells that were not contaminated in the winter sampling was 0.6 mg L^{-1}. There was a strong correlation between the nitrate concentrations measured at the two times, but the bacteria concentrations found in the summer were not correlated with the concentrations measured in the winter. In other words, the set of bacteria-contaminated wells differed beween the winter and summer samplings, even though the total percentage of bacterial-contaminated wells were similar for the two samplings. These results confirm the view that bacterial contamination is subject to considerable seasonal variability, whereas nitrate contamination is more consistent.

The distribution of nitrate contamination for both the winter and summer sampling programmes is shown in Maps 12-14. The results for the south-eastern and south-western regions of Southern Ontario are superimposed on a base map prepared by the Ministry of the Environment and Energy, Water Resources Branch (1980). This map, based on hydrogeological data, shows the susceptibility of groundwater to contamination. The legend for the map is given in Fig. 16. A comparable base map was not available for Northern Ontario. Current contamination of farm wells appears to be closely related to sand plains and other permeable deposits that are classified as high risk. However, some contamination was also found in areas classified as low risk, and this suggests that the soil variability in some areas requires more precise assessments if susceptibility assessments are to be made more accurate. It may also imply that factors other than soil characteristics are influencing the level of contamination.

The general distribution of wells contaminated with bacteria in the two sampling programmes are shown in Maps 15-17 for the whole of Ontario. The distribution was much more uniform than the pattern seen for nitrate contamination.

The general distribution of wells where pesticides were detected in either sampling programme appeared to be closely similar to the distribution of nitrate contamination (Maps 18 and 19). Contamination with pesticides was similar in both sampling programmes (Table 13). However, the incidence of detections of atrazine and its breakdown product, d-ethyl atrazine, were significantly greater in the summer than in the previous winter (Table 14). The mean concentration of pesticides in wells where their presence was detected showed some differences in the summer samples compared with the previous winter. The mean concentration of atrazine was slightly smaller in the summer, whereas that of the metabolite d-ethyl atrazine almost doubled. Mean concentrations of metribuzin and cyanazine were both much smaller in the summer than in the winter. In both sampling programmes, frequency of pesticide detections was about 20% greater when nitrate-N concentration was more than 10.0 mg L^{-1}.

Table 13. *Comparison of the distribution of bacterial and nitrate contamination in those Ontario farm wells sampled in both winter and summer programmes.*

Contaminant	Wells Tested	Exceeds Objectives	
		Winter	Summer
	no.	%	%
Bacteria			
Total coliform >10	1219	25.0±2.5†	27.2±2.5
Total coliform >5	1219	30.3±2.6	32.2±2.7
Faecal coliform >0	605	20.2±3.3	25.6±3.5*
E. coli >0	271	17.0±4.6	24.7±5.2*
F. strep >0	340	11.5±3.5	24.1±4.6***
Enterococci >0	69	15.9±8.8	46.4±12.0***
F.strep or entero >10	416	5.8±2.3	16.6±3.6***
Total >10 or faecal >0	602	29.2±3.7	33.9±3.9
Total >10 or faecal or *E. coli* >0	1217	30.1±2.6	32.5±2.7
Nitrate >10	1229	12.9±1.9	14.4±2.0
Bacteria‡ or nitrate	1213	36.4±2.8	40.4±2.8*
Bacteria & nitrate	1213	6.7±1.4	6.6±1.4
Pesticides (common name and trade name)			
Alachlor (Lasso)	1192	0	0.08±0.2
Metolachlor (Dual)	1192	0.08±0.2	0.08±0.2
Atrazine (Aatrex)	1192	0	0
d-ethyl atrazine	1192	0	0
Metribuzin (Sencor)	1192	0	0
Cyanazine (Bladex)	1192	0	0

† ±95% confidence interval.
‡ Bacteria include total coliforms, and faecal coliforms or *E. coli*.
* Difference between the results for the two sampling programmes significant at $p<0.05$
*** Difference between the results for the two sampling programmes significant at $p<0.001$

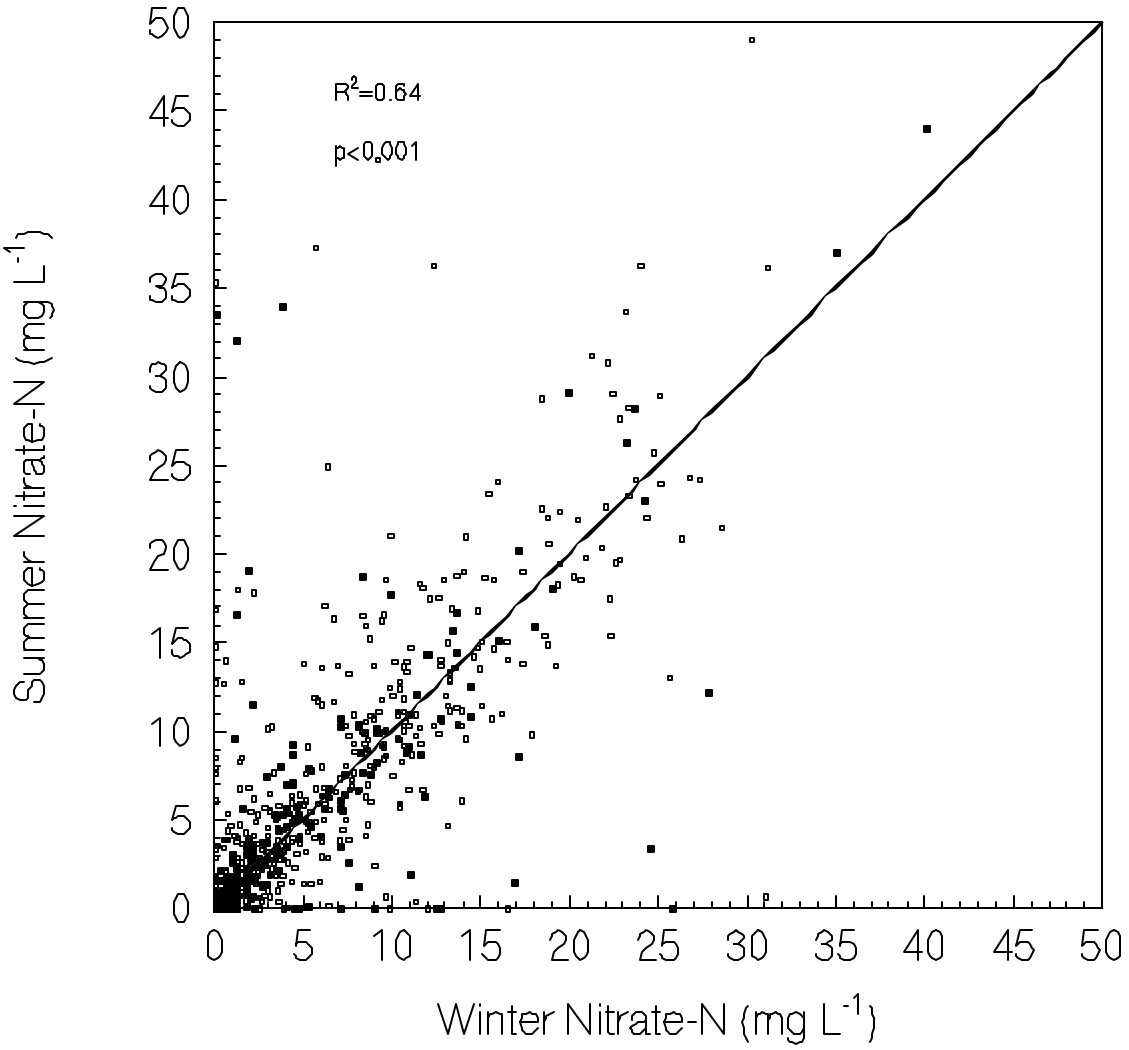
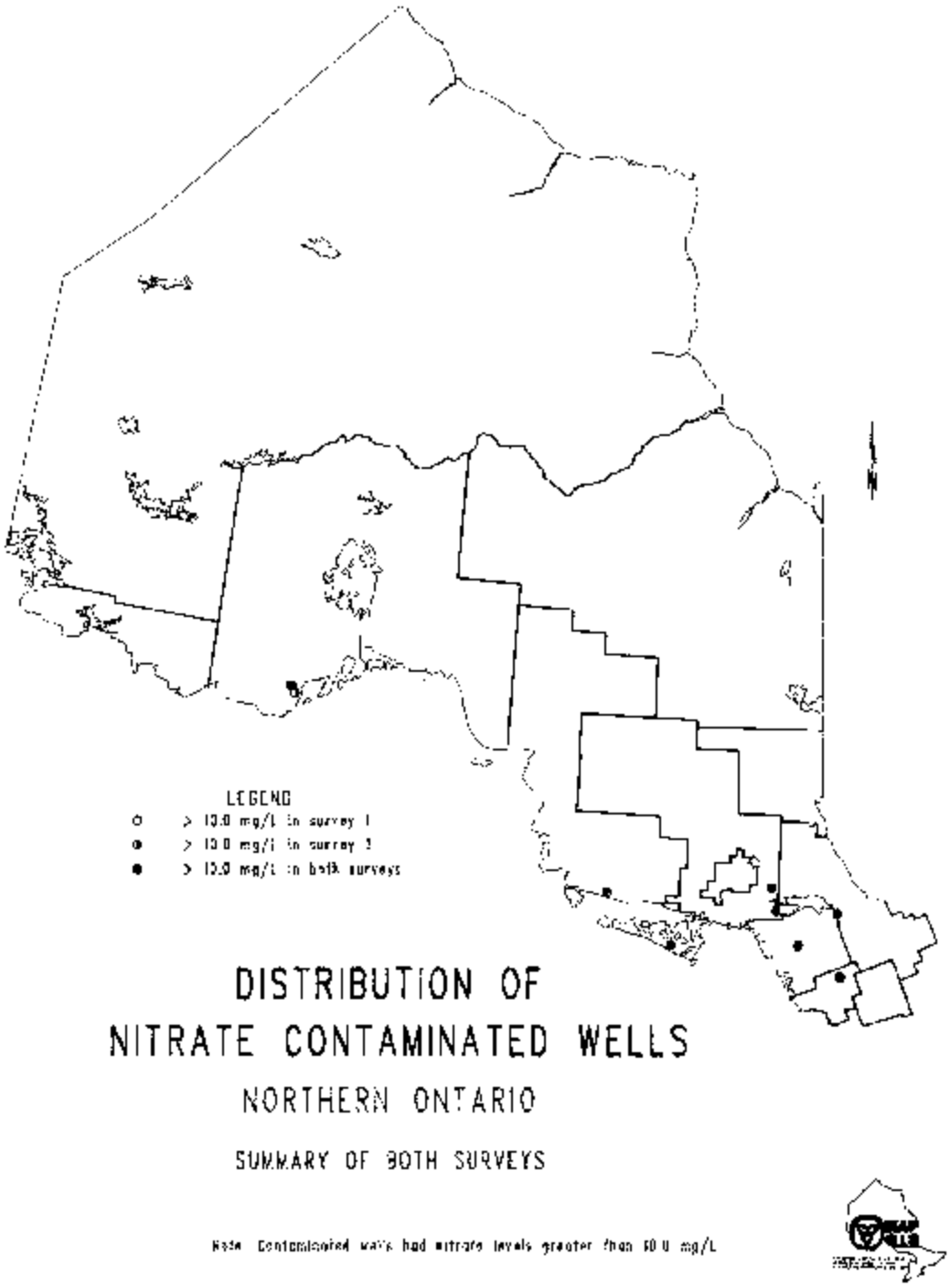
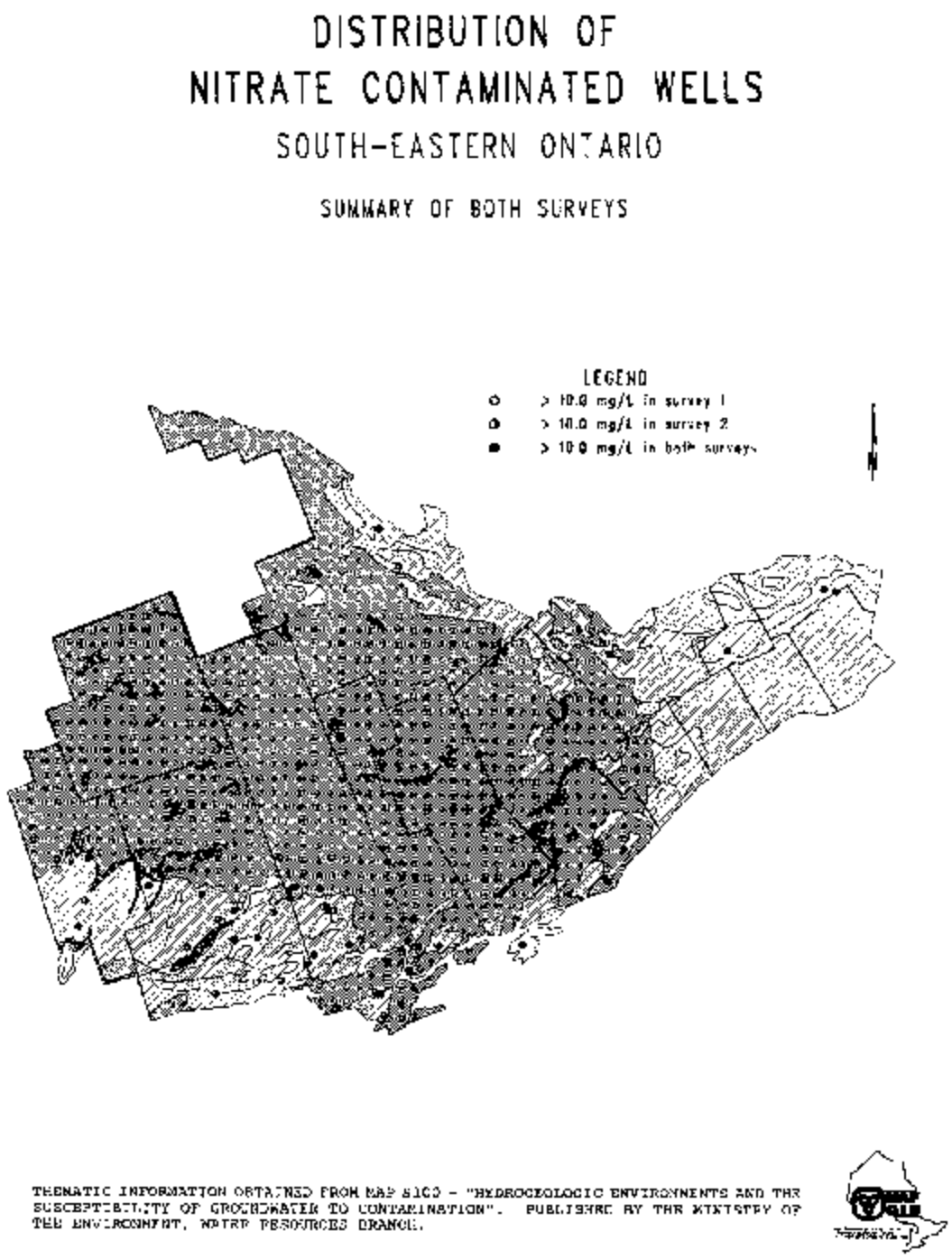


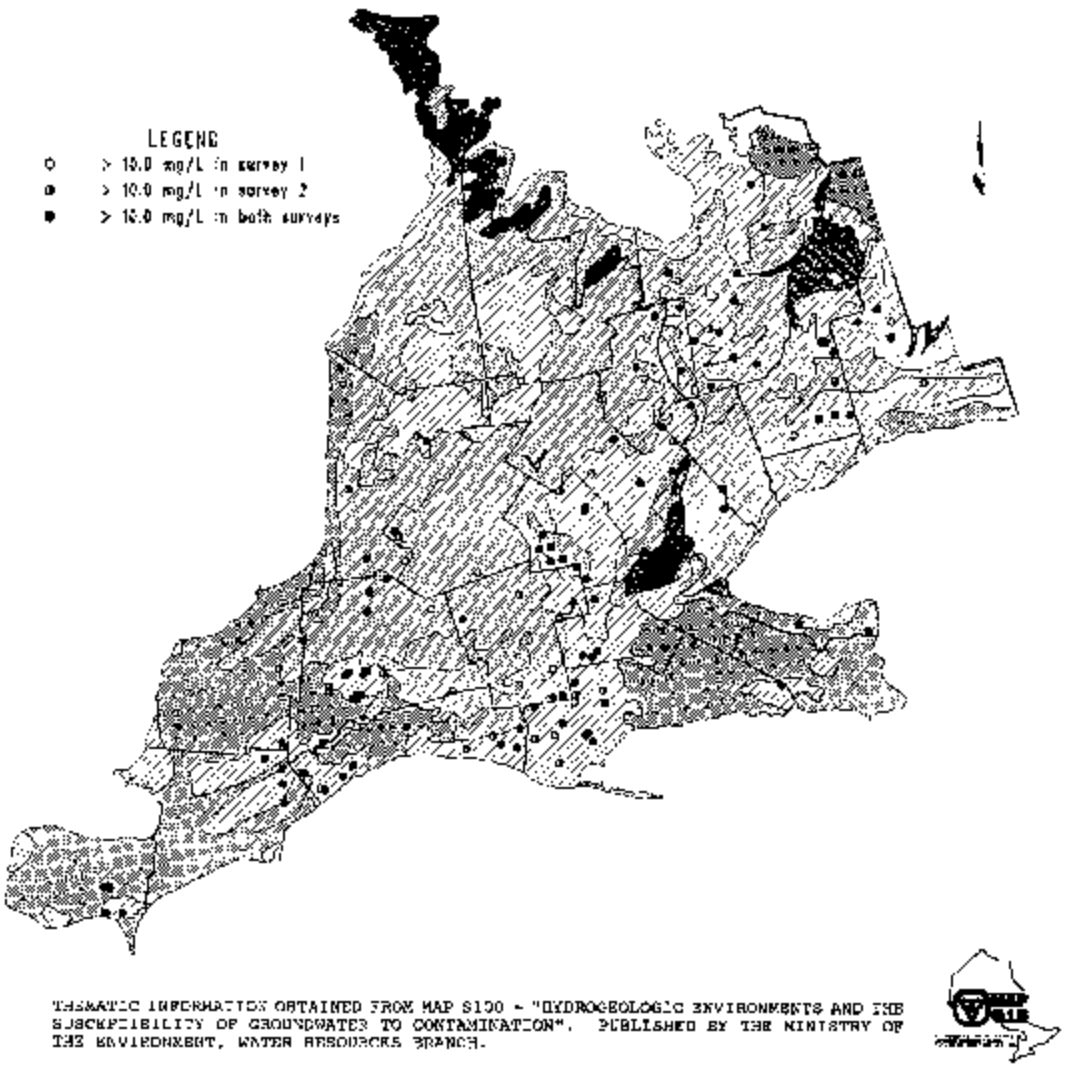
Fig. 15. *Relationship between water well nitrate-N concentrations in the winter and summer sampling programmes.*



Map 12. *Distribution of wells containing nitrate concentrations in excess of drinking water objectives - Northern Ontario - summary of both surveys.*



Map 13. *Distribution of wells containing nitrate concentrations in excess of drinking water objectives - South-Eastern Ontario - summary of both surveys overlaid on "Susceptibility of Groundwater to Contamination" map.*



Map 14. *Distribution of wells containing nitrate concentrations in excess of drinking water objectives - South-Eastern Ontario - summary of both surveys overlaid on "Susceptibility of Groundwater to Contamination" map.*

