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Agricultural Watersheds Overview: Data Analysis and Extrapolation: Final Report, Project 1B, Agricultural Watershed Studies, Task Group C, Canadian Section, Activity 1

International Reference Group on Great Lakes Pollution from Land Use Activities

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INTERNATIONAL JOINT COMMISSION

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FINAL REPORT - PROJECT 1B
AGRICULTURAL WATERSHED STUDIES
TASK GROUP C (CANADIAN SECTION) ACTIVITY 1,
INTERNATIONAL REFERENCE GROUP ON
GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES,
INTERNATIONAL JOINT COMMISSION

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DISCLAIMER

The study discussed in this document was carried out as part of the efforts of the International Reference Group on Great Lakes Pollution from Land Use Activities, an organization of the International Joint Commission, established under the Canada-U.S. Great Lakes Water Quality Agreement of 1972. Funding was provided through Agriculture Canada's Research Branch, with data-gathering support being provided through cooperative projects with the Ontario Ministry of Agriculture and Food, and the Ontario Ministry of the Environment.

Findings and conclusions are those of the authors, and do not necessarily reflect the views of the Reference Group or its recommendations to the International Joint Commission.

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1.0 SUMMARY AND CONCLUSIONS

There has been a persistent gap between the two most generally available forms of information on the effects of agriculture on water quality. These two forms of information are the results of small scale "plot" studies and large scale river basin or lake loading analyses. The former are usually limited in terms of variability of soil, management and climatic conditions; the latter generally fail to distinguish between even distinctly different types of agricultural environments. The results of this study help to bridge the gap between these different approaches.

The role of soil particle size as a major influence on total phosphorus, organic nitrogen, zinc and atrazine loadings from agricultural land has been clearly indicated. This holds important implications in terms of the efficacy of remedial measures if they are selected without regard to soil texture. In cultivated areas, reduction of current loadings may be difficult to achieve with standard remedial programs. Furthermore, losses of some of these materials from fine-textured soils may be unavoidable regardless of the land use practice employed.

The influence of source material availability on stream loadings of the more water soluble contaminants in streams is evidenced by the loadings of soluble ortho-phosphorus and nitrate nitrogen which can be accounted for to a considerable degree by the inputs (fertilizer and manure) of phosphorus and nitrogen respectively. Endosulfan, an example of the currently used pesticides, was present in relation to the area of the crops on which it was used. Reductions in loadings of these materials can probably be expected if inputs are reduced.

The results indicate that some materials, such as PCB and copper, are essentially unrelated to any aspect of agriculture. Control or reductions should not be expected through any remedial programs applied to agricultural activities.

Prediction equations based on statistical regressions of stream loadings on physical and management characteristics of the watersheds appear to be feasible for some water quality parameters such as total and soluble ortho-phosphorus, total nitrogen and nitrate (plus nitrite) nitrogen. Attempts to extrapolate regression equations for sediment (suspended solids) appear less satisfactory. For most other parameters, the extrapolation of regression equations would appear unreliable, though the occurrence of pesticides which are fairly specific to certain crops may be extrapolated by considering the distribution of the appropriate crops.

2.0 INTRODUCTION

During the winter of 1972-73, Agriculture Canada took its first step towards the implementation of the Great Lakes Water Quality Agreement by setting up a Task Force which reviewed the state of knowledge of the interrelationships between agriculture and water quality in the Canadian Great Lakes Basin. In their report on the activities of this Task Force, Harris, Hore and MacLean (1973) reviewed extensively the information available from existing water quality monitoring networks and data on agricultural cropping and livestock production activities and pesticide and fertilizer useage in the Canadian Great Lakes Basin. They found that few sites which were being monitored within water quality networks were located in such a way as to facilitate the assignment of water quality parameter loading values to distinctly agricultural land areas. Most sites were for sampling catchment areas which contained urban activity, and frequently a sewage treatment plant was located a short distance upstream. This was probably a reflection of the objectives of the existing monitoring networks which had primarily been intended for surveillance of known or suspected sources of pollutant material and for which agricultural land had not been considered in anything other than the broadest terms. In spite of this constraint on the availability of suitable monitoring data, attempts were made to characterize the primarily agricultural drainage basins, and comparisons with water quality data were made. Although not statistically significant, trends were evident which associated increases in the ratio of improved land to total land with increases in the concentrations of total and suspended solids in streams. There was also a tendency for higher estimated average rates of application of manure and fertilizer nitrogen to be associated with higher concentrations of nitrate-nitrogen in streams, but no relationship could be discerned between phosphorus concentrations and any of the estimated phosphorus useage parameters in the watersheds.

Other more recent studies have also run into the problem of watershed data being too general for inferences to be drawn regarding agricultural soils or practices. McBean and Gorrie (1975) concluded that the multiple linear regression approach to analyzing non-point source pollution problems relative to the characteristics of watershed areas (as used in this report) was viable, but that additional data collection was necessary if the technique was to be applied successfully. Haith (1976) also applied this statistical approach to New York watersheds, but also ran into problems due to the diversity of the watersheds and difficulty of describing them fully. Omernik (1976), used a general agricultural/forestry/urban classification to analyze a large quantity of watershed load data. The overlap between ranges of values in each category was so broad that extrapolatable values could not be obtained, even by geologic sub-categorization.

Taken together with other information extracted from available literature, Hore and MacLean's results (Harris et al., 1973) led them to make, among others, the following recommendation:

> "Selected agricultural watersheds should be monitored for their contribution of nutrients and any likely pollutants to water. The sites should be representative of varying intensity of cropping and/or livestock enterprises; they should be no larger than required

from hydrological or farming considerations so as to arrive at reasonably precise nutrient budgets including losses to water; ...."

The recommendation went on to suggest cooperative projects between various agencies which would integrate studies on pollutant transport processes and agricultural management alternatives with the water quality monitoring. The recommendation further suggested that this approach should be considered for inclusion in the efforts of the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG), then in its infancy.

In March 1973, the PLUARG prepared its first Study Plan, which outlined four distinct tasks (known as Tasks A, B, C and D). Task C was described as:

"Intensive studies of a small number of representative watersheds, selected and conducted to permit some extrapolation of data to the entire Great Lakes Basin and to relate contamination of water quality, which may be found at river mouths on the Great Lakes, to specific land uses and practices."

Activity 1 of Task C (Canada) was further identified as "Pilot Agricultural Watershed Surveys", and described as follows:

"Intensive studies on a selection of representative watersheds and in some cases of subwatersheds within selected watersheds, are needed to provide information on output and proportions of yields of nutrients, sediment and pesticides in particular specific sources." (Sic)

During the period from the summer 1973 to 1977, the Agricultural Watershed Studies were planned, implemented in two phases and then integrated along lines similar to those suggested in the recommendation of Hore and MacLean (Harris et al., 1973). The subject of this report is the "overview" analysis of the monitoring data collected during the 1975-1977 intensive study phase of the Agricultural Watershed Studies. The report outlines the methodology and rational for the selection of suitable monitoring sites, the methods used for water quality and quantity data acquisition, the estimation of watershed characteristics, and the statistical analyses of the variance within the data sets. Finally, some conclusions are drawn which are applied to an extrapolation model which attempts to determine areas of the lower Canadian Great Lakes Basin which fall into selected ranges of pollutant contribution rates to streams.

3.0 METHODS AND PROCEDURES

During the fall and winter of 1973-74, data were prepared by which rational selections could be made of sites which would meet the requirements of representativeness of the major differentiable agricultural land use areas of the Canadian Great Lakes Basin.

The procedures followed, the evaluations made and the resulting selections of "agricultural regions" and "representative sub-watersheds" are described in "Agricultural Land Uses, Livestock and Soils of the Canadian Great Lakes Basin, a Report of the Activities of the Engineering Research Service and the Soil Research Institute as part of Agriculture Canada's Contribution to the Implementation of the Great Lakes Water Quality Agreement, 1973-74" (Coote, MacDonald and Wall; 1974). For the purposes of this report, the following summary of these procedures is included:

1. The "agricultural" portion of the Great Lakes Basin was separated from the remainder on the basis of the presence of significant agricultural land use. In practice, this meant that only that portion of the basin below the 45th parallel was considered in further analyses.

2. A soil map was prepared which separated soil types according to their potential to transport pollutants (if present) to surface or ground water. This classification of soils recognized high, medium and low potentials to surface and ground water, and resulted in 5 orders of potential, which were subdivided into 3 major soil texture groups, with additional groups for shallow or organic soils. The criteria for the inclusion of each soil series in a particular Pollutant Transfer Potential group included slope, permeability (based primarily on texture and structure), drainage class, and depth. Each of the soil series in the designated agricultural area was classified according to this system by the leader of the Soil Survey Project (C.J. Acton, Project Leader, Agricultural Watershed Project 7 - Soil Survey, Ontario Soil Survey Unit, Agriculture Canada, Guelph), and a composite soil map of the area was prepared.

3. Climatic data were considered, including frost-free period, growing degree days, corn heat units and precipitation. The area was subsequently divided into two major climatic regions, -viz. the lower elevation regions closest to the lake shores with longer frost-free periods and higher heat units, and the cooler, higher precipitation zone of the Dundalk uplands encompassing parts of Bruce, Dufferin, Grey, Huron, Perth and Wellington Counties.

4. Census of Agriculture data (1971) were prepared and mapped, by the SYMAP computer mapping procedure, to give a distribution pattern for each of the major crops and livestock types of the basin. Estimates were made of the usage of fertilizers and manure nutrients and the patterns were also mapped.

When the results of the four procedures summarized above were combined, twenty-one fairly definable agricultural regions emerged, with boundaries following closely the major changes in soil pollutant transfer potential groups. These regions are shown in Figure 1. They cover approximately 85% of the agricultural part of the Canadian Great Lakes Basin. The remaining areas are either urban land (such as Toronto and Hamilton areas) or are complexes of agricultural soils and cropping which were not sufficiently uniform to be categorized as an "agricultural area". These latter areas were treated as mixtures of the other areas in the extrapolations discussed later in this report.

Maps and airphotos were then searched for small watersheds in each of these agricultural regions. Area 21, the organic soils of the Bradford-Holland marsh were excluded because of existing monitoring being carried out in the Erieau marsh (Miller, 1974) and studies being planned for the organic soil area of northwestern New York. Drainage areas suitable for monitoring were sought which were in the range of 20-50 km^2. This size was considered large enough to be hydrologically stable with few periods of zero or excessively high (unmonitorable) flow, and yet small enough to still enable the definition of the agricultural characteristics, based on reasonably homogenious areas, free of unrelated non-agricultural land uses. After a small number of potential monitoring sites were located, maps of the drainage sub-basins upstream of each site were prepared, and the sites visited to select the most desirable in each case on the basis of the ease of sampling and flow measurement, the absence of non-agricultural activities not seen on the airphotos and the general appearance of the sub-basin as "representative" of the agricultural region.

Seventeen sites were selected and monitored from March 1974 to October 1974 (no suitable sites were found in agricultural areas 17, 18, and 20, and it was concluded that the program would not suffer by exclusion of these areas as sampling resources were already over-extended). A cooperative agreement was reached with the Ontario Ministry of the Environment to install staff gauges, collect water samples (grab sampling) and conduct routine water quality analyses. These included three phosphorus forms (total, total dissolved, soluble ortho-P), four nitrogen forms (Total Kjeldahl, nitrate, nitrite, dissolved ammonia), suspended solids, total and organic carbon, potassium, calcium, sodium, chloride, sulphate, and a number of trace elements (Pb, Zn, Cu, Hg, Cr, Fe, Al, Ni, As, Ca, Bo). A similar agreement was reached with the Ontario Ministry of Agriculture and Food and the London Research Institute of Agriculture Canada to conduct analyses for selected insecticides and herbicides. The Ontario Soil Survey Unit of Agriculture Canada conducted an evaluation of the soil erosion potential of each of these monitored sub-watersheds.

After the six-month period of initial monitoring and observation, the data were evaluated and some sites were found to be unsuitable. The most common problem was that of obtaining reliable estimates of flow, while secondary problems arose where watersheds were found to be less representative of the agricultural areas than previously thought. Constraints in sampling and flow measurement resources were also considered, together with the need for more intensive sampling at most locations. Eleven agricultural areas were finally selected for continued monitoring, for which four sites were considered adequate (AG-1, 3, 4, and 5). To

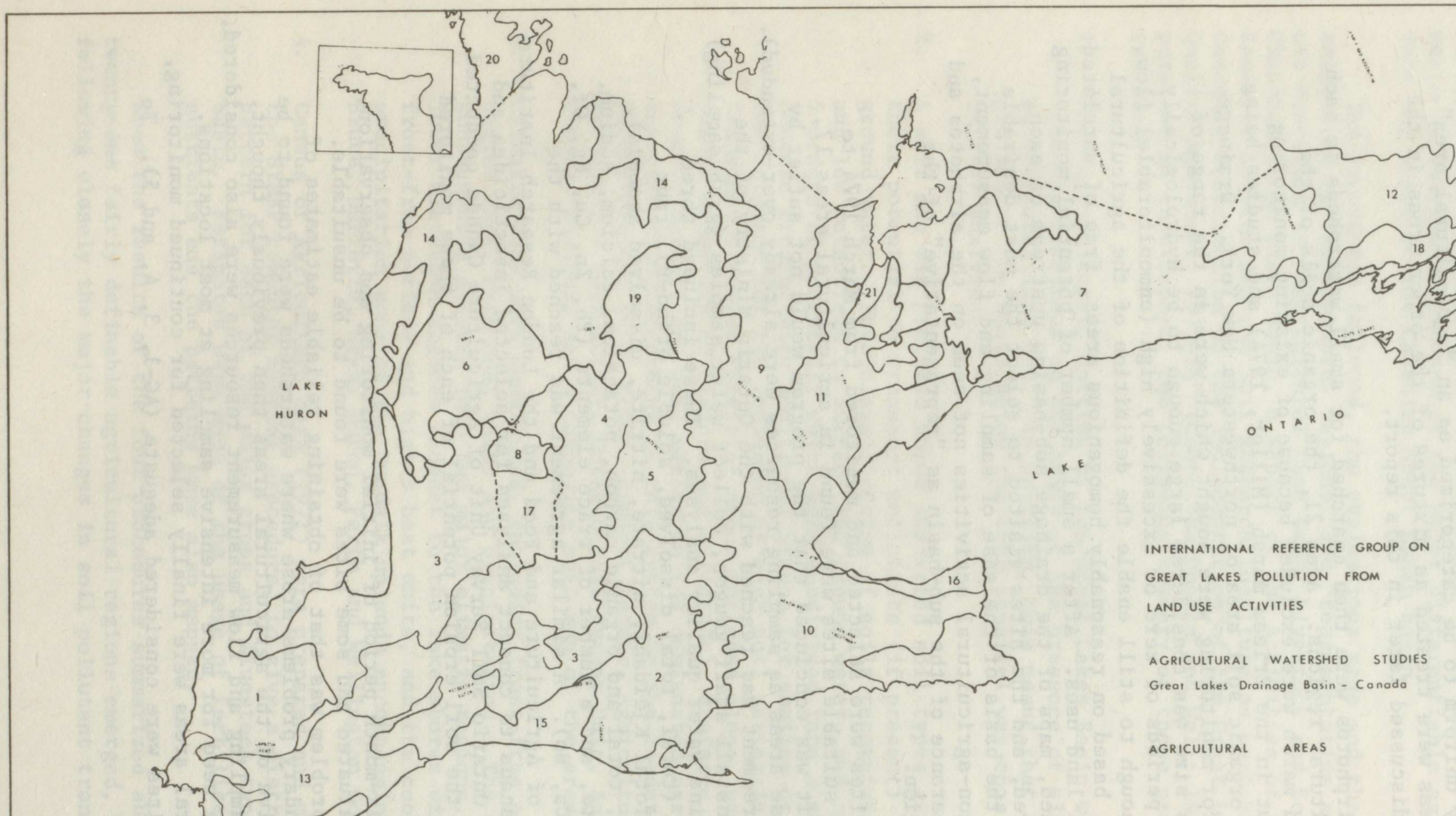

Figure 1: Agricultural Regions of Southern Ontario

establish the remaining seven sites, the selection procedure involving airphoto interpretation and ground surveys was repeated. In one case, the monitoring site was shifted upstream a short distance to take advantage of better flow monitoring conditions (AG-10); four other sites were re-located on different branches of the same stream to give improved monitoring capability (AG-2, 11, 13 and 14); and two sites were moved to a new drainage basin entirely (AG-6 and 7). The selection procedures are discussed in more detail in Section I of the Annual Report of the Agricultural Watershed Studies for 1974-75 (Agric. Sub-Comm., 1975).

From March of 1975 to the end of April 1977, the eleven sites were sampled regularly at least once per week. Six of the sites monitoring watersheds, identified as locations suitable for more intensive studies of pollutant transport and transformations, were instrumented with automatic pumping samplers (C.A.E. Aircraft Ltd., Winnipeg, Man., Model 304) designed to sample on a time or stage height activation basis. The mechanisms were set to sample daily except when flow events took place, when samples were collected more frequently. All sites were equipped with continuous-recording flow stage-height recorders.

Samples were collected and transported by the Ontario Ministry of the Environment to their laboratories at Rexdale or London, Ontario. Complete descriptions of sampling methods, sample handling procedures, and laboratory analyses are to be found in: "Work Plan, Task Group C (Canadian Section), Activities 1, 3 and 4 Studies, International Reference Group on Great Lakes Pollution from Land Use Activities, International Joint Commission" (Ontario Ministry of the Environment, 1976).

A number of methods have been used to obtain information on the characteristics of the watersheds. The primary sources of information were the farm-by-farm survey of agricultural practices conducted by the Ontario Ministry of Agriculture and Food (Frank and Ripley, 1977), and the detailed inspection of soil maps and 1:50,000 topographical maps.

Water quality and quantity data were processed as received by utilizing the Environment Canada water quality data bank (NAQUADAT). Output from this system was by way of summaries, plots, means, regressions, and cumulative loadings. The methods used are described in the "NAQUADAT Users Manual" (DeMayo and Hunt, 1975). Equations describing the regression of water quality parameter concentrations on flow were used to make estimates of concentrations to fill gaps in the record (missing data) and to correct the loading calculation at points in time when flow changed significantly (usually an increase or decrease of more than about 20%), but no samples were collected. Loadings were divided by watershed areas to obtain unit area loadings, and by total flow to obtain flow-weighted mean concentrations. These values for each watershed, together with the data on the characteristics of each watershed, were input to a computerized stepwise multiple linear regression procedure developed by the Engineering and Statistical Research Service of Agriculture Canada. Output was in the form of correlation coefficient matrices, and the 100 combinations of parameters with the highest r^2 values using one, two or three independent variables at a time. Following this variable selection technique, the selected data were input to a terminal operated computer package and run through multiple linear and polynomial regression procedures to determine the statistical significance of variables and to obtain the coefficients for suitable predictive equations.

The extrapolation of unit-area and flow-weighted mean concentration data to the remainder of the Canadian Great Lakes Basin was then tested by comparing predicted with measured values at a small number of predominantly agricultural watersheds which are routinely monitored by the Ontario Ministry of the Environment as part of its Water Quality Monitoring network and which also have Water Survey of Canada flow gauging at, or nearby, the sampling sites. Data were obtained from the Ontario Ministry of the Environment (1964-74), and from the Water Survey of Canada (1964-74). Predicted values were also compared with OMOE monitoring data collected under the PLUARG program at predominantly agricultural sectors of the Grand and Saugeen Rivers (Hore and Ostry, 1978 a and b). Following this procedure, the best predictive equations were selected on the basis of r^2 values, statistical significance of individual independent variables, and availability of data.

Census of Agriculture data, collected in 1971, were used to estimate the values of independent variables, using the Canada Land Inventory computerized Geographic Information System to overlay Water Survey of Canada watershed sub-basins (subdivided further in some instances) upon the boundaries of Census Enumeration Areas. A tape of 1971 agricultural census data, on an enumeration area basis, was then accessed to extract values of each appropriate variable. These variables were updated to reflect 1976 values by applying, county by county, correction factors to reflect the change with time over the 1971 to 1976 period. The factors were obtained by comparing county data from the Ontario Agricultural Census for these two years (Ontario Ministry of Agriculture and Food, 1972 and 1977), and determining the percent increase or decrease in the area grown in each county of each crop type and in the number of animals raised.

Finally, the watershed drainage basin boundaries were mapped. These were developed from Water Survey of Canada maps and modified by additional sub-division to meet PLUARG objectives. The values of major pollutants generated from the application of the prediction equations were then plotted on these maps to give a distribution pattern of potential loading rates of selected pollutants to streams from agricultural land.

A further extrapolation was made, using procedures selected by other participants in the PLUARG Agricultural Watershed Studies, to the entire Great Lakes Basin. The results of this activity, carried out for the report prepared by the Task C Synthesis and Extrapolation Work Group (Chesters et al., 1978), appear in the Appendix.

4.0 RESULTS

4.1 Preliminary Analyses

A number of analyses were conducted on the data by way of preliminary elimination of alternative approaches and checking the validity of data. Many of these analyses have been described in previous progress reports of this project (Coote, 1975; Coote and Leuty, 1976 a and b) and will not be repeated in this final report. A brief discussion of the results of these analyses follows.

4.1.1 Validity of NAQUADAT loadings

A comparison was carried out between loading values calculated by the NAQUADAT method with those supplied by OMOE, calculated by the Beale Ratio Estimator method. NAQUADAT loadings were also calculated after a "missing data" correction was employed. This was achieved by determining the equations to the line of best fit relating concentrations with flow (discharge). The daily data were then searched for days on which stream flow changed by more than 20% (approximately) without a sample being collected. On these occasions, the concentration was estimated from the linear relationship with flow, and these estimates were recorded in the NAQUADAT system for use in loading calculations. This procedure was followed for the three phosphorus forms and for suspended solids - these being parameters which are highly flow-dependent and for which sufficient data existed for these estimates to be reasonably made.

Correlation coefficients between NAQUADAT and Beale R.E. loadings ranged from 0.83 for suspended solids to 0.98 for nitrate plus nitrite-nitrogen. Comparison with the results of the investigation of Projects 16 and 17 (Erosion Losses and Sediment Delivery Ratios) indicated that the NAQUADAT loadings, with estimates, were the most reliable values for suspended solids - the most difficult parameter to measure accurately as loadings (Van Vliet, Wall and Dickinson, 1978). The validity of the NAQUADAT loading data base was therefore accepted.

4.1.2 Seasonal Variation

An analysis of seasonal trends in loads and concentrations compared with correlated independent variables was also carried out. This analysis was both inconclusive and incomplete. There was considerable variation in month to month correlations with independent variables, but there was a tendency for the group of variables which was best correlated to remain significant in all months, - but with varying ranking. Coupled with this finding was the concern expressed within PLUARG for total annual loadings to the Great Lakes. In other words, PLUARG intended to pursue the loading problem of the Lakes themselves on a "Total Annual Load" basis, and this gave weight to the decision to concentrate on investigations of relationships between agricultural land use and annual stream loadings. The field of investigation involving seasonal loads in PLUARG agricultural watershed data remains open for further work.

4.2 Correlation and Regression Analysis

The data which have been collected and which were used in the statistical analyses are presented in the appendix. The correlation coefficient matrices for unit-area loads and flow-weighted mean concentrations are also presented in the appendix. All "loads" and "concentrations" referred to in this discussion are unit-area loads and flow-weighted mean concentrations, respectively. Correlations among variables will be discussed below, first by watershed characteristics, then by water quality parameters and finally the correlations between these two groups. (All correlations significant at $p \leq 0.05$ unless otherwise stated).

4.2.1 Correlations among watershed characteristics

It is important to look at correlations among watershed characteristics, as these may explain some aspects of the correlations observed between watershed characteristics and water quality parameters. There is a need to remain aware of the potential for misinterpretation of such correlations, and to compare results with rational hypotheses, rather than accept all relationships which appear to be statistically significant.

Area (AR): There is a tendency (not statistically significant) for area to be related with woodland. This is because the larger watersheds had more woodland, especially watersheds 2 and 7.

% Cultivated (CL): The watershed characteristics which are statistically correlated with cultivated land included fertilizer use (both nitrogen and phosphorus), total phosphorus inputs (fertilizer plus manure), the density of tile drains and total row crops.

Soil Clay Content (SC): Clay content was strongly correlated with the index of pollutant transfer potential to surface water, which might be expected as it was in part a determinant of this index, and negatively correlated with woodland and tobacco area.

Soil Sand Content (SA): Sand content was negatively correlated with the index of pollutant transfer potential to surface water and positively correlated with that to ground water for the same reason mentioned above for soil-clay. Soil extractable phosphorus was strongly correlated with sand content, probably because of the high fertilizer applications in sandy watersheds 2 and 13 where tobacco is grown. Three closely related watershed characteristics, -animal units, manure nitrogen and manure phosphorus were negatively correlated with soil sand. This result appears to reflect the use of Ontario's sandy soils for tobacco, vegetables and orchards where livestock densities are low.

Erosion potential (EP): Erosion potential was developed from the application of the Universal Soil Loss Equation to the eleven watersheds.[1] It was correlated with row crops, as might be expected, but it was also correlated with percent nonagricultural land. This appears to be an anomaly resulting from the coincidence of non-agricultural land and a high erosion potential in Watershed 13. Watershed 13 is an intensively cultivated area with the highest density of residences and other non-farmed areas. Erosion potential was also correlated with fertilizer nitrogen use and tile drains - probably by way of the interrelationships with row crops.

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[1] Prepared by G.J. Wall and L.J.P. van Vliet, Agriculture Canada, Ontario Soil Survey, Guelph.

Pollutant Transport Potential to Surface Waters (PS): This dimensionless index of the probability of surface water movement to streams was related to two characteristics other than soil texture. There was a negative correlation with woodland and soil extractable phosphorus, which appears to reflect the high woodland and soil extractable phosphorus found in Watershed 2, where the surface water transfer potential was very low.

Pollutant Transport Potential to Groundwater (PG): This index is strongly correlated with soil sand content, and negatively correlated with livestock and manure nutrients, - for the same reason as given under the discussion of sand content above.

Stream density (SD): This characteristic appeared to be independent of all others measured or estimated in this study.

Rural Residences (RR): It is assumed here that the primary impact, if any, of rural residences would be by way of the effect of septic tanks on water quality. Rural residences were correlated with vegetables, orchards, non-agricultural land and fertilizer phosphorus use - all of which are noticeably high in Watershed 13 where the highest density of rural residences is found. This association is one which must be considered in any relationship involving rural residences.

Road Density (RD): This characteristic appeared to be independent of all others except non-agricultural land.

Row Crops (RC): As well as being correlated with cultivated land and each of the characteristics with which this was correlated, row crops were also related to corn and vegetable areas.

Corn Area (CA): Corn area was correlated with fertilizer nitrogen, total nitrogen (fertilizer plus manure) and tile drainage density.

Soybeans (SY): Soybeans were correlated with row crops and fertilizer nitrogen. The latter correlation is almost certainly the result of the association of fertilizer inputs with row crops, as it would otherwise be unreasonable.

Tobacco (TO): This was strongly correlated with soil sand content and pollutant transfer potential to groundwater.

Vegetables and Orchards (VA, OR): These two crops were closely correlated with each other and with fertilizer inputs and tile drainage density. The tendency for most of the vegetables and orchards in the study areas to be found in Watershed 13 must be considered when these crops are included in any predictive equation.

Cereals (CC): Cereals were not correlated with any characteristic other than exposed streambank - a relationship which cannot be readily explained.

Pasture and Hay (PA): Pasture and hay was strongly negatively correlated with row crops and cultivated land. This characteristic was therefore negatively correlated with many of the characteristics which were positively correlated with row crops and cultivated land. It was also positively correlated with animal units.

Woodland (WA): There was a tendency (not statistically significant) for woodland to be negatively correlated with most crops and inputs such as fertilizer and manure.

Non-agricultural Land (NA): This characteristic was highest in Watershed 13, and this resulted in some spurious correlations with orchards and vegetables, which are not otherwise explainable.

Animal Units (AU): Manure nutrients and pasture and hay were strongly correlated with animal units, which is hardly surprising.

Soil Extractable Phosphorus (SP): This characteristic was arrived at by estimates from county average $NaHCO_3$ extractable P values by crop type. It was positively correlated with fertilizer inputs, row crops, tobacco, and vegetables. It appears to reflect a composite of many parameters, of which fertilizer P and sandy soils seem to be dominant.

Slope (AG): This characteristic was not significantly correlated with any other which may reflect the difficulty of applying a mean value of this characteristic to an entire watershed.

Exposed Streambank (ES): This estimate of unvegetated streambank (made by K. Knap in the streambank erosion study), was correlated only with cereal crops which remains unexplained.

Tile Drainage Density (TD): The estimates of tile drainage densities were made by O.M.A.F. Agricultural Extension Engineers. The values were correlated with fertilizer inputs, row crops, cultivated land, corn and vegetables.

Fertilizer Nitrogen (FN), Phosphorus (FP), and Potassium (FK): These three input characteristics were strongly correlated one with the other, and with cultivated land, row crops, vegetables and with the soil extractable phosphorus index. In addition, fertilizer nitrogen was correlated with corn area. Negative correlations also existed with pasture and hay land.

Manure nitrogen (MN), Phosphorus (MP) and Potassium (MK): Estimates were made of the quantity of nutrients contained in manure generated by the livestock in each watershed. These values were correlated with animal units and pasture and hay.

Total Nitrogen (TN), Phosphorus (TP) and Potassium (TK): The values used for these characteristics were the combination of the fertilizer and manure inputs discussed above. In general, the fertilizer values dominated, in that most of the correlations with the fertilizer nutrients were also seen with the total nutrients.

Precipitation (PP): Total precipitation (rainfall plus snow) was considered as a variable, but then omitted due to the very small variation on a mean annual basis between the sites in the 2 year period of the study (range from 803 to 920 mm/yr).

4.2.2 Correlations among water quality parameter loads and flow weighted mean concentrations

The parameters can be loosely classified into two main groups - those associated with sediment (suspended solids) and those which are not.

Suspended solids flow weighted mean concentrations were correlated with those of potassium, total Kjeldahl-, ammonium- and total nitrogen, total- and dissolved ortho-phosphorus, zinc, lead, copper and the pesticide endosulphan. Nitrate (plus nitrite) nitrogen, total dissolved phosphorus, atrazine and PCB concentrations were not correlated with suspended solids. Unit area loads of the parameters were not correlated to the same extent as the concentrations. Suspended solids loads were well correlated with copper, zinc, ammonium- and total Kjeldahl- nitrogen and total phosphorus loads, but not with the other parameters which were correlated with suspended solids as concentrations.

Total Kjeldahl nitrogen concentrations and loads were strongly correlated with many other parameters in addition to suspended solids, including all 3 forms of phosphorus, ammonium and potassium, but not with nitrate nitrogen. Total and total Kjeldahl nitrogen concentrations were correlated, but not the loads.

Atrazine was correlated with all forms of phosphorus as loads, but not as concentrations. PCB loads were negatively correlated with sediment and related parameters, but these correlations did not appear among the flow weighted mean concentrations.

4.2.3 Relationships among water quality parameters and watershed characteristics

4.2.3.1 Simple linear correlation

Since many water quality parameters were related to suspended solids (sediment), this parameter is discussed first.

Suspended solids (SS) loads and flow-weighted mean concentrations were correlated statistically with percent cultivated land, row crops, soybeans and fertilizer nitrogen use. Loads of this parameter were also statistically negatively correlated with woodland. Examination of these results will show that cultivated land and row crop area are the dominant determinants (since soybeans were only present in a small number of watersheds), fertilizer nitrogen is a reflection of cultivation and row crops, and woodland is strongly affected by cultivated land. Of cultivated land and row crops, the former has the higher correlation coefficients (r = 0.74 and 0.71 for suspended solids load and concentration respectively). These correlation coefficients are low compared to those of many of the other parameters. This appears to be a general reflection on the nature of the sediment yield problem - large variability between sites and between seasons, due primarily to the flow dependency of this parameter.

Total phosphorus (PT) loads and flow-weighted mean concentrations were both positively correlated only with soil clay content and negatively with woodland. This latter correlation suggests a farmland influence on total P loads, though neither cultivated land, row crops, nor any of the phosphorus input parameters were significantly correlated with total phosphorus loads or concentrations. Loads were correlated with the index of pollutant transfer potential to surface water, which is highly correlated with soil clay content. There was also a correlation observed between total phosphorus flow-weighted mean concentrations and soybean acreage - a relationship which is probably due to the correlation between suspended solids and soybeans, and which has already been questioned due to the absence of beans in many of the watersheds studied.

Total dissolved phosphorus (PD) loads and flow-weighted mean concentrations had similar correlations with watershed characteristics. The strongest correlations were with soil clay content and pollutant transfer potential to surface waters. Again, as with total phosphorus, negative correlations were seen to exist with woodland. Other watershed characteristics correlated with total dissolved phosphorus were total watershed area (negative) and perennial stream density (positive) suggesting that this parameter is strongly influenced by surface transport processes. Total dissolved phosphorus is, unfortunately, a parameter in which confidence in 2-year data is limited due to change in laboratory filter size at the beginning of 1976.[1] However, on the basis of a correlation coefficient matrix developed for March and April, 1976, concentration data, the same characteristics were significantly correlated with total dissolved phosphorus, as also were rural residences, so that the correlations noted above are likely to be valid.

Dissolved ortho-phosphorus (PO) loads and flow-weighted mean concentrations were both positively correlated only with soil clay content and pollutant transfer potential to surface waters. They were also negatively correlated with woodland.

Total Nitrogen (NT) loads and flow-weighted mean concentrations were correlated with cultivated land, row crops and, more specifically, with corn area. They were also correlated with the estimate of the tile-drained area in each watershed, and negatively correlated with woodland. Among the watershed input variables, total nitrogen was correlated with fertilizer and fertilizer plus manure inputs of both nitrogen and phosphorus. Nitrogen and phosphorus inputs are closely correlated one with the other so that this apparent anomaly of nitrogen being related to phosphorus inputs is entirely the result of this relationship.

Nitrate (plus nitrite) Nitrogen (NN) loads and flow-weighted mean concentrations were related to watershed characteristics in almost exactly the same way as was total nitrogen described above. This is to be expected, however, since nitrate nitrogen is the dominant form found in the watersheds studied. It is worth noting that while nitrate nitrogen and total nitrogen were strongly correlated with both total nitrogen inputs (fertilizer plus manure) and row crops, these two characteristics were not significantly correlated one with the other. However, total

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[1] This change also made a two-year determination of "sediment-phosphorus" impossible.

nitrogen inputs were strongly correlated with corn area, which was also correlated with total and nitrate nitrogen loads and concentrations. These results suggest that the combination of fertilizer and manure nitrogen inputs is a more significant determinant of nitrogen than intensive cultivation per se. This suggests that mineralization of soil organic N as a result of cultivation is less significant as a source of N in water than are the manure and fertilizer inputs.

Total Kjeldahl Nitrogen (NK) was related quite differently to watershed characteristics from nitrate, being strongly affected by sediment yield. The only statistical correlations found were with soil clay content, and negatively with woodland.

Ammonia Nitrogen (AN) loads and concentrations were negatively correlated with watershed area and with woodland. Since these two characteristics were correlated one with the other, but woodland was also correlated with cultivated land, with which ammonia was not correlated, these data suggest that the relationship with area is the most relevant. This may suggest stream or other transport losses and/or transformations.

Potassium (KA) loads and flow-weighted mean concentrations were both correlated with watershed area (negative), stream density and rural residences. This suggests that this parameter is also strongly affected by transmission factors. It may also leach from septic tanks. Potassium was not correlated with manure or fertilizer inputs.

Heavy metals: Very few characteristics of the watersheds were significantly correlated with heavy metal loads or flow-weighted mean concentrations. Of the three examples used here, copper (CU) loads were not correlated with any characteristic but flow-weighted mean concentrations were correlated with cultivated land (CL) and beans (SY). Since copper was strongly correlated with suspended solids, these correlations can be explained as reflecting sediment concentrations. Zinc (ZN) loads and flow-weighted mean concentrations were correlated with soil clay content (SC). Both zinc and copper concentrations were strongly correlated with total phosphorus (PT) concentrations, and so this apparent effect of clay content appears to be valid. Lead (PB) loads were negatively correlated with watershed slope (AG) and potassium inputs (TN) (fertilizer plus manure); flow-weighted mean concentrations were correlated with soybean area. No explanations exist for these correlations. Lead loads were not correlated with suspended solids but concentrations were. However, none of the other parameters related to suspended solids (e.g. cultivated land) were correlated with lead.

Pesticides: Atrazine (AT) and endosulphan (EN) were included in this analysis as representative of currently used herbicides and insecticides respectively.[1] Both loads and flow-weighted mean concentrations of atrazine were correlated with soil clay content (SC). Loads were also correlated with pollutant transport potential to surface water (PS), and (negatively) to woodland (WA). Concentrations were negatively correlated with slope (AG). As a parameter, atrazine was strongly correlated only with total Kjeldahl nitrogen (NK), so the influence of clay content on atrazine seems dominant.

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[1] Pesticides which are no longer used such as DDT were found consistently and were related to sediment. However, no analysis was done on these data as the materials are essentially of historical interest only.

It is noticeable that, while corn is the only crop on which atrazine is used, neither loads nor concentrations were significantly correlated with corn area (CA). Endosulphan loads and flow-weighted mean concentrations were correlated with orchards (OR) and vegetables (VA), the crops to which it is most frequently applied. Unfortunately, these crops were found predominantly in Watershed 13, and so many of the watershed characteristics which had high values in this watershed had significant correlations with endosulphan. Examples were non-agricultural land, rural residences, and fertilizer use. However, the expected incidence of this material in association with its use pattern was confirmed by these results, and the extraneous correlations with the other characteristics can be ignored.

PCB (PC): This ubiquitous member of the toxic industrial organic contaminants family of compounds was found very consistently in the water draining from the agricultural watersheds. Curiously, while loads of PCB were statistically negatively correlated with those of a number of parameters (e.g. total Kjeldahl N, zinc, potassium, ammonia, dissolved P), flow-weighted mean concentrations were not correlated with those of any other parameters. Similar inconsistency was seen between loads and flow-weighted mean concentrations and watershed characteristics. The loads were positively correlated with tobacco (TO) and woodland (WA), and negatively correlated with clay (SC) and pollutant transfer potential to surface water (PS). The concentrations were positively correlated with pollutant transfer potential to ground water (PG), row crops (RC), soil extractable phosphorus (SP), fertilizer nitrogen (FM) and fertilizer phosphorus (FP); they were negatively correlated with pasture and hay (PA) and exposed streambanks (ES). There appears to be no reasonable explanation for any of these results, which suggests they are essentially spurious. This fits well with the concept that PCB inputs to watersheds are by way of atmospheric fallout or spills (there are no other known sources) and that the loss rates of PCB to streams is not controlled by any factor or characteristic measured or estimated in these agricultural watersheds.

4.2.3.2 Multiple linear regression analysis:

Each of the water quality parameters discussed so far both as loads and as flow-weighted mean concentrations, were tested with a multiple linear regression package to see if more variability could be explained with combinations of watershed characteristics. To be included in this analysis, the regressions and individual characteristics were only considered if statistically significant at least at the 95% level of probability ($p < 0.05$).

The resulting regression equations are listed in Tables 1 through 7. Those equations containing variables similar to those which have a higher r^2 value are flagged. For example, soil potential for pollutant transfer to surface water is often substituted in equations for soil clay content - with which it is correlated. Whichever equation has the lower r^2 value is flagged as an alternative to the more statistically desirable equation.