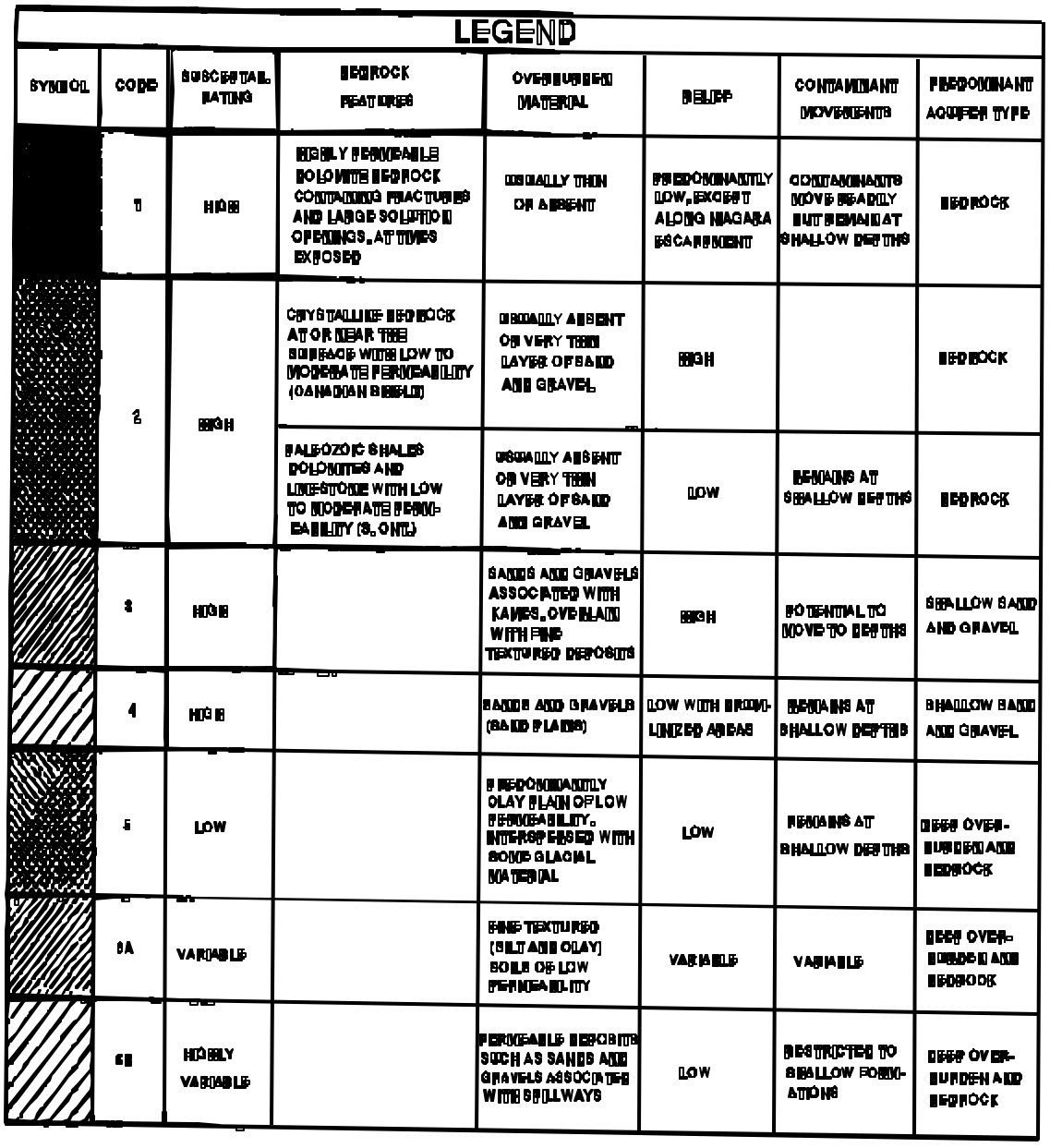
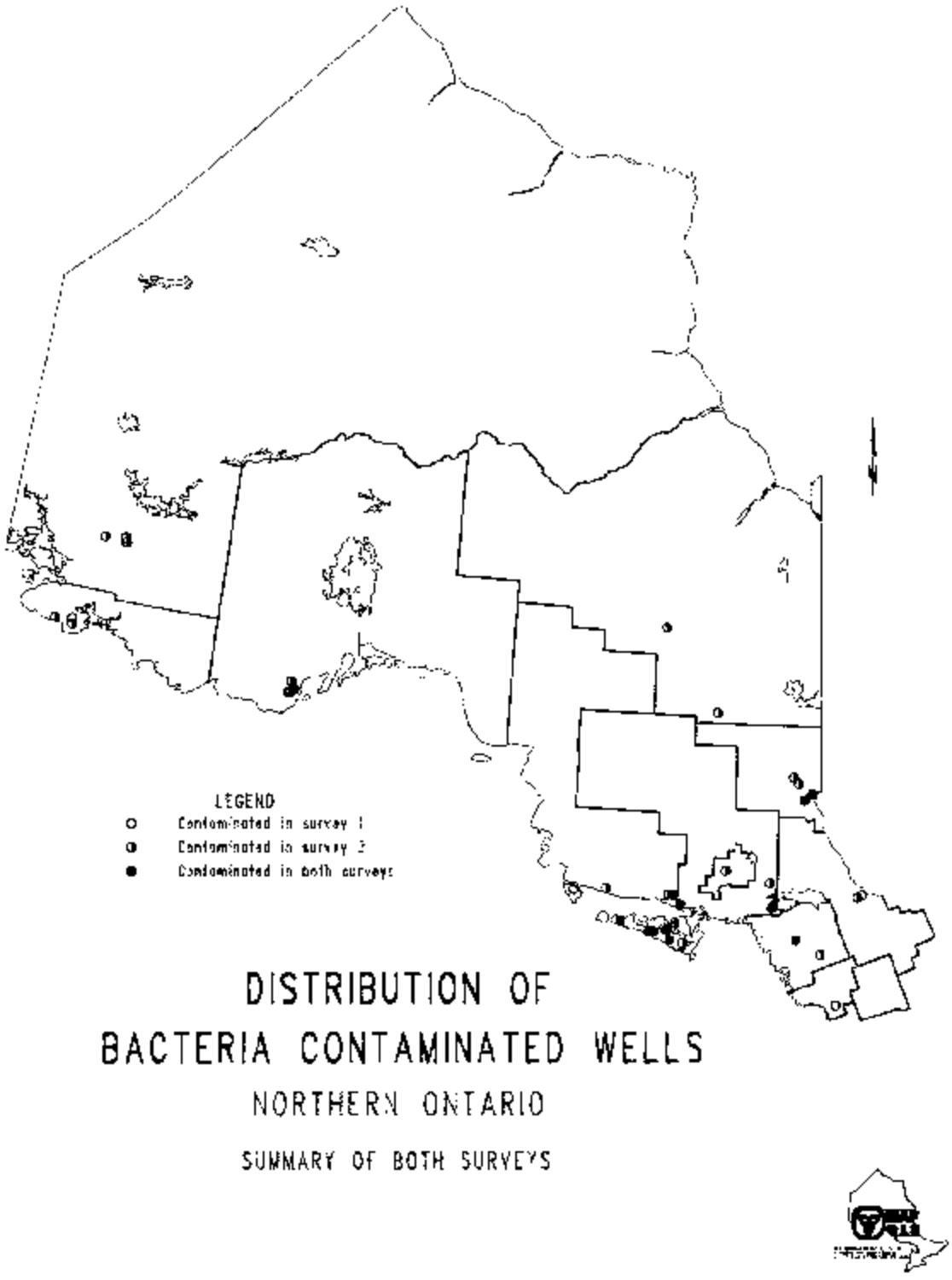
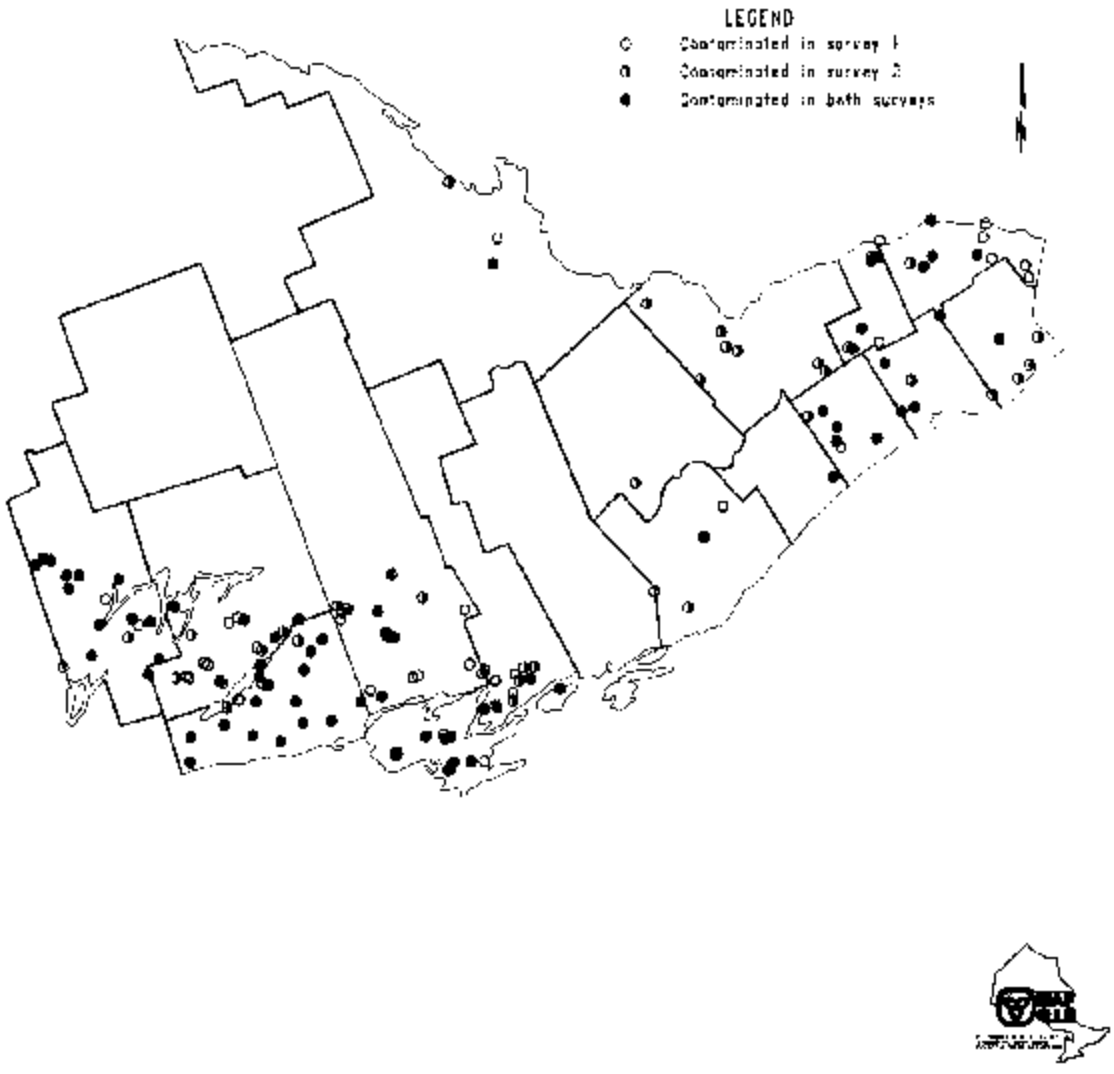


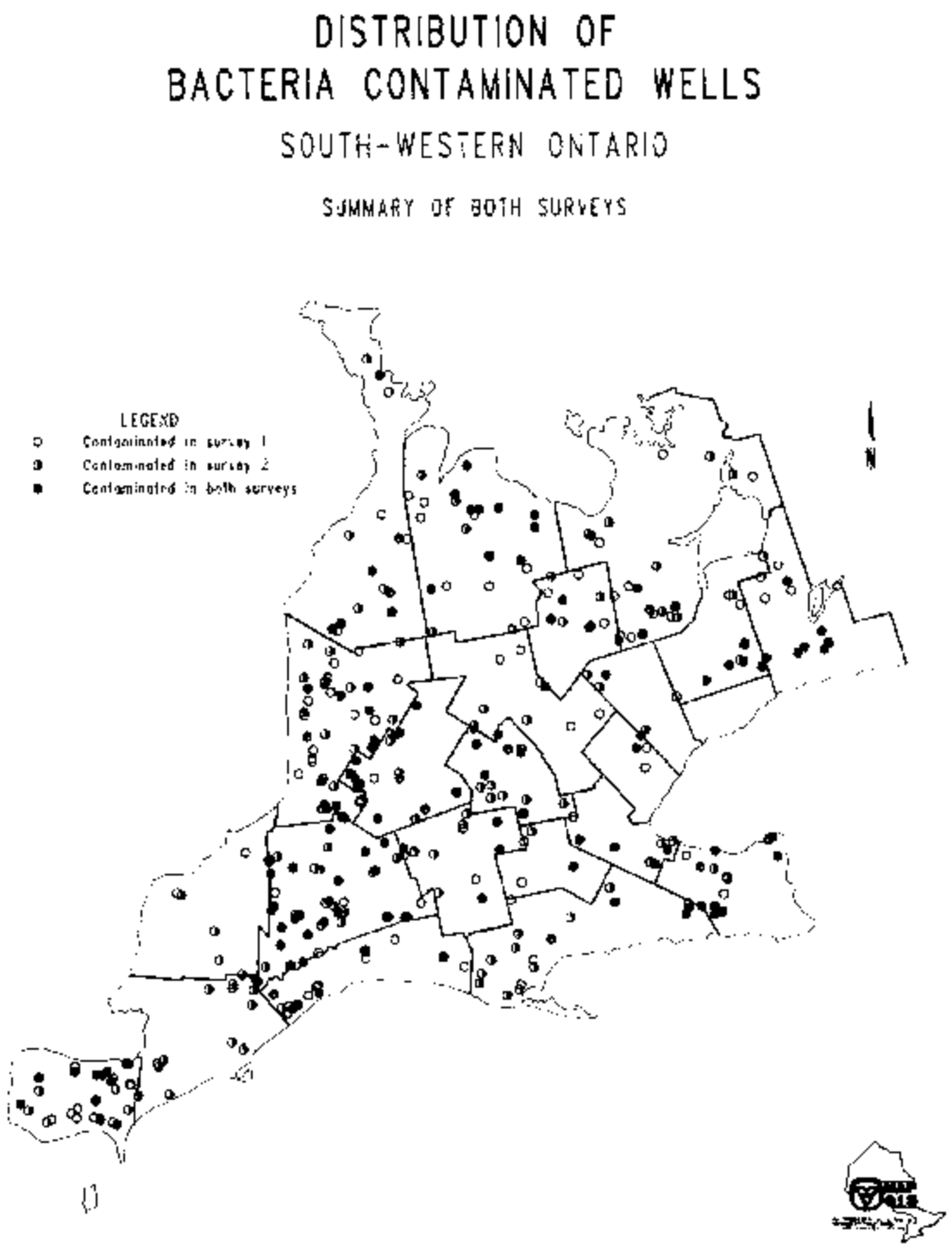
Fig. 16. *Legend for 'Susceptibility of Groundwater to Contamination' map.*



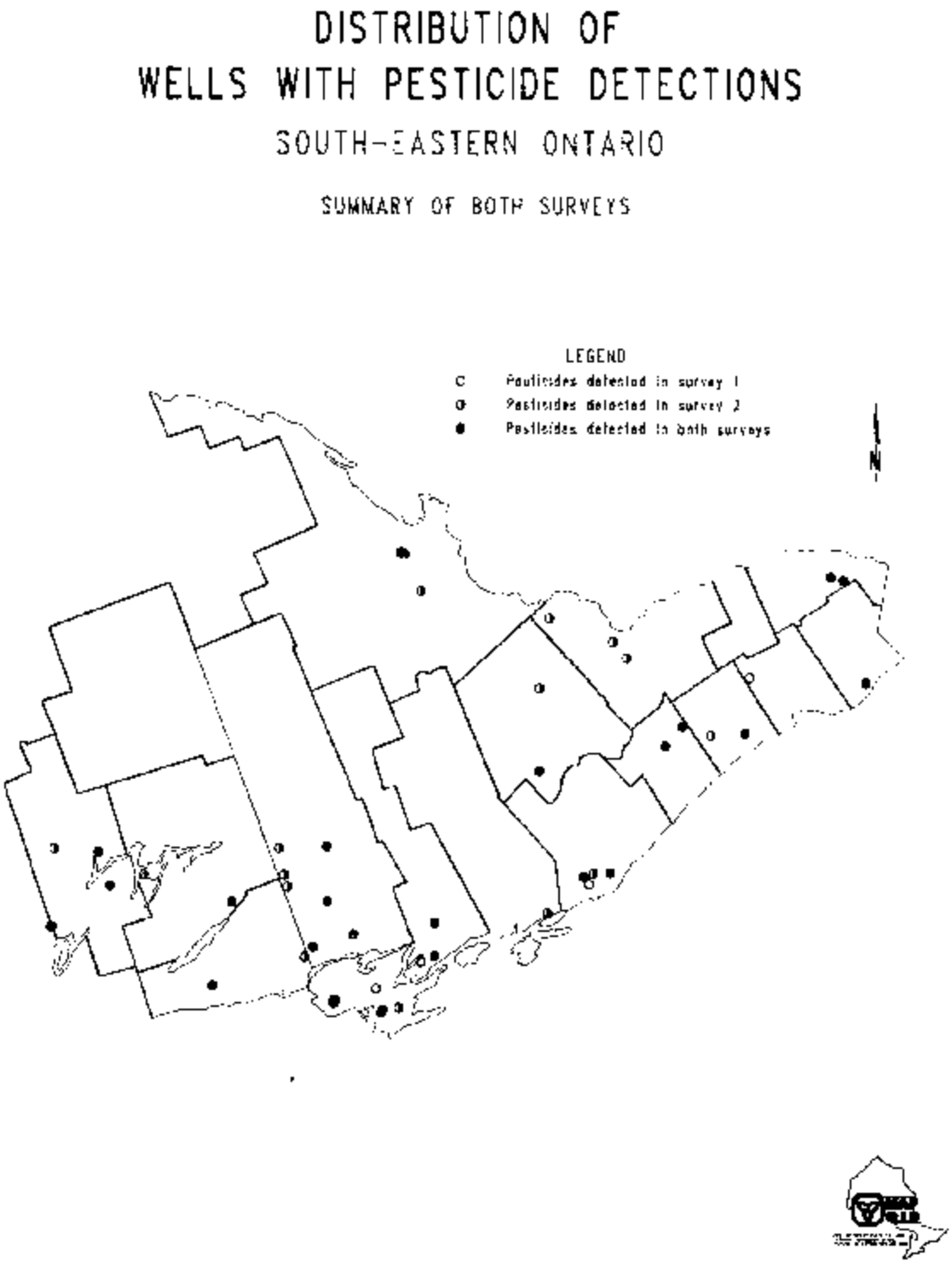
Map 15. *Distribution of wells containing coliform bacteria in excess of drinking water objectives - Northern Ontario - summary of both surveys.*



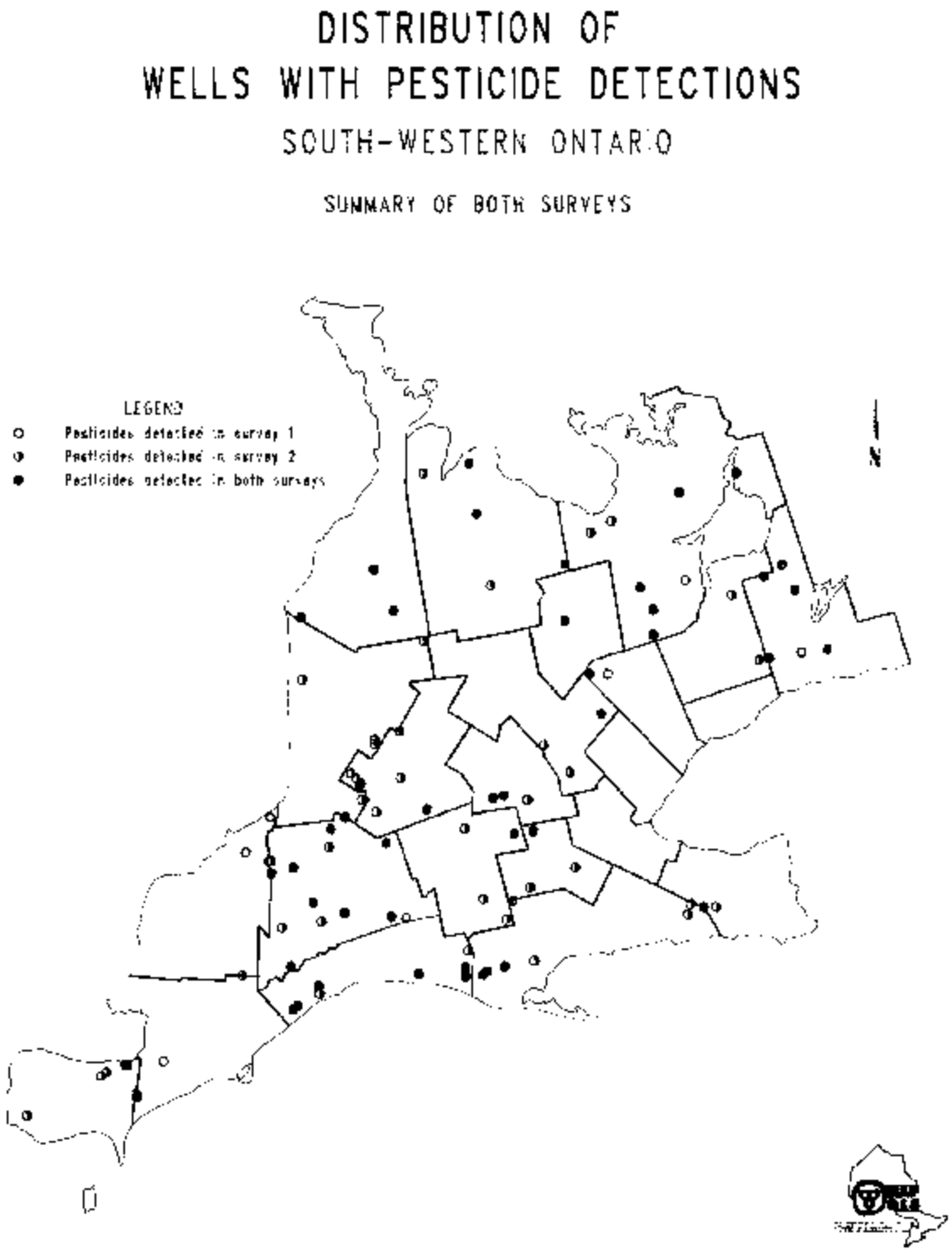
Map 16. *Distribution of wells containing coliform bacteria in excess of drinking water objectives - South-eastern Ontario - summary of both surveys.*



Map 17. *Distribution of wells containing coliform bacteria in excess of drinking water objectives - South-western Ontario - summary of both surveys.*



Map 18. *Distribution of wells containing detectable concentrations of pesticide residues - South-eastern Ontario - summary of both surveys.*



Map 19. *Distribution of wells containing detectable concentrations of pesticide residues - South-western Ontario - summary of both surveys.*

Table 14. *Incidence of detectable levels of pesticides in drinking water wells where analysis was done for winter and summer sampling.*

Pesticide Residue	Wells Tested	Detections	
		Winter	Summer
	no.	%	%
Alachlor	1192	0.0±0.0	0.1±0.2
Metolachlor	1192	0.8±0.5	0.8±0.5
Atrazine	1192	6.8±1.5	10.5±1.8**
d-ethyl atrazine	1192	4.0±1.1	6.3±1.4*
Metribuzin	1192	0.4±0.4	0.3±0.3
Cyanazine	1192	0.1±0.2	0.3±0.3
Any of above	1192	7.6±1.5	11.6±1.9***

* Difference between the results for the two sampling programmes significant at $p<0.05$

** Difference between the results for the two sampling programmes significant at $p<0.01$

*** Difference between the results for the two sampling programmes significant at $p<0.001$

5.3.5.2 Influence of Agricultural Land-Use

The results reported for this sampling programme with the revised information on land-use showed that there was no significant differences in the level of contamination, either by nitrate or bacteria, between land-use classes (Fig. 8 and Fig. 10). The findings in the winter programme had highlighted the corn system as having the greatest incidence of nitrate contamination. The data from the first sampling were reanalysed using the revised land-use information, and the corn system did not show significantly more contamination than any of the other land-use classes (Fig. 17).

The new information identifying farms where manure was spread showed from analysis of results for the summer sampling that contamination of wells with total bacteria increased whereas contamination with nitrate decreased compared with farms not applying manure. The results from the winter sampling programme were re-analysed to see if the same trends had been evident earlier. However, no trends were observed for either form of contamination (Table 15).

About 400 farmers from the first sampling programme completed a questionnaire on their nitrogen usage. The results of this voluntary exercise are not complete, but it is clear that contamination of wells depends on many interactive factors. Contamination is less on farms obtaining heavy yields, compared to the county average. Animal-based enterprises can have a considerable potential for nitrate contamination (Table 16). There is clearly an opportunity to select different crop rotations to reduce the potential for nitrate contamination (Table 17).

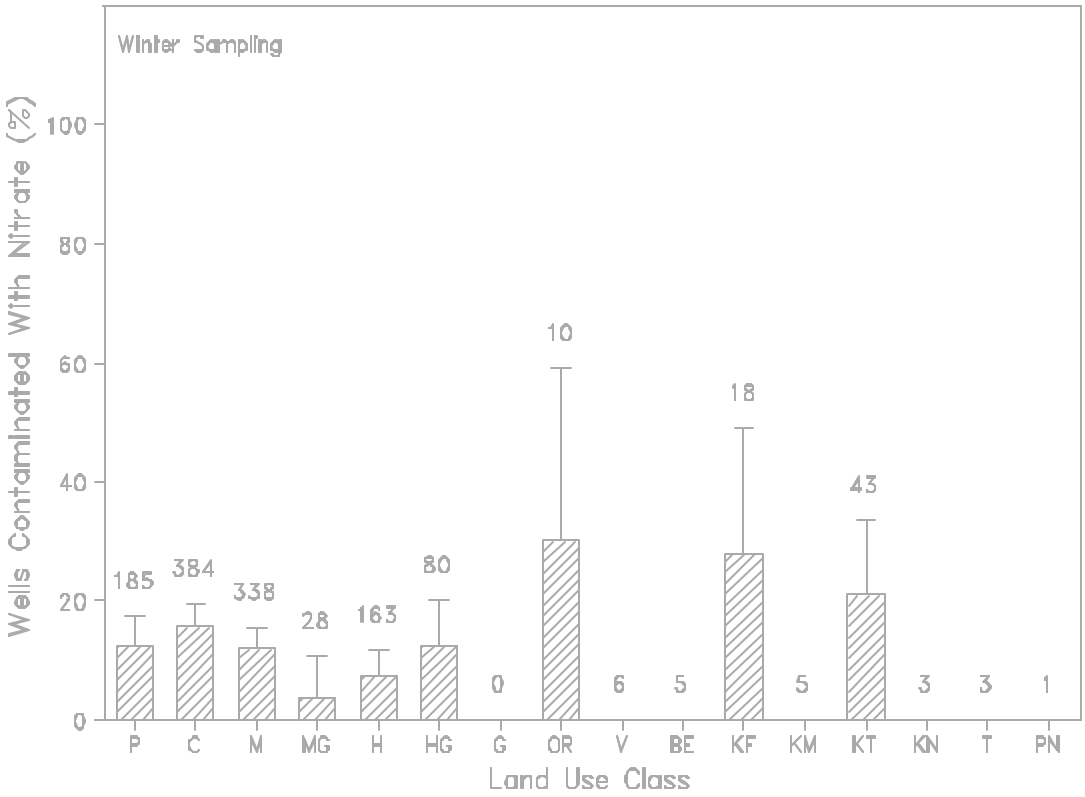


Fig. 17. *Frequency distribution showing the number of wells contaminated with nitrate in the winter sampling as a percentage of wells located on farms with the given land-use system. The number at the head of each column indicates the total number of wells in that land-use system. The error bars indicate the upper bound of the 95% confidence interval.*

P- Continuous row crops (corn,bean rotation)
C-Corn (corn, beans, grain, (hay))
M-Mixed (grain, corn, soybeans, hay)
MG-Grain (sod and grain, no row crops)
H-Hay (good quality hay production)
HG-Pasture (extensive or unconfined grazing)
G-Grazing (rough grazing)
OR-Orchard (hardy fruits)
V-Vineyard (grapes)
BE-Berries (soft fruit)
KF- Extensive Field Vegetables
KM- Market Gardens
KT-Tobacco
KN-Nursery (trees, shrubs)
T-Sod
PN-Peanut

Table 15. *Contamination of well water in the winter sampling, on farms where manure is spread compared to farms where manure is not spread.*

Contaminant	Spread		Not Spread	
	Tested	High	Tested	High
	no.	%	no.	%
Bacteria				
Total coliform >10	938	25.2±2.8[†]	335	25.4±4.8
Total coliform >5	938	30.5±3.0	335	30.1±5.0
Faecal coliform >0	938	20.0±2.6	334	19.5±4.3
E. coli >0	293	18.1±4.5	31	9.7±10.6
F. strep >0	374	11.5±3.3	26	0.0±0.0
Enterococci >0	119	24.4±7.9	10	0.0±0.0
F.strep or entero >10	457	6.1±2.2	32	0.0±0.0
Total >10 or faecal >0	937	30.2±3.0	334	30.8±5.1
Total >10 or faecal or *E. coli* >0	937	30.2±3.0	334	30.8±5.1
Nitrate >10	941	12.1±2.1	333	14.7±3.9
Mixed contamination				
Bacteria[‡] or nitrate	936	36.2±3.1	331	38.4±5.3
Bacteria & nitrate	936	6.2±1.6	331	7.6±2.9
Pesticide detects	938	7.4±1.7	331	8.2±3.0

[†] ±95% confidence interval.