A less extensive list of equations is provided in the Tables for flow-weighted mean concentrations. This is because this form of data

TABLE 1. Selected Results of Regression of Suspended Solids and Total Phosphorus Unit-Area Loads and Flow-Weighted Mean Concentrations

Para.	Units	No. Var.	Equation	Explained Var. (r^2)	F^3
SS(L)[1]	kg/ha	1	-148 + 8.90CL	0.55	9.62*
		1	548 - 13.68WA	0.41	5.56*
		2	-762 + 22.46SC + 24.59SP	0.75	10.46**
		2A[2]	-300 + 7.96SC + 8.46CL	0.66	6.66*
		3	319.9 - 0.079AR + 16.08CL - 22.54TP	0.92	23.01**
		3	577 - 24.25WA + 23.2SP - 18.43TP	0.85	11.67**
PT(L)	kg/ha	1	0.13 + 0.029SC	0.51	8.40*
		1	1.22 - 0.026WA	0.51	8.40*
		1A	0.35 + 0.84PS	0.42	5.69*
		2	-1.08 + 0.047SC + 0.035SP	0.91	33.81**
		2A	-0.42 + 0.037SC + 0.025FP	0.83	17.34**
		2	-0.26 + 0.029SC + 0.012RC	0.80	13.72**
		2	-0.21 + 0.034SC + 0.053RR	0.79	12.79**
		2	-0.50 + 0.56SD + 0.016CL	0.65	6.57*
		3	-0.65 + 0.043SC + 0.034SP - 0.00007AR	0.99	249.72**
		3	-0.95 + 0.037SC - 1.05AU - 0.00013AR	0.90	17.75**
		3	-0.63 + 0.015CL + 0.65PS + 0.40SD	0.87	13.81**
SS(C)	mg/L	1	-13.63 + 3.35RC	0.43	6.14*
		1	-0.73 + 3.21FN	0.42	5.68*
		2	-331.3 + 8.85SC + 9.72SP	0.76	11.18**
		2	-103.9 + 4.41SC + 3.42FN	0.64	6.12*
		3	91.94 - 0.028AR + 6.48CL - 9.73TP	0.89	16.90**
PT(C)	mg/L	1	-0.0026 + 0.01SC	0.43	5.92*
		1A	0.37 - 0.0089WA	0.41	5.53*
		2	-0.53 + 0.018SC + 0.015SP	0.93	57.26**
		2	-0.34 + 0.016SC + 0.40PG	0.75	10.61**
		2	-0.16 + 0.010SC + 0.0048RC	0.75	10.41**
		3	-0.41 - 0.00002AR + 0.017SC + 0.015SP	0.98	79.74**
		3	-0.18 - 0.00004AR + 0.016SC + 0.47PG	0.92	22.89**
		3	0.30 + 0.015SC - 0.49AU - 0.000045AR	0.91	19.93**

[1] L = unit-area loads
C = flow-weighted mean concentrations. For flow-weighted mean concentrations a maximum of 3 equations, for each of 1, 2 and 3 variables, is included in this table.

[2] A = alternate equation - one or more variables significantly correlated with those of equation with higher r^2 value.

[3] F values followed by ** are significant at $p \leq 0.01$
F values followed by * are significant at $p \leq 0.05$

expression is less useful for extrapolation purposes than unit-area loads, and because many of the relationships are similar to those presented for unit-area loads.

Suspended Solids (sediment) (SS): Both loads and concentrations of suspended solids were positively related to soil clay (SC) and soil extractable phosphorus (SP) in multiple linear regression (Table 1). When three variables were included, watershed area (AR), woodland (WA) and total phosphorus inputs (TP) presented a negative effect. The latter is unexplainable, and so the three-variable equation does not seem to be a satisfactory improvement over the soil clay (SC) and cultivated land (CL) equation which has valid extrapolation potential.

Total Phosphorus (PT): A considerable increase in explained variability of total phosphorus loads was obtained by combinations of one of several (correlated) parameters together with soil clay content (SC) (Table 1). The estimate of soil ($NaHCO_3$) extractable phosphorus (SP) presented the best addition to soil clay content for both load and concentrations. Considerably poorer were a group of equations with fertilizer phosphorus (FP), row-crops (RC) and rural residencies (RR), respectively, in combination with soil clay content. The relationship which includes fertilizer phosphorus is one deserving of closer attention. It would be tempting to draw a direct cause:effect relationship between phosphorus fertilizer use and total phosphorus loads. However, the problem exists of determining if the effect is one of enrichment of runoff with phosphorus by fertilizer or one of increased soil erosion susceptibility under row-crops - the cropping practice with which fertilizer input is closely correlated. Row-crops, however, is far better correlated with total phosphorus loads than is fertilizer phosphorus. Furthermore, if the effect was predominantly one of runoff enrichment, then total phosphorus (which includes manure phosphorus) would be expected to be a more useful variable than fertilizer phosphorus alone. This was not the case however (unlike soluble phosphorus which is discussed below) even though fertilizer phosphorus use is correlated with total phosphorus inputs as well as with row-crops. The well established principles of soil chemistry also dictate that most phosphorus added as fertilizer will be readily sorbed by soil particles, which, in the agricultural watersheds, already contained up to 2500 kg/ha in the top 17 cm (from soil sample analysis - Whitby, MacLean, Schnitzer and Gaynor, 1978). The average 21 kg/ha/yr of fertilizer phosphorus added to these watershed soils should, therefore, increase the total soil phosphorus content by less than 1%, assuming no crop uptake. For this reason, it was felt that the inclusion of fertilizer phosphorus in this equation would be misleading - it is most likely that this variable was acting as a substitute for the effect of intensive cropping on soil erosion and sediment movement.

The other alternative variable listed in Table 1 for inclusion with soil clay content is rural residences (RR). It is also tempting to draw a cause:effect conclusion regarding this variable, but the presence of a high density of rural residences in one watershed with soils having high soil extractable phosphorus contents, high fertilizer inputs and a high density of row-crops, suggests that this watershed characteristic is a poor one for extrapolation purposes. Another combination of variables which was statistically significant in regression of total phosphorus loadings was stream density (SD) and % cultivated land (CL).

The most general effect of increasing the number of variables in the equation from two to three was to bring in the negative influence of watershed area (AR). This is a recognized effect related to the stream delivery-ratio concept, but is of little benefit in landscape extrapolation. The most appropriate extrapolation equations for total phosphorus loads and flow-weighted mean concentrations appear to be those based on soil clay content (SC) and soil extractable phosphorus (SP) - the latter being the preferred alternative to cultivated land as it is correlated with both row-crop land and fertilizer phosphorus use. Where an estimate of soil extractable phosphorus is not available, the use of row-crop density is considered to be the best alternative.

Total Dissolved Phosphorus (PD): As discussed earlier in this report, 2-yr. loadings of total dissolved phosphorus are not reliable due to a change in laboratory procedures during the monitoring period. It has therefore been decided that regression equations will not be presented here. Nevertheless, it is worth noting that the results of the regression analysis were very similar to those obtained for dissolved ortho-phosphorus, discussed below.

Dissolved Ortho-Phosphorus (PO): Loadings of dissolved ortho-phosphorus were well accounted for by a two-variable regression equation which included soil clay content (SC) and total phosphorus inputs (fertilizer plus manure TP) (Table 2). Alternative equations included soil potential to transfer pollutants to surface water (PS) and fertilizer phosphorus (FP) as substitutes for soil clay content and total phosphorus inputs, respectively. Rural residencies were also significant in several 2-variable regression equations. The stronger correlations between dissolved ortho-phosphorus and fertilizer phosphorus, total phosphorus inputs and rural residencies compared with the relationships between these variables and total phosphorus is not surprising. The degree of dissociation of phosphorus from its fixed forms to the soluble state is known to be related to the degree of fixation by Fe, Al, Mn, Ca and Mg compounds in the soil which, in turn, is somewhat dependant on time as well as soil chemical conditions (Brady, 1974) - so the most recent additions of phosphorus (e.g. by manure or fertilizer) will be most readily desorbed and thus an enrichment in the solution phase may result. Thus the dominance of the input parameters (FP, MP, TP, RR) over soil erosion factors (e.g. percent row-crops) is not surprising, and appears acceptable for extrapolation purposes.

At the three-variable level regression equation, the effect of drainage area is not as apparent as it was for total phosphorus - presumably because soluble ortho-phosphorus is not as dependant on sediment transport as is total phosphorus. Instead, combinations of variables involving livestock (AU) or rural residencies (RR) with fertilizer phosphorus (FP) and total phosphorus (TP), respectively, always with soil clay content (SC), have the highest r^2 values (Table 2) for loading regressions. For flow-weighted mean concentrations of dissolved ortho-phosphorus, rural residencies (RR), soil clay (SC), and alternatives related to intensive cultivation (e.g. row-crops, soil extractable phosphorus) were found at the three-variable equation level.

Total Nitrogen (NT): Multiple linear regression on total nitrogen loads indicated a strong influence of nitrogen input and cultivation

TABLE 2. Selected Results of Regression of Ortho-Phosphorus Unit-Area Loads and Flow-Weighted Mean Concentrations

Para.[1]	Units	No. Var.[2]	Equation	Explained Var. (r^2)	F^3
PO(L)	kg/ha	1	0.42 - 0.01WA	0.68	17.34**
		1	0.005 + 0.011SC	0.61	12.60**
		1A	0.073 + 0.34PS	0.59	11.53**
		2	-0.20 + 0.012SC + 0.0084TP	0.90	32.50**
		2A	-0.17 + 0.013SC + 0.0079FP	0.89	29.06**
		2	0.31 - 0.01WA + 0.14SD	0.88	26.89**
		2A	-0.12 + 0.37PS + 0.0084TP	0.88	24.89**
		2	-0.11 + 0.012SC + 0.017RR	0.87	23.78**
		2A	-0.081 + 0.42PS + 0.0077FP	0.86	21.41**
		2A	-0.031 + 0.39PS + 0.017RR	0.85	19.62**
		2A	-0.040 + 0.35PS + 0.003RC	0.78	12.49**
		3	-0.20 + 0.012SC + 0.0057TP + 0.01RR	0.96	44.48**
		3			
		3	-0.25 + 0.012SC + 0.19AU + 0.011FP	0.95	36.44**
		3	-0.20 + 0.016SC + 0.004RC + 0.016FP	0.95	35.20**
		3A	0.056 + 0.37PS + 0.000022AR + 0.0067FP	0.93	26.08**
		3A	-0.19 + 0.36PS + 0.21AU + 0.011FP	0.93	25.79**
		3	-0.099 + 0.37PS + 0.017RR + 0.0042CA	0.93	25.37**
		3A	-0.21 + 0.28PS + 0.004CL + 0.13SD	0.92	22.22**
		3	-0.11 + 0.38PS + 0.002CL + 0.014RR	0.92	22.19**
		3A	0.085 + 0.29PS + 0.0029CL - 0.000031AR	0.91	20.61**
PO(C)	mg/L	1	0.12 - 0.0031WA	0.58	11.24**
		1	-0.006 + 0.0034SC	0.55	9.92*
		2	-0.049 + 0.004SC + 0.0067RR	0.91	33.88**
		2	-0.068 + 0.0043SC + 0.0028FP	0.89	27.64**
		2	-0.12 + 0.0051SC + 0.0034SP	0.86	21.47**
		3	-0.10 + 0.0048SC + 0.0046RR + 0.0019SP	0.97	70.09**
		3	-0.069 + 0.00057CL + 0.0038SC + 0.0056RR	0.96	47.16**
		3	-0.060 + 0.0039SC + 0.0052RR + 0.00061RC	0.95	39.17**

[1]L = unit-area loads
C = flow-weighted mean concentrations. For flow-weighted mean concentrations a maximum of 3 equations, for each of 1, 2 and 3 variables, is included in this table.

[2]A = alternate equation - one or more variables significantly correlated with those of equation with higher r^2 value.

[3]F values followed by ** are significant at $p \leq 0.01$
F values followed by * are significant at $p \leq 0.05$

variables. The highest r^2 values obtained with two variables included row-crops (RC) together with manure nitrogen (MN) and cultivated land (CL) together with total nitrogen input (TN) (Table 3). The former is preferred as it avoids any problems caused by the tendency for interdependance of total nitrogen inputs and cultivated land. Flow-weighted mean concentrations were also influenced by watershed area (AR) and tile drain density (TD).

Little improvement in the regression occurred by adding a third variable. Tile drainage density, added to cultivated land and manure nitrogen inputs gave the highest r^2 values for loadings (Table 3), while concentrations were best described by exposed streambank (ES) added to row-crops (RC) and manure nitrogen (MN).

Nitrate (plus nitrite) Nitrogen (NN): There was a tendency for greater residual variability with nitrate (plus nitrite) nitrogen than with total nitrogen. Similar variables to those selected for total nitrogen were included in the regression equations, (Table 3), however, and the comments made above for total nitrogen apply equally to the nitrate (plus nitrite) parameter.

These results do little to clarify the question of the contribution of mineralized organic nitrogen which might be expected to arise from intensively cultivated soils. This is because the most intensively cultivated soils tend to have the highest fertilizer and manure nitrogen inputs. Further research will be required to determine the significance of this factor.

Total Kjeldahl Nitrogen (NK): There was a similarity between the results for total Kjeldahl nitrogen loadings and flow-weighted mean concentrations and those for total phosphorous. Since Kjeldahl nitrogen includes organic and ammonium nitrogen, which are associated with sediment (as is total phosphorous) this result is not surprising. Residual variability, however, is greater with Kjeldahl nitrogen than with total phosphorous, and few significant three-variable equations were available (Table 4).

Ammonium Nitrogen (AN): Both loads and flow-weighted mean concentrations of ammonium were related to the combination of soil clay content (SC) and rural residencies (RR) (Table 4). Watershed area (AR), tile drainage density (TD) and exposed streambank (ES) all seemed to be effective additions to the equations at the three-variable level, suggesting that stream transport factors are important for this water quality parameter. Rural residencies (RR) are a poor variable because of the tendency for this variable to have high values in only one watershed. Nevertheless, although this same watershed had soils with low clay content, soil clay was also positively related with ammonium load and flow-weighted mean concentration. This suggests that rural residencies may, in fact, be influencing ammonium levels.

Potassium (KA): Regression of potassium loads and flow-weighted mean concentrations showed many similarities with ammonium (Tables 4 and 5). Since these two cations behave similarly, in many respects, in the soil, this result tends to confirm the discussion above for ammonium, and supports the principle of rural residencies being a possible source of both pollutants, - the transport of which is influenced by stream conditions such as stream density (SD) and exposed streambanks (ES), and by the drainage area (AR).

TABLE 3. Selected Results of Regression of Total Nitrogen and Nitrate & Nitrite Nitrogen Unit-Area Loads and Flow-Weighted Mean Concentrations

Para.	Units	No. Var.	Equation	Explained Var. (r^2)	F[3]
NT(L)	kg/ha	1	-6.65 + 0.42TN	0.81	33.17**
		1A	2.65 + 0.72CA	0.77	27.01**
		1A	9.89 + 0.18TD	0.65	14.83**
		1	1.77 + 0.29CL	0.56	10.05**
		1A	7.25 + 0.30RC	0.51	8.26*
		1	24.84 - 0.47WA	0.46	6.91*
		1A	8.94 + 0.27FN	0.43	5.93*
		2	-7.73 + 0.47RC + 0.35MN	0.92	42.97**
		2	-0.27 + 0.33TN + 0.15CL	0.92	37.95**
		2	-4.02 + 0.45TN - 5.19SD	0.90	29.90**
		2A	-6.31 + 0.34TN + 0.13RC	0.87	23.64**
		2A	-8.16 + 0.49RC + 22.84AU	0.87	22.67**
		2A	-6.16 + 0.46FN + 0.36MN	0.84	18.82**
		2A	-10.51 + 0.39CL + 0.27MN	0.84	17.90**
		2	0.91 + 0.41CC + 0.20TD	0.81	15.17**
		3	-6.96 + 0.25CL + 0.25MN + 0.11TD	0.95	36.03**
NN(L)	kg/ha	1	-0.20 + 0.66CA	0.75	24.89**
		1A	-7.46 + 0.36TN	0.70	18.28**
		1A	6.46 + 0.16TD	0.63	13.85**
		1	-0.55 + 0.26CL	0.51	8.27*
		1A	4.11 + 0.27RC	0.49	7.58*
		1A	5.65 + 0.24FN	0.41	5.51*
		2	-4.15 + 0.40TN - 6.53SD	0.86	21.69**
		2	-8.41 + 0.42RC + 0.29MN	0.82	16.22**
		2A	-6.94 + 0.30MN + 0.40FN	0.74	10.16**
		2A	-8.03 + 0.42RC + 17.99AU	0.74	10.14**
NT(C)	mg/L	1	-0.96 + 0.10CL	0.75	24.07**
		1	-2.17 + 0.12TN	0.67	16.20**
		2	-3.44 + 0.073CL + 0.073TN	0.94	54.27**
		2	2.083 - 4.48PG + 0.15RC	0.92	40.63**
		3	-3.33 + 0.16RC + 0.06MN + 13.24ES	0.97	62.51**
NN(C)	mg/L	1	1.34 + 0.052TD	0.80	32.16**
		1A	0.29 + 0.096RC	0.76	24.72**
		1	-2.22 + 0.099TN	0.66	15.61**
		2	1.26 - 3.64PG + 0.12RC	0.93	45.20**
		3	-0.89 + 0.043CL + 0.03SC + 0.034TD	0.93	25.11**

[1] L = unit-area loads
C = flow-weighted mean concentrations. For flow-weighted mean concentrations a maximum of 3 equations, for each of 1, 2 and 3 variables, is included in this table.

[2] A = alternate equation - one or more variables significantly correlated with those of equation with higher r^2 value.

[3] F values followed by ** are significant at $p \leq 0.01$
F values followed by * are significant at $p \leq 0.05$

TABLE 4. Selected Results of Regression of Total Kjeldahl and Ammonium Nitrogen, Unit-Area Loads and Flow-Weighted Mean Concentrations.

Para.	Units	No. Var.	Equation	Explained Var. (r^2)	F[3]
NK(L)	kg/ha	1	5.64 - 0.097WA	0.42	5.86*
		2	0.25 + 0.30SC - 5.59PS	0.73	9.44*
		2	8.49 - 0.32AG - 0.00068AR	0.64	6.24*
		3	2.22 - 0.0004AR + 0.28SC - 5.71PS	0.86	12.46**
		3	-0.68 + 0.30SC - 5.3PS + 0.15RR	0.86	12.25**
AN(L)	kg/ha	1	1.67 - 0.00022AR	0.59	11.61**
		1	1.18 - 0.029WA	0.43	5.98*
		2	-0.43 + 0.035SC + 0.075RR	0.69	7.96*
		2	0.75 + 0.55SD - 0.030WA	0.68	7.53*
		2A	-0.17 + 1.040PS + 0.074RR	0.62	5.81*
		3	1.37 - 0.00030AR + 0.021CL - 0.011TD	0.92	21.62**
		3A	1.80 - 0.00032AR + 0.032RC - 0.018TD	0.89	15.50**
		3	-1.40 + 0.018CL + 0.77SD + 6.15ES	0.85	11.06**
		3A	-1.22 + 0.021RC + 0.71SD + 7.86ES	0.85	11.02**
NK(C)	mg/L	1	0.05 + 0.048SC	0.52	8.56*
		2	-1.79 + 0.075SC + 0.052SP	0.86	21.54**
		3	-0.43 - 0.0002AR + 0.065SC + 1.63PG	0.88	14.03**
AN(C)	mg/L	1	0.48 - 0.000064AR	0.48	7.31*
		1	0.35 - 0.0091WA	0.40	5.39*
		2	-0.17 + 0.012SC + 0.026RR	0.76	10.27**
		2	-0.12 + 0.012SC + 0.013UA	0.64	6.11*
		3	0.041 - 0.000066AR + 0.019SC + 0.38PG	0.89	16.84**
		3	-0.72 + 0.016SC + 0.017SP + 1.87ES	0.86	11.90**
		3	0.49 - 0.000096AR + 0.011RC - 0.0057TD	0.83	9.49*

[1] L = unit-area loads
C = flow-weighted mean concentrations. For flow-weighted mean concentrations a maximum of 3 equations, for each of 1, 2 and 3 variables, is included in this table.

[2] A = alternate equation - one or more variables significantly correlated with those of equation with higher r^2 value.

[3] F values followed by ** are significant at $p \leq 0.01$
F values followed by * are significant at $p \geq 0.05$

TABLE 5. Selected Results of Regression of Potassium and Copper Unit-Area Loads and Flow-Weighted Mean Concentrations.

Para.	Units	No. Var.	Equation	Explained Var. (r^2)	F[3]
KA(L)	kg/ha	1	7.88 + 1.097RR	0.52	8.69*
		1	23.93 - 0.0025AR	0.48	7.30*
		1	5.34 + 9.29SD	0.45	6.63*
		2	-1.70 + 0.39SC + 1.31RR	0.89	28.46**
		2A	0.94 + 11.98PS + 1.30RR	0.86	21.51**
		2	31.81 - 0.0031AR - 1.18AG	0.81	14.07**
		2	10.75 + 9.48SD - 0.33WA	0.79	13.22**
		2	-1.49 + 11.037SD + 0.19FN	0.74	10.06**
		2A	-2.32 + 11.37SD + 0.19RC	0.73	9.47**
		2	-0.0016 + 0.00014SC + 0.0045PG	0.70	8.32*
		2	-0.0022 + 0.00013SC + 0.00012SP	0.63	5.96*
		3	13.85 + 12.40SD - 0.38WA - 0.20MP	0.96	53.32**
		3	13.96 + 12.51SD - 0.38WA - 11.80AU	0.96	50.98**
		3	-2.30 + 0.31SC + 3.86SD + 1.15RR	0.95	35.91**
		3	-9.38 + 11.31SD + 0.27FN + 61.94ES	0.92	22.78**
CU(L)	kg/ha	2	0.0039 + 0.0016RR + 0.00096CC	0.65	6.43*
		2	0.00037 + 0.00039CL + 0.11ES	0.64	6.23*
		3	0.037 - 0.0000047AR + 0.0012CC - 0.0014MP	0.92	22.15**
		3	-0.032 + 0.00088SC + 0.0013SP + 0.15ES	0.90	18.57**
		3	0.018 + 0.00057 - 0.00055 + 0.16ES	0.85	11.12**
		3A	0.042 - 0.0000049AR + 0.00099CC - 0.023AU	0.84	10.60**
		3	0.028 - 0.0000045AR + 0.0006CL - 0.00024TD	0.83	9.71*
		3A	0.022 + 0.018PS - 0.0006PH + 0.17ES	0.81	8.66*
		3	0.005 + 0.00071CL + 0.0027RR - 0.0016FP	0.80	7.82*
		3	0.016 - 0.0000037AR + 0.00092CC + 0.00051SP	0.79	7.63*
		3	0.022 - 0.0000045AR + 0.00094CC + 0.018PG	0.79	7.61*
		3	-0.027 + 0.00084SC + 0.044PG + 0.19ES	0.77	6.81*
		3	0.036 - 0.0000039AR + 0.00057CL - 0.00082TP	0.77	6.68*
		3	-0.013 + 0.0005SC + 0.0011CC + 0.0021NA	0.74	5.68*
		3	-0.0026 + 0.00095FN - 0.003TD + 0.19ES	0.71	4.87*
		3	-0.016 + 0.00071SC + 0.00056CC + 0.00084SP	0.71	4.82*
KA(C)	mg/L	1	1.72 + 0.41RR	0.54	9.39*
		2	-1.78 + 0.14SC + 0.49RR	0.91	35.45**
		2	-1.77 + 3.69SD + 0.080FN	0.75	10.23**
		3	-4.26 + 3.78SD + 0.11FN + 19.58ES	0.88	14.42**
CU(C)	mg/L	1	0.00081 + 0.00014CL	0.41	5.59*
		2	-0.012 + 0.00043SC + 0.00044SP	0.77	11.54**
		2	0.0055 - 0.000001AR + 0.00014CL	0.58	4.77*
		3	-0.019 + 0.00044SC + 0.00058SP + 0.0044ES	0.94	33.30**
		3	0.010 - 0.0000017AR + 0.00027CL - 0.00041TP	0.84	10.53**

[1] L = unit-area loads
C = flow-weighted mean concentrations. For flow-weighted mean concentrations a maximum of 3 equations, for each of 1, 2 and 3 variables, is included in this table.

[2] A = alternate equation - one or more variables significantly correlated with those of equation with higher r^2 value.

[3] F values followed by ** are significant at $p \leq 0.01$
F values followed by * are significant at $p \leq 0.05$

Copper (CU): Table 5 lists a large number of alternative regression equations for copper. However, few contain combinations of variables which conform to established or expected cause:effect relationships. The appearance of cereal crop area (CC), for example, is difficult to explain. One three-variable equation gave high r^2 values for both loading and flow-weighted mean concentrations - this was based on soil clay content (SC), soil extractable phosphorus (SP) and exposed streambanks (ES). Since copper was closely correlated with the suspended solids, this equation almost certainly reflects this sediment association.

Lead (PB): Table 6 displays a number of regression equations for lead. However, investigation of these alternatives failed to reveal consistent trends that fit any reasonable cause:effect relationship. Since lead was not used in any agricultural practices, and was not correlated with suspended solids, this failure to find regression equations, which could be applied with any confidence, is a satisfactory result.

Zinc (ZN): Soil clay content (SC) is seen in Table 6 to be a consistent component of many of the multiple linear regression equations for zinc. Other variables included were soil extractable phosphorous (SP), and exposed streambank (ES). Zinc loadings and concentrations were highly correlated with sediments (suspended solids), so that these equations probably reflect this sediment influence.

Endosulfan (EN): Endosulfan loads and flow-weighted mean concentrations were very unevenly distributed among the watersheds, with highest levels in watershed #13. This resulted in regressions which contained many variables which were high in this watershed, without regard to the cause:effect relationships. Thus rural residences (RR) and negative animal units (-AU) appeared to account for as much variability as orchards and vegetable crops - two of the land uses in which endosulfan is used (Table 7). Combining all crops on which this insecticide is used (i.e. vegetables, orchards, tobacco) into one variable did not reduce the residual variability. This would, however, be a reasonable approach to the extrapolation problem.

Atrazine (AT): In spite of the fact that atrazine is used only on corn, Table 7 shows that it was only at the three-variable regression equation level that corn (CA) is a significant variable. Soil clay content (SC) and potential to transfer pollutants to surface water (PS) were more significant in explaining atrazine variability than was corn area.

PCB (PC): As with lead, discussed above, no reasonable combination of variables appeared to account for PCB loads and flow-weighted mean concentrations in any way which might reflect likely cause:effect relationships. Soil clay content (SC), rural residences (RR) and exposed streambank (ES) all showed negative relationships with PCB loads and concentrations (Table 7). Since PCB, like lead, is suspected of being primarily of atmospheric origin in the agricultural watersheds, it is not surprising that these results were obtained.

4.2.3.3 Non-Linear Regression

An attempt has been made to identify any tendency for the relationships discussed above to be non-linear. This was done by plotting

TABLE 6. Selected Results of Regression of Lead and Zinc Unit-Area Loads and Flow-Weighted Mean Concentrations.

Para.[1]	Units	No. Var.	Equation	Explained Var. (r^2)	F[3]
PB(L)	kg/ha	1	0.018 - 0.00079AG	0.46	6.91*
		3	0.016 + 0.0034EP - 0.00089AG - 0.000086TD	0.89	15.55**
		3A	0.037 - 0.00024SA - 0.026AU - 0.000074TD	0.85	11.29**
		3A	0.036 - 0.00024SA - 0.00026CA - 0.02AU	0.83	9.68*
		3A	0.042 - 0.00026SA - 0.00017RC - 0.03AU	0.81	8.50*
		3	0.20 + 0.0020EP - 0.0002TP - 0.00088AG	0.79	7.45*
		3A	0.026 - 0.0098AU - 0.00026FP - 0.00076AG	0.77	6.67*
		3	0.054 - 0.00031PH - 0.001SP - 0.001MP	0.76	6.30*
		3	0.039 - 0.00024SA - 0.020AU - 0.00013TN	0.74	5.66*
		3	0.031 - 0.00030SA + 0.00026WA - 0.00037MN	0.72	5.23*
		3A	0.030 - 0.00026SA + 0.0002WA - 0.022AU	0.72	5.17*
		3	-0.0029 + 0.0000022AR + 0.00023SC + 0.0005RR	0.72	5.16*
		3	0.034 - 0.00017SA - 0.00025FP - 0.024AU	0.71	4.85*
		3A	0.034 - 0.00018SA - 0.00021TP - 0.02AU	0.70	4.78*
ZN(L)	kg/ha	1	0.013 + 0.002SC	0.43	6.11*
		3	-0.14 + 0.0036SC + 0.14PG + 0.57ES	0.96	48.61**
		3	-0.13 + 0.0035SC + 0.0035SP + 0.41ES	0.93	25.42**
		3	0.0041 + 0.0026SC + 0.0013PH + 0.41ES	0.78	7.27*
		3A	0.021 + 0.086PS - 0.0015PH + 0.44ES	0.78	7.25*
		3	-0.086 + 0.0030SC + 0.0015CC + 0.0022SP	0.78	7.20*
		3A	-0.097 + 0.099PS + 0.0032SP + 0.39ES	0.78	7.02*
		3	-0.074 + 0.0024SC + 0.0029CC + 0.0051NA	0.77	6.64*
		3A	-0.10 + 0.0042SC + 0.0042SP - 0.00094FN	0.76	6.36*
		3A	-0.077 + 0.091PS + 0.002CC + 0.00022SP	0.75	6.09*
		3	0.12 + 0.15PG - 0.0043WA - 0.004FP	0.75	5.88*
		3	-0.0097 + 0.0025CL + 0.0089RR - 0.0064FP	0.74	5.58*
		3	0.079 - 0.0038WA + 0.0052SP - 0.005FP	0.73	5.35*
		3	-0.037 + 0.063PS + 0.004RR + 0.0025CC	0.72	5.29*
PB(C)	mg/L	2	-0.0016 + 0.00014SC + 0.0045PG	0.70	8.32*
		2	-0.0022 + 0.00013SC + 0.00012SP	0.63	5.96*
ZN(C)	mg/L	2	-0.038 + 0.0014SC + 0.0011SP	0.77	11.64**
		2	-0.014 + 0.00029CL + 0.00075SC	0.59	4.98*
		3	-0.057 + 0.0014SC + 0.0014SP + 0.12ES	0.91	19.10**
		3	-0.056 + 0.0014SC + 0.055PG + 0.18ES	0.89	16.69**
		3	0.037 + 0.066PG - 0.0017WA - 0.0016FP	0.78	7.29*

[1] L = unit-area loads
C = flow-weighted mean concentrations. For flow-weighted mean concentrations a maximum of 3 equations, for each of 1, 2 and 3 variables, is included in this table.

[2] A = alternate equation - one or more variables significantly correlated with those of equation with higher r^2 value.

[3] F values followed by ** are significant at $p \leq 0.01$
F values followed by * are significant at $p \leq 0.05$

TABLE 7. Selected Results of Regression of Endosulfan Atrazine and Polychorinated Biphenyls, Unit-Area Loads and Flow-Weighted Mean Concentrations.

Para.	Units	No. Var.	Equation	Explained Var. (r^2)	F[3]
EN(L)	g/ha	1	0.0041 + 0.0018VA	0.86	48.11**
		1	0.0056 + 0.013OR	0.85	46.51**
		1	-0.0036 + 0.0032RR	0.81	33.30**
		1	-0.0068 + 0.00054RC	0.46	6.84*
		2	0.014 + 0.010OR - 0.019AU	0.94	51.83**
		2	0.012 + 0.0015UA - 0.00027MN	0.94	50.85**
		2	-0.00038 + 0.010OR + 0.00024FN	0.91	35.69**
		2	0.0033 - 0.010SD + 0.0035RR	0.90	33.08**
		3	0.0042 - 0.00055CA + 0.0080OR + 0.00048FN	0.98	85.28**
		3	0.0032 + 0.00040CL + 0.015OR - 0.00089TP	0.98	84.59**
		3	0.0045 + 0.00016CL + 0.010R - 0.00091MP	0.97	72.28**
AT(L)	kg/ha	1	-0.0006 + 0.00011SC	0.73	21.86**
		1	0.000081 + 0.0033PS	0.69	17.59**
		1	0.003 - 0.000072WA	0.40	5.39*
		2	-0.0012 + 0.0033PS + 0.000024CL	0.83	17.61**
		3	-0.0023 + 0.0034PS + 0.00066CA + 0.00000025AR	0.90	18.84**
		3	-0.0027 + 0.00000024AR + 0.00011SC + 0.000051CA	0.90	18.13**
		3	-0.0002 + 0.0028PS + 0.000054CA - 0.00011AG	0.87	13.30**
PC(L)	g/ha	1	0.19 - 0.0025SC	0.65	14.80**
		1	0.17 - 0.077PS	0.62	13.04**
		3	0.22 - 0.0024SC - 0.0031RR - 0.25ES	0.97	71.90**
		3	0.21 - 0.075PS - 0.0031RR 0.25ES	0.93	26.42**
		3	0.20 - 0.0029SC - 0.0045RR + 0.0006RC	0.91	20.53**
EN(C)	µg/L	1	-1.48 + 1.036RR	0.80	31.41**
		1	-3.003 + 0.41FP	0.71	20.02**
		1	-1.93 + 0.98NA	0.70	18.60**
		2	-3.35 + 0.75RR + 0.11FN	0.91	35.17**
		2	-3.56 + 0.83RR + 0.094RC	0.89	29.46**
		3	1.80 + 0.60RR - 0.31CA + 0.12TD	0.97	65.19
AT(C)	mg/L	1	-0.089 + 0.029SC	0.64	14.36**
PC(C)	µg/L	1	0.018 + 0.00067SP	0.78	28.95**
		1	0.022 + 0.022PG	0.76	24.70**
		1	0.025 + 0.00028FN	0.59	11.28**
		2	0.016 + 0.023PG + 0.00032CA	0.94	56.39**
		3	0.020 + 0.023PG - 0.0005RR + 0.0001TD	0.98	96.00**
		3	0.018 + 0.022PG - 0.0022SD + 0.00030CA	0.96	49.66**
		3	0.02 + 0.024PG - 0.0027RD + 0.00034CA	0.95	41.43**

[1] L = unit-area loads
C = flow-weighted mean concentrations. For flow-weighted mean concentrations a maximum of 3 equations, for each of 1, 2 and 3 variables, is included in this table.

[2] A = alternate equation - one or more variables significantly correlated with those of equation with higher r^2 value.

[3] F values followed by ** are significant at $p \leq 0.01$
F values followed by * are significant at $p \leq 0.05$

the measured against the predicted values using the best linear regressions, and then formulating some non-linear expansions of these equations in an attempt to reduce the residual variability in unit-area loads. Time did not permit a comprehensive evaluation of the many alternatives, or the extension of the approach to flow-weighted mean concentrations.

The procedure yielded worthwhile results only for suspended solids, total phosphorus and nitrate (plus nitrite) nitrogen. No significant improvement was obtained with the other water quality parameters.

Suspended Solids (sediment) (SS): Table 1 shows that statistical improvement was obtained in the explanation of suspended solids unit-area loads by the addition of characteristics into the regression equation which were hard to explain in a physical sense - e.g. negative effect of total phosphorus additions (TP), and positive effect of soil extractable P (SP). Non-linear expansion of the "soil clay, cultivated land" equation did not yield statistical improvement. The simple linear regression on % cultivated land (CL), however, was investigated further and it was found that an improved equation was as follows:

$$SS = 97 + 0.0010\ CL^3$$
$$r^2 = 0.70$$

where SS = suspended solids unit area load (in kg/ha/yr)
CL = % of land area in cultivated crops

Total Phosphorus (PT): In view of the discussion of total phosphorus in section 4.2.3.2 above, the non-linear regression investigation looked at the combination of soil clay content (SC) and row-crops (RC) as a way to obtain a better relationship for extrapolation purposes. Although a number of non-linear equations were considered, the following equation was felt to be most appropriate.

$$PT = 0.149 + (6.550\ SC^2 \times 10^{-4}) + (1.622\ RC^2 \times 10^{-4})$$
$$r^2 = 0.85$$

where PT = total phosphorus unit area load (in kg/ha/yr)
SC = soil mean clay content in %
RC = % of total area in row-crops.

Nitrate (plus nitrite) Nitrogen (NN): A non-linear expansion of the most appropriate extrapolation equation for nitrate (plus nitrite) nitrogen seen in Table 3 was found to be a slight improvement over the linear version. The expression is as follows:

$$NN = -1.605 + 0.284X + 0.017X^2$$
$$r^2 = 0.83$$

where $X = 0.42\ RC + 0.29\ MN$

where NN = nitrate (plus nitrite) nitrogen unit-area load (in kg/ha/yr)
RC = % of total area in row-crops
MN = nitrogen inputs to soils as manure (kg/ha/yr).

5.0 EXTRAPOLATION OF RESULTS

The purpose of this section is to present an approach to selection of suitable equations for use in an attempt to extrapolate the mean annual data obtained in the agricultural watershed studies to other Canadian Great Lakes agricultural areas.

5.1 Constraints to extrapolation

Clearly, the main constraint to the use of extrapolation procedures is data - both data with which to extrapolate, and data by which to verify the accuracy (or plain reasonableness) of extrapolation attempts. Certain land or land-use variables are inappropriate for extrapolation purposes, though they may be useful determinants of water quality, if these variables cannot be readily measured outside a small area. Examples would be "exposed streambank", "soil extractable phosphorus", "tile drainage density," etc. Other, more useful, data may be available from such sources as the census of agriculture, soil surveys and maps, while others may be estimated by applying coefficients to one data set to generate another, - e.g. manure production as a function of livestock types and numbers.

The constraints on the acceptability of characteristics to be included in extrapolation functions can be used as a guide to equation selection. However, testing the validity of an extrapolation attempt is a more difficult problem to solve. The chief constraint for agricultural purposes is that of obtaining reliable stream monitoring data from catchment areas with an entirely agricultural land use. Most of the long-term "historical" monitoring network sites in southern Ontario were clearly chosen for purposes other than monitoring agriculture. Furthermore, many of these sites have inadequate flow monitoring, accompanying the routine sampling, to permit reliable loadings to be calculated. The authors searched the OMOE historical records and obtained 97 possible sites, of which only nine could supply loading data with sufficient reliability to be included in this validation process. With five mostly agricultural sub-basins of the Grand and Saugeen rivers, monitored by PLUARG, there were 14 sites (referred to as "historic") used to test extrapolation as outlined in the discussions which follow.

5.2 Extrapolation to the Canadian Great Lakes Basin

Suspended solids (sediment): The equations available to describe and predict sediment loads were not encouraging. Values of explained variance were low, even for the non-linear equation involving cultivated land. When this equation was used to predict the sediment loadings in the 14 OMOE "historic" agricultural sub-basins, a measured:predicted correlation coefficient of only 0.34 was obtained (i.e. only 11% of variability in measured loads accounted for by the prediction equation). The distribution of the measured and the predicted values, both for the 10 agricultural watersheds and for the 14 OMOE sites is shown in figure 2, together with the best-fit regression lines.

The poor relationship found in the verification process for suspended solids suggested that it was not possible to extrapolate this parameter. No further extrapolations were therefore attempted.