[‡] Bacteria include total coliforms, and faecal coliforms or *E. coli*.

Table 16. *Nitrogen budget for a mixed farm growing corn beans and wheat to feed hogs and poultry.*

Input		Export	
	kg N ha^{-1}		kg N ha^{-1}
Seed	1.7	Plant/Plant products	1.9
Feed	65.5	Animals/ animal products	16.6
Fertilizers	30.0	Gaseous loss	107.3
Livestock	0.1		
Legume and non-legume nitrogen fixation	46.7		
Atmospheric deposition	18.4		
TOTAL	**162.4**		**125.9**
Imbalance*	*36.5*		
Predicted groundwater contamination	**22.8** (mg L^{-1})	Measured groundwater contamination	**19.9** (mg L^{-1})

*Total Inputs-exports, leaching loss not included.
Note: Methodology of N-budget calculations is given in Appendix G.

Table 17. *Nitrogen budget for a cash cropping farm growing corn, soybeans and wheat, with corn following two years of soybeans, and wheat following alternate corn crops.*

Input		Export	
	kg N ha^{-1}		kg N ha^{-1}
Seed	5.4	Plant/Plant products	163.0
Fertilizer	50.2		
Legume and non-legume nitrogen fixation	88.7		
Atmospheric deposition	18.4		
TOTAL	**162.7**		**163.0**
Imbalance*	-0.3		
Predicted groundwater contamination	**0** (mg L^{-1})	Measured groundwater contamination	**0** (mg L^{-1})

*Total Inputs-exports, leaching loss not included.
Note: Methodology of N-budget calculations is given in Appendix G.

5.4 Multilevel Monitoring Well Survey Results

As part of the initial survey conducted in the fall and winter months of 1991-1992, a total of 160 multilevel monitoring wells were installed throughout the study area. These monitoring wells are referred to as multilevels in this part of the report. They were located in fields relatively close to the farm water wells sampled as part of the well survey. An attempt was made to install the multilevels in a variety of different soil types and in areas of different agricultural land-use practices. Sixteen of the 160 multilevels were placed in uncultivated woodlots adjacent to the field where another multilevel was located under cultivated conditions. Telephone cable markers attached to the outside of the multilevels when they were buried in the winter, allowed the multilevels to be located using a marker detector. Nineteen (19) of the multilevels could not be sampled during the summer sampling due to conditions at the site, such as flooding of the multilevel or heavy crop cover which made it impossible to find the multilevel. A more detailed description of multilevel site selection and multilevel construction is given in the initial report on the winter survey (OFGQS, 1992). However, some additional information is contained in Appendix A.

In contrast to the individual farm water wells, the multilevel monitoring wells enabled sampling from various discrete depths at a single location. As a result there was a set of water chemistry analyses that must be considered for each multilevel as opposed to a single sample from the wells. Many bored or dug wells are open to the aquifer material over a considerable depth. In some cases this may be from the watertable to the bottom of the well. As such, water samples taken from these types of wells likely represent a mixture of groundwater from the entire open depth of the well as opposed to an isolated portion of the aquifer. Drilled wells, that are cased and only screened at depth, and sandpoints tend to draw water from a much more localized or discrete portion of the aquifer unit.

In order to evaluate the chemical results from the multilevels, the data will be presented in two forms. In the first case, the maximum concentrations of both nitrate and bacteria from each multilevel monitoring well will be evaluated as a group. Again, Ontario drinking water objectives will be used to indicate whether a site is contaminated or not. This will help to recognize the occurrence of contamination in groundwater beneath the agricultural field. The data will also be analyzed as the average concentration of all depths at a given multilevel site.

This may more realistically represent the concentration that would be found in a fully-open shallow bored or dug well.

5.4.1 General Distribution of Contaminants

5.4.1.1 Nitrate

The most elevated nitrate-N concentrations observed at each multilevel site are shown cumulatively in Fig. 18. A total of 44% of the 141 multilevel sites sampled for nitrate-N had maximum concentrations greater than 10 mg L^{-1} and an additional 13% had concentrations between 5 to 10 mg L^{-1}. Of all the multilevel sites, the maximum nitrate-N concentration measured in the summer sampling was 87 mg L^{-1}, similar to that found in the winter sampling (78 mg L^{-1}).

The percent occurrence of nitrate-N at concentrations above the drinking water objectives in at least one of the levels of the multilevel monitoring wells is considerably higher than that observed for the drinking water wells analyzed during the well survey (14% in the summer survey). If the maximum concentrations in the multilevels are compared to the concentrations in the wells on the farms where the multilevels are installed, the percentage of wells above the drinking water limit is more similar (33% in the summer survey). Further correlations between the multilevel concentrations and concentrations in the water wells on the multilevel sites will be discussed later.

When the average concentrations at each multilevel site are considered, the occurrence of sites in exceedence of 10 mg L^{-1} was 21% (Fig. 19). This is somewhat lower than the 33% of associated water wells that exceeded the drinking water objective.

The percentage of multilevels with nitrate-N concentrations greater than 10 mg L^{-1} in the summer sampling was very similar to that found during the winter sampling (Table 18). Of the 62 multilevels with nitrate-N concentrations in excess of 10 mg L^{-1} in the summer survey, 50 sites or 81% were also over the objective in the winter. Another way to compare the nitrate-N concentrations from the summer and winter surveys at each multilevel is to perform a linear regression of winter versus summer nitrate-N concentrations. The r^2 for this analysis was 0.46. Based on this coefficient and the number of nitrate samples (141), the correlation is significant within a confidence interval of 99%.

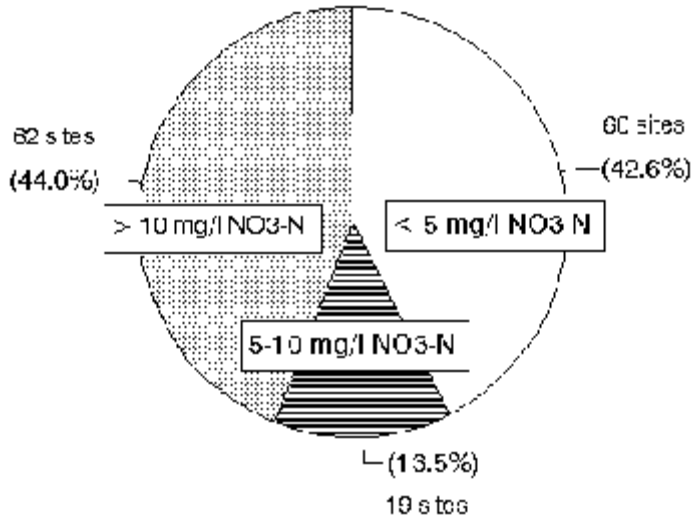


Fig. 18: *Maximum nitrate-N concentrations measured at any level in each multilevel well.*

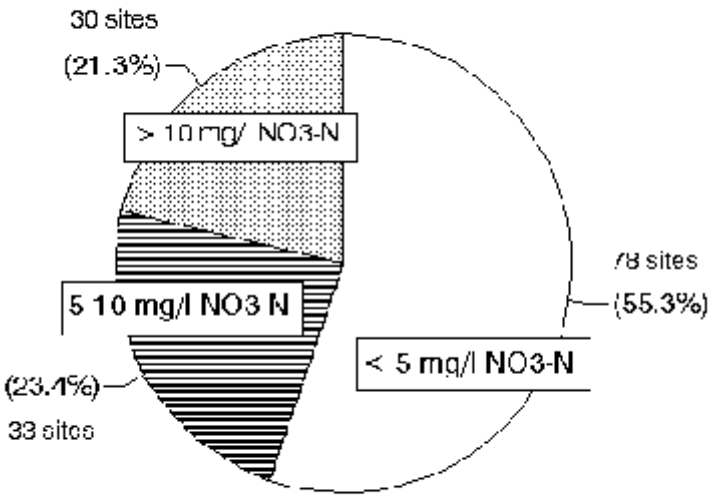


Fig. 19: *Nitrate-N concentrations averaged over all levels of each multilevel well.*

Table 18: *Comparison between the summer and winter samplings of the percentage of multilevels exceeding drinking water objectives for nitrate-N, total coliforms, and faecal coliforms, using maximum or average concentrations measured in the multilevel wells.*

		MAXIMUM CONCENTRATION Summer [Winter]	AVERAGE CONCENTRATION Summer [Winter]
Nitrate-N	> 10 mg L^{-1}	44.0% [44.4%]	21.3% [23.6%]
	5-10 mg L^{-1}	13.5% [16.7%]	23.4% [22.9%]
	< 5 mg L^{-1}	42.5% [38.9%]	55.3% [53.5%]
Total Coliforms	> 10 col. /100 mL	34.0% [63.2%]	32.0% [59.6%]
	# 10 col. /100 mL	66.0% [36.8%]	68.0% [40.4%]
Faecal Coliforms	$ 1 col. /100 mL	13.5% [22.8%]	9.6% [22.8%]
	<1 col. /100 mL	86.5% [77.2%]	90.4% [77.2%]
Total or Faecal Coliforms	exceeds objectives†	38.2% [64.9%]	34.0% [63.2%]
	does not exceed objectives	61.8% [35.1%]	66.0% [36.8%]

† drinking water objectives: total coliforms #10 colonies $(100\ mL)^{-1}$ and faecal coliforms = 0 colonies $(100\ mL)^{-1}$.

5.4.1.2 Total Coliform Bacteria

The presence of total coliform bacteria was investigated in 50 of the multilevels in the summer sampling. Most of these sites had livestock operations. Since the reporting of the results of the winter sampling, the Ministry of Health has changed the drinking water limit for total coliforms from #10 to #5 colonies per 100 mL. Both the percentage of wells in excess of the new drinking water objective of #5 colonies per 100 mL and, for the purpose of comparison with the winter sampling, wells in excess of 10 colonies per 100 mL, are presented. When the number of colonies per 100 mL was greater than 80, the laboratory reported the result as '>80' colonies per 100 mL. Therefore no precise maximum concentration for the multilevels can be specified. For data analysis, counts that were reported as >80 were assigned the value of 81 colonies per 100 mL.

The maximum total coliform count at each multilevel site was greater than 5 colonies per 100 mL at 42% of the sites (Fig. 20). Thirty-four (34%) percent of the multilevel sites had total coliform concentrations over 10 colonies per 100 mL (Table 18). This was nearly one half of the number of multilevel sites found over the drinking water limit for total coliforms in the winter sampling (63%).

There was little difference between the average concentration distribution (Fig. 21) and the maximum concentration distribution for total coliforms (Table 18). This finding contrasts with the nitrate-N results. The maximum concentrations of total coliforms tended to be much higher than the permissible 10 colonies per 100 mL, causing the averaged values to exceed this objective. In the case of nitrate, the maximum concentrations tended to be closer to the 10 mg L^{-1} limit, so that averaged values were more frequently lower than the limit.

The occurrence of total coliforms above the drinking water objective in the farm drinking water wells (27% of 1227 wells in the summer survey) is similar to that found in the summer survey of the multilevels. The water wells on farms where a multilevel was installed exceeded the objective at 30% of the sites in the summer.

Of the 17 multilevels over the drinking water objective in the summer, 12 (or 71%) were also over in the winter. Linear regression of the paired total coliform concentrations from the winter and summer, however, showed a poor correlation of total coliform concentration between the two surveys. Considering the number of total coliform samples collected, the correlation (r^2 = 0.02) was not significant at a 95% confidence level.

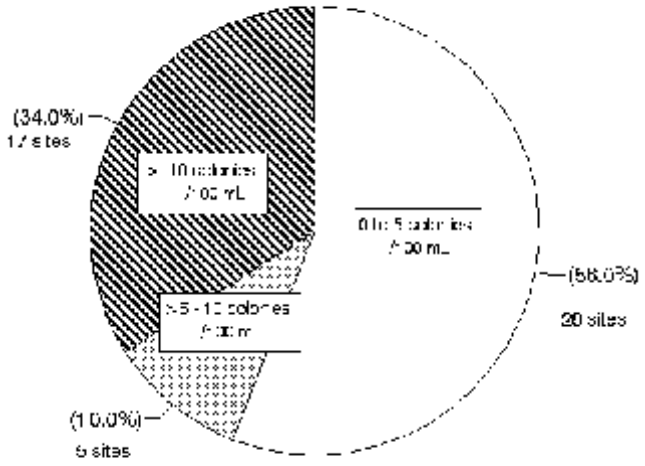


Fig. 20: *Maximum total coliform concentration measured at any level in each multilevel well.*

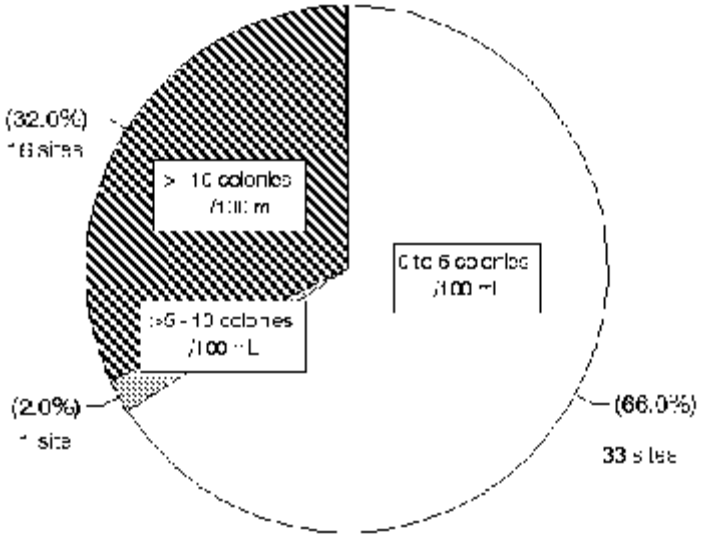


Fig. 21: *Total coliform concentration averaged over all levels of each multilevel well.*

5.4.1.3 Faecal Coliform Bacteria

The maximum concentration distribution for faecal coliform bacteria at the 52 multilevel sites selected for this analysis is shown in Fig. 22. Fourteen percent (14%) of the multilevel sites had measurable faecal coliform concentrations. This was about 2/3 of the number of multilevel sites found to be over the drinking water limit for faecal coliforms during the winter sampling (23%) (Table 18).

The summer sampling of the 1300 water wells also had nearly twice the number of wells over the drinking water limit (25%) than was observed in the multilevels. If the maximum faecal coliform concentrations in the multilevels are compared to the concentrations in the wells on the farms where the multilevels were installed, the percent occurrences is also nearly double in the wells (25% in the summer survey).

Faecal coliform concentrations in excess of 60 colonies per 100 mL were reported as '>60' colonies per 100 mL. These results were assigned a value of 61 colonies per 100 mL for data analysis. The average faecal coliform concentrations at the multilevel sites showed a slightly lower percentage (10%) of contaminated sites than did the maximum concentrations (Fig. 23). This small difference reflected the low value of the drinking water objective (0 faecal coliforms per 100 mL) relative to the high reported concentrations.

Of the 7 multilevels exceeding drinking water objectives during the summer, only two multilevels (29%) also exceeded the objectives in the winter. Using linear regression analysis, the paired faecal coliform concentrations from the winter and summer had a low correlation ($r^2 = 0.03$) and given the number of faecal coliform samples, the correlation of faecal coliform concentration between the winter and summer surveys was not significant at a 95% confidence level.

The results of both the maximum total coliform and faecal coliform bacterial analysis are shown cumulatively in Fig. 24. Using the new drinking water standard for total coliforms of 5 colonies per 100 mL, 45% of the sites visited had maximum concentrations of total or faecal coliform bacteria that exceeded the recommended safe drinking water limit. A smaller percentage of multilevel sites (38%) are above the bacteriological drinking water limit when the previous total coliform drinking water standard of 10 colonies per 100 mL is considered. This is one half the number of sites that were over the drinking water limit in the winter sampling (65%) (Table 18). A slightly lower number of contaminated sites (34%) is observed using the average concentrations for total and faecal coliforms (Fig. 25).

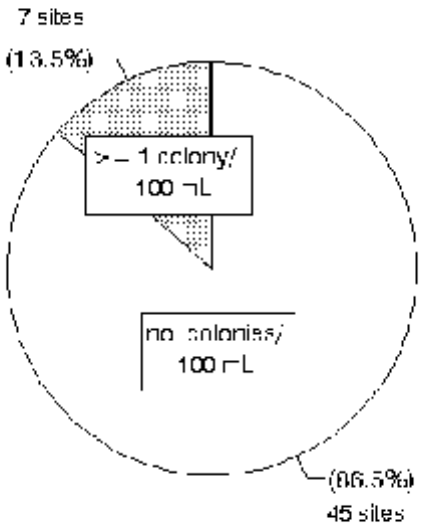


Fig. 22: *Maximum faecal coliform concentration measured at any level in each multilevel well.*

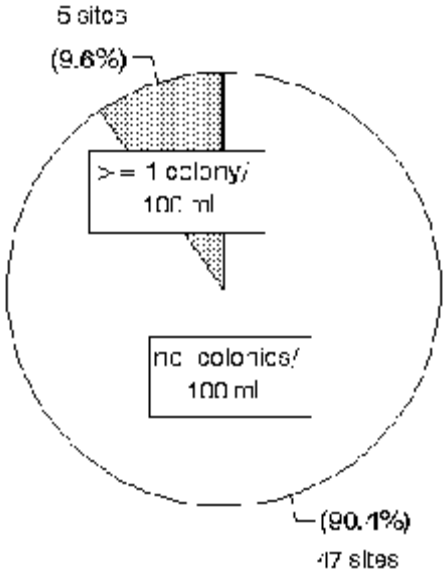


Fig. 23: *Faecal coliform concentration averaged over all levels of each multilevel well.*

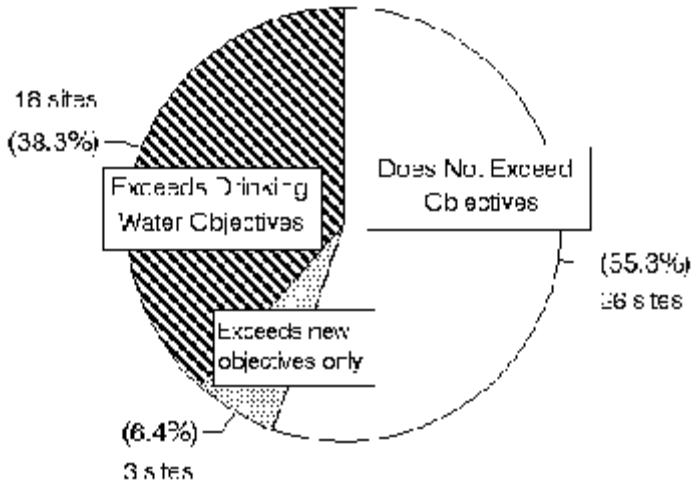


Fig. 24: *Exceedence of bacteriological drinking water limit by maximum total or faecal coliform concentrations measured in each multilevel well.*

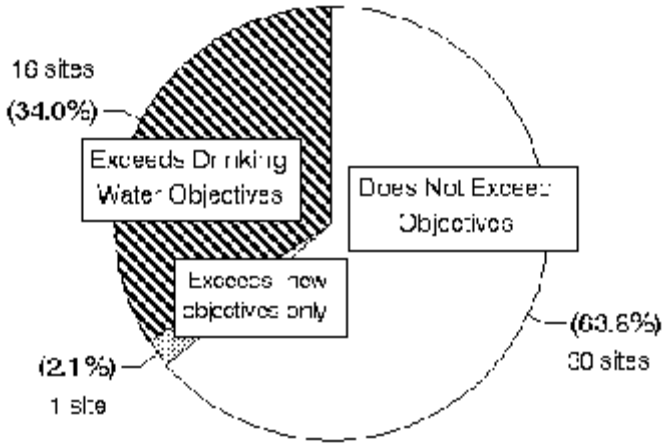


Fig. 25: *Exceedence of bacteriological drinking water limit by total or faecal coliform concentrations averaged over all levels of each multilevel well.*

5.4.1.4 *Escherichia Coli* Bacteria

Escherichia coli (*E. coli*) was measured at 50 multilevel sites to further examine the effect of animal manure or septic systems on groundwater, since the presence of this type of faecal coliform bacteria was considered a definitive indicator of the presence of animal or human waste.

Four percent of the multilevel sites had at least one interval with a measurable concentration of *E. coli* (Fig. 26). This rate of contamination was only one fifth of that observed in the drinking water wells in the survey (Table 3). If just those water wells where multilevels were installed were considered, 11% had detected *E. coli* bacteria. The percentage of multilevels contaminated was 2% when average concentrations were considered (Fig. 27).

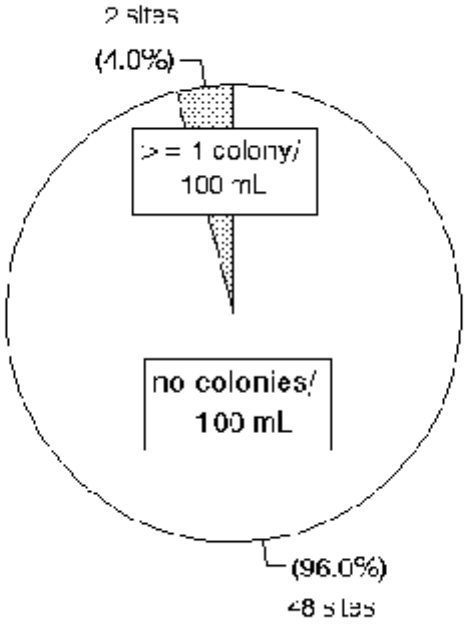


Fig. 26: *Maximum Escherichia coli concentration measured at any level in each multilevel well.*

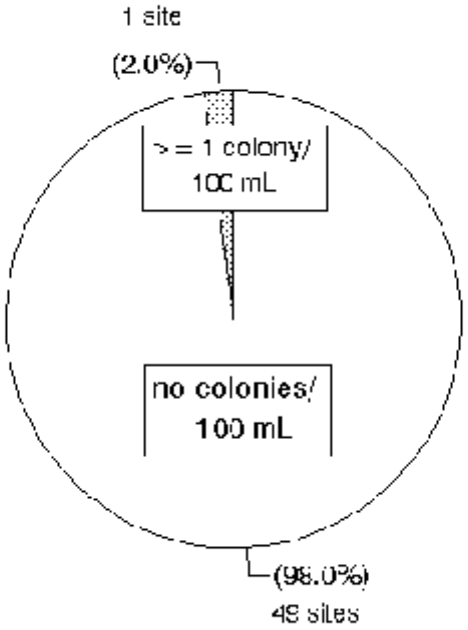


Fig. 27: *Escherichia coli concentration averaged over all levels of each multilevel well.*

5.4.1.5 Faecal Streptococcus and Enterococcus Bacteria

Faecal streptococcal and enterococcal bacteria are indicators of contamination from animal sources. Enterococcus refers to a subgroup of faecal streptococcal bacteria. No formal drinking water standards for these bacteria have been set by the Ministry of Health, but concentrations in excess of 10 colonies per 100 mL and from one to 10 colonies per 100 mL are reported for both types of bacteria.