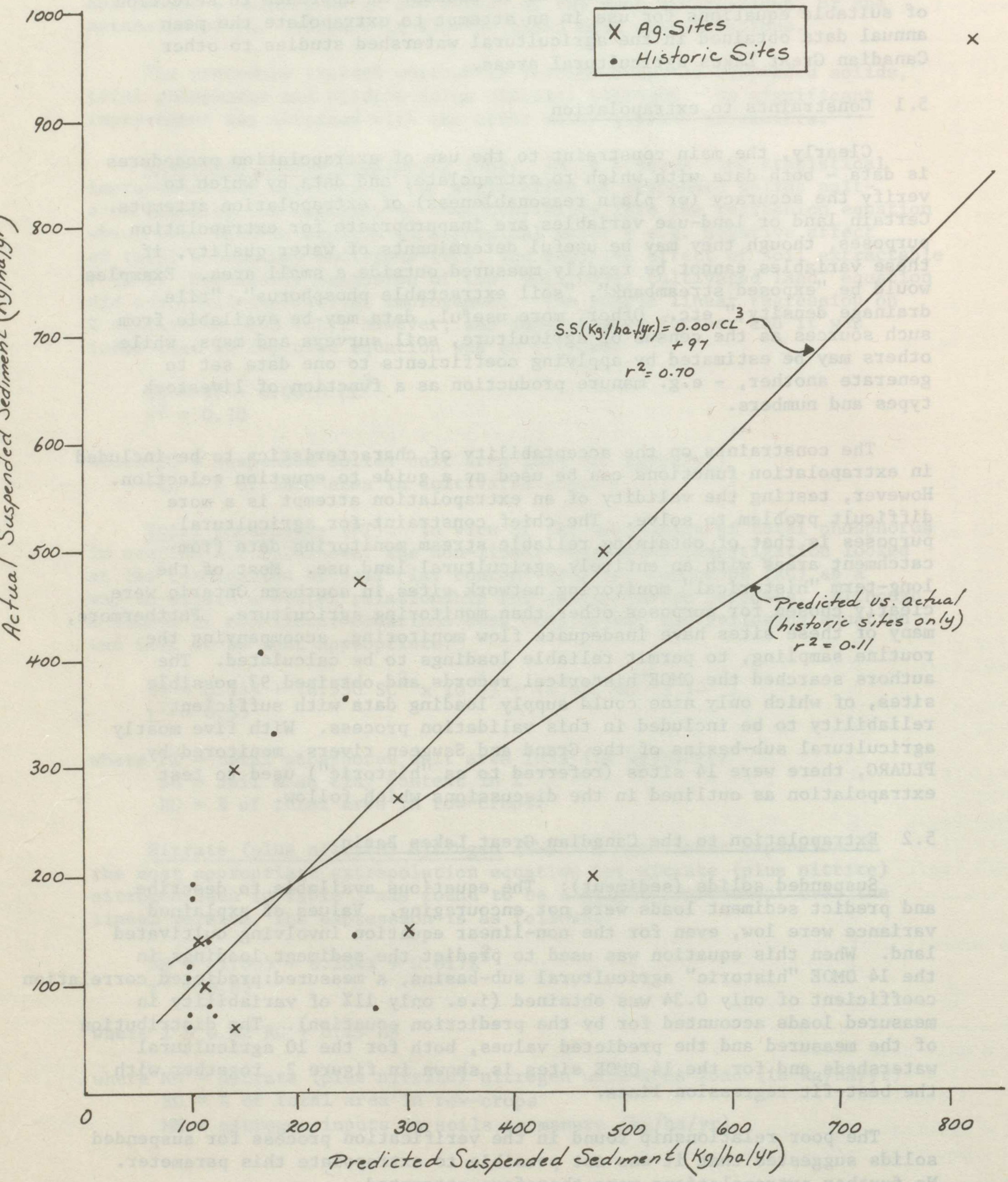

Fig. 2 Measured and predicted values of suspended sediment for 10 PLUARG agricultural and 14 OMOE historical sites

Total phosphorus: The second order prediction equation involving soil clay content and row-crop density was used to predict loadings of total phosphorus in the 14 OMOE sub-basins. These values are plotted on figure 3, together with the loadings obtained in the 10 agricultural watershed sites. Figure 3 indicates that, while the correlation between measured and predicted values was poor, the relationship between the predicted values and the agricultural watersheds in general was good. It can also be seen that the equation tended to over-predict total phosphorus in the OMOE sub-basins. This is a satisfactory result, as the OMOE basins were all larger than those used in the agricultural studies, and were all sampled less frequently. Both of these factors would tend to result in lower measured total phosphorus values, except at very low loads where other sources such as stream banks and septic tanks may become significant.

Using the equation discussed above, figure 4 was prepared for the agricultural portion of the Canadian Great Lakes basins. Soil clay content was obtained by applying representative values to each of the soil pollutant transfer potential subgroups developed and mapped (Coote, et al., 1974) and extracting the data on a watershed basis (Water Survey of Canada System) from the Canada Land Inventory computerized Geographic Information System. Row-crop data were obtained from the 1971 census of agriculture, extracted and updated as described on page 8. The data presented in figure 4 represent upstream loadings from rural land in general - to the extent that such land is represented by the agricultural watersheds, - in other words, woodland, highways, streams and households which are normally found in an agricultural area are included - but waste disposal, urban and extensive forest land are not.

Soluble ortho-phosphorus: Soluble ortho-phosphorus loads were well accounted for by multiple linear regression. A number of alternative prediction equations were available, but many involved variables which are difficult to obtain or, as in the case of watershed area, difficult to apply to a landscape distribution extrapolation. The following equation was chosen for testing:

$$OP\ (kg/ha/yr) = -0.251 + 0.0117\ CL + 0.192\ AU + 0.0106\ FP$$

where CL = mean surface soil clay content (%)
AU = animal unit density (no./ha)
FP = fertilizer phosphorus input (kg)

Figure 5 shows the distribution of the agricultural watershed and OMOE sub-basins soluble ortho-phosphorus load data. The correlation coefficient between predicted and measured loads at the OMOE sites was an acceptable 0.70. As with total phosphorus, the phenomenon of apparent overestimation at higher loads was also observed with soluble ortho-phosphorus. Since this was also considered an acceptable result (for the same reasons), the extrapolation for landscape distribution purposes was pursued. Figure 6 presents the extrapolation of soluble ortho-phosphorus to the agricultural part of the Canadian Great Lakes basin, using the same data base discussed above for total phosphorus.

Total nitrogen: The multiple linear regression equation for total nitrogen based on row-crops and manure nitrogen was considered to be

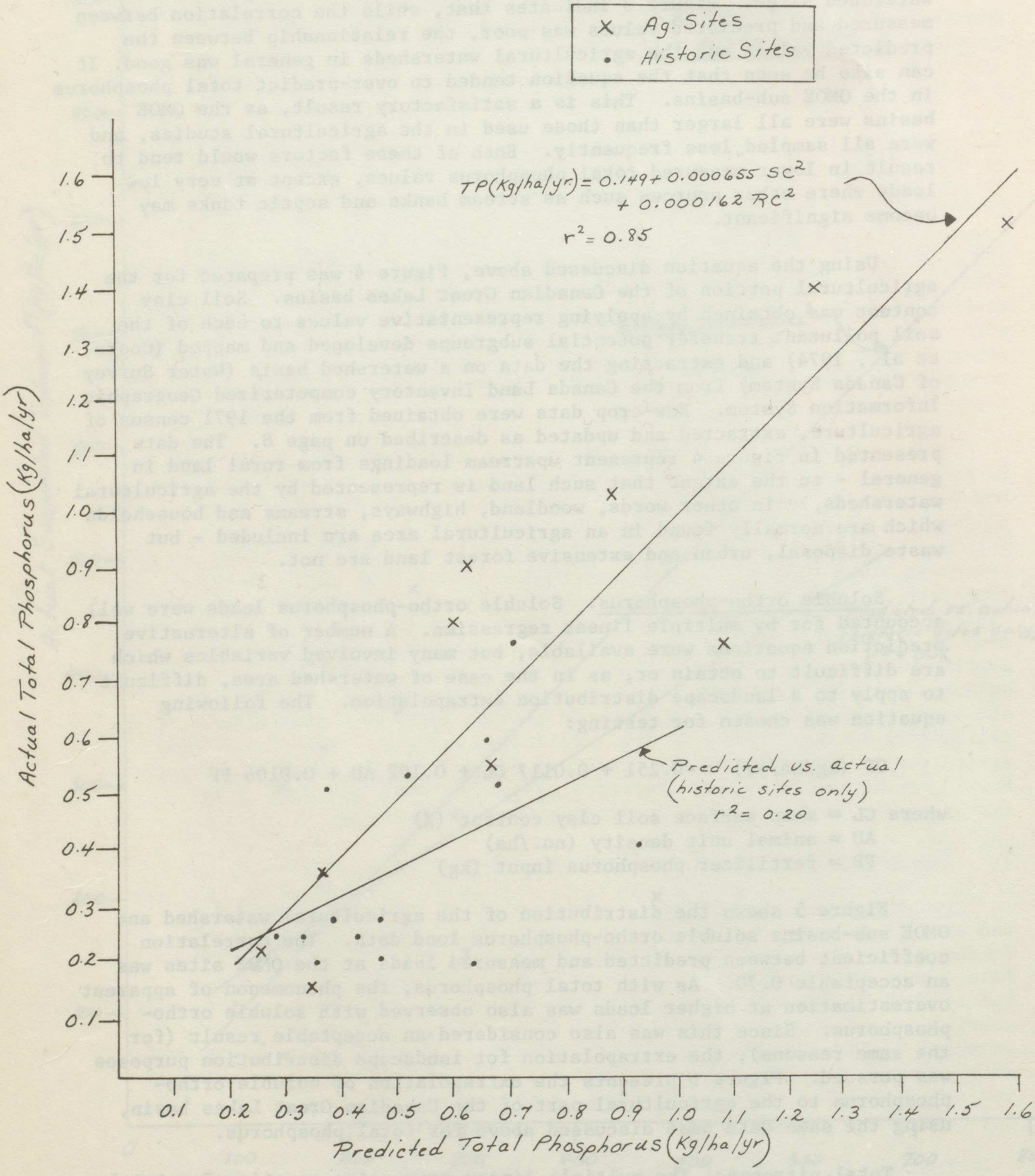

Fig. 3 Measured and predicted values of total phosphorus for 10 PLUARG agricultural and 14 OMOE historical sites

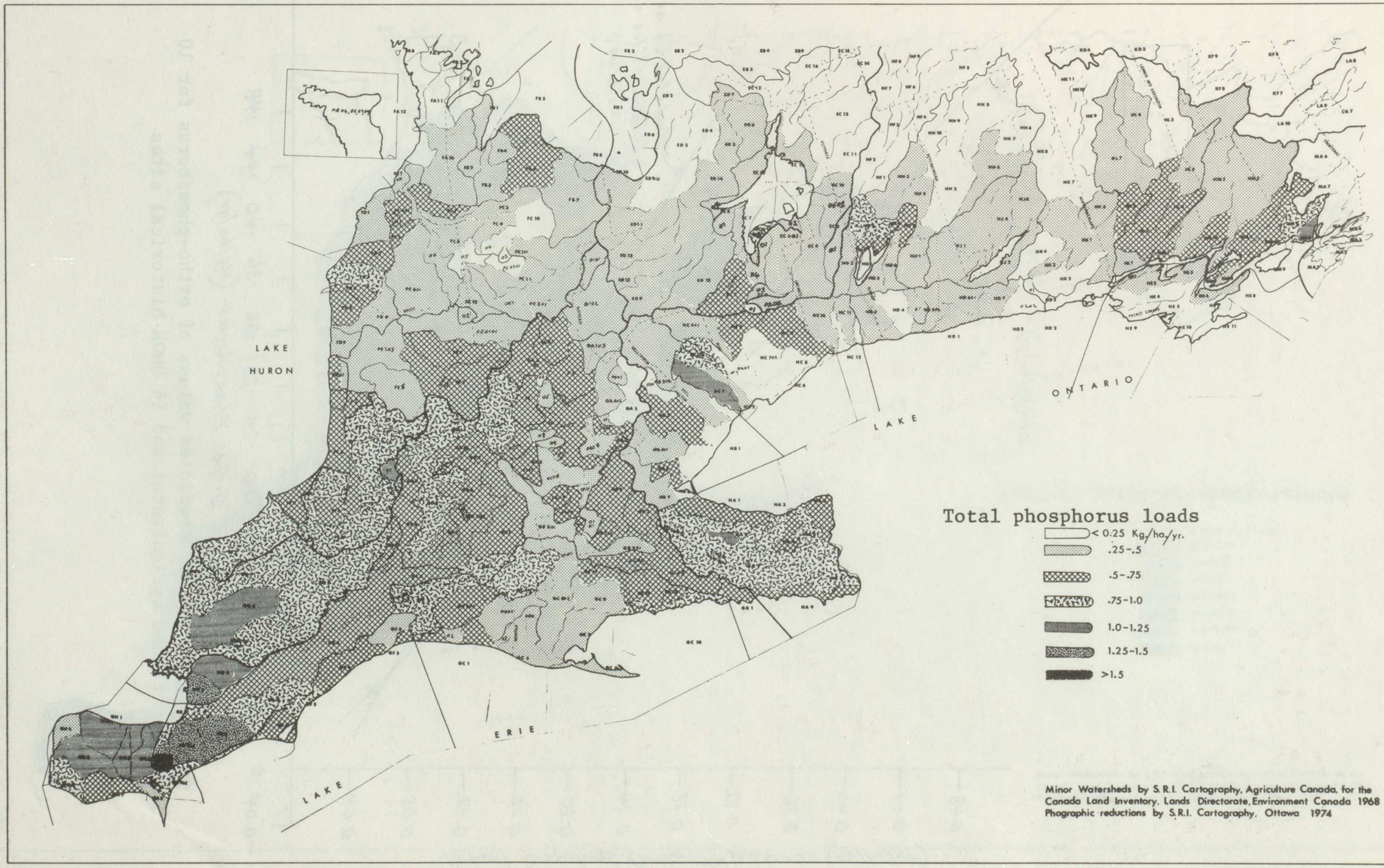

Figure 4: Unit-area loads of total phosphorus from agricultural lands, averaged over all rural land, as estimated with a regression model

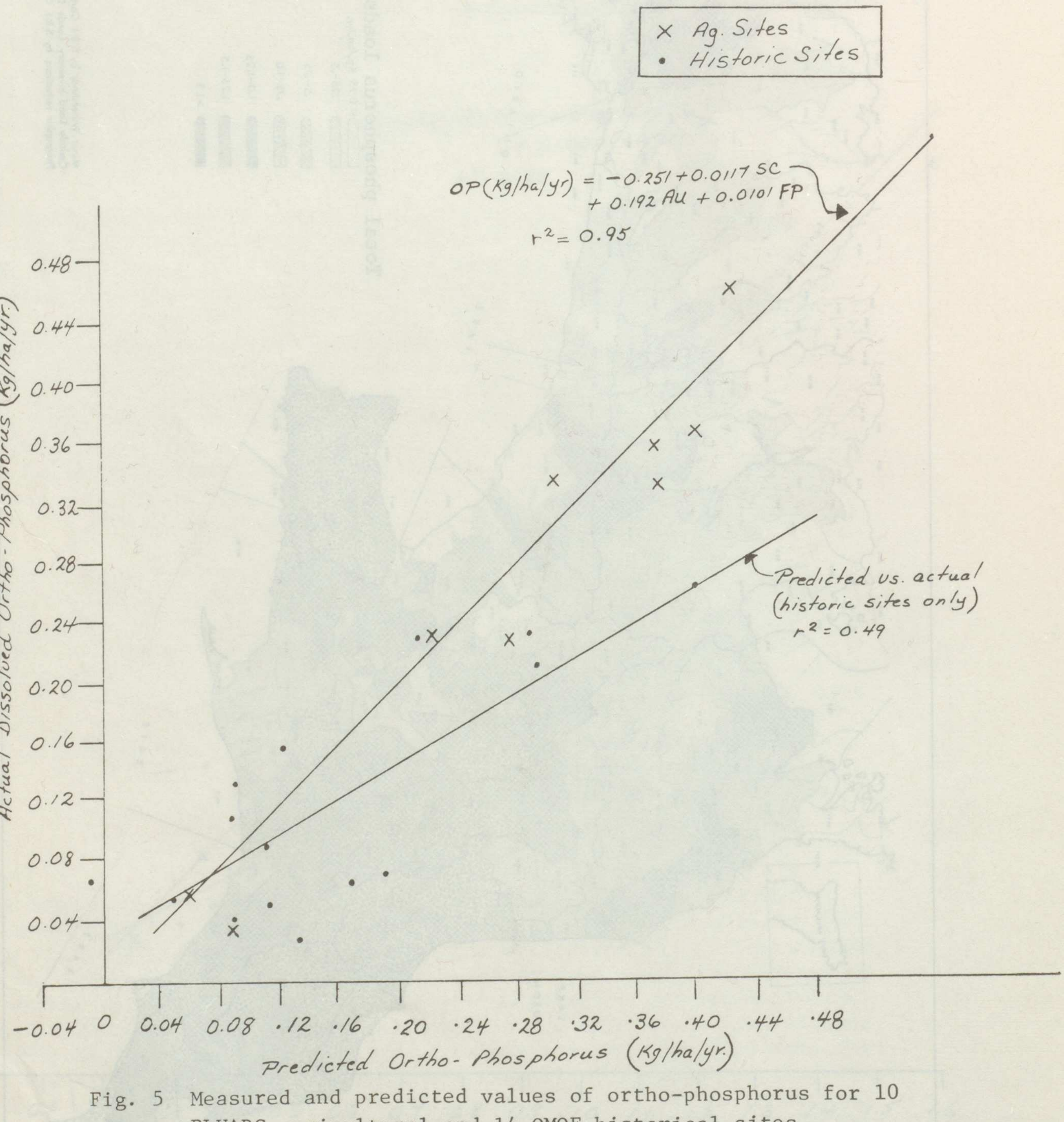

Fig. 5 Measured and predicted values of ortho-phosphorus for 10 PLUARG agricultural and 14 OMOE historical sites

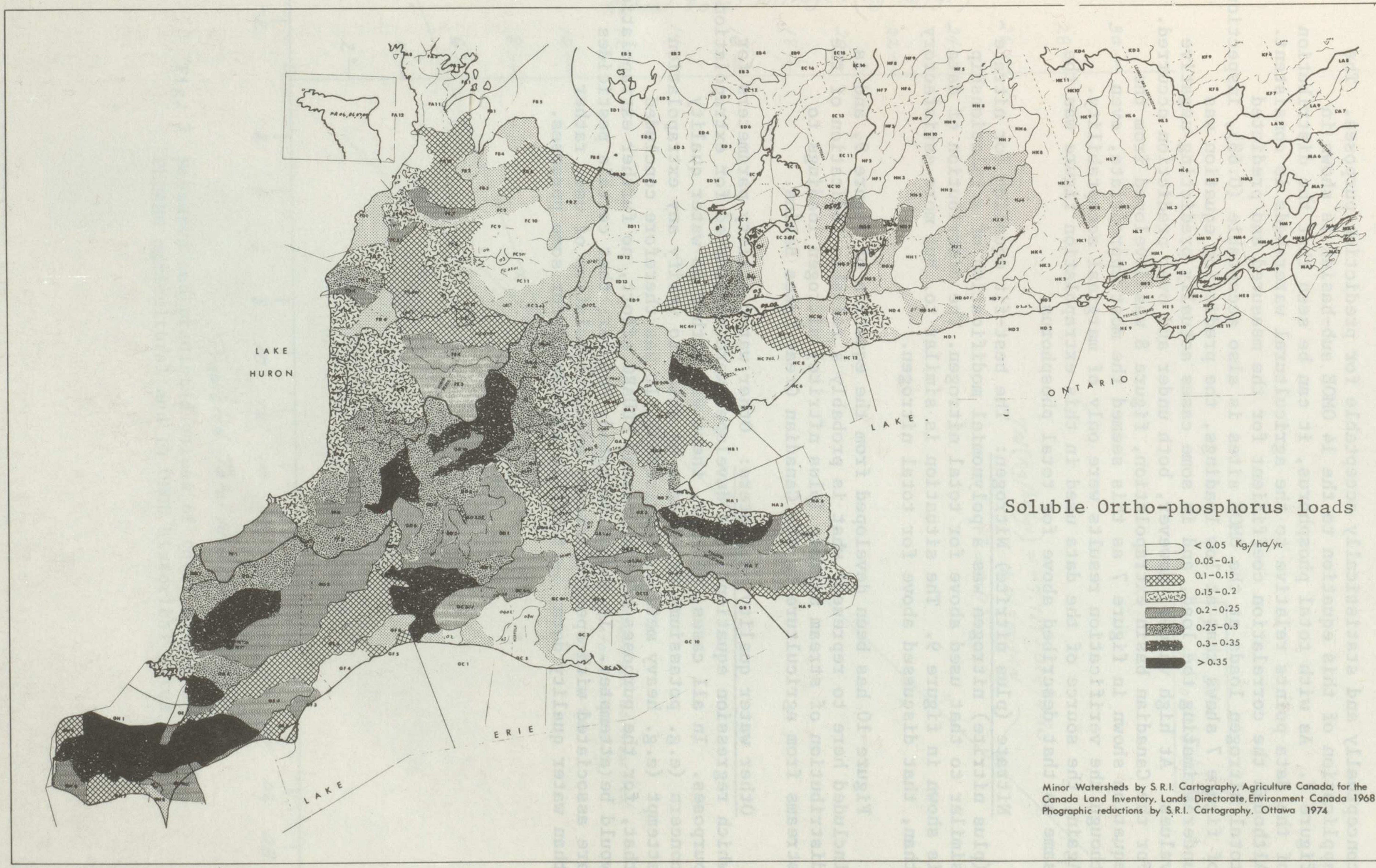

Fig. 6 Unit-area loads of soluble ortho-phosphorus from agricultural lands, averaged over all rural land, as estimated with a regression model.

conceptually and statistically acceptable for prediction purposes. The application of this equation to the 14 OMOE sub-basins is shown in figure 7. As with total phosphorus, it can be seen that the distribution of the data points relative to the agricultural watersheds is consistent. Although the correlation coefficient for the measured and predicted total nitrogen loads at the OMOE sites is also acceptable (0.68), inspection of figure 7 shows that at low loadings, the prediction equation was underestimating the load, and in some cases actually predicting negative values. At high values, however, both under and over prediction occurred. For the Canadian basin extrapolation, figure 8 was developed from the equation shown in figure 7 as this seemed the most appropriate, even though the verification results were only of marginal acceptability. Again, the source of the data used in this extrapolation figure was the same as that described above for total phosphorus.