In Fig. 28, the cumulative distribution of maximum faecal streptococcus concentration is shown for 51 of the multilevel sites. Some 14% of the multilevel sites had faecal streptococcus concentrations in excess of 10 colonies per 100 mL, and an additional 22% had between one and ten colonies per 100 mL. A similar percentage of the total set of water wells (27%) had measurable faecal streptococcus concentrations. When only those water wells where multilevels were installed are examined, 20% of the wells had measurable faecal streptococcus concentrations. Average multilevel concentrations were also considered (Fig. 29). The percentage of multilevels where the average faecal streptococcus concentration was in excess of 10 colonies per 100 mL was 12%, and an additional 20% of the multilevels had faecal streptococcus between one and ten colonies per 100 mL.

Forty-two (42) of the multilevel sites were sampled for enterococcal bacteria. Maximum enterococcus concentrations in excess of 10 colonies per 100 mL were found in 7% of the multilevel sites (Fig. 30) and an additional 12% of the multilevel sites had concentrations between one and ten colonies per 100 mL. A much larger percentage (44%) of the water wells analyzed for enterococcus had measurable concentrations than did the multilevel sites, yet a very similar 18% of the water wells where multilevel monitoring wells had been installed had detectable enterococcus concentrations. The percentage of multilevels whose average enterococcus concentrations were in excess of 10 colonies per 100 mL was 7%, and an additional 7% of the sites had concentrations between one and ten colonies per 100 mL (Fig. 31).

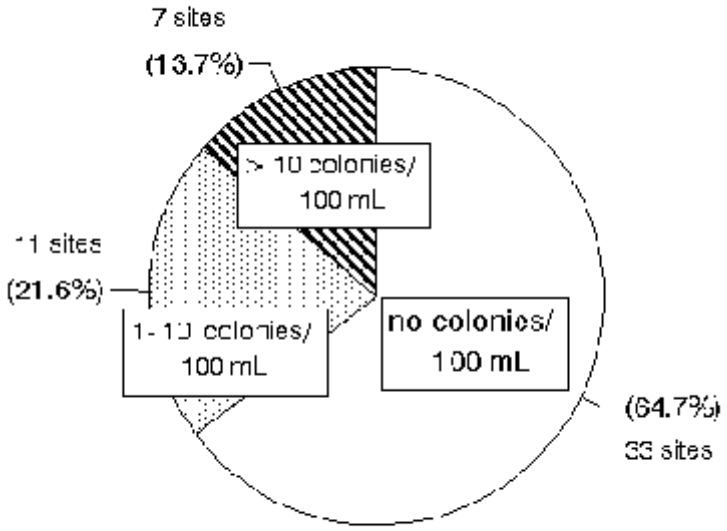


Fig. 28: *Maximum faecal streptococcus concentration measured at any level in each multilevel well.*

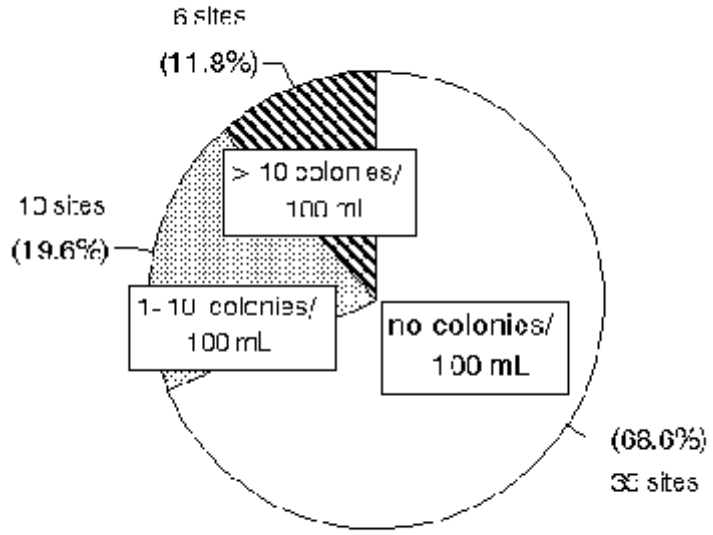


Fig. 29: *Faecal streptococcus concentration average over all levels of each multilevel well.*

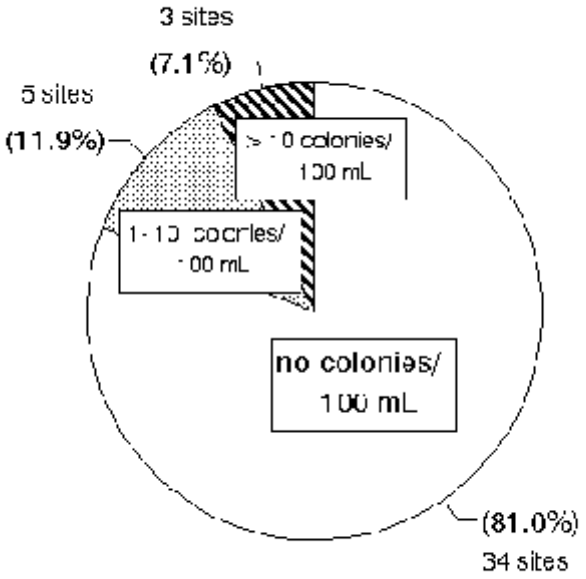


Fig. 30: *Maximum enterococcus concentration measured at any level in each multilevel well.*

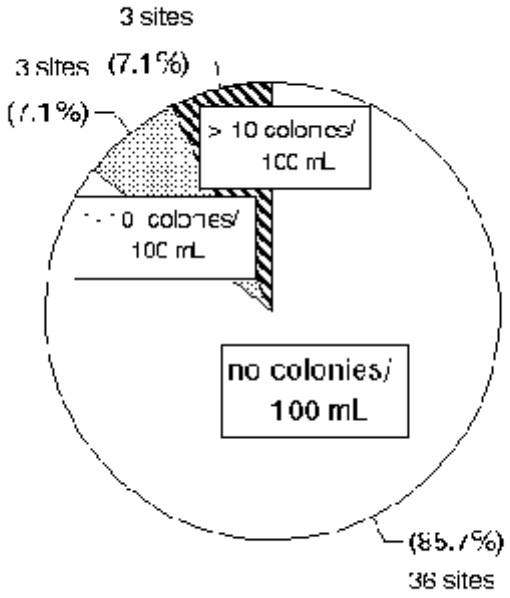


Fig. 31: *Enterococcus concentrations averaged over all levels of each multilevel well.*

5.4.1.6 Pesticides

A total of 562 water samples from the 141 multilevel monitoring wells were analyzed for pesticide residues (Table 19). Eighteen (18) of the samples had detections of pesticide residues at eight different sites (3.2% of the samples; 5.7% of the multilevel sites). The frequency of detections was about half of that observed in the overall water well survey. In total, there were 34 detections of pesticide residues in the multilevel samples. These were either atrazine (17 detections), atrazine's metabolite, d-ethyl atrazine (16 detections), or cyanazine (1 detection). The sample with measurable cyanazine levels had a concentration of 60 µg L^{-1}, which exceeded the interim maximum acceptable concentration (IMAC) for cyanazine of 10 µg L^{-1}. No cyanazine was detected at this multilevel in the winter and none was detected in the adjacent drinking water well. No samples with detections of atrazine or d-ethyl atrazine exceeded the IMAC for combined atrazine and atrazine metabolites of 60 µg L^{-1}, but 11 samples (2.0% of the total samples) exceeded the U.S. drinking water limit. The maximum concentration for atrazine was 4.7 µg L^{-1} and for d-ethyl atrazine 6.7 µg L^{-1}.

In the winter sampling, the number of samples with detections of pesticides (2.5%) was slightly lower and the maximum concentrations for atrazine (3.1 µg L^{-1}) and d-ethyl atrazine (1.9 µg L^{-1}) were also lower than those found in the summer survey. No detections of cyanazine were recorded. Of the 6 multilevels with detections of atrazine or d-ethyl atrazine in the winter sampling, 5 of them were again contaminated in the summer survey. Often the same intervals were contaminated in both samplings.

It is interesting to note that atrazine and d-ethyl atrazine were found in higher concentrations in the summer than in the winter, but the effect was much more pronounced for d-ethyl atrazine. In the winter, the multilevels provided only one groundwater sample in which d-ethyl atrazine was in excess of 1 µg L^{-1}, In the summer, this number had risen to 12. For atrazine, one multilevel site from the winter sampling contained more than 1 µg atrazine L^{-1}, while three sites contained more than 1 µg L^{-1} in the summer sampling.

Table 19: *Detections of pesticide residues in winter and summer samplings.*

		Winter	Summer
Number of multilevel sites sampled		144	141
Number of samples analyzed		606	562
Total number of pesticide detections		25	34
Number of samples with at least one pesticide residue		15 (2.5%)	18 (3.2%)
Number of multilevel sites with pesticide residue in at least one interval		6 (4.2%)	8 (5.7%)
health standard for combined atrazine and d-ethyl atrazine concentration	Canadian IMAC (60 µg L^{-1})	0%	0%
	U.S. Limit (3 µg L^{-1})	0.2%	2.0%
atrazine	maximum concentration (µg L^{-1})	3.1	4.7
	percentage of samples over 1 µg L^{-1}	0.2%	0.5%
d-ethyl atrazine	maximum concentration (µg L^{-1})	1.9	6.7
	percentage of samples over 1 µg L^{-1}	0.2%	2.1%

5.4.2 Influence of Agricultural Land-Use Practice

Relationships between contaminant occurrence in the multilevel monitoring wells and certain environmental factors are examined under this heading, using the data sets for nitrate-N, total coliform, and faecal coliform. Since total and faecal coliform bacteria manifest very similar trends to those seen when the three other indicator bacteria are studied, no discussion of the *Escherichia coli*, faecal streptococcus, and enterococcus correlations will be included.

5.4.2.1 Nitrate Occurrence

Classification of the land-use practice at five (5) sites was not possible and, as a result, the total number of sites considered for this correlation was 136. New land-use codes were assigned to 61 of the 141 multilevel sites, based on more detailed data collected in the summer sampling. The correlations for both the winter and summer sampling were done using these new codes.

Maximum nitrate-N concentrations at each multilevel site were considered. Generally, the percentage of multilevel sites for any given agricultural activity that were in excess of the drinking water objective of 10 mg nitrate-N L^{-1} was similar between the winter and summer sampling campaigns. About 51% of the 'corn' sites had nitrate-N concentrations greater than 10 mg L^{-1}, compared to 49% contaminated in the winter sampling (Table 20). In the summer sampling, 39% of the 'tobacco' sites exceeded the drinking water objective, similar to the 42% observed in the winter. An additional 25% (as compared to 28% in the winter) of the 'tobacco' sites were in the range from 5 to 10 mg L^{-1}. Row crops (summer: 43%, winter: 38%) also had fairly high percentages of sites where at least one of the multilevel-well water samples exceeded the drinking water objective. As with the results from the winter sampling of the multilevel sites, significant concentrations of nitrate-N occurred under most agricultural land-use practices investigated although the 'corn' sites again had the highest percentages of occurrences of groundwater nitrate-N concentrations above the drinking water objective.

The relationship between nitrate-N concentrations and the presence of a manure system on the farm was examined (Table 21). This correlation appeared to be fairly weak in both samplings. In the summer sampling, 49% of farms where a manure system was present had at least one interval with greater than 10 mg nitrate-N L^{-1}, while 42% of farms on which no manure system was reported had maximum nitrate-N concentrations in exceedence of 10 mg L^{-1}. This is similar to the finding that 52% and 41% of sites with and

without manure systems respectively were over the nitrate-N drinking water limit in the winter sampling.

During the summer survey, further information was collected with respect to manure spreading on the field where the multilevel was located. Multilevel sites were classified as to whether manure had been spread near the multilevel in the last year or not. In the summer sampling, there was little difference between the number of multilevel sites over the drinking water objective where manure was spread (49%) and those sites where no manure was spread (44%) (Table 22). The winter survey had a similar number of multilevels contaminated at sites where manure was used (47%) and where manure was not used (44%). No significant difference, therefore, was observed between sites where manure was applied and was not applied. These findings are similar to the percentages of sites over the drinking water limit when sites with and without manure systems were examined (Table 21).

A further analysis of the nitrate-N data from multilevel sites was undertaken based on nitrogen management on the farm site. Data collected during the summer survey allowed the classification of multilevel sites according to the risk of shallow groundwater contamination. Farms where the amount of nitrogen applied was less than would be recommended for maximum crop production were classified as 'low risk' sites. Farms where the nitrogen application followed accepted standards were classified as 'moderate risk' sites, and farms where the application was in excess of the accepted standards were classified as 'high risk' sites (Table 23). Accepted standards for nitrogen application were based on the amounts and type of commercial fertilizer and manure spread on the farm, consideration of the type of crop and its nitrogen growth requirement, and whether a winter cover crop had been planted to take up excess nitrogen in the winter months. These standards follow the risk assessment strategy set forth by the Ontario Ministry of Agriculture and Food (OMAF, 1990).

A greater proportion of high and medium risk sites, compared to low risk sites, had maximum nitrate-N concentrations in excess of the drinking water objective of 10 mg nitrate-N L^{-1} in both the summer and winter samplings (Table 23). In the summer, 25% of the low risk sites were above the drinking water objective, compared to 52% of medium risk sites and 39% of high risk sites. These proportions for the winter survey were 25% of low risk sites, 46% of medium risk sites, and 55% of high risk sites. A similar trend was observed in the number of sites where maximum nitrate-N concentrations were greater than 5 mg L^{-1}. These proportions were 38% of low risk sites, 64% of medium risk sites and 61% of high risk sites in the summer, and 38% of low risk sites and 68% of medium and high risk sites in the winter.

Table 20: *Land-use vs. maximum nitrate-N concentration in multilevel wells (data from Winter 1992 given in brackets).*

		NITRATE-N CONCENTRATION*				
		< 5 mg/L NO_3^--N Summer [Winter]	5-10 mg/L NO_3^--N Summer [Winter]	> 10 mg/L NO_3^--N Summer [Winter]	Percentage of sites > 10 mg/L NO_3^--N Summer [Winter]	Total
LAND-USE SYSTEM	row crops	16 [19]	5 [5]	16 [15]	43% [38%]	37 [39]
	peanuts	1 [1]	0 [0]	0 [0]	0% [0%]	1 [1]
	corn	17 [16]	2 [5]	20 [20]	51% [49%]	39 [41]
	mixed	2 [2]	1 [2]	2 [1]	40% [20%]	5 [5]
	grain	1 [1]	0 [0]	2 [2]	67% [67%]	3 [3]
	hay	0 [0]	0 [0]	2 [2]	100% [100%]	2 [2]
	orchard	2 [2]	0 [0]	0 [0]	0% [0%]	2 [2]
	vegetables	1 [1]	1 [0]	5 [6]	71% [86%]	7 [7]
	market garden	2 [2]	1 [1]	0 [0]	0% [0%]	3 [3]
	tobacco	13 [11]	9 [10]	14 [15]	39% [42%]	36 [36]
	berries	0 [0]	0 [0]	1 [1]	100% [100%]	1 [1]
	TOTAL	55 [55]	19 [23]	62 [62]		136 [140]

* multilevel concentration from interval with highest concentration.

Table 21: *Presence of manure system vs. maximum nitrate-N concentration in multilevel wells (data from Winter 1992 given in brackets).*

		NITRATE-N CONCENTRATION *				
		< 5 mg/L NO_3^--N Summer [Winter]	5-10 mg/L NO_3^--N Summer [Winter]	> 10 mg/L NO_3^--N Summer [Winter]	Percentage of sites > 10 mg/L NO_3^--N Summer [Winter]	Total
MANURE SYSTEM	manure system present	20 [21]	1 [0]	20 [23]	49% [52%]	41 [44]
	manure system absent	40 [35]	18 [24]	42 [41]	42% [41%]	100 [100]
	TOTAL	60 [56]	19 [24]	62 [64]		141 [144]

* multilevel concentration from interval with highest concentration.

Table 22: *Manure use in vicinity of multilevel vs. maximum nitrate-N concentration in multilevel wells (data from Winter 1992 given in brackets).*

		NITRATE-N CONCENTRATION *				
		< 5 mg/L NO_3^--N	5-10 mg/L NO_3^--N	> 10 mg/L NO_3^--N	Percentage of sites > 10 mg/L NO_3^--N	Total
MANURE USE	manure applied	14 [14]	3 [4]	16 [16]	49% [47%]	33 [34]
	no manure applied	42 [37]	16 [21]	45 [46]	44% [44%]	103 [104]
	TOTAL	56 [51]	19 [25]	61 [62]		136 [138]

* multilevel concentration from interval with highest concentration.

Table 23: *Risk assessment for nitrate leaching vs. maximum nitrate-N concentration in multilevel wells (data from Winter 1992 given in brackets).*

		NITRATE-N CONCENTRATION *				
		< 5 mg/L NO_3^--N	5-10 mg/L NO_3^--N	> 10 mg/L NO_3^--N	Percentage of sites > 10 mg/L NO_3^--N	Total
NITRATE LEACHING Risk Assessment**	LOW	10 [10]	2 [2]	4 [4]	25% [25%]	16 [16]
	MEDIUM	30 [28]	10 [18]	43 [38]	52% [46%]	83 [82]
	HIGH	11 [10]	6 [4]	11 [17]	39% [55%]	28 [31]
	TOTAL	51 [48]	18 [24]	58 [59]		127 [131]

* multilevel concentration from interval with highest concentration.

** risk assessment was determined by examining the amounts of commercial fertilizer and manure applied to the field, and the crops grown over the last two years on the field, in order to determine if the nitrogen application was less than (low risk), approximately equal to (medium risk), or in excess of (high risk) crop nutrient requirements.

5.4.2.2 Bacteria Occurrence

Of the sites selected for total coliform analysis in the summer multilevel sampling, 48 sites were classified according to land-use practice assigned using recent data collected in the summer sampling. These sites can be grouped into seven agricultural practices including row crops, corn, mixed farming, grain, hay, vegetables and tobacco (Table 24). Four main land-use practices will be focused on in this discussion (row crops, corn, mixed farming and tobacco) as they represent the majority of the conditions encountered at this subset of multilevel sites. Again, maximum bacteria counts in each multilevel well will be considered.

As noted earlier, the overall number of sites where at least one of the monitoring intervals exceeded drinking water objectives for total coliforms (previous limit of 10 colonies per 100 mL) declined between the winter and summer samplings. In the summer sampling, 33% of the tobacco sites were above the limit, compared to 71% in the winter sampling (Table 24). In addition, the drinking water objective was exceeded at 38% and 29% of the sites in the summer sampling for the row crop and corn sites respectively, considerably lower than the 67% and 58% of sites in the winter survey. Although the sample size is small (3 sites), a decrease from 67% (winter) to 33% (summer) was observed in the mixed farm sites.

The occurrence of faecal coliforms with respect to land-use is shown in Table 25. Of the sites sampled for faecal coliforms, 50 were classified according to land-use. In the summer sampling, 19% and 17% of the row crop and corn sites respectively had maximum concentrations in excess of 0 colonies per 100 mL, while 22% and 29% exceeded this level in the winter sampling. A smaller number of tobacco sites in both summer (0%) and winter (14%) samplings were above the drinking water limit. The three mixed farming sites showed no occurrence of faecal coliform bacteria.

When both total coliform and faecal coliform results are considered together (Table 26), over 40% of the row crop sites and 38% of the corn sites had at least one of the bacteria concentrations greater than the maximum acceptable limit. This is again lower than the winter occurrences (67% row crops and 62% corn). Tobacco farms had a smaller number of sites (20%) over the drinking water limit in the summer, compared to 71% in the winter.

Sites where total coliforms were analyzed were classified according to the presence or absence of a manure system (livestock). Total coliform concentrations were above the maximum acceptable concentration in at least one interval of the multilevels in 28% of those farms that had a manure system, and 44% that did not have a manure system (Table 27). This is

significantly different than the trend seen in data from the winter sampling where 66% of those farms with a manure system and 58% without a manure system were over the drinking water limit.

About 11% of multilevels on farms having a manure system in the summer sampling had at least one interval that contained faecal coliform bacteria, compared to 18% of multilevels on farms with no manure system (Table 28). This again was considerably different than the results of the winter survey, where 32% of multilevels on farms with manure systems and 5% without manure systems had at least one level over the drinking water limit. Based on the two sampling episodes, it is very difficult to recognize consistent trends in the data regarding the influence of manure application.

As in the case of nitrate-N analysis, the sites were classified as to whether manure had been spread on the field in which the multilevel was located in the last year or not, using new land-use information collected during the summer survey. The percentage of sites with maximum total coliform concentration over the drinking water limit in the summer were approximately the same for sites with manure applied (30%) as for sites with no manure applied (36%) (Table 29). However, in the winter survey, manure sites (76%) were considerably more contaminated than were non-manure sites (55%). It is interesting to note that these same summer and winter trends were noted in the correlation between sites with and without manure *systems* (Table 27).

Comparison of the faecal coliform concentration in multilevels at sites with and without recent manure application show similar trends to the equivalent total coliform correlation. In the summer, the percentage of site with detectable faecal coliform counts was lower for those sites where manure had been spread (5%), compared to sites where manure had not been used (21%), while in the winter sites with manure application were much higher (38%) than sites without (9%) (Table 30). As with the total coliform data, these trends are similar to those seen in correlations between faecal coliform concentration and manure *system* presence or absence on the farm (Table 28).

Table 24: *Land-use vs. maximum total coliform concentration in multilevel wells (data from Winter 1992 given in brackets).*

		TOTAL COLIFORM CONCENTRATION *			
		# 10 colonies /100 mL Summer [Winter]	> 10 colonies /100 mL Summer [Winter]	Percentage of sites > 10 colonies /100 mL Summer [Winter]	Total
LAND-USE SYSTEM	row crops	10 [6]	6 [12]	38% [67%]	16 [18]
	corn	15 [10]	6 [14]	29% [58%]	21 [24]
	mixed	2 [1]	1 [2]	33% [67%]	3 [3]
	grain	0 [1]	0 [0]	[0%]	0 [1]
	hay	1 [0]	0 [1]	0% [100%]	1 [1]
	vegetables	1 [1]	0 [0]	0% [0%]	1 [1]
	tobacco	4 [2]	2 [5]	33% [71%]	6 [7]
	TOTAL	33 [21]	15 [34]		48 [55]

* multilevel concentration from interval with highest concentration.
** certain land-uses missing due to smaller bacteriological sample size.

Table 25: *Land-use vs. maximum faecal coliform concentration in multilevel wells (data from Winter 1992 given in brackets).*

		FAECAL COLIFORM CONCENTRATION *			
		no colonies /100 mL	$ 1 colony /100 mL	Percentage of sites $ 1 colony/ 100 mL	Total
		Summer [Winter]	Summer [Winter]	Summer [Winter]	
LAND-USE SYSTEM**	row crops	13 [14]	3 [4]	19% [22%]	16 [18]
	corn	19 [17]	4 [7]	17% [29%]	23 [24]
	mixed	3 [3]	0 [0]	0% [0%]	3 [3]
	grain	1 [0]	0 [1]	0% [100%]	1 [1]
	hay	0 [1]	0 [0]	[0%]	0 [1]
	vegetables	1 [1]	0 [0]	0% [0%]	1 [1]
	tobacco	6 [6]	0 [1]	0% [14%]	6 [7]
	TOTAL	43 [42]	7 [13]		50 [55]

* multilevel concentration from interval with highest concentration.
** certain land-uses missing due to smaller bacteriological sample size.

Table 26: *Land-use vs. maximum total and faecal total coliform concentration in multilevel wells (data from Winter 1992 given in brackets).*

		TOTAL AND FAECAL COLIFORM CONCENTRATION *			
		does not exceed total and faecal coliforms drinking water objectives *** Summer [Winter]	exceeds total or faecal coliforms drinking water objectives Summer [Winter]	percentage that exceeds total or faecal coliforms drinking water objectives Summer [Winter]	Total
LAND-USE SYSTEM**	row crops	9 [6]	6 [12]	40% [67%]	15 [18]
	corn	13 [9]	8 [15]	38% [62%]	21 [24]
	mixed	2 [1]	1 [2]	33% [67%]	3 [3]
	grain	0 [0]	0 [1]	[100%]	0 [1]
	hay	1 [0]	0 [1]	0% [100%]	1 [1]
	vegetables	0 [1]	0 [0]	[0%]	0 [1]
	tobacco	4 [2]	1 [5]	20% [71%]	5 [7]
	TOTAL	29 [19]	16 [36]		45 [55]

* multilevel concentration from interval with highest concentration.

** certain land-uses missing due to smaller bacteriological sample size.

*** drinking water objectives are #10 total coliforms $(100\ mL)^{-1}$ and 0 faecal coliforms $(100\ mL)^{-1}$

Table 27: *Presence of manure system vs. maximum total coliform concentration in multilevel wells (data from Winter 1992 given in brackets).*

		TOTAL COLIFORM CONCENTRATION *			
		# 10 colonies/100 mL Summer [Winter]	> 10 colonies/100 mL Summer [Winter]	Percentage of sites > 10 colonies/100 mL Summer [Winter]	Total
MANURE SYSTEM	manure system present	23 [13]	9 [25]	28% [66%]	32 [38]
	manure system absent	10 [8]	8 [11]	44% [58%]	18 [19]
	TOTAL	33 [21]	17 [36]		50 [57]

* multilevel concentration from interval with highest concentration.

Table 28: *Presence of manure system vs. maximum faecal coliform concentration in multilevel wells (data from Winter 1992 given in brackets).*

		FAECAL COLIFORM CONCENTRATION *			
		no colonies/100 mL Summer [Winter]	$ 1 colony/100 mL Summer [Winter]	Percentage of sites $ 1 colony/100 mL Summer [Winter]	Total
MANURE SYSTEM	manure system present	31 [26]	4 [12]	11% [32%]	35 [38]
	manure system absent	14 [18]	3 [1]	18% [5%]	17 [19]
	TOTAL	45 [44]	7 [13]		52 [57]

* multilevel concentration from interval with highest concentration.

Table 29: *Manure use in vicinity of multilevel vs. maximum total coliform concentration in multilevel wells (data from Winter 1992 given in brackets).*

		TOTAL COLIFORM CONCENTRATION *			
		# 10 colonies/100 mL Summer [Winter]	> 10 colonies/100 mL Summer [Winter]	Percentage of sites > 10 colonies/100 mL Summer [Winter]	Total
MANURE USE	manure applied	14 [5]	6 [16]	30% [76%]	20 [21]
	no manure applied	18 [15]	10 [18]	36% [56%]	28 [33]
	TOTAL	32 [20]	16 [34]		48 [54]

* multilevel concentration from interval with highest concentration.

Table 30: *Manure use in vicinity of multilevel vs. maximum faecal coliform concentration in multilevel wells (data from Winter 1992 given in brackets).*

		FAECAL COLIFORM CONCENTRATION *			
		no colonies/100 mL Summer [Winter]	$ 1 colony/100 mL Summer [Winter]	Percentage of sites $ 1 colony/100 mL Summer [Winter]	Total
MANURE USE	manure applied	21 [13]	1 [8]	5% [38%]	22 [21]
	no manure applied	22 [30]	6 [3]	21% [9%]	28 [33]
	TOTAL	43 [43]	7 [11]		53 [54]

* multilevel concentration from interval with highest concentration.

5.4.3 Relationship Between Contaminants in Water Wells and Multilevel Monitoring Wells

5.4.3.1 Nitrate Occurrence

Of the 141 multilevel installations in cultivated farm fields, water samples were collected and analyzed from water wells at 134 of the sites. Table 31 shows the relationship between the nitrate-N concentrations observed in the water well and the maximum levels observed in the multilevel on the same farm. For convenience, these results and those for total and faecal coliforms are summarized in Table 32.

In the summer sampling, 48% of the sites were classified in the same nitrate-N concentration category in both the drinking water well and the multilevel (Table 31). At 19% of the sites, the water well had higher nitrate-N concentration than was observed in the multilevel monitoring wells. At 33% of the sites, the maximum nitrate-N concentration of the multilevel site fell in a higher concentration category than that of the water wells.

This was similar to the findings of the winter survey. About the same percentage of sites (49%) were classified in the same nitrate-N category in the winter sampling (Table 32). The percentage of sites that had maximum multilevel nitrate-N concentrations that were in a higher concentration category than the water well on site (35%) and in a lower concentration category than the water well (16%) were also similar values to those found in the summer survey results.

In the majority of cases where the maximum multilevel nitrate-N concentration and the water well concentration exceeded the drinking water limit, the multilevel had higher maximum nitrate-N concentrations (average maximum concentration: 28 mg L^{-1}) than did water wells (16 mg L^{-1}). This agrees with the finding in the winter survey, where the equivalent average maximum concentrations were 24 mg L^{-1} and 17 L^{-1} respectively. If the average nitrate-N concentrations from the multilevels are considered, the concentrations seen in the water wells and the multilevels match much more closely. The average nitrate-N concentration for the multilevel sites where both the multilevel and the water well were in excess of the drinking water limit was 16 mg L^{-1} in the summer survey and 13 mg L^{-1} in the winter survey.

When the average nitrate-N concentration of all intervals in each multilevel were compared to the associated water well concentrations (Table 33), a somewhat different situation was observed. At 46% of the sites, the average concentration category was the same between the multilevel and the water well (Table 32).

A total of 32% of the sites had a water well concentration category that was higher than the corresponding multilevel concentration category, and at 22% of the sites, the multilevel had higher average concentrations than the water wells.

This is somewhat similar to the findings in the winter survey. Fifty percent (50%) of the sites had similar water well and average multilevel nitrate-N concentrations, while at 26% of the sites the water well was in a higher concentration category than was the multilevel and 24% the multilevel was in a higher category than was the water well (Table 32).

Table 31: *Water well nitrate-N concentration vs. maximum nitrate-N concentration in multilevel wells (data from Winter 1992 given in brackets).*

		MULTILEVEL SITES *			
		< 5 mg/L NO_3^--N	5-10 mg/L NO_3^--N	> 10 mg/L NO_3^--N	
		Summer [Winter]	Summer [Winter]	Summer [Winter]	Total
ADJACENT WATER WELL	< 5 mg/L NO_3^--N	31 [39]	10 [11]	27 [27]	68 [77]
	5-10 mg/L NO_3^--N	8 [4]	7 [6]	7 [10]	22 [20]
	> 10 mg/L NO_3^--N	15 [12]	2 [5]	27 [22]	44 [39]
	TOTAL	54 [55]	19 [22]	61 [59]	134 [136]

* multilevel concentration from interval with highest concentration.

Table 32: *Comparison of water well and multilevel contamination categories in the winter and summer surveys for each contaminant.*

		percentage of sites where multilevel is in *higher* concentration category than is the water well	percentage of sites where multilevel is in the *same* concentration category as the water well	percentage of sites where multilevel is in *lower* concentration category than is the water well
		Summer [Winter]	Summer [Winter]	Summer [Winter]
Nitrate-N	Maximum	33% [35%]	48% [49%]	19% [16%]
	Average	22% [26%]	46% [50%]	32% [24%]
Total Coliforms (maximum)		24% [46%]	55% [43%]	21% [11%]
Faecal Coliforms (maximum)		6% [20%]	75% [71%]	19% [9%]
Total and Faecal Coliforms (maximum)		25% [47%]	55% [48%]	20% [5%]

Table 33: *Water well nitrate-N concentration vs.* average *nitrate-N concentration in multilevel wells (data from Winter 1992 given in brackets).*

		MULTILEVEL SITES *			
		< 5 mg/L NO_3^--N	5-10 mg/L NO_3^--N	> 10 mg/L NO_3^--N	
		Summer [Winter]	Summer [Winter]	Summer [Winter]	Total
ADJACENT WATER WELL	< 5 mg/L NO_3^--N	40 [47]	14 [13]	14 [17]	68 [77]
	5-10 mg/L NO_3^--N	13 [8]	7 [9]	2 [3]	22 [20]
	> 10 mg/L NO_3^--N	19 [19]	11 [8]	14 [12]	44 [39]
	TOTAL	72 [74]	32 [30]	30 [32]	134 [136]

* multilevel concentration based on average concentration for all intervals.

5.4.3.2 Bacteria Occurrence

At 47 farms, water samples from multilevel monitoring wells and from adjacent drinking water wells were analyzed for total coliform bacteria (Table 34). As was also noted in the winter survey, the percentage of occurrences in each contaminant category were not much affected by whether maximum or average values were considered. Thus it is only necessary to present maximum multilevel concentrations for these interpretations.

At 55% of the 47 sites, total coliform concentrations in the water well and multilevel fell into the same category (Table 32). At 21% of the sites, the water wells were classified in a higher concentration category than the multilevels and at 24% of the sites, the total coliform concentrations in the multilevels were grouped higher than in the water wells.

The total coliform data collected in the winter gave somewhat different results. The percentage of sites where the maximum multilevel concentration and the water well concentration were in the same category was 43%. A small percentage (11%) of sites had higher total coliform concentrations in the water well than in the multilevel, while at over 46% of the sites, the multilevel had a higher maximum concentration than the concentration measured in the water well.

Faecal coliform data from paired water wells and multilevels are shown in Table 35. The majority of the sites (75%) were grouped in the same faecal coliform concentration category for both the multilevel and the water well (Table 32). At only 6% of the sites the multilevels were in a higher concentration category, while nearly 19% of the sites had levels of faecal coliforms in the water wells that were higher than those seen in the adjacent multilevel.

In the winter sampling, the trends were not the same. Water well and maximum multilevel concentrations matched at 71% of the sites, the multilevel fell into a higher faecal coliform concentration category than did the water well at 20% of the sites, and the water well faecal coliform counts exceeded the multilevel values at 9% of the sites.

When the total and faecal coliform bacteria data from both the water wells and the multilevels are considered together (Table 36), a high percentage of the sites (55%) were classified in the same contamination category for both the multilevels and water wells (Table 32). At 25% of the sites, the multilevel concentration category was higher than the water well category, and at 20% of the sites, the water well category was higher.

Total and faecal coliform bacteria data from the winter survey gave quite different results (Table 32). At a large percentage of the sites (47%), coliform bacteria concentrations were classified in a higher contamination category in the multilevels than in the water wells. At 48% of the sites, the categories were the same, and at only 5%, the water wells were in a higher category.

Table 34: *Water well total coliform concentration vs. maximum total coliform concentration in multilevel wells (data from Winter 1992 given in brackets).*

		MULTILEVEL SITES *		
		# 10 colonies/100 mL Summer [Winter]	> 10 colonies/100 mL Summer [Winter]	Total
ADJACENT WATER WELL	# 10 colonies/100 mL	22 [18]	11 [26]	33 [44]
	> 10 colonies/100 mL	10 [6]	4 [6]	14 [12]
	TOTAL	32 [24]	15 [32]	47 [56]

* multilevel concentration from interval with highest concentration.

Table 35: *Water well faecal coliform concentration vs. maximum faecal coliform concentration in multilevel wells (data from Winter 1992 given in brackets).*

		MULTILEVEL SITES *		
		no colonies/100 mL Summer [Winter]	$ 1 colony/100 mL Summer [Winter]	Total
ADJACENT WATER WELL	no colonies/100 mL	33 [38]	3 [11]	42 [49]
	$ 1 colony/100 mL	9 [5]	3 [2]	6 [7]
	TOTAL	36 [43]	12 [13]	48 [56]

* multilevel concentration from interval with highest concentration.

Table 36: *Water well total and faecal total coliform concentration vs. maximum total and faecal coliform concentration in multilevel wells (data from Winter 1992 given in brackets).*

		MULTILEVEL SITES *		
		does not exceed total and faecal coliform drinking water standard * Summer [Winter]	exceeds total or faecal coliform drinking water standard Summer [Winter]	Total
ADJACENT WATER WELL **	does not exceed total and faecal coliform drinking water standard	19 [18]	11 [26]	30 [44]
	exceeds total or faecal coliform drinking water standard	9 [3]	5 [9]	14 [12]
	TOTAL	28 [21]	16 [35]	44 [56]

* multilevel concentration from interval with highest concentration.

** total coliform and faecal coliform drinking water limits are > 10 colonies/100 mL and $ 1 colony/100 mL respectively.

5.4.3.3 Pesticide Occurrence

In comparing the occurence of detectable pesticides in both the farm well and the multilevel wells (Table 37), it is apparent that detections were more frequent in the drinking wells than in the monitoring wells. This was consistent in both the winter and summer sampling data sets.

Table 37: *Incidence of pesticide detections and exceedances of IMAC values in multilevel sampling wells compared to adjacent drinking water wells (data from Winter 1992 given in brackets).*

		FIELD MULTILEVEL			
		No Detects	Detects but <IMAC	>IMAC	
		Summer [Winter]	Summer [Winter]	Summer [Winter]	Well Totals
ADJACENT WATER WELL	No detects	94 [113]	5 [6]	1† [0]	100 [119]
	Detect but <IMAC	18 [12]	2 [0]	0 [0]	20 [12]
	>IMAC	0 [1]‡	0 [0]	0 [0]	0 [1]
	Multilevel totals	112 [126]	7 [6]	1 [0]	120 [133]

† 60 µg L^{-1} cyanazine.
‡ 110 µg L^{-1} metolachlor.
Note: One drinking water well had >IMAC for alachlor in winter, and another had >IMAC for metolachlor in winter, but multilevel sampling wells were not installed at these two sites.

5.4.4 Nitrate and Bacteria Concentration Under Cultivated and Uncultivated Conditions

At 16 of the multilevel sites, a second multilevel was installed in uncultivated woodlots adjacent to the field multilevel. Only one of the woodlot sites had nitrate-N concentrations above 10 mg L^{-1}, compared to four sites where high nitrate-N concentrations were observed in the adjacent cultivated field (Table 38). This observation agrees with the findings of the winter sampling.

Table 39 indicates that the percentage of field sites (60%) and woodlot sites (50%) that show total coliform counts above the previous maximum acceptable limit (10 colonies per 100 mL) were similar. In the winter, percentage of the maximum total coliform concentrations exceeding the objective for the multilevel sites was also similar, although somewhat higher (80% for both field and woodlot sites).

This trend is also seen for faecal coliforms (Table 40), where in the summer, 33% of both field and woodlot sites were in excess of the faecal coliform drinking water limit, and in the winter, 60% and 40% of the field and woodlot sites were over the drinking water limit. Since total and faecal coliform bacteria counts were conducted at only 5 sites in the summer and 6 sites in the winter, the above correlations are not statistically significant. The number of sites in excess of either the total coliform or the faecal coliform drinking water limit decreased somewhat during the summer sampling (Table 41).

It should be noted that the number of sites where cultivated and uncultivated conditions were compared is quite small and it is difficult to draw direct conclusions from this data. It is apparent, however, that bacterial contamination exists and persists in the groundwater under both the cultivated and uncultivated conditions in both the summer and the winter. It may be noted that agriculture is not responsible for all total coliform bacteria levels. Total coliform bacteria are also encountered where organic material is degraded naturally, although it is not commonly encountered in groundwater at levels approaching the maximum acceptable limit. Nitrate, however, does not seem to occur in high concentrations in the uncultivated woodlot setting even if high concentrations are observed in the adjacent cultivated field.

Table 38: *Maximum nitrate-N concentration in field vs. woodlot multilevel sites (data from Winter 1992 given in brackets).*

		NITRATE-N CONCENTRATION *				
		< 5 mg/L NO_3^--N Summer [Winter]	5-10 mg/L NO_3^--N Summer [Winter]	> 10 mg/L NO_3^--N Summer [Winter]	Percentage of sites > 10 mg/L NO_3^--N Summer [Winter]	Total
TYPE OF SITE	field sites	8 [7]	4 [3]	4 [6]	25% [38%]	16 [16]
	woodlot sites	12 [14]	3 [1]	1 [1]	6% [6%]	16 [16]
	TOTAL	20 [21]	7 [4]	5 [7]		32 [32]

* multilevel concentration from interval with highest concentration.

Table 39: *Maximum total coliform concentration in field vs. woodlot multilevel sites (data from Winter 1992 given in brackets).*

		TOTAL COLIFORM CONCENTRATION *			
		# 10 colonies/100 mL Summer [Winter]	> 10 colonies/100 mL Summer [Winter]	Percentage of sites > 10 colonies/100 mL Summer [Winter]	Total
TYPE OF SITE	field sites	2 [1]	3 [4]	60% [80%]	5 [5]
	woodlot sites	3 [1]	3 [4]	50% [80%]	6 [5]
	TOTAL	5 [2]	6 [8]		11 [10]

* multilevel concentration from interval with highest concentration.

Table 40: *Maximum faecal coliform concentration in field vs. woodlot multilevel sites (data from Winter 1992 given in brackets).*

		FAECAL COLIFORM CONCENTRATION *			
		no colonies/100 mL Summer [Winter]	$ 1 colony/100 mL Summer [Winter]	Percentage of sites $ 1 colony/100 mL Summer [Winter]	Total
TYPE OF SITE	field sites	4 [2]	2 [3]	33% [60%]	6 [5]
	woodlot sites	4 [3]	2 [2]	33% [40%]	6 [5]
	TOTAL	8 [5]	4 [5]		12 [10]

* multilevel concentration from interval with highest concentration.

Table 41: *Maximum total and faecal total coliform concentration in field vs. woodlot multilevel sites (data from Winter 1992 given in brackets).*

		TOTAL AND FAECAL COLIFORM CONCENTRATION *			
		does not exceed total and faecal coliform drinking water standard ** Summer [Winter]	exceeds total or faecal coliform drinking water standard Summer [Winter]	percentage that exceeds total or faecal coliform drinking water standard Summer [Winter]	Total
TYPE OF SITE	field sites	2 [0]	3 [5]	60% [100%]	5 [5]
	woodlot sites	2 [0]	4 [5]	67% [100%]	6 [5]
	TOTAL	4 [0]	7 [10]		11 [10]

* multilevel concentration from interval with highest concentration.
** drinking water objectives are #10 total coliform $(100\ mL)^{-1}$ and 0 faecal coliform $(100\ mL)^{-1}$.

5.4.5 Influence of Sediment Type on Nitrate and Bacteria Occurrence and Persistence with Depth

To examine the vertical distribution of nitrate and bacteria, all analyses from each level in the multilevel wells were considered together and plotted on Fig. 32 to 35. The depth intervals ranged from near the watertable for level 1 to approximately 10 m at level 6.

In the summer survey, nitrate-N was seen to decrease almost linearly with depth as average concentrations dropped from 10.8 mg L^{-1} in the shallowest interval to 3.1 mg L^{-1} in the deepest interval (Fig. 32). This is very similar to the findings of the winter survey, where average concentrations decreased from 9.3 mg L^{-1} to 3.3 mg L^{-1}.

In both the summer and winter samplings, the total coliform and faecal coliform data both showed a greater persistence with depth than was observed for nitrate and were in fact more prevalent at medium depths around 5 m (Fig. 33 and 34). Both showed a decreasing trend with depth below approximately 5 m. The average concentrations of both total and faecal coliform bacteria, however, decreased significantly in the summer sampling.

It was also possible to compare depth persistence with sediment type for nitrate given the size of this data set. This plot, shown in Fig. 35, indicated that the same trends were observed in both the clay sediments and the sandy sediments although the monitoring wells in the clay materials did not go as deep as those in sandier sediments. On average, the concentrations at shallow depth in clay materials in the summer and winter were somewhat higher than those observed in the sand. In all sediments, concentrations of nitrate-N generally decreased with depth.