Nitrate (plus nitrite) Nitrogen: The best-fit equation for nitrate (plus nitrite) nitrogen was a polynomial modification of a relationship similar to that used above for total nitrogen. The distribution of data is shown in figure 9. The situation is similar to, but more satisfactory than, that discussed above for total nitrogen.

Figure 10 has been developed from the equation of figure 9, and is included here to represent what is probably a reliable indication of the distribution of stream nitrate (plus nitrite) nitrogen loadings to streams from agriculture in the Canadian Great Lakes Basins.

Other water quality parameters: Other water quality parameters for which regression equations were developed were considered for extrapolation purposes. In all cases, however, there was either no water quality concern (e.g. potassium) or no data by which to verify any extrapolation attempt (e.g. heavy metals, pesticides). It was therefore concluded that, for the purposes of the present PLUARG effort, no further extrapolations would be attempted. It should be noted, however, that certain pesticides are associated with specific crops, and extrapolation of use, rather than water quality data, is feasible and useful for some purposes.

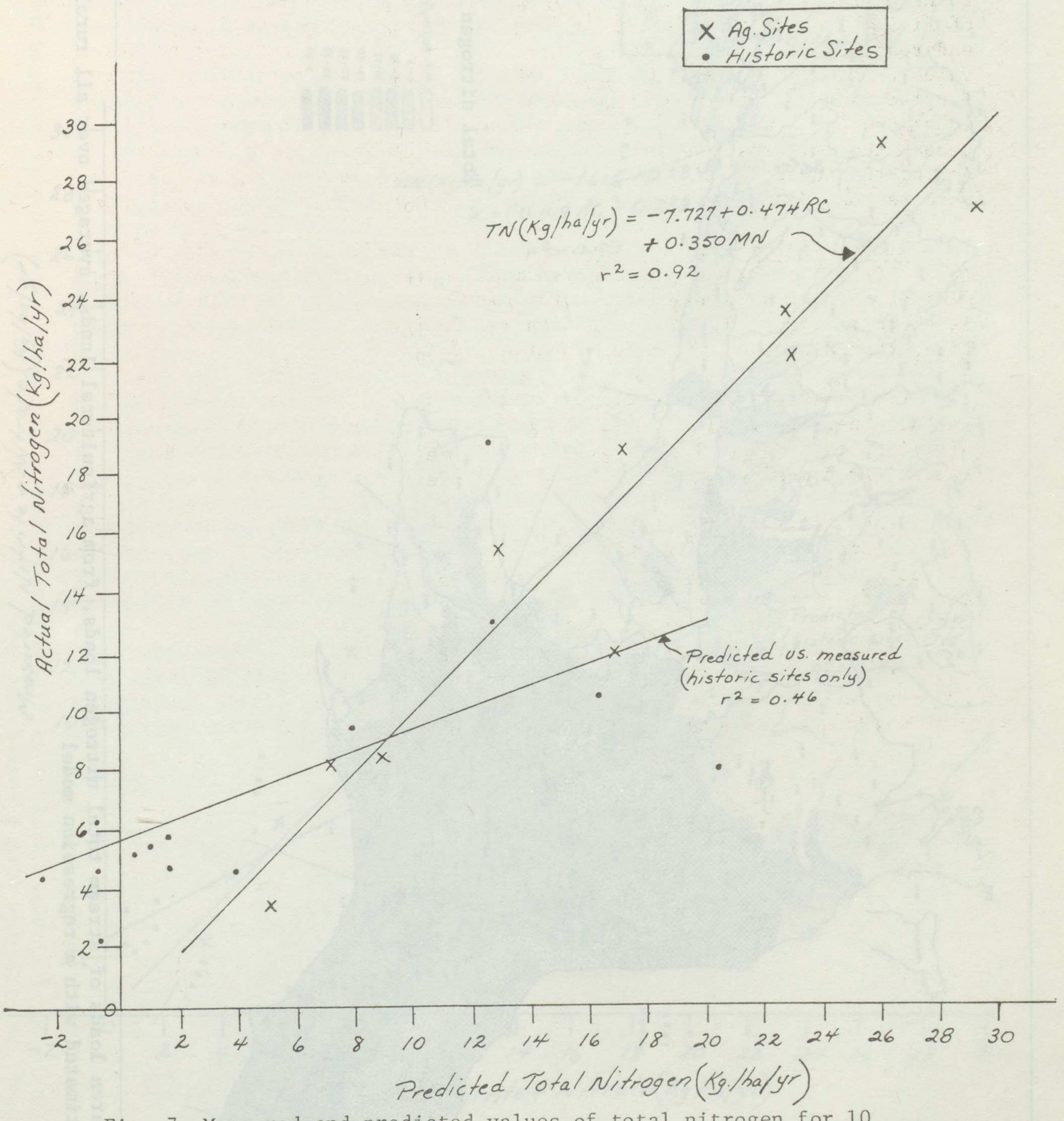

Fig. 7 Measured and predicted values of total nitrogen for 10 PLUARG agricultural and 14 OMOE historical sites

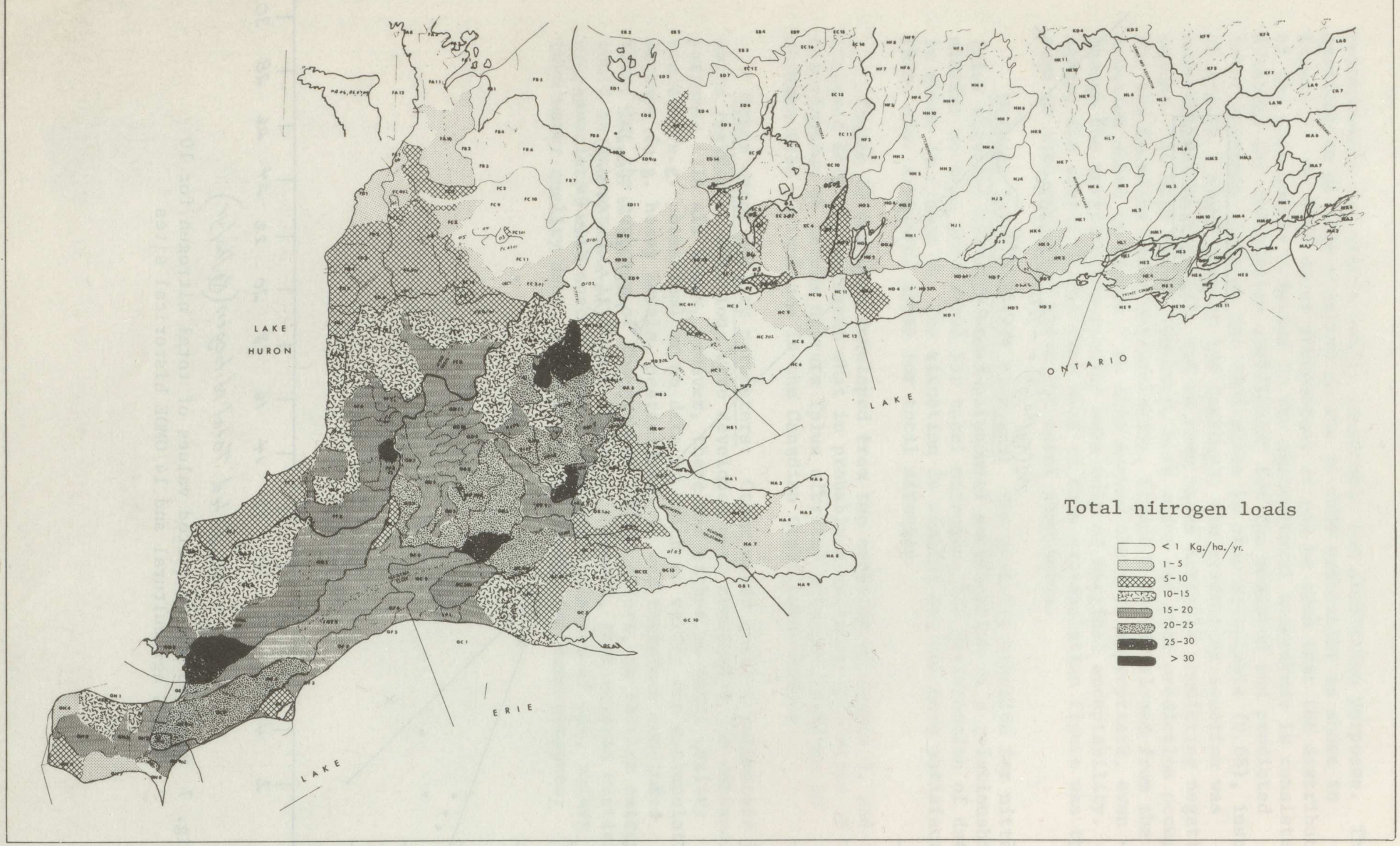

Fig. 8 Unit-area loads of stream total nitrogen loads, from agricultural lands, averaged over all rural land, as estimated with a regression model

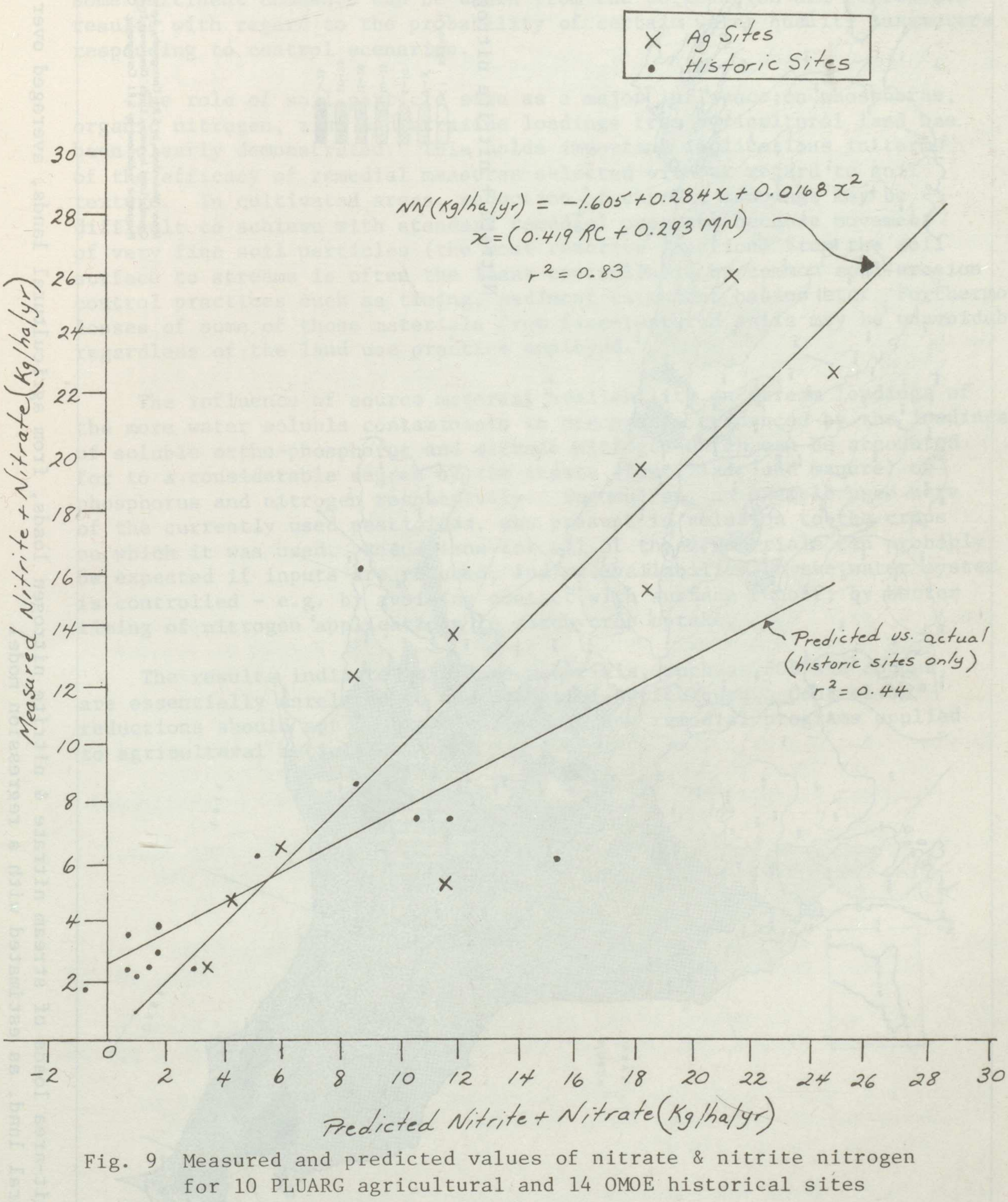

Fig. 9 Measured and predicted values of nitrate & nitrite nitrogen for 10 PLUARG agricultural and 14 OMOE historical sites

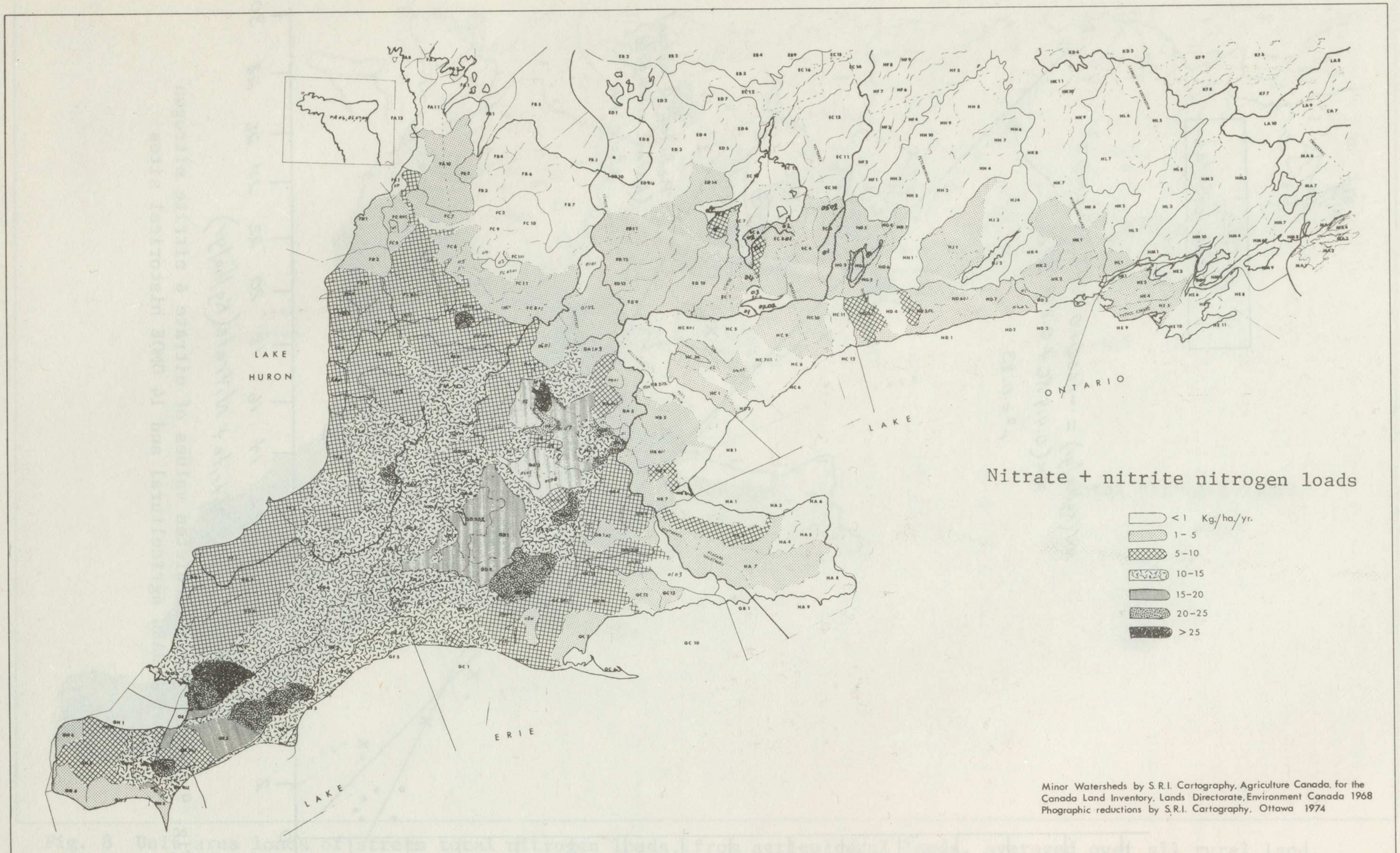

Fig. 10 Unit-area loads of stream nitrate & nitrite nitrogen loads, from agricultural lands, averaged over all rural land, as estimated with a regression model

6. REMEDIAL MEASURES IMPLICATIONS

The Agricultural Watershed Studies Overview Analysis was not formulated with any expressed objective of determining remedial measures. However, some pertinent comments can be drawn from the correlation and regression results with regard to the probability of certain water quality parameters responding to control scenarios.

The role of soil particle size as a major influence on phosphorus, organic nitrogen, zinc and atrazine loadings from agricultural land has been clearly demonstrated. This holds important implications in terms of the efficacy of remedial measures selected without regard to soil texture. In cultivated areas, reduction of current loadings may be difficult to achieve with standard remedial programs because movement of very fine soil particles (the most reactive fraction) from the soil surface to streams is often the least controllable by common soil erosion control practices such as timing, sediment catchment basins etc. Furthermore, losses of some of these materials from fine-textured soils may be unavoidable regardless of the land use practice employed.

The influence of source material availability on stream loadings of the more water soluble contaminants in streams is evidenced by the loadings of soluble ortho-phosphorus and nitrate nitrogen which can be accounted for to a considerable degree by the inputs (fertilizer and manure) of phosphorus and nitrogen respectively. Endosulfan, an example used here of the currently used pesticides, was present in relation to the crops on which it was used. Reductions for all of these materials can probably be expected if inputs are reduced, and/or availability to the water system is controlled - e.g. by avoiding contact with surface runoff; by better timing of nitrogen applications to match crop uptake.

The results indicate that some materials, such as PCB and copper, are essentially unrelated to any aspect of agriculture. Control or reductions should not be expected through any remedial programs applied to agricultural activities.

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APPENDIX A

WATERSHED LOCATIONS, CHARACTERISTICS AND WATER QUALITY DATA

(From data of Frank and Ripley, 1977; and data collected by Ontario Ministry of the Environment, Water Resources and Laboratories Branches, and processed by NAQUADAT system into unit-area loads and flow-weighted mean concentrations. Statistical program by Engineering and Statistical Research Institute.)

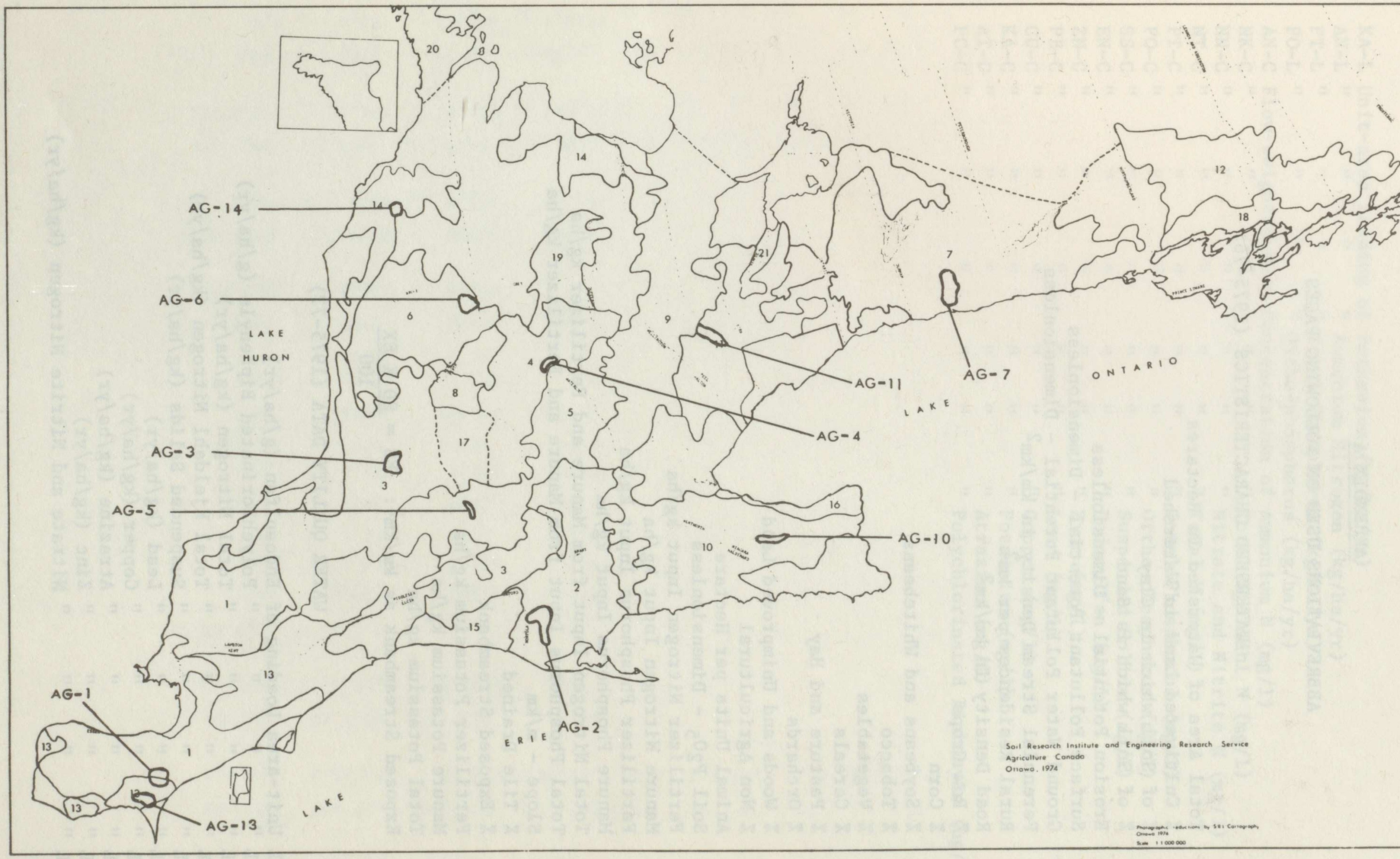

Figure A-1: Locations of eleven PLUARG Agricultural Watersheds in Southern Ontario

APPENDIX A

ABBREVIATIONS USED ON FOLLOWING PAGES

WATERSHED CHARACTERISTICS (1975-76)

AR	Total Area of Watershed In Hectares
CL	% Cultivated Land in Watershed
SC	% of Soil which is Clay
SA	% of Soil which is Sand
EP	Erosion Potential - Dimensionless
PS	Surface Pollutant Potential - Dimensionless
PG	Ground Water Pollutant Potential - Dimensionless
SD	Perennial Stream Density in km/km^2
RR	Rural Residences per km^2
RD	Road Density in km/km^2
RC	% Row Crops
CA	% Corn
SY	% Soybeans and Whitebeans
TO	% Tobacco
VA	% Vegetables
CC	% Cereals
PH	% Pasture and Hay
OR	% Orchards
WA	% Woods and Unimproved Land
NA	% Non Agricultural
AU	Animal Units per Hectare
SP	Soil P_2O_5 - Dimensionless
FN	Fertilizer Nitrogen Input kg/ha
MN	Manure Nitrogen Input kg/ha
FP	Fertilizer Phosphorus Input kg/ha
MP	Manure Phosphorus Input kg/ha
TN	Total Nitrogen Input from Manure and Fertilizer kg/ha
TP	Total Phosphorus Input from Manure and Fertilizer kg/ha
AG	Slope - m/km
TD	% Tile Drained
EX	% Exposed Streambank
FK	Fertilizer Potassium kg/ha
MK	Manure Potassium kg/ha
TK	Total Potassium kg/ha
ES	Exposed Streambank as km/km^2: $ES = \frac{SD \times EX}{100}$

WATER QUALITY DATA (1975-77)

EN-L	Unit-area Loading of Endosulfan (g/ha/yr)
PC-L	" " " " Polychlorinated Biphenyls (g/ha/yr)
NT-L	" " " " Total Nitrogen (kg/ha/yr)
NK-L	" " " " Total Kjeldahl Nitrogen (kg/ha/yr)
SS-L	" " " " Suspended Solids (kg/ha/yr)
PB-L	" " " " Lead (kg/ha/yr)
CU-L	" " " " Copper (kg/ha/yr)
AT-L	" " " " Atrazine (kg/ha/yr)
ZN-L	" " " " Zinc (kg/ha/yr)
NN-L	" " " " Nitrate and Nitrite Nitrogen (kg/ha/yr)

KA-L Unit-area Loading of Potassium (kg/ha/yr)
AN-L " " " " Ammonium Nitrogen (kg/ha/yr)
PT-L " " " " Total Phosphorus (kg/ha/yr)
PO-L " " " " Ortho-phosphorus (kg/ha/yr)
AN-C Flow-weighted Mean Concentration of Ammonium N (mg/l)
NK-C " " " " " " Total Kjeldahl N (mg/l)
NN-C " " " " " " Nitrate and Nitrite N (mg/l)
NT-C " " " " " " Total N (mg/l)
PT-C " " " " " " Total Phosphorus (mg/l)
PO-C " " " " " " Ortho-phosphorus (mg/l)
SS-C " " " " " " Suspended Solids (mg/l)
EN-C " " " " " " Endosulfan (ug/l)
ZN-C " " " " " " Zinc (mg/l)
PB-C " " " " " " Lead (mg/l)
CU-C " " " " " " Copper (mg/l)
KA-C " " " " " " Potassium (mg/l)
AT-C " " " " " " Atrazine (mg/l)
PC-C " " " " " " Polychlorinated Biphenyls (ug/l)

WATERSHED 1

WATERSHED CHARACTERISTICS

AR	CL	SC	SA	EP	PS	PG	SD	RR	RD	RC	CA	SY	TO
5080.	89.3	35.0	35.0	2.9	0.80	0.70	0.288	4.1	2.0	62.2	23.0	37.4	0.02

VA	CC	PH	OR	WA	NA	AU	SP	FN	MN	FP	MP	TN	TP
1.8	27.1	1.7	0.001	3.9	5.1	0.08	31.4	58.4	3.7	18.9	1.0	62.1	19.9

AG	TD	EX	FK	MK	TK
1.14	80.0	21.0	26.3	2.5	28.8

WATER QUALITY DATA

EN-L	PC-L	NT-L	NK-L
.021	.107	22.0	6.71

SS-L	PB-L	CU-L	AT-L
961.7	0.020	0.049	.00309

ZN-L	NN-L	KA-L	AN-L
0.134	15.29	14.89	1.06

PT-L	PD-L	PO-L
1.51	0.261	0.358

AN-C	NK-C	NN-C	NT-C
0.401	2.54	5.788	8.328

PT-C	PD-C	PO-C	SS-C
0.572	0.099	0.136	364.06

EN-C	ZN-C	PB-C	CU-C
7.9	0.051	0.0076	0.0185

KA-C	AT-C	PC-C
5.637	1.17	0.041

WATERSHED 2

WATERSHED CHARACTERISTICS

AR	CL	SC	SA	EP	PS	PG	SD	RR	RD	RC	CA	SY	TO
7913.	58.7	6.6	80.0	0.4	0.05	1.00	0.503	2.5	1.8	33.7	10.1	0.6	22.2

VA	CC	PH	OR	WA	NA	AU	SP	FN	MN	FP	MP	TN	TP
0.8	25.0	3.0	0.001	36.3	2.1	0.04	36.8	27.9	1.5	21.1	0.4	29.4	21.5

AG	TD	EX	FK	MK	TK
2.86	2.0	6.0	50.1	1.3	51.4

WATER QUALITY DATA

EN-L	PC-L	NT-L	NK-L
.011	.195	8.36	1.98

SS-L	PB-L	CU-L	AT-L
153.2	0.015	0.026	.000549

ZN-L	NN-L	KA-L	AN-L
0.038	6.38	5.79	0.116

PT-L	PD-L	PO-L
0.364	0.077	0.058

AN-C	NK-C	NN-C	NT-C
0.024	.417	1.343	1.760

PT-C	PD-C	PO-C	SS-C
0.077	0.016	0.012	32.25

EN-C	ZN-C	PB-C	CU-C
2.3	0.008	0.0032	0.0055

KA-C	AT-C	PC-C
1.219	0.12	0.041

WATERSHED 3

WATERSHED CHARACTERISTICS

AR	CL	SC	SA	EP	PS	PG	SD	RR	RD	RC	CA	SY	TO
6200.	71.7	30.0	10.0	1.9	0.78	0.38	0.567	2.6	2.4	45.3	31.3	12.1	0.001

VA	CC	PH	OR	WA	NA	AU	SP	FN	MN	FP	MP	TN	TP
1.9	26.4	17.9	0.001	7.6	2.8	0.48	17.1	35.4	35.2	19.4	14.5	70.6	33.9

AG	TD	EX	FK	MK	TK
2.86	50.0	9.0	25.3	29.8	55.1

WATER QUALITY DATA

EN-L	PC-L	NT-L	NK-L
.00015	.137	29.28	3.31

SS-L	PB-L	CU-L	AT-L
196.8	0.017	0.023	.00447

ZN-L	NN-L	KA-L	AN-L
0.047	25.97	9.37	0.414

PT-L	PD-L	PO-L
0.771	0.400	0.363

AN-C	NK-C	NN-C	NT-C
0.096	.764	5.997	6.761

PT-C	PD-C	PO-C	SS-C
0.178	0.092	0.084	45.44

EN-C	ZN-C	PB-C	CU-C
0.035	0.011	0.0039	0.0053

KA-C	AT-C	PC-C
2.164	1.03	0.032

WATERSHED 4

WATERSHED CHARACTERISTICS

AR	CL	SC	SA	EP	PS	PG	SD	RR	RD	RC	CA	BY	TO
1860.	54.0	25.0	25.0	0.9	0.60	0.25	0.641	3.8	1.7	18.7	18.7	0.001	0.001

VA	CC	PH	OR	WA	NA	AU	SP	FN	MN	FP	MP	TN	TP
0.001	35.3	37.2	0.001	6.9	2.0	0.75	18.3	12.3	45.5	10.1	14.5	57.8	24.6

AG	TD	EX	FK	MK	TK
8.57	20.0	33.0	17.7	42.2	59.9

WATER QUALITY DATA

EN-L	PC-L	NT-L	NK-L
.0013	.102	18.96	4.96

SS-L	PB-L	CU-L	AT-L
464.4	0.009	0.046	.00169

ZN-L	NN-L	KA-L	AN-L
0.111	14.00	12.65	1.48

PT-L	PD-L	PO-L
0.913	0.397	0.332

AN-C	NK-C	NN-C	NT-C
0.384	1.29	3.636	4.924

PT-C	PD-C	PO-C	SS-C
0.237	0.103	0.086	120.60

EN-C	ZN-C	PB-C	CU-C
0.34	0.029	0.0023	0.0119

KA-C	AT-C	PC-C
3.285	0.439	0.026

WATERSHED 5

WATERSHED CHARACTERISTICS

AR	CL	SC	SA	EP	PS	PG	SD	RR	RD	RC	CA	SY	TO
3000.	58.1	20.0	25.0	1.7	0.40	0.40	0.732	1.4	2.1	45.9	42.3	0.001	0.001

VA	CC	PH	OR	WA	NA	AU	SP	FN	MN	FP	MP	TN	TP
3.6	12.2	22.8	0.001	15.4	3.7	0.61	23.3	45.6	43.7	16.8	10.0	89.3	26.8

AG	TD	EX	FK	MK	TK
8.57	98.0	6.0	29.9	39.8	69.7

WATER QUALITY DATA

EN-L	PC-L	NT-L	NK-L
.004	.168	27.14	4.38

SS-L	PB-L	CU-L	AT-L
274.5	0.007	0.023	.00174

ZN-L	NN-L	KA-L	AN-L
0.027	22.76	10.31	0.507

PT-L	PD-L	PO-L
0.808	0.302	0.230

AN-C	NK-C	NN-C	NT-C
0.121	1.05	5.447	6.495

PT-C	PD-C	PO-C	SS-C
0.193	0.072	0.055	65.70

EN-C	ZN-C	PB-C	CU-C
0.96	0.006	0.0017	0.0055

KA-C	AT-C	PC-C
2.468	0.416	0.040

WATERSHED 6

WATERSHED CHARACTERISTICS

AR	CL	SC	SA	EP	PS	PG	SD	RR	RD	RC	CA	SY	TO
5472.	34.6	15.7	24.0	1.8	0.12	0.24	0.816	2.8	2.1	12.3	12.3	0.001	0.001

VA	CC	PH	OR	WA	NA	AU	SP	FN	MN	FP	MP	TN	TP
0.001	22.3	33.4	0.001	28.2	3.9	0.51	15.3	11.3	42.0	5.3	8.0	53.3	13.3

AG	TD	EX	FK	MK	TK
1.27	25.0	14.0	11.7	29.9	41.6

WATER QUALITY DATA

EN-L	PC-L	NT-L	NK-L
.007	.147	15.50	3.16

SS-L	PB-L	CU-L	AT-L
60.1	0.019	0.024	.000488

ZN-L	NN-L	KA-L	AN-L
0.027	12.34	7.85	0.119

PT-L	PD-L	PO-L
0.160	0.074	0.037

AN-C	NK-C	NN-C	NT-C
0.021	.546	2.131	2.676

PT-C	PD-C	PO-C	SS-C
0.028	0.013	0.0064	10.38

EN-C	ZN-C	PB-C	CU-C
1.2	0.005	0.0033	0.0041

KA-C	AT-C	PC-C
1.356	0.843	0.025

WATERSHED 7

WATERSHED CHARACTERISTICS

AR	CL	SC	SA	EP	PS	PU	SD	RR	RD	RC	CA	SY	TO
5645.	24.9	9.9	61.0	2.5	0.20	0.80	0.609	3.2	2.4	14.2	10.4	0.001	3.7

VA	CC	PM	OR	WA	NA	AU	SP	FN	MN	FP	MP	TN	TP
0.06	10.7	28.5	0.001	37.6	9.1	0.28	27.8	15.5	17.1	6.0	3.4	32.6	9.4

AG	TD	EX	FK	MK	TK
10.96	5.0	7.0	14.8	12.3	27.1

WATER QUALITY DATA

EN-L	PC-L	NT-L	NK-L
.0021	.169	3.54	1.12

SS-L	PB-L	CU-L	AT-L
97.8	0.015	0.017	.000021

ZN-L	NN-L	KA-L	AN-L
0.033	2.42	4.60	0.079

PT-L	PD-L	PO-L
0.220	0.037	0.017

AN-C	NK-C	NN-C	NT-C
0.018	.261	0.564	0.825

PT-C	PD-C	PO-C	SS-C
0.051	0.0086	0.0040	22.78

EN-C	ZN-C	PB-C	CU-C
0.49	0.008	0.0035	0.0040

KA-C	AT-C	PC-C
1.072	0.005	0.039

WATERSHED 10

WATERSHED CHARACTERISTICS

AR	CL	SC	SA	EP	PS	PG	SD	RR	RD	RC	CA	SY	TO
3025.	34.6	40.0	10.0	0.5	1.00	0.35	2.164	5.4	2.5	16.2	16.2	0.001	0.001

VA	CC	PH	OR	WA	NA	AU	SP	FN	MN	FP	MP	TN	TP
0.001	18.4	44.2	0.001	17.8	3.4	0.77	15.1	13.6	48.1	5.5	8.8	61.7	14.3

AG	TD	EX	FK	MK	TK
1.25	0.001	4.0	4.8	42.6	47.4

WATER QUALITY DATA

EN-L	PC-L	NT-L	NK-L
.0003	.086	12.22	7.04

SS-L	PB-L	CU-L	AT-L
300.2	0.016	0.037	.00311

ZN-L	NN-L	KA-L	AN-L
0.098	5.18	24.68	1.50

PT-L	PD-L	PO-L
1.40	0.636	0.460

AN-C	NK-C	NN-C	NT-C
0.461	2.16	1.591	3.753

PT-C	PD-C	PO-C	SS-C
0.430	0.195	0.141	92.19

EN-C	ZN-C	PB-C	CU-C
0.092	0.030	0.0049	0.0114

KA-C	AT-C	PC-C
7.579	0.955	0.026

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WATERSHED 13

WATERSHED CHARACTERISTICS

AR	CL	SC	SA	EP	PS	PG	SD	RR	RD	RC	CA	SY	TO
1990.	72.4	10.5	75.0	3.2	0.18	0.85	1.002	17.3	2.6	63.5	22.8	7.9	5.0

VA	CC	PM	OR	WA	NA	AU	SP	FN	MN	FP	MP	TN	TP
27.8	8.9	0.001	3.8	7.0	16.9	0.01	41.2	67.0	1.1	40.5	0.3	68.1	40.8

AG	TD	EX	FK	MK	TK
3.92	99.0	7.0	83.4	1.1	84.5

WATER QUALITY DATA

EN-L	PC-L	NT-L	NK-L
.054	.128	23.58	4.14

SS-L	PB-L	CU-L	AT-L
499.8	0.012	0.038	.000582

ZN-L	NN-L	KA-L	AN-L
0.060	19.44	25.11	1.17

PT-L	PD-L	PO-L
1.04	0.337	0.334

AN-C	NK-C	NN-C	NT-C
0.371	1.31	6.172	7.487

PT-C	PD-C	PO-C	SS-C
0.330	0.107	0.106	158.69

EN-C	ZN-C	PB-C	CU-C
17.100	0.019	0.0038	0.0121

KA-C	AT-C	PC-C
7.972	0.185	0.041

WATERSHED 14

WATERSHED CHARACTERISTICS

AR	CL	SC	SA	EP	PS	PG	SD	RR	RD	RC	CA	SY	TO
4504.	21.6	27.5	25.6	0.6	0.90	0.10	0.651	1.3	1.6	9.5	9.5	0.001	0.001

VA	CC	PH	OR	WA	NA	AU	SP	FN	MN	FP	MP	TN	TP
0.001	12.1	66.6	0.001	9.4	2.4	0.55	10.8	8.1	28.9	4.9	7.7	37.0	12.6

AG	TD	EX	FK	MK	TK
3.81	13.0	21.0	7.0	26.8	33.8

WATER QUALITY DATA

EN-L	PC-L	NT-L	NK-L
.004	.113	7.97	3.16

SS-L	PB-L	CU-L	AT-L
138.7	0.013	0.018	.00187

ZN-L	NN-L	KA-L	AN-L
0.048	4.81	12.29	0.415

PT-L	PD-L	PO-L
0.553	0.306	0.234

AN-C	NK-C	NN-C	NT-C
0.085	.649	0.988	1.637

PT-C	PD-C	PO-C	SS-C
0.114	0.063	0.048	28.49

EN-C	ZN-C	PB-C	CU-C
0.82	0.010	0.0027	0.0037

KA-C	AT-C	PC-C
2.524	0.384	0.023

APPENDIX B

CORRELATION COEFFICIENT MATRIX

(Statistical program by Engineering and Statistical Research Institute, Agriculture Canada)