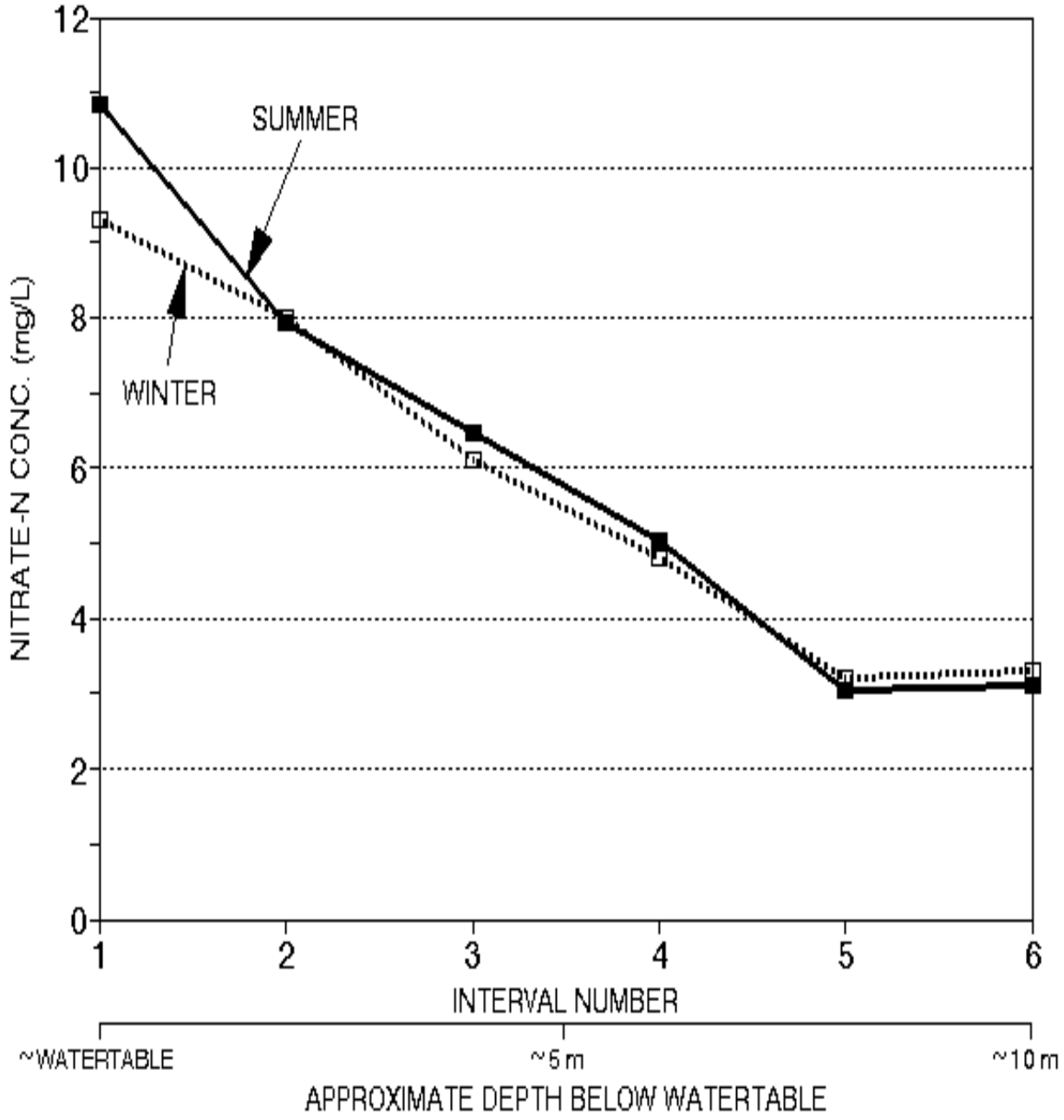


Fig. 32: *Average nitrate-N concentration versus depth below watertable.*

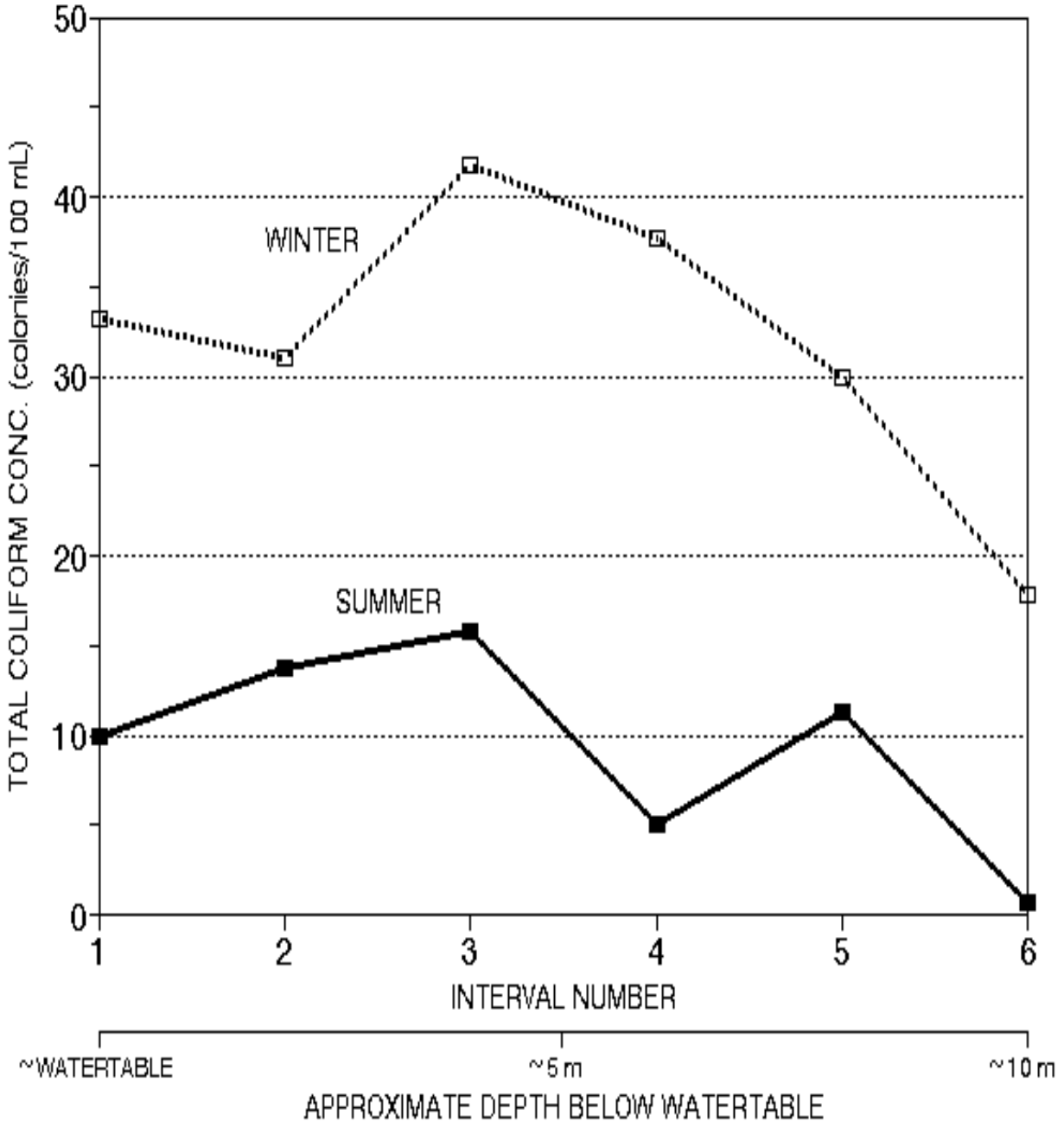


Fig. 33: *Average total coliform concentration versus depth below watertable.*

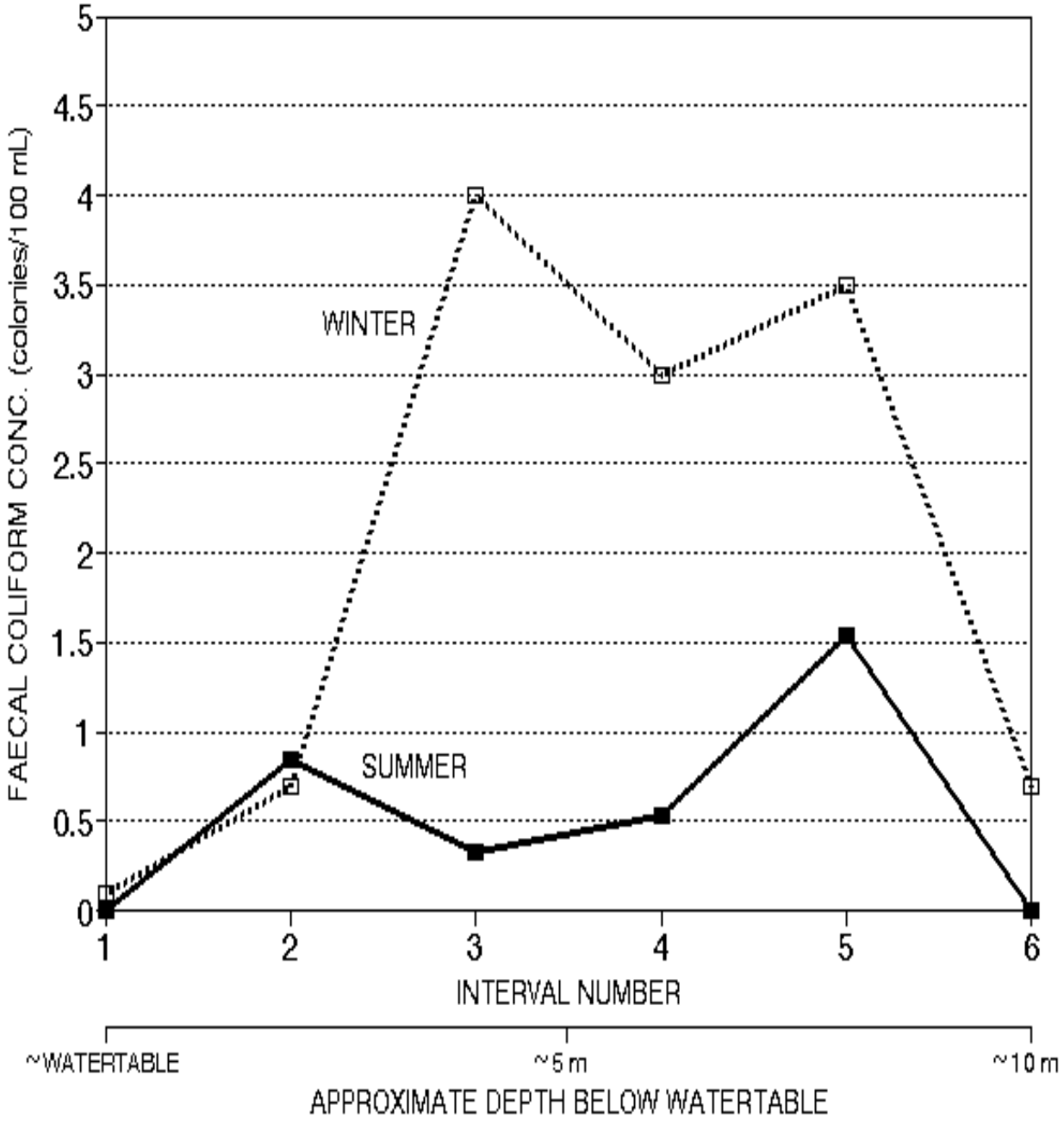


Fig. 34: *Average faecal coliform concentration versus depth below watertable.*

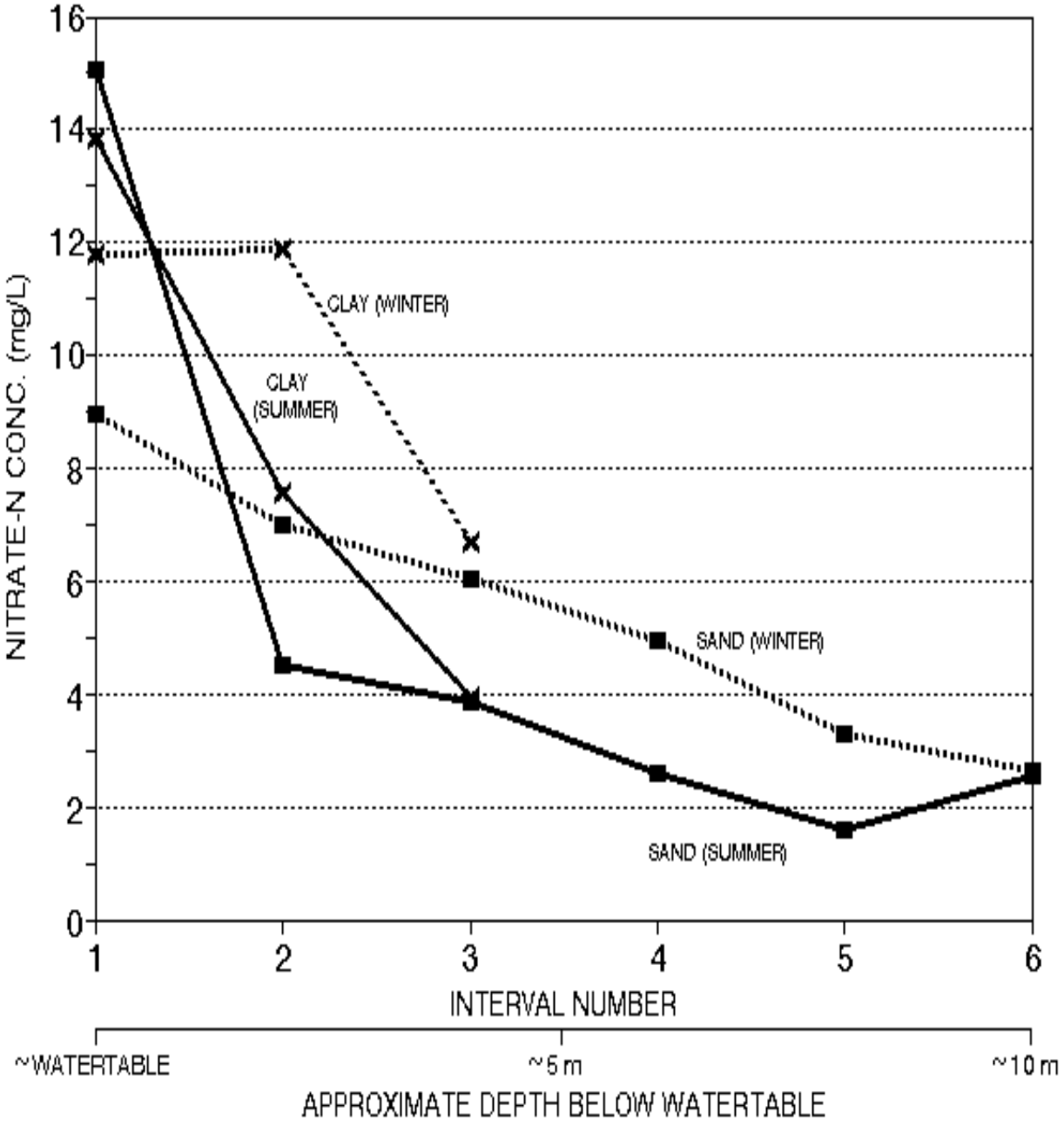


Fig. 35: *Average nitrate-N concentration versus depth below watertable by principal sediment types.*

6.0 Discussion

6.1 Water Well Results

The main objectives in conducting a summer sampling of the water wells and multilevel wells sampled during the winter of 1991-1992, were to verify the general trends and conclusions drawn from the first sampling, and to investigate the influence of seasonal change on contaminant distribution. The second data set provided considerable insight into both of these questions and provided additional information on the regional condition of rural groundwater resources.

The summer sampling indicated that 40% of the drinking water wells were in exceedence of the drinking water objectives for at least one of the target contaminants (nitrate-N, coliform bacteria, and several common herbicides). This value was very similar to the 37% encountered during the winter survey, and provides further confidence that this level of contamination is fairly representative of provincial conditions.

For the specific contaminants, coliform bacteria was again confirmed to be the most common contaminant, occurring above the Ontario drinking water objective in over 32% of the test wells. For nitrate-N, about 14% of the wells were in exceedence of the objective. These values are very similar to those encountered during the winter survey. However, several additional observations can be made. A strong correlation between the wells found to be contaminated with nitrate occurred between the winter and the summer. Although the mean concentration increased by 7% in the summer sampling, the magnitude and distribution of nitrate contamination remained fairly constant between the two seasons. Further monitoring of nitrate-N levels would be required to determine whether this increase in average concentration and frequency of contamination is due to a seasonal effect or evidence of a longer-term trend.

The bacterial distribution presents a somewhat different situation. The levels of total and faecal coliform bacteria increased somewhat in the summer sampling but, in addition, many wells not contaminated in the winter sampling showed elevated levels in the summer and vice versa. This illustrates the inherent variability in bacterial concentrations in the groundwater environment. This result was not unexpected. It has previously been noted in monitoring programs of the MOH (M. Brodsky, pers. commun.) The variability is likely due in part to many factors, including seasonal climate changes, manure application schedules, and variations in agricultural activities during the year. Bacteria

appear to be much more susceptible to these changes than nitrate and as such, more variable.

It must be noted that the interpretation of bacterial concentration data was based on a single water sample from each well during each of the sampling rounds. Because significant variations in bacteria levels are often seen between samples taken over a short period of time, the Ministry of Health recommends three (3) samples be taken in succession to provide a more realistic representation of the actual concentrations. Single sample results cannot provide conclusive evidence for correlations but they can provide evidence for trends or relationships between bacterial counts and various other factors. Nevertheless, significant variations in bacteria counts were observed between the winter and summer samplings, and a more continuous record of concentrations over the entire year would be required to understand the nature of this variability.

The results of the winter survey indicated that bacterial levels in Southern Ontario appeared to be higher in general than those encountered in Northern Ontario. The results of the summer survey do not substantiate this conclusion. The levels of contamination by all the target contaminants do not appear to differ significantly between the north and south of the Province.

As was observed in the winter survey, the occurrence of pesticide residues above the maximum acceptable limits was extremely low. Only two (2) wells were found in exceedence of these limits and one was the result of a documented spill. If the U.S. standards had been used to classify the level of contamination, 1% of the wells surveyed would have been in excess of the acceptable limits. The number of wells with detectable levels of pesticides was somewhat higher in the summer (11.5%) compared to the winter (7.5%).

When specific physical correlations were attempted with the summer data, trends and observations similar to those seen from interpretation of the winter survey results emerged. Firstly, dug or bored wells and driven sandpoints were more frequently contaminated than drilled wells, even when completed to the same depth. The drilled and cased well construction appears to provide certain advantages with respect to maintaining high water quality in the rural environment.

Other correlations can be made that agree with those observed during the winter survey. The frequency of contamination tends to increase with well age and decrease with well depth. As noted during the winter survey, there were no clear correlations between the specific agricultural land-use practices and the occurrence of groundwater contamination. The weak trend towards higher nitrate-N concentrations observed in 'corn systems' (rotations in which corn

and/or soybeans occupy more than 30% but less than 90% of the land area) during the winter was not seen in the summer sampling results.

Livestock operations were also shown to have a significant impact on well water quality. Comparisons between sites where manure systems were present or absent, or manure was applied or not, showed that bacteria concentrations were above the acceptable limit on more farms with manure systems, and where manure was being used regularly than on other farms. The impact of manure application was greatest on faecal coliform levels. In addition, the closer the wells were to a feedlot, the greater the contamination with bacteria. In contrast, the occurrence of nitrate-N above the drinking water objective was unaffected by the presence of manure systems, or the distance from a feedlot. Furthermore, the occurrence of nitrate-N above drinking water objective was somewhat higher on sites where manure was not applied than where it was being used. This difference could be explained, in part, by an interaction between soil type and effect of manure use on contamination occurence.

The influence of soil type and hydrologic characteristic on the occurrence of bacteria contamination did not show a simple relationship. However, in both the winter and summer samplings, bacteria contamination tended to be lowest in the most permeable soils. Nitrate contamination was most frequent in the coarser, more permeable sediments, and decreased as the permeability and infiltration capacity of the sediment declined. When the summer data was superimposed on the risk map of susceptibility to groundwater contamination prepared by the Ministry of the Environment, the nitrate contaminated wells correlated closely to the high risk areas. The wells contaminated with coliform bacteria were much more widely distributed, indicating that many other factors may influence the occurrence of bacteria contamination in the water wells. Also of interest was the fact that pesticide detections were much more frequent in wells where high nitrate was observed, indicating a similarity between the transport pathways for both types of contaminant.

The influence of point sources on the farm were also investigated during the summer survey and, as was seen in the winter, only the proximity of the feedlots to the water wells correlated to the bacteria levels encountered in the well. Feedlots may represent a significant point source of contamination on farms. A trend indicating an increased frequency of bacteria contamination with increasing distance from the septic tank, not the weeping bed, was observed. The significance of this correlation remains a question.

6.2 Multilevel Results

The multilevel monitoring wells were designed as permanent installations below the active farm fields to permit sampling of groundwater on a continuous basis if required. After the samples were taken from these monitoring wells in the winter of 1991, they were covered over with natural soil and routine agricultural activity proceeded over the subsequent 7 to 8-month period until they were resampled in the summer of 1992. Samples taken during the summer survey will reflect any variations in groundwater quality that may have occurred as the seasons and the nature of the agriculture change. The majority of multilevel wells were installed in permeable, sandy soils.

In considering concentrations of nitrate-N in the multilevels, both the maximum of each site and the average over all depths were considered. The average may be more comparable to the concentrations one might encounter in a shallow dug or bored well that is continuously screened from the watertable to its maximum depth. During both the summer and winter samplings, the percentage of sites that had at least one sampling interval in exceedence of the drinking water objective was about 44%. If average concentrations were taken, 21% of sites were above the limit in the summer, very similar to the 24% of sites in the winter. In addition, over 80% of the sites where nitrate levels were found above the limit in the summer also exceeded the drinking water objectives in the winter.

Based on the information from the two surveys, it appears as though there was little or no effect of seasonality on the magnitude and general distribution of nitrate contamination from under the active farm fields. The occurrence of bacterial levels above the drinking water objective appeared to decrease significantly in the summer sampling. Multilevel samples taken in the summer exceeded the recommended objectives at approximately one half (½) as many sites as in the winter. It can also be noted, however, that about 70% of the multilevels exceeding the bacterial objectives in the summer were also in exceedence in the winter.

These significant variations in levels of bacteria beneath the farm fields between winter and summer likely reflects the influence of manure application schedules, variations in surface hydrology between the winter and summer seasons, and variations in biological activity in the root zone during the growing and dormant cycles. Bacterial levels under the active agricultural fields appear to be quite sensitive to seasonal change.

The occurrence of pesticide residue detections increased slightly in the summer sampling from 2.5% to 3.2% of the total suite of samples analyzed. Only one detection (60 µg L^{-1} cyanazine in the

summer) exceeded the interim acceptable standards. There appeared to be an increase in the number of detections of the atrazine metabolite, d-ethyl atrazine, in the summer. This increase may be related to application schedules for the herbicide and its breakdown rate during the different seasons.

As seen during the winter survey, no clear correlation was observed between the cropping practice on an individual farm and the level of nitrate, total coliform or faecal coliform bacteria encountered in groundwater beneath the active fields. In the case of nitrate, the percent occurrence of samples exceeding the drinking water objective was highest where corn was the dominant crop. This result agrees with the winter findings. The presence or absence of a manure system again showed no relationship to nitrate-N levels.

In order to evaluate the nitrate data in more detail, all multilevel sites were classified as low, medium, or high risk sites for potential leaching of nitrate. The classification was based on amounts and types of commercial fertilizers and manures used on the farm, types of crops and their nitrogen growth requirements, and use of winter cover crops. It was found to represent the data set quite reasonably and may prove useful in evaluating potential risk on a general basis.

In considering the bacteria data from the summer sampling, drinking water objectives were exceeded by a higher percentage of sites without manure systems compared to sites with a manure system. This is the reverse of the trend observed in the winter season and contrasts with the results of the water well survey. It again indicates the variability of bacterial concentrations in the shallow groundwater. It should also be pointed out that all the multilevel wells from which samples for bacteria analysis were obtained had been installed in permeable, sandy soils.

Of particular interest in the evaluation of the multilevel data is the relationship between the levels of contamination found in the monitoring wells placed in the farm fields and the contaminant levels in the drinking water wells on the associated farms. Considering the average nitrate-N concentrations in the multilevels, at about 50% of the sites both the drinking water well and the multilevel were classified in the same concentration category. This trend was observed both in the winter and summer samplings and indicates a strong correlation between levels of nitrate-N in the shallow groundwater under farm fields and levels in the drinking water well. It should also be noted that about 80% of the water wells on the multilevel sites are shallow dug or bored wells.

The smaller subset of multilevel wells that were analyzed for bacteria concentration showed somewhat different results from those seen in the nitrate data. The majority of the paired water wells

and multilevels fell into the same concentration category (55% for total coliform and 75% for faecal coliform), as was observed in the winter sampling. In the summer, however, a higher percentage of the water wells were classified in a higher concentration category than the adjacent multilevel, again illustrating the inherent variability in bacteria levels in the groundwater. Both the summer and winter surveys indicate that levels of bacteria concentration in the water wells correlates fairly closely to the bacteria levels under adjacent active farm fields.

One of the interesting observations made with respect to the winter survey data related to the occurrence of nitrate and bacteria in woodlot areas. Bacteria concentrations were similar under the cultivated fields compared to the woodlot areas. Nitrate however was generally not found in the woodlots even at sites where relatively high levels were observed under the adjacent agricultural field. This same trend was seen during the summer season. Although the sample size is small, it suggests the possibility that processes associated with woodlots may lead to the removal of nitrate from groundwater. Further research on this topic is currently underway.

As a final physical correlation, the average nitrate-N, total coliform, and faecal coliform concentrations at all depths in the multilevels were plotted with respect to monitoring point depth. The nitrate data showed nearly the identical trend of decreasing concentration with depth as was seen in the winter survey. The average concentrations at all depths were the same in winter and summer. The bacteria data illustrated the same trends as observed during the winter sampling, including a somewhat greater persistence with depth than was observed for nitrate. Average bacteria concentrations, however, were significantly less in the summer survey.

Data from the multilevel monitoring wells sampled during the summer and winter indicate little or no seasonal variation in the nitrate-N concentrations, and an overall decrease in bacteria concentrations, although most general trends remained constant. The multilevel monitoring wells provide insight into the correlation between levels of groundwater contamination in farm drinking water wells and in the shallow groundwater in agricultural fields adjacent to the wells.

The installation of a series of multilevel monitoring wells spatially distributed throughout the cultivated field and in the vicinity of the well would help to provide a clearer understanding of the movement of groundwater contaminants on farms. Studying the transient movement of these contaminants in the shallow groundwater regime will be crucial in the development of strategies to minimize the impact of agriculture on rural groundwater resources.

7.0 Future Research Directions

The results of the survey have provided baseline information on the general occurrence in Ontario of groundwater contaminants commonly associated with agriculturally developed areas. The information obtained also raises a series of additional questions, and points towards several areas that require research to develop a stronger knowledge base in the area of groundwater contamination and the quality of water in rural water wells.

An indication of seasonal changes in contaminant levels in the surveyed wells was apparent from the two data sets. Temporal variations in contaminant concentrations need to be documented throughout the entire year and efforts should be made to relate these variations to local hydrology, soil conditions and the scheduling of manure, fertilizer and pesticide applications. In addition, the possibility of long-term trends in the level of contamination for nitrate, bacteria and pesticides needs to be established unequivocally. This will require the establishment of a small representative network of wells throughout the Province that can be sampled on a regular basis for analysis of water quality.

Several of the specific correlations made between physical conditions on the farm and the occurrence of groundwater contamination warrant further investigation. The storage and land application of manure appear to be significant in determining the bacteria concentrations found in wells. Research related to improved manure handling and strategic use of woodlots, wetland areas and crop rotation schedules, will be critical.

More information is required to explain the differences between farms where manure was spread and where it was not, in the frequency of nitrate contamination. At the level of processes, the importance of the additional carbon returned to the soil in manure compared with mineral fertilizer could be a factor. Recent studies have suggested that greater knowledge of soluble or colloidal carbon fractions in the soil is necessary to understand the persistence of nitrate below the root zone.

The impact of local hydrology on contaminant loading to the water table beneath cultivated fields needs to be investigated in more detail. Surface topography and surface runoff and transport can redistribute fertilizers and pesticides such that certain areas of the field contribute more significantly than others. The variation of concentration with depth below the water table and the relative placement of shallow well screens is also an area of interest.

The significance of septic systems and other point sources of nitrate and bacteria for contamination of groundwater on farms also needs to be clarified.

Underlying the programme on groundwater quality is the assumption that there is a significant health risk associated with drinking contaminated water. These studies need to be augmented with a detailed epidemiological investigation to identify the health risks to farm families from the levels of contamination current in groundwater.

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Appendix A: Methods

A.1 Multilevel Monitoring Well Installation Methods

The multilevel monitoring wells were installed during October 1991 to March 1992. An auger drill rig (Canterra CT150) owned by the University of Waterloo was used until early January 1992, when field conditions became too difficult to use this tire-mounted rig. Dominion Soils Ltd. (London, Ontario) was contracted between January and March 1992 to complete the remaining installations, with a CME 55 drill rig mounted on wide tracks. Both drill rigs operate with solid or hollow-stem auger flights. The auger drilling does not require the use of any drilling fluid.

The type of monitoring well installation used at a given site was dictated by the nature of the subsurface materials encountered. Where non-cohesive materials such as sand and gravel were encountered, bundle-type monitoring wells were installed. In this procedure, the hollow-stem auger flights were used to drill to the desired depth and then the monitoring well was lowered down the inside of the hollow-stem augers. The monitoring well in this instance consists of 2.0 cm PVC centre stock with individual 1.5 cm polyethylene tubes fastened to the centre stock at different levels. Each of the polyethylene tubes and the PVC centre stock were furnished with a short well-screen (Fig. A1a). The auger flights were removed and the non-cohesive material naturally collapsed around the multilevel monitoring well below the watertable. A bentonite seal was placed 0.5 m above the watertable and the remaining part of the borehole back-filled to surface. Commonly, installations of this type of material were between 8 and 12 metres in depth with five to six discrete monitoring levels in each borehole.

At sites where the subsurface material was cohesive and not expected to collapse after drilling, such as clay, till, and clay-rich loams, solid-stem auger flights were used to drill the borehole. Two installation techniques were used in these types of materials. The first involved the placement of individual 2.0 cm PVC pipes with well screens at various depth intervals in the same borehole. A sand pack was placed around each well screen and the individual monitoring levels were separated by a bentonite seal (Fig. A1b). Generally, three to four monitoring points were installed in each borehole. Where the subsurface material was very stiff, the auger flights could cause severe smearing of the borehole wall. This smearing could restrict groundwater movement into the sand pack around the well. To prevent smearing, individual boreholes were drilled for each monitoring point. The borehole was advanced to 30 cm above the target depth and the augers were removed. A thin-walled sampling tube (Shelby) was then pushed into

the base of the borehole to produce a less altered hole for the monitoring well screen. The well was then placed into the cored hole, a sand pack placed around the screen and the hole back filled with a bentonite seal. In the cohesive materials (clay), a depth of 5 m below the watertable was a common maximum depth for the installations (Fig. A1, design 'c').

In some cases, a combination of the two soil types described above was encountered on site. In these cases, an appropriate combination of the different installation methods was used.

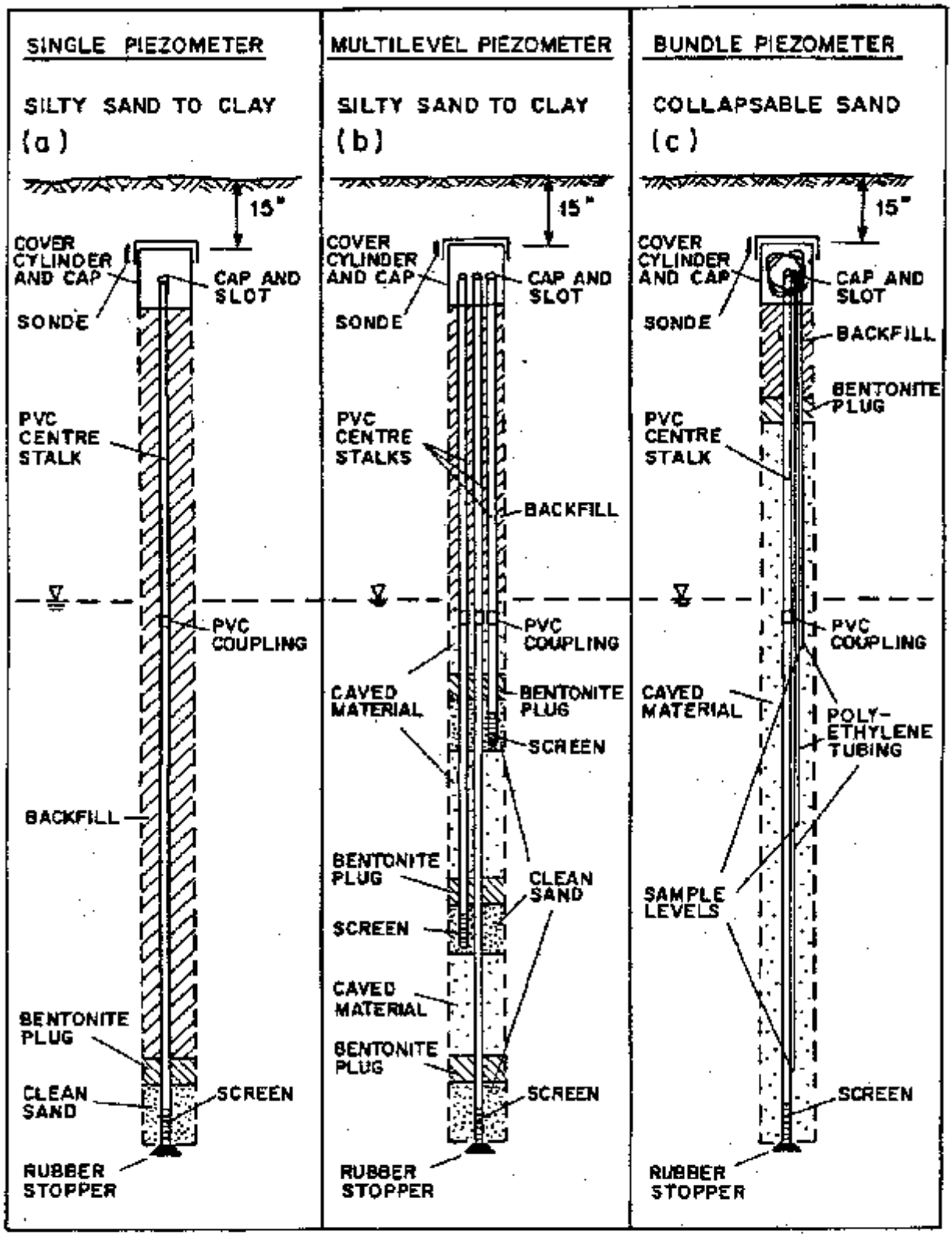

Fig. A1. *Construction of multilevel monitoring wells.*

A.2 Groundwater Sampling and Reporting Procedures

A.2.1 Water Well Sampling and Reporting Procedures

Drinking water wells were sampled for five herbicides, a herbicide metabolite, nitrate, and bacteria. A subsample of the survey water wells (160 sites) were sampled for petroleum derivatives, but only during the winter sampling programme. Field inspectors from OSCIA were trained in water sampling during a weekend course in Etobicoke, Ontario in August 1991. They were instructed to collect samples from the tap closest to the well head before the water had passed through any water treatment device. The majority of samples were collected from kitchen taps. The taps were opened for a period of at least 5 minutes prior to sampling, to allow fresh water to enter from the formation around the well and to flush any bacteria from the exposed parts of the tap. Aerators and other faucet attachments were removed before a sample was collected.

Inspectors collected pesticide samples in 1-L amber glass bottles, nitrate samples in 20 mL polyethylene vials, and bacteriological samples in a 250 mL plastic, sterile, screw-capped bacteriological bottle that contained a preservative (sodium thiosulphate). Care was taken not to touch the inside of the cap or the neck of bacteriological samples to avoid contamination. All samples were stored in the dark at cool temperatures. Bacteriological samples were analyzed within 24 hours at local Ministry of Health laboratories, and the results mailed to The Centre For Land and Water Stewardship, Univ. of Guelph. Samples for nitrate and pesticide analysis were shipped weekly to the Centre for Land and Water Stewardship, where they were distributed to the appropriate laboratories. The samples for pesticide residue analyses were collected in one litre amber glass bottles, sealed with Teflon-lined caps and stored as received [room temperature]. The storage time prior to analysis ranged from two to six weeks. In-house studies by OMAF have shown that the herbicides chosen for residue analysis are stable for extended periods of time under these conditions. Gasoline derivative (BTEX) samples were analyzed within one week of collection in the field.

When a problem level of bacteria, nitrate, or pesticide was detected in a sample, the cooperating landowner was promptly contacted by OSCIA personnel. The landowner was advised to request assistance from the local Board of Health or the Ontario Ministry of the Environment for interpretation and remedial suggestions. At the end of the project, an individual water analysis report was mailed to each cooperator.

A.2.2 Multilevel Sampling Procedure

At all sites, water levels in each sampling tube of the multilevel wells were measured at time of sampling to determine the vertical hydraulic gradient. The collection depth of some sampling tubes was above the watertable and thus samples from each depth interval of a multilevel well could not always be collected. Care was taken to minimize cross-contamination between intervals, and between multilevels. Sampling was done from the deepest to the shallowest interval in all multilevels since deeper levels were expected to have the lowest concentrations of contaminants. A length of Teflon tubing connected to a battery-driven peristaltic pump was lowered into each sampling tube to collected a water sample. This collection system was emptied of water and then rinsed with 1 L water from the interval being sampled, before taking the samples.

Water samples from the multilevel monitoring wells underwent the same analyses as those from the drinking water wells. Bacteriological samples were mostly taken on farms which indicated livestock as one of the farming practices. Some samples were taken on farms with no livestock for comparison purposes. Bacteriological water samples containing silt were filtered with a Whatman 40 filter before submitting them to the laboratory. Bacteriological samples were always submitted for analysis within 24 hours of sampling.

On completion of the sampling process, a capped section of pvc pipe was placed over the top of the monitoring wells. A 3M telephone sonde marker was securely fastened to the cap using electrical tape for ease of future relocation. All multilevels were buried 0.4-0.5 m deep and their location marked on a site map after using a trundle wheel to determine distances.

Blanks of deionized water for nitrate, pesticide, and bacteria analysis, were treated in the same fashion as the actual samples. The blanks were sampled through the Teflon tube using a battery-driven peristaltic pump. All results were below the detection limit, so it was felt that cross contamination due to residues in the Teflon tube was unlikely.

Duplicates of all types of analyses were taken from 21 multilevels (12% of the total number of sites). The pooled standard deviation of the nitrate duplicates is not greater than 0.53 mg L^{-1} NO_3^--N (within a 95% confidence interval). The total coliform counts showed a pooled standard deviation not greater than 11.1 colonies per 100 mL (within a 95% confidence interval). All the faecal coliform duplicates that were collected were below detection.

Nitrate-N standards (0.0102, 0.102, 1.02, and 10.2 mg L^{-1} NO_3^--N) were submitted regularly throughout the sampling period. The

average 1.02 mg L^{-1} standard deviated +8.8% from the true value (ó = 0.07 mg L^{-1}), and the average 10.2 mg L standard deviated -3.9% from the true value (ó = 0.19 mg L^{-1}). The average 0.102 mg L^{-1} standard deviated 66.7% from the true value (ó = 0.02 mg L^{-1}), probably due to less accuracy at low concentrations. All the 0.0102 mg L^{-1} standards were below the detection limit of 0.02 mg L^{-1}, as expected.

The distribution of multilevel wells sampled during the summer survey is shown in Table A1.

A.3 Analytical Methods for Water Chemistry

A.3.1 Nitrate-N

The nitrate-nitrogen (nitrate-N) content of the well water was analyzed at the Analytical Services Laboratory, Department of Land Resource Science, University of Guelph. A Traacs-800 auto-analyzer was used to measure the nitrate-N content colorimetrically after reduction to nitrite, using a copper-cadmium column, and formation of an azo dye using N-1-naphthylethylene diamine. The limit of detection for nitrate was 0.02 mg N L^{-1}.

A.3.2 Bacteria

Well water samples were sent to regional laboratories of the Ontario Ministry of Health. All samples were tested for total coliforms and faecal coliforms. In addition a proportion of farms carrying livestock were tested for faecal streptococcus, *Escherichia coli*, and enterococcus spp. Results were reported as colonies per 100 mL. Not all MOH labotratories were able to conduct the latter three tests, and thus some water samples from farms with livestock did not undergo those tests.

Depending on the size of the sample submitted some laboratories reported the actual number for any value, while others reported large numbers as "greater than" a limiting value for a particular contaminant. For example, in the winter sampling programme there were ten samples that were reported as actual numbers of total coliforms when in excess of 80, and 114 samples that were reported as ">80".

Total coliforms are defined as oxidase negative, gram negative, non-spore-forming, facultatively anaerobic, rod-shaped bacteria capable of fermenting lactose with the production of acid and gas within 48 h when incubated at 35 ± 0.2EC. When incubated on m-Endo-LES agar, coliform colonies develop a

Table A1. *Distribution of multilevel wells sampled in Southern Ontario during the summer survey.*

County	Township	No.	County	Township	No.
Brant	Burford	3	Niagara N.	W.Lincoln	2
Brant	Oakland	1	Niagara S.	Pelham	1
Brant	S.Dumfries	2	Niagara S.	Wainfleet	5
Elgin	Aldborough	4	Norfolk	Charoletteville	6
Elgin	Bayham	4	Norfolk	Delhi	1
Elgin	Dunwich	1	Norfolk	Houghton	2
Elgin	Malahide	4	Norfolk	Middleton	4
Elgin	Yarmouth	1	Norfolk	N.Walsingham	6
Essex	Gosfield N.	2	Norfolk	S.Walsingham	1
Essex	Gosfield S.	2	Norfolk	Townsend	0
Essex	Mersea	3	Norfolk	Windham	10
Kent	Dover	5	Norfolk	Blandford-Blenheim	5
Kent	Orford	4	Oxford	Norwich	5
Kent	Zone	5	Oxford	Zorra	8
Lambton	Euphemia	8	Oxford	Essa	1
Lambton	Warwick	0	Simcoe S.	Innisfil	3
Middlesex	Caradoc	19	Simcoe S.	Tecumseth	4
Middlesex	Lobo	1	Simcoe S.	Tosorontio	2
Middlesex	Mosa	1	Simcoe S.	N.Dumfries	1
Middlesex	N.Dorchester	1	Waterloo	Wilmot	3
			Waterloo	total	141

characteristic metallic green sheen imparted by reaction between their metabolic byproducts and components in the agar. The formulation for the agar used for total coliform is given in Appendix B. Each water sample was drawn through a cellulose-acetate membrane filter having a 0.45 µm pore size. The filter was then placed on an m-Endo-LES agar plate and incubated at 35 ± 0.2EC for 22±2 h.

Faecal coliforms are defined as coliform bacteria with the additional attribute of fermenting lactose with the liberation of gas when incubated for 24 h at 44.5±0.2EC. On m-FC agar, faecal coliform colonies were identified by the production of a blue coloration. The formulation for the agar used for faecal coliforms is given in Appendix B. The cellulose acetate filter was placed on an m-FC agar plate for this test.

E. coli were identified following seeding onto an m-FC agar plate in which 4-methyl-umbelliferyl-â-d-glucuronide replaced aniline blue dye and rosolic acid. Colonies which fluoresced under UV light were counted as *E. coli*.

Faecal streptococci were identified as reddish-brown colonies after seeding on KF-streptococcus agar.

Enterococcus spp were identified as a subset of those bacteria grown on KF-streptococcus agar, and were identified by the pyrrolidonyl peptidase test.

A.3.3 Pesticides (Herbicides)

Each water sample was analyzed for the following herbicides:

- Alachlor
- Metolachlor
- Atrazine
- D-ethyl atrazine
- Metribuzin
- Cyanazine

Well waters were analyzed as received and the multilevel samples were filtered prior to analysis in order to remove visible particulate. Initially, a 100 mL aliquot of each sample was analyzed using a solid phase extraction technique (Appendix C - Method 1). Residues of herbicides were detected by capillary gas chromatography using nitrogen selective detectors. Any samples found to be positive or those that showed any remarkable characteristics were repeated using another 100 mL aliquot. Quantitation was done using fortified samples run in conjunction with actual samples. The confirmed positive samples were then

analyzed by current liquid-liquid extraction procedures (Appendix C - Method 2) and final results reported as indicated. All well waters and multilevel samples were also analyzed by an enzyme linked immunoassay system (ELISA) for the presence or absence of the herbicide atrazine. The test was sensitive and specific for only atrazine and was used as an alternate confirmation only for positive samples.

A.4 Statistical Treatment of the Results

The percentage of contaminated wells in each category (eg. well construction type and depth, well age, hydrologic group) was determined arithmetically, and then a 95% confidence interval (C.I.) was calculated for each percentage contamination figure by assuming a binomial distribution. The equation used to calculate a 95% C.I. for percentage of contaminated wells is:

$$95\%\ C.I.\ ' \pm 2\sqrt{\frac{P(100\ \&\ P)}{n}}$$

where:

P = percentage of contaminated wells
n = total number of wells in a category

The confidence intervals were used to help asses whether differences in percentage of wells contaminated were real or due to a chance selection of wells. A difference between two values of percent wells contaminated was considered real (statistically significant) if the values ± their 95% C.I. did not overlap each other. The upper limit of the 95% C.I. is indicated by a line at the top of each bar on some of the graphs in this report.

The impact of point source contamination was studied by using logistic multiple regression analysis (proc logist in SAS software). The independent variables used in the model included: distance from feedlots, distance from manure storage systems, and distance from septic fields. For this analysis, a value of one was assigned to the response (dependent variable) if the level of contamination exceeded the drinking water objective, otherwise it was assigned a value of zero. Output from the regression procedure is given in Tables A2 and A3.

Table A2. *Response profiles from two models tested by logistic regression.*

Response Variable	Does not Exceed Objectives	Exceeds Objectives
	no. wells	no. wells
Total or (faecal colif. or e.coli)	259	125
Nitrate-N	336	50

Note: Regression analysis only included sites where distances from the well to the feedlot, manure storage, and septic system weeping bed and tank were all known and none were more than 300 ft (91.2 m).

Table A3. *Analysis of maximum likelihood estimates from stepwise logistic regression models of effect of well depth and distance from point sources on bacterial and nitrate contamination of water wells during the summer sampling.*

Variable†	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
Response Variable: Nitrate-N > 10.0 mg L^{-1}				
INTERCPT	-0.0640	0.2950	0.0470	0.8283
WDEPTH	0.0318	0.00568	31.3980	0.0001
Response Variable: Total or (faecal colif. or e.coli) > objectives				
INTERCPT	-0.4919	0.2624	3.5133	0.0609
WDEPTH	0.00893	0.00198	20.4017	0.0001
FLDIS	0.00305	0.00133	5.2239	0.0223

† Independent variables in the model statement were well depth (WDEPTH)(feet), and distances (feet) from the feedlot (FLDIS), manure storage system, septic system weeping bed, and septic tank. Results are shown only for those variables that were found to have a significant effect on contamination.

Appendix B: Agar Composition

Formulation of m-ENDO-LES AGAR

Yeast extract	1.2 g
Casitone or trypticase	3.7 g
Thiopeptone or thiotone	3.7 g
Tryptose	7.5 g
Lactose	9.4 g
Potassium Hydrogen phosphate	3.3 g
Potassium dihydrogen phosphate	1.0 g
Sodium chloride	3.7 g
Sodium desoxycholate	0.1 g
Sodium lauryl sulphate	0.05 g
Sodium sulphite	1.6 g
Basic fuchsin	0.8 g
Agar	15.0 g
Distilled water	1000 mL

Commercially available

Reference: A.W.W.A. and A.P.H.A. 1985. Standard Methods for Water. 16th ed.

Formulation of m-FC AGAR

Tryptose	10 g
Proteose Peptone No. 3, Difco	5 g
Yeast Extract	3 g
Lactose	12.5 g
Bile Salts No. 3	1.5 g
Sodium Chloride	5 g
Agar	15 g
Aniline Blue	0.1 g
Distilled water	1000 mL

Final pH 7.4 ± 0.2 at 25EC

Rosolic acid	150.0 mg
0.2N NaOH	15.0 mL

Commercially available

Reference: Difco Manual. 1984. 10th ed. pp. 351-353.

Appendix C: Pesticide Analysis Methodology

Details of Pesticide Residue Analysis

Method 1: solid phase extraction for water samples

1) Sample Arrangement

a) Arrange one set of 12 water samples. (Include one or two spiked samples, blanks or duplicates).

b) Write the sample number on the supplied sheet. (Ensure that the sample layout matches the extraction positions on the vacuum manifold)

2) Sample Preparation

Well water (no particulate matter)

a) Measure a 100 mL. aliquot of the water sample into a 100mL. cylinder. (Shake the sample bottles before sub-sampling

Water (with visual particulate)

a) Transfer approximately 125 mL. of each sample into a 100 mL. cylinder. This will ensure that 100 mL. of sample can be recovered after filtration.

b) Filter the sample through a glass filter paper on a Buchner funnel using suction.

c) Measure the filtered sample into a clean 100 mL. cylinders.

3) Cartridge Activation

a) Pass 3.0 mL. of MeOH through the C18 cartridge. (Allow approximately 40 seconds to complete)

b) Remove any remaining MeOH with air from the empty syringe.

c) Fill the cartridge with distilled water. (Do not allow the cartridge to go to dryness).

4) Apparatus Assembly

a) Attach the reservoir via the pink gasket to the top of the cartridge.

b) Insert the whole assembly onto the Teflon vacuum plate.

c) Carefully, transfer approximately 60 mL of each water sample into the assemblies, making sure that the samples MATCH the initial sample layout (Step 1B).

d) Open the Teflon holder a quarter turn. This will allow the water to pass through the whole assembly.

e) Turn on vacuum pump and adjust vacuum gauge to 5 psi.

f) As elution of each tube proceeds, sequentially add the remainder of the 100 mL sample to the appropriate reservoirs until the 100 mL graduated cylinders are empty.

5) Sample Elution

a) Once the entire sample has passed through the assembly, remove the cartridge.

b) Remove any remaining water with a 3 mL syringe. Pass air through the cartridge in order to remove water.

c) Insert the tip of the cartridge into a sample vial and using an Eppendorf pipettor, transfer exactly 1.0 mL of MeOH into the cartridge.

d) Use a 3 mL syringe and very slowly elute the components. Allow approximately 40 seconds for this step.

e) Cap and seal the vial.

f) Place in appropriate rack for GLC analysis.

Experimental conditions and equipment

Gas Chromatograph: Hewlett Packard 5890

Detector: OI-Nitrogen

Column: HP-1(Crosslinked Methyl Silicone Gum)
30 m x 0.53 mm
2.65 µm film thickness
Hewlett-Packard

Carrier Gas: He
20 psi
30 cm sec^{-1} linear velocity

Oven Profile:

Temperature 1	170EC	
Hold	7 minutes	
Ramp Rate 1	30E min^{-1}	
Temperature 2	200EC	
Hold	0 minute	
Ramp Rate 2	5E min^{-1}	
Temperature 3	250EC	
Hold	6 minutes	

Injector Temperature: 250EC

Detector Temperature: 250EC

Injection: 2 µl, split 10:1

Alternate: Perkin Elmer 8500 Gas Chromatographs
Hall Detector (Nitrogen mode) and
Nitrogen/Phosphorous detectors
(Conditions similar as above)

Elisa: Commercial Kit -Agri Diagnostics Associates, Moorestown N.J.

Type: 96 well plate

Method 2: liquid/liquid extraction for water

1. Transfer a measured volume (approximately 800 mL) of sample water into a 1000 mL separatory funnel.

2. Adjust pH to 9 by adding a few drops of ammonium hydroxide (dil 1:2.5).

3. Add 100 mL of chloroform ($CHCl_3$) and shake for 1 min.

4. Let layers separate, then drain the chloroform phase through a piece of $CHCl_3$ pre-washed and dried cotton into a 500 mL boiling flask.

5. Repeat extraction with 100 mL of $CHCl_3$.

6. Evaporate the combined $CHCl_3$ extracts on a rotary evaporator (50-60EC water bath) almost to dryness.

7. Add to the residue 10 mL of iso-octane and continue evaporation to dryness.

8. Dissolve the triazine residue in 5 mL of methanol.

9. Use GLC system to quantitate the residues.

Appendix D: Water Well Questionnaire for the Summer Sampling Programme

Cooperating Landowner Information Sheet (tear off)

ONTARIO FARM GROUNDWATER QUALITY SURVEY

ROUND 2 QUESTIONNAIRE SUMMER 1992

This project is funded by Agriculture Canada through a contribution agreement with the Ontario Soil and Crop Improvement Association (OSCIA). Other agencies providing expertise include: the University of Waterloo Centre for Groundwater Research, the University of Guelph Centre for Land and Water Stewardship, the Ontario Ministry of Agriculture and Food's Resource Management Branch and Pesticide Residue Laboratory, the Ontario Ministry of the Environment and the Ontario Ministry of Health.

Confidentiality

Cooperating landowners are assured by each of the participating agencies, in compliance with the Freedom of Information and Protection of Privacy Act, S.O. 1987, c.25, that the information collected in the questionnaire and through the water sampling will be used only for the purpose of general analysis on an aggregate basis, maintaining individual confidentiality.

If Results Exceed Drinking Water Standards

If problem levels of bacteria, nitrate or pesticides are detected in the drinking water samples by the labs, the cooperating landowner will be promptly contacted by OSCIA personnel and notified of the level. At the end of the project, an individual water analysis report will be prepared and mailed to each cooperator. Landowners are encouraged to request assistance from the local Board of Health or the Ontario Ministry of the Environment for interpretation and remedial suggestions. Corrective measures will be voluntary and the responsibility of the cooperator.

COOPERATING FARM LANDOWNERS ARE ASKED TO COMPLETE THIS QUESTIONNAIRE TO THE BEST OF THEIR ABILITY. THE QUESTIONS ARE TO BE ANSWERED AS THEY APPLY TO THE SPECIFIC WELL ON THE FARM PROPERTY WHERE HOUSEHOLD DRINKING WATER IS OBTAINED. THIS WILL BE THE SAME WELL WHICH WAS SAMPLED DURING ROUND ONE. THE OSCIA FIELD INSPECTOR NAMED BELOW IS RESPONSIBLE TO RETRIEVE THE COMPLETED QUESTIONNAIRE AND CONDUCT THE ACTUAL WATER SAMPLING, BEFORE FORWARDING THEM ACCORDINGLY. THANK YOU.

OSCIA FIELD INSPECTOR _____ **TELEPHONE** _____

Fig. D1. *Well water questionnaire for the summer sampling programme.*

ONTARIO FARM GROUNDWATER QUALITY SURVEY - ROUND 2 - JULY 1992

place adhesive name/address label here

If information provided on the address label is incorrect, please provide corrections below.

First Name Last Name

Mailing Address

City/Town Province ONT Postal Code

Please fill in the Blank, or circle the correct response for each question.
THE SAME WELL WHICH WAS SAMPLED IN ROUND 1 IS TO BE SAMPLED AGAIN IN ROUND 2.

GENERAL INFORMATION ON FARM PROPERTY WHERE DRINKING WATER WELL IS LOCATED

1. Lot _____ Conc. _____ Township _____.
(please include precise location as necessary, eg. north half Lot 6)
2. Total acreage of farm property where the well to be sampled is located: _____ acres.
3. What percentages of the farm property are in the following crops at this time.
   % in row crop (ie. corn, soybeans, edible beans, etc.)_____
   % in small grain (ie. oats, barley, etc.)_____
   % in pasture (improved and unimproved)_____
   % in hay _____
   % in specialty crop _____. Please name the principal crop based on total acreage (ie. tobacco, tree fruits, vegetables, etc.) _____
4. (a) Are animal manures spread on the farm? 1. Yes 2. No
   (b) If yes, what type?_____
5. Has sewage sludge been applied to the farm within the last two years? 1. Yes 2. No
6. Do you apply commercial fertilizers in accordance with soil test recommendations? 1. Yes 2. No
7. a) Have there been any changes around the farmstead that could present a new potential source of groundwater contamination? (ie. new septic system or manure storage, etc.) 1. Yes 2. No
   b) If yes, please describe. _____

SPECIFIC INFORMATION REGARDING THE DRINKING WATER WELL TO BE SAMPLED

(If several wells were identified on the original questionnaire, please describe the one that was sampled.)
8. Please indicate the land use surrounding the well.
   (1) planted or drilled field (2) idle land or pasture field
   (3) yard (4) woodlot (5) other (describe) _____
9. (a) Will the water sample for Round 2 be obtained from the same tap as Round 1? 1. Yes 2. No
   (b) If no, give reason _____
10. (a) Have there been any changes in the water supply system since Round 1? 1. Yes 2. No
    (b) If yes, please describe _____
11. (a) What is the approximate total depth to which the well was dug or drilled? _____ feet.
    (b) What is the distance from ground surface to water level? _____ feet.
12. (a) Is the well water used for drinking also used to fill your field sprayer directly? 1. Yes 2. No
    (b) Do you mix pesticides in your sprayer within 50 feet of the well? 1. Yes 2. No
13. (a) Have crop protection chemicals been applied on the fields adjacent to the well this past spring? 1. Yes 2. No
    (b) If yes, please indicate the chemical names:
    _____ _____
    _____ _____
14. (a) Please comment on the material used at the top of the well at ground surface:
    (1) concrete (2) wood (3) steel cap (4) other (describe)
    _____
    (b) Please indicate the general condition of the top of the well (ie. concrete cracked, no well cap, etc.) _____
    _____
    (c) Does surface water drain towards the well? 1. Yes 2. No

DRINKING WATER QUALITY

15. (a) Has there been any noticeable changes in well water quality since the Round 1 sampling? 1. Yes 2. No
    (b) If yes, please describe _____
16. (a) Have you had your well water resampled since the OSCIA Field Inspector conducted Round 1? 1. Yes 2. No
    (b) If yes, what was the sample analyzed for? _____
    (c) If part (b) was answered, can a copy of the results be obtained by the program representative? 1. Yes 2. No
17. Were the analysis results from the Round 1 sampling:
    (1) as expected, (2) worse than expected, (3) better than expected?

THANK YOU FOR COMPLETING THE ROUND 2 QUESTIONNAIRE.
DISTRIBUTION: White – Centre for Land & Water Stewardship, U. of Guelph; Yellow – Program Representative

Fig. D1. *(cont'd.)*

Appendix E: Classification Systems

E.1 Soil Series

Table E1. *The soil series, drainage and hydrologic group (H.G.) identified for the farm wells.*

Soil Series	Drainage	H.G.	Soil Series	Drainage	H.G.
Albany	imper	-	Carp	poor	C
Allendale	poor	C	Casey	imper	B
Alliston	imper	B	Cashel	well	C
Ameliasburg	well	D	Casimir	poor	-
Atherley	poor	D	Castor	imper	C
Azilda	poor	-	Chartrand	imper	-
Bainsville	poor	C	Chesley	poor	D
Baldwin	well	-	Chinguacousy	imper	C
Bearbrook	poor	D	Clyde	poor	D
Bennington	well	B	Conover	imper	C
Berrien	imper	C	Darlington	well	B
Beverly	imper	C	Deloro	well	B
Binbrook	well	C	Donnybrook	well	A
Blackwell	poor	D	Dorking	poor	D
Bondhead	well	B	Dumfries	well	A
Bookton	well	B	Dummer	well	B
Bradley	imper	-	Dundonald	well	B
Brady	imper	B	Eamer	well	B
Brant	well	B	Earlton	imper	B
Brantford	well	C	Eganville	well	B
Brighton	well	A	Elderslie	imper	C
Brinco	well	-	Eldorado	well	B
Brisbane	imper	B	Embro	imper	C
Brookston	poor	D	Emily	imper	B
Burford	well	A	Farmington	well	B
Buzwah	well	C	Ferndale	poor	D
Caistor	imper	C	Fox	well	A
Caledon	well	A	Foxboro	poor	C

Table E1. (continued).

Soil Series	Drainage	H.G.	Soil Series	Drainage	H.G.
Gilford	poor	C	Magnetawan	well	C
Gordon	imper	D	Mallard	well	B
Granby	poor	C	Mannheim	well	B
Grenville	well	B	Maplewood	poor	C
Grimsby	well	A	Marionville	poor	C
Guelph	well	B	Miami	well	C
Haldimand	imper	C	Milliken	imper	B
Harkaway	well	B	Monteagle	well	B
Harriston	well	-	Morley	poor	D
Harrow	well	A	Muck	poor	-
Hillier	well	B	Napanee	poor	D
Hillsburgh	well	A	Norham	well	B
Himsworth	imper	-	North Gower	poor	D
Honeywood	well	B	Oneida	well	C
Howland	imper	B	Osgoode	poor	C
Huron	well	C	Oshtemo	well	A
Jeddo	poor	D	Osprey	well	B
Kars	well	A	Otonabee	well	B
Kemble	imper	C	Parkhill	poor	C
Kenogami	poor	-	Percy	well	B
King	well	C	Perth	imper	C
Lambton	imper	C	Pike Lake	well	A
Lansdowne	imper	D	Plainfield	well	A
Leech	imper	D	Pontypool	well	A
Lincoln	poor	D	Powassan	poor	-
Lisbon	well	A	Renfrew	imper	D
Listowel	imper	B	Rideau	imper	D
London	imper	B	Rubicon	imper	B
Lovering	imper	C	Saugeen	well	C
Lyons	poor	C	Schomberg	well	C

Table E1. (continued).

Soil Series	Drainage	H.G.	Soil Series	Drainage	H.G.
Shetland	poor	-	Vars	well	B
Sidney	poor	D	Vasey	well	B
Smithfield	imper	C	Vincent	well	C
Solmesville	imper	C	Waterloo	well	A
South Bay	well	C	Watrin	poor	C
St.Jacobs	well	A	Waupoos	well	C
Stinson	well	-	Wauseon	poor	C
Tavistock	imper	C	Wendigo	well	A
Teeswater	well	B	White Lake	well	A
Tennyson	well	B	Wiarton	imper	B
Tioga	well	A	Woburn	well	B
Toledo	poor	D	Wolf	poor	-
Trent	imper	C	Wolford	well	C
Tunis	poor	-	Wolsey	poor	D
Tuscola	poor	C	Wooler	well	B
Tweed	well	B	Woolwich	well	B
Upland	well	A	Wyevale	well	A

Note: For Northern Ontario soils there were no hydrologic indices available.

E.2 Agricultural Land-Use Systems

Agricultural land-use system descriptions used in this report. These descriptions are based on those given in "Agricultural Resource Inventory" (1988, Soil and Water Management Branch, Ontario Ministry of Agriculture and Food. Toronto, Ontario). The descriptions for "field crops" systems (P, C, M, MG, H, HG) have been modified so that information on percentage of land in various crops on a farm could be used more easily to assign the land-use codes to farms in the survey.

FIELD CROPS

P)CONTINUOUS ROW CROPS Row crops occupy at least 90% of the area.

C)CORN SYSTEM Row crops occupy at least 30%, but less than 90% of the area.

M)MIXED SYSTEM All areas where row crops occupy at least 5% but less than 30% of the area. Also includes areas with no row crops, but where small grains occupy <= 85% of the area and hay is not predominant.

MG)GRAIN SYSTEM Small grains occupy more than 85% of the area. Row crops occupy less than 5% of the area.

H)HAY SYSTEM Hay and pasture occupy more than 50% of the area. The proportion of hay is greater than the proportions of small grains and pasture. Row crops occupy less than 5% of the area.

HG)PASTURE SYSTEM Hay and pasture occupy the whole area, and pasture occupies at least 50% of the area. There are no row crops or small grains.

FRUIT AND GRAPE SYSTEMS

PE)PEACHES Primarily tender fruit production with peaches dominant. Peaches occupy more than 50% of the area, cherries less than 20% of the area. The remainder is a combination of other fruit and grapes.

CH)CHERRIES Primarily tender fruit production with cherries dominant. Cherries occupy more than 50% and peaches less than 20% of the area. The remainder is other fruit or grapes.

PC)PEACHES-CHERRIES Primarily tender fruit production with peaches and cherries together being dominant. Peaches plus cherries occupy more than 50% of the area, but neither by itself is more than 50%. The remainder is other fruit and/or grapes.

OR)ORCHARD Primarily hardy fruit production, usually with a combination of pears, plums and applies dominant. Orchard must occupy more than 90% of the area. If peaches and/or cherries occur, they must occupy less than 50% of the area.

V)VINEYARD Primarily grape production with vines occupying more than 90% of the area.

OV)ORCHARD-VINEYARD A combination of fruit and grape production with hardy fruit dominant. Hardy fruit occupies more than 40% but less than 90%, peaches and/or cherries less than 50%, the remainder is grapes.

VO)VINEYARD-ORCHARD A combination of grape and fruit production with grapes dominant. Grapes occupy more than 60% but less than 90% of the area. The remainder is fruit.

BE)BERRIES Strawberry, raspberry, blueberry or other bushberry production including associated fallow or plough-down crops. Does not include berries interplanted with fruit trees.

SPECIALTY AGRICULTURE

KF)EXTENSIVE FIELD VEGETABLES Large fields of cucumbers, broccoli, tomatoes, peas, etc. Includes associated fallow or plough-down crops.

KM)MARKET GARDENS/TRUCK FARMS Small intensive plots of lettuce, onions, carrots, celery and the like. In general, these operations will be less than 30 acres in size.

KT)TOBACCO SYSTEM Tobacco occupies more than 50% of the area, but corn in rotation may occur. Includes associated ploughdown or fallow crops.

KN)NURSERY Intensive production of trees, shrubs, vines or flowers for transplant or sale. Includes associated fallow or plough-down crops.

NON-SYSTEM LAND-USES

PN)PEANUTS

T)SOD FARMS Public or commercial sale of grass sod.

E.3 Hydrologic Soil Groupings

USDA Soil Conservation Services hydrologic soil groupings:

The hydrologic soil groups, according to their infiltration and transmission rates are:

A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted. These consist chiefly of deep, well to excessively drained sand and gravels. These soils have a high rate of water transmission in that water readily passes through them.

B. Soils having moderately infiltration rates when thoroughly wetted. These consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse texture. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted. These consist chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine textures. These soils have a slow rate of water transmission.

D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted. These consist chiefly of clay soils with a high swelling potential, soils with a permanent high watertable, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Reference: Proc. 13th Drainage Engineers Conf., 1981. Tech. report 126-58.

Appendix F: Well and Water Quality Data

Table F1. *Numbers of water wells of each construction type, depth, and age, sampled in the summer programme.*

	Well Type†								Total
	na	1	2	3	4	12	13	14	
Well Depth									
feet	number of wells								
na	2	4	6	3	3	0	0	0	18
0-20	0	170	7	44	6	0	0	1	228
21-40	2	149	55	21	0	2	2	0	231
41-60	0	38	85	3	0	5	1	0	132
61-80	0	18	94	2	0	3	0	0	117
81-100	0	17	108	1	0	1	0	0	127
>100	0	25	357	2	0	0	0	0	384
Total	4	421	712	76	9	11	3	1	1237
Well Age									
years	number of wells								
na	2	32	60	5	2	3	0	0	104
0-20	2	105	265	30	0	0	0	0	402
21-40	0	78	190	30	1	2	1	0	302
41-60	0	78	125	10	4	2	0	0	219
61-80	0	38	52	1	2	2	1	1	97
81-100	0	48	15	0	0	2	0	0	65
>100	0	42	5	0	0	0	1	0	48
Total	4	421	712	76	9	11	3	1	1237

Note: na indicates information was not available.
† Well type 1 = dug or bored, 2 = drilled, 3 = sandpoint, 4 = spring, and 12, 13, and 14 are combinations of types 1 to 4.

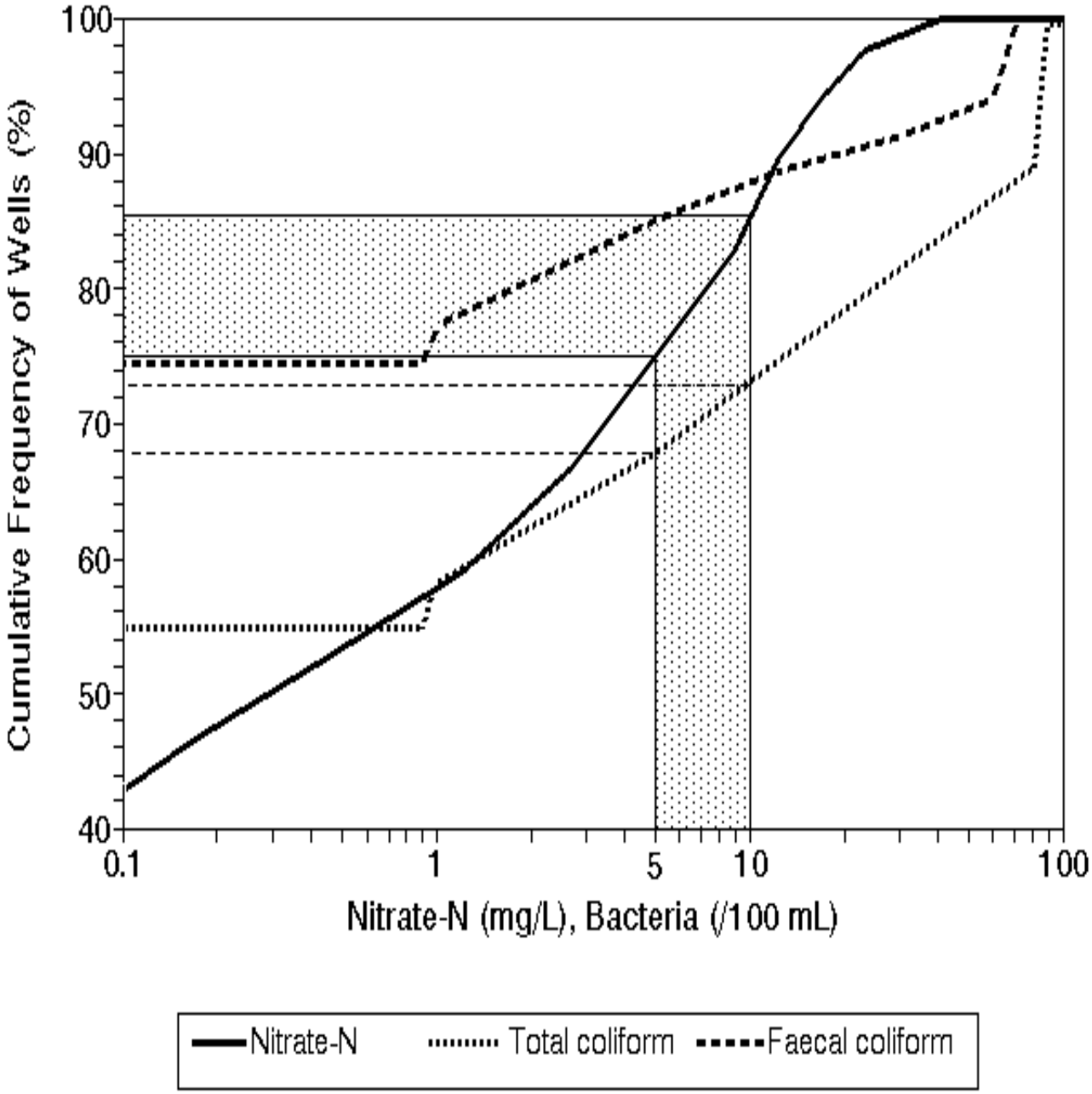

Fig. F1. *Cumulative frequency plot for the two major groups of bacterial contamination (faecal and total coliforms), and for nitrate-N. The hatched area helps identify the percentage of wells with nitrate-N concentrations 5-10 mg* L^{-1}.

Appendix G: Methodology Used in Calculating Nitrogen Budgets

The basic relationships for the nitrogen budget of a farm were calculated as: ***nitrogen in inputs = nitrogen in output + change in the nitrogen contents of the soil, livestock and other components.***

The N budget was further simplified by assuming that there was no net change in the nitrogen content of farm assets. Thus for an arable farm it was assumed that soil organic matter content, and consequently soil N content, remained constant on a yearly basis for monoculture systems or over the course of a rotation. Similarly for a livestock operation it is assumed that the number of animals and their demography remained constant. The N-budget for one cycle of the farming system, either one year or the length of a crop rotation was then used to indicate the long term potential of a given farming system to cause nitrate contamination of groundwater.

The main components of the nitrogen inputs to agricultural systems are derived from direct purchases from off-farm suppliers (eg animals, seed, fertilizers and feed), and from natural processes that occur during the growth of crops (eg symbiotic nitrogen fixation) or from natural processes that are influenced by anthropogenic activity (eg atmospheric deposition).
Fertilizer inputs were obtained from the questionnaire. Average nitrogen contents of animal manures (solid or liquid) were used in this study to convert weights or volumes of organic fertilizer applied to fields to an equivalent weight of nitrogen (Fraser, 1985). The nitrogen content of seeds used in crop production were obtained from average contents published by analysts (eg McBride,1987) together with farmer data on seeding rates. Feed contents were determined in the same way. The nitrogen in animals bought in were estimated from average weights of cattle, pigs or poultry typically purchased for fattening, breeding or milking, and assuming typical values for protein content.

Natural inputs through symbiotic nitrogen fixation were estimated from empirical relationships between plant/crop growth and nitrogen fixed.

The value used for atmospheric deposition was obtained from the literature. Wet deposition in precipitation and mist was estimated at 10.4 kg N ha^{-1}. Dry deposition in dust and other particulate material plus gaseous absorption was estimated at 8 kg N ha^{-1}.

The main components of the nitrogen outputs from agricultural systems are derived from direct sales of plant and animal materials, and from gaseous and leaching losses. Sales were calculated from the crude protein content or nitrogen concentration of materials, and the weight of the material. Gaseous losses were assumed to be

zero except for volatilization of ammonia from organic manures used or produced on the farm. Loss from animal manures was estimated to be 39% of the total manure nitrogen (Beauchamp and Burton, 1985).

The budgets were formulated to calculate the excess nitrogen on the farm at the end of a crop cycle. This weight of nitrogen was assumed to be susceptible to leaching. The annual through drainage was calculated from examination of stream discharge over the province, and was estimated to be 160 mm (Coote *et al.* 1982).

A simple system that would be expected to be a good test of the budgetary approach would be a well established orchard. Close agreement was found between the concentration of nitrate-N predicted to be in the groundwater (13.5 mg N L^{-1}), and the value measured in the well water (13.6 mg N L^{-1}).

Many livestock farms appear to give large imbalances (Table G1). One cash crop farming system was identified where there was a true balance. The rotation included corn soybeans and wheat, with two years of soybean always being grown before corn. No nitrate was found in the well, and none was predicted (Table G2). Even in systems where there was poor agreement between the predicted and measured concentration in the farm well, the approach has indicated that there will be contamination even if the actual amount is over estimated. The approach seems amenable for use in comparing the potential of different farming systems to cause contamination of the environment.

Table G1. *Nitrogen budget for a mixed farm growing corn beans and wheat to feed hogs and poultry.*

Input		Export	
	kg N ha^{-1}		kg N ha^{-1}
Seed	1.7	Plant/Plant products	1.9
Feed	65.5	Animals/ animal products	16.6
Fertilizers	30.0	Gaseous loss	107.3
Livestock	0.1		
Legume and non-legume nitrogen fixation	46.7		
Atmospheric deposition	18.4		
TOTAL	**162.4**		**125.9**
Imbalance*	*36.5*		
Predicted groundwater contamination	**22.8** (mg L^{-1})	Measured groundwater contamination	**19.9** (mg L^{-1})

*Total Inputs-exports, leaching loss not included.
Note: Methodology of N-budget calculations is given in Appendix G.

Table G2. *Nitrogen budget for a cash cropping farm growing corn, soybeans and wheat, with corn following two years of soybeans, and wheat following alternate corn crops.*

Input		Export	
	kg N ha^{-1}		kg N ha^{-1}
Seed	5.4	Plant/Plant products	163.0
Fertilizer	50.2		
Legume and non-legume nitrogen fixation	88.7		
Atmospheric deposition	18.4		
TOTAL	**162.7**		**163.0**
Imbalance*	-0.3		
Predicted groundwater contamination	**0** (mg L^{-1})	Measured groundwater contamination	**0** (mg L^{-1})

*Total Inputs-exports, leaching loss not included.
Note: Methodology of N-budget calculations is given in Appendix G.

Literature Cited in Appendix G

Beauchamp, E.G., and D.L. Burton. 1985. *Ammonia Losses From Manures*. Ontario Ministry of Agriculture and Food Factsheet (AGDEX 538, Order no. 85-071), Toronto, Ontario.

Coote, D.R., E.M. MacDonald, W.T. Dickinson, R.C. Ostry, and R. Frank. 1982. Agriculture and Water Quality in the Canadian Great Lakes Basin: I. Representative Agricultural Watersheds. Journal of Environmental Quality, 11:473-481.

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