WATERSHED CHARACTERISTICS

CORRELATION COEFFICIENTS

	EN-L	PC-L	NT-L	NK-L	SS-L	PB-L	CU-L	AT-L
1 EN-L	1.000							
2 PC-L	-0.030	1.000						
3 NT-L	0.208	-0.160	1.000					
4 NK-L	0.110	-0.778	0.420	1.000				
5 SS-L	0.408	-0.491	0.434	0.710	1.000			
6 PB-L	-0.005	-0.106	-0.174	0.061	0.118	1.000		
7 CU-L	0.381	-0.611	0.348	0.779	0.805	0.058	1.000	
8 AT-L	-0.284	-0.532	0.534	0.578	0.330	0.229	0.264	1.000
9 ZN-L	0.119	-0.764	0.169	0.804	0.834	0.174	0.905	0.458
10 NN-L	0.263	0.002	0.978	0.229	0.302	-0.202	0.194	0.440
11 KA-L	0.542	-0.702	0.268	0.722	0.473	-0.074	0.584	0.202
12 AN-L	0.261	-0.808	0.315	0.841	0.650	-0.208	0.845	0.368
13 PT-L	0.283	-0.711	0.465	0.914	0.814	0.022	0.786	0.622
14 PD-L	-0.048	-0.765	0.389	0.753	0.289	-0.206	0.440	0.694
15 PO-L	0.153	-0.795	0.545	0.827	0.581	-0.083	0.627	0.704
16 AN-C	0.354	-0.791	0.310	0.878	0.755	-0.063	0.889	0.371
17 NK-C	0.242	-0.720	0.361	0.958	0.841	0.175	0.830	0.529
18 NN-C	0.482	-0.160	0.950	0.411	0.013	-0.132	0.454	0.447
19 NT-C	0.476	-0.336	0.906	0.614	0.753	-0.063	0.615	0.526
20 PT-C	0.362	-0.668	0.395	0.893	0.880	0.171	0.820	0.531
21 PD-C	0.098	-0.795	0.358	0.854	0.462	-0.084	0.598	0.636
22 PO-C	0.293	-0.788	0.486	0.898	0.749	0.063	0.762	0.670
23 SS-C	0.468	-0.470	0.379	0.689	0.440	0.233	0.825	0.326
24 EN-C	0.493	-0.106	0.307	0.186	0.555	0.018	0.444	-0.208
25 ZN-C	0.223	-0.694	0.206	0.809	0.908	0.275	0.893	0.442
26 PB-C	0.272	-0.407	0.081	0.532	0.695	0.747	0.546	0.414
27 CU-C	0.453	-0.609	0.339	0.800	0.950	0.158	0.954	0.322
28 KA-C	0.597	-0.672	0.283	0.756	0.621	0.019	0.681	0.272
29 AT-C	-0.197	-0.556	0.467	0.671	0.394	0.574	0.386	0.787
30 PC-C	0.503	0.552	0.204	-0.154	0.358	-0.056	0.088	-0.217
31 -AR-	-0.283	0.603	-0.339	-0.550	-0.344	0.599	-0.478	-0.032
32 -CL-	0.503	-0.031	0.746	0.384	0.739	0.093	0.600	0.390
33 -SC-	-0.334	-0.806	0.272	0.789	0.411	0.226	0.407	0.856
34 -SA-	0.606	0.569	-0.337	-0.495	0.019	-0.069	-0.042	-0.710
35 -EP-	0.625	0.051	0.408	0.004	0.457	0.203	0.186	-0.096
36 -PS-	-0.340	-0.787	0.161	0.649	0.320	0.107	0.276	0.829
37 -PG-	0.534	0.524	-0.137	-0.267	0.226	0.147	0.112	-0.380
38 -SD-	-0.050	-0.449	-0.127	0.461	-0.156	-0.022	0.119	0.144
39 -RR-	0.898	-0.219	0.239	0.180	0.345	-0.087	0.409	-0.214
40 -RD-	0.342	-0.031	0.250	0.099	-0.002	0.195	-0.009	0.099
41 -RC-	0.679	0.060	0.713	0.297	0.670	0.004	0.428	0.260
42 -CA-	0.071	0.031	0.878	0.329	0.293	-0.398	0.121	0.461
43 -SW-	0.346	-0.284	0.418	0.462	0.833	0.515	0.553	0.473
44 -TO-	0.191	0.653	-0.373	-0.463	-0.203	0.026	-0.138	-0.437
45 -VA-	0.927	-0.030	0.369	0.049	0.277	-0.232	0.237	-0.236
46 -CC-	-0.325	-0.222	0.216	0.274	0.301	0.228	0.519	0.382
47 -PH-	-0.600	-0.397	-0.422	-0.000	-0.403	-0.175	-0.344	0.069
48 -OR-	0.924	-0.073	0.270	0.027	0.240	-0.195	0.241	-0.289
49 -WA-	-0.282	0.714	-0.681	-0.650	-0.640	0.169	-0.555	-0.634
50 -NA-	0.840	0.037	0.098	-0.097	0.219	-0.064	0.122	-0.407
51 -AU-	-0.702	-0.431	0.048	0.291	-0.315	-0.326	-0.084	0.336
52 -SP-	0.747	0.422	0.074	-0.134	0.391	-0.021	0.272	-0.405
53 -FN-	0.760	0.075	0.652	0.271	0.649	-0.035	0.392	0.134
54 -MN-	-0.679	-0.329	0.153	0.251	-0.362	-0.268	-0.132	0.314
55 -FP-	0.852	0.165	0.536	0.045	0.415	-0.150	0.314	-0.041
56 -MP-	-0.645	-0.313	0.357	0.147	-0.270	-0.300	-0.088	0.504
57 -TN-	0.166	-0.252	0.897	0.504	0.366	-0.314	0.309	0.474
58 -TP-	0.596	0.015	0.785	0.130	0.314	-0.328	0.300	0.225
59 -AG-	-0.215	0.318	-0.135	-0.407	-0.207	-0.081	-0.253	-0.398
60 -TD-	0.609	-0.003	0.806	0.303	0.550	-0.239	0.287	0.157
61 -EX-	-0.136	-0.487	0.040	0.230	0.380	-0.104	0.454	0.099
62 -FK-	0.862	0.316	0.336	-0.124	0.265	-0.210	0.212	-0.297
63 -MK-	-0.665	-0.369	0.177	0.244	-0.307	-0.368	-0.083	0.355
64 -TK-	0.499	0.066	0.604	0.110	0.057	-0.017	0.199	-0.053
65 -ES-	-0.190	-0.598	-0.064	0.243	0.055	-0.271	0.337	-0.006

CONTINUED - LOWER RIGHT HAND CORNER

		ZN-L	NN-L	KA-L	AN-L	PT-L	PD-L	PO-L	AN-C
9	ZN-L	1.000							
10	NN-L	-0.005	1.000						
11	KA-L	0.519	0.120	1.000					
12	AN-L	0.821	0.143	0.819	1.000				
13	PT-L	0.823	0.287	0.767	0.851	1.000			
14	PD-L	0.527	0.244	0.752	0.795	0.759	1.000		
15	PO-L	0.694	0.394	0.773	0.841	0.902	0.931	1.000	
16	AN-C	0.866	0.130	0.842	0.977	0.909	0.733	0.829	1.000
17	NK-C	0.866	0.167	0.708	0.811	0.956	0.636	0.784	0.894
18	NN-C	0.269	0.926	0.332	0.356	0.543	0.306	0.542	0.393
19	NT-C	0.468	0.831	0.478	0.527	0.726	0.436	0.677	0.581
20	PT-C	0.850	0.218	0.724	0.790	0.974	0.610	0.800	0.888
21	PD-C	0.880	0.187	0.850	0.878	0.876	0.961	0.944	0.864
22	PO-C	0.805	0.315	0.819	0.873	0.979	0.826	0.954	0.915
23	SB-C	0.813	0.248	0.447	0.583	0.789	0.228	0.530	0.711
24	EN-C	0.207	0.287	0.576	0.322	0.370	0.003	0.228	0.424
25	ZN-C	0.973	0.034	0.522	0.753	0.852	0.442	0.655	0.842
26	PB-C	0.653	-0.036	0.341	0.311	0.612	0.141	0.380	0.487
27	CU-C	0.911	0.179	0.626	0.794	0.869	0.425	0.656	0.891
28	KA-C	0.616	0.128	0.974	0.828	0.838	0.683	0.766	0.888
29	AT-C	0.493	0.347	0.243	0.307	0.538	0.452	0.550	0.369
30	PC-C	-0.080	0.255	-0.083	-0.161	0.106	-0.367	-0.166	-0.039
31	-AR-	-0.381	-0.236	-0.691	-0.776	-0.515	-0.613	-0.574	-0.691
32	-CL-	0.422	0.713	0.220	0.312	0.557	0.135	0.430	0.398
33	-SC-	0.658	0.110	0.430	0.564	0.716	0.764	0.782	0.573
34	-SA-	-0.234	-0.247	-0.098	-0.253	-0.287	-0.579	-0.483	-0.183
35	-EP-	0.052	0.437	0.134	0.001	0.163	-0.240	0.011	0.124
36	-PS-	0.585	0.023	0.404	0.510	0.045	0.767	0.768	0.497
37	-PG-	-0.044	-0.086	-0.042	-0.153	-0.011	-0.426	-0.271	-0.029
38	-SD-	0.136	-0.243	0.673	0.490	0.353	0.656	0.429	0.461
39	-RR-	0.168	0.213	0.722	0.465	0.347	0.216	0.321	0.511
40	-RD-	-0.104	0.246	0.431	0.144	0.221	0.237	0.232	0.212
41	-RC-	0.235	0.698	0.320	0.220	0.524	0.099	0.380	0.336
42	-CA-	-0.002	0.868	0.136	0.185	0.397	0.349	0.424	0.171
43	-SY-	0.602	0.342	0.174	0.235	0.593	0.047	0.384	0.391
44	-TO-	-0.275	-0.293	-0.276	-0.353	-0.338	-0.453	-0.457	-0.322
45	-UA-	-0.038	0.385	0.592	0.280	0.237	0.112	0.231	0.323
46	-CC-	0.525	0.168	-0.199	0.257	0.189	0.112	0.200	0.222
47	-PH-	-0.083	-0.453	-0.028	0.011	-0.197	0.267	0.022	-0.111
48	-OR-	-0.021	0.284	0.610	0.302	0.202	0.104	0.207	0.334
49	-WA-	-0.582	-0.581	-0.565	-0.654	-0.716	-0.661	-0.827	-0.634
50	-NA-	-0.074	0.128	0.447	0.145	0.101	-0.103	0.014	0.222
51	-AU-	0.059	-0.016	0.053	0.265	0.051	0.536	0.287	0.114
52	-SP-	0.028	0.112	0.117	0.004	0.107	-0.351	-0.151	0.117
53	-FN-	0.180	0.039	0.369	0.217	0.494	0.054	0.323	0.332
54	-MN-	-0.048	0.107	-0.004	0.174	-0.018	0.459	0.215	0.032
55	-FP-	0.030	0.565	0.385	0.193	0.290	0.037	0.241	0.253
56	-MP-	0.008	0.349	-0.108	0.160	-0.001	0.476	0.321	0.004
57	-TN-	0.155	0.834	0.414	0.424	0.542	0.532	0.587	0.410
58	-TP-	0.037	0.814	0.308	0.302	0.328	0.297	0.440	0.283
59	-AG-	-0.247	-0.051	-0.305	-0.122	-0.320	-0.230	-0.305	-0.216
60	-TD-	0.073	0.796	0.315	0.202	0.420	0.109	0.327	0.265
61	-EX-	0.539	-0.010	-0.078	0.333	0.128	0.058	0.165	0.266
62	-FK-	-0.107	0.392	0.297	0.082	0.100	-0.127	0.029	0.132
63	-MK-	0.010	0.121	0.051	0.254	0.061	0.541	0.300	0.101
64	-TK-	-0.130	0.622	0.434	0.345	0.194	0.339	0.318	0.266
65	-ES-	0.378	-0.125	0.152	0.453	0.051	0.291	0.219	0.319

CONTINUED - LOWER RIGHT HAND CORNER

	NK-C	NN-C	NT-C	PT-C	PD-C	PO-C	SS-C	EN-C
17 NK-C	1.000							
18 NN-C	0.435	1.000						
19 NT-C	0.647	0.968	1.000					
20 PT-C	0.977	0.516	0.709	1.000				
21 PD-C	0.794	0.335	0.504	0.776	1.000			
22 PO-C	0.917	0.547	0.718	0.930	0.921	1.000		
23 SS-C	0.839	0.568	0.714	0.885	0.419	0.722	1.000	
24 EN-C	0.329	0.532	0.543	0.452	0.160	0.376	0.557	1.000
25 ZN-C	0.913	0.341	0.542	0.914	0.615	0.814	0.909	0.317
26 PB-C	0.710	0.238	0.399	0.744	0.348	0.592	0.776	0.350
27 CU-C	0.908	0.496	0.672	0.930	0.616	0.829	0.937	0.534
28 KA-C	0.799	0.394	0.556	0.832	0.828	0.800	0.607	0.645
29 AT-C	0.621	0.368	0.484	0.548	0.486	0.575	0.437	-0.131
30 PC-C	0.055	0.407	0.360	0.195	-0.225	-0.010	0.374	0.515
31 -AR-	-0.458	-0.338	-0.413	-0.425	-0.619	-0.540	-0.260	-0.314
32 -CL-	0.491	0.862	0.860	0.587	0.234	0.517	0.714	0.551
33 -SC-	0.719	0.191	0.361	0.652	0.755	0.744	0.413	-0.249
34 -SA-	-0.308	-0.115	-0.182	-0.183	-0.460	-0.345	0.031	0.557
35 -EP-	0.176	0.592	0.551	0.286	-0.105	0.165	0.494	0.668
36 -PS-	0.589	0.104	0.252	0.550	0.717	0.685	0.313	-0.259
37 -PG-	-0.033	0.089	0.067	0.105	-0.253	-0.088	0.256	0.522
38 -SD-	0.351	-0.227	-0.095	0.275	0.687	0.411	-0.159	-0.055
39 -RR-	0.271	0.405	0.419	0.374	0.341	0.411	0.324	0.893
40 -RD-	0.164	0.290	0.292	0.234	0.331	0.290	0.028	0.357
41 -RC-	0.429	0.869	0.856	0.560	0.209	0.479	0.659	0.719
42 -CA-	0.272	0.816	0.767	0.302	0.300	0.358	0.238	0.111
43 -SY-	0.636	0.584	0.672	0.704	0.200	0.550	0.880	0.432
44 -TO-	-0.365	-0.287	-0.344	-0.290	-0.409	-0.400	-0.197	0.123
45 -UA-	0.122	0.525	0.479	0.240	0.191	0.283	0.248	0.911
46 -CC-	0.237	0.141	0.185	0.172	0.103	0.187	0.263	-0.298
47 -PH-	-0.174	-0.584	-0.543	-0.292	0.112	-0.137	-0.472	-0.607
48 -OR-	0.099	0.430	0.392	0.217	0.187	0.262	0.214	0.903
49 -WA-	-0.608	-0.705	-0.766	-0.634	-0.632	-0.764	-0.583	-0.352
50 -NA-	0.048	0.305	0.272	0.176	0.029	0.136	0.229	0.836
51 -AU-	0.050	-0.204	-0.160	-0.101	0.377	0.101	-0.369	-0.692
52 -SP-	0.072	0.315	0.287	0.212	-0.176	0.030	0.397	0.737
53 -FN-	0.412	0.828	0.816	0.543	0.181	0.443	0.644	0.795
54 -MN-	-0.001	-0.123	-0.105	-0.157	0.303	0.036	-0.408	-0.677
55 -FP-	0.156	0.699	0.636	0.305	0.117	0.299	0.382	0.845
56 -MP-	-0.075	0.108	0.070	-0.164	0.271	0.084	-0.343	-0.031
57 -TN-	0.466	0.813	0.818	0.453	0.515	0.539	0.313	0.209
58 -TP-	0.132	0.832	0.742	0.250	0.275	0.376	0.239	0.597
59 -AG-	-0.395	-0.108	-0.201	-0.367	-0.298	-0.369	-0.269	-0.214
60 -TD-	0.348	0.895	0.855	0.420	0.164	0.379	0.526	0.645
61 -EX-	0.187	0.049	0.093	0.130	0.019	0.139	0.331	-0.099
62 -FK-	-0.013	0.507	0.427	0.131	-0.045	0.098	0.233	0.830
63 -MK-	0.047	-0.089	-0.063	-0.101	0.370	0.107	-0.308	-0.658
64 -TK-	0.027	0.575	0.495	0.076	0.244	0.227	-0.041	0.464
65 -ES-	0.091	-0.151	-0.103	-0.015	0.205	0.120	-0.016	-0.180

CONTINUED - LUWER RIGHT HAND CURNFR

		ZN-C	PB-C	CU-C	KA-C	AT-C	PC-C	-AR-	-CL-
25	ZN-C	1.000							
26	PB-C	0.781	1.000						
27	CU-C	0.954	0.714	1.000					
28	KA-C	0.652	0.503	0.755	1.000				
29	AT-C	0.530	0.618	0.422	0.289	1.000			
30	PC-C	0.077	0.239	0.232	0.077	-0.308	1.000		
31	-AR-	-0.314	0.171	-0.422	-0.620	0.025	0.202	1.000	
32	-CL-	0.509	0.468	0.641	0.351	0.346	0.592	-0.025	1.000
33	-SC-	0.626	0.477	0.460	0.427	0.801	-0.453	-0.269	0.112
34	-SA-	-0.164	-0.028	-0.004	-0.014	-0.729	0.678	0.234	0.145
35	-EP-	0.212	0.406	0.340	0.260	0.062	0.568	-0.127	0.485
36	-PS-	0.530	0.361	0.346	0.377	0.621	-0.473	-0.261	0.009
37	-PG-	0.075	0.301	0.212	0.109	-0.413	0.869	0.345	0.415
38	-SD-	0.090	0.040	0.102	0.584	0.176	-0.371	-0.428	-0.351
39	-RR-	0.214	0.185	0.440	0.735	-0.193	0.307	-0.488	0.339
40	-RD-	-0.009	0.263	0.106	0.463	0.118	0.297	-0.164	0.137
41	-RC-	0.370	0.418	0.546	0.441	0.177	0.737	-0.095	0.921
42	-CA-	0.052	-0.081	0.163	0.154	0.275	0.349	-0.334	0.576
43	-SY-	0.737	0.853	0.712	0.340	0.579	0.401	0.125	0.748
44	-TO-	-0.263	-0.107	-0.179	-0.234	-0.522	0.470	0.555	0.108
45	-VA-	0.029	0.023	0.284	0.592	-0.286	0.422	-0.441	0.402
46	-CC-	0.425	0.205	0.345	-0.150	0.464	-0.235	0.162	0.373
47	-PH-	-0.215	-0.382	-0.402	-0.184	0.014	-0.851	-0.220	-0.816
48	-OR-	0.031	0.024	0.275	0.601	-0.314	0.345	-0.443	0.319
49	-WA-	-0.557	-0.248	-0.577	-0.553	-0.473	0.162	0.578	-0.513
50	-NA-	0.028	0.142	0.231	0.493	-0.370	0.487	-0.336	0.197
51	-AU-	-0.072	-0.408	-0.217	-0.080	0.274	-0.767	-0.415	-0.489
52	-SP-	0.147	0.249	0.350	0.255	-0.416	0.885	0.100	0.565
53	-FN-	0.331	0.302	0.528	0.485	0.087	0.765	-0.164	0.845
54	-MN-	-0.177	-0.420	-0.271	-0.141	0.331	-0.720	-0.363	-0.434
55	-FP-	0.114	0.142	0.361	0.444	-0.174	0.668	-0.147	0.745
56	-MP-	-0.147	-0.427	-0.242	-0.231	0.338	-0.643	-0.278	-0.179
57	-TN-	0.195	0.013	0.321	0.406	0.438	0.130	-0.558	0.514
58	-TP-	0.047	-0.073	0.270	0.367	-0.011	0.394	-0.312	0.729
59	-AG-	-0.303	-0.568	-0.282	-0.363	-0.653	0.207	-0.265	-0.263
60	-TD-	0.199	0.149	0.387	0.375	0.148	0.539	-0.381	0.708
61	-EX-	0.426	0.009	0.329	-0.080	0.159	-0.436	-0.276	0.056
62	-FK-	-0.034	0.000	0.231	0.343	-0.392	0.678	-0.100	0.590
63	-MK-	-0.131	-0.442	-0.272	-0.085	0.294	-0.698	-0.429	-0.396
64	-TK-	-0.166	-0.412	0.043	0.363	-0.234	0.229	-0.530	0.396
65	-ES-	0.201	-0.273	0.138	0.042	0.061	-0.749	-0.523	-0.285

	-SC-	-SA-	-EP-	-PS-	-PG-	-SD-	-RR-	-RD-
33 -SC-	1.000							
34 -SA-	-0.807	1.000						
35 -EP-	-0.190	0.280	1.000					
36 -PS-	0.951	-0.731	-0.269	1.000				
37 -PG-	-0.503	0.800	0.404	-0.565	1.000			
38 -SD-	0.367	-0.294	-0.311	0.312	-0.220	1.000		
39 -RR-	-0.225	0.464	0.529	-0.227	0.413	0.279	1.000	
40 -RD-	-0.012	0.063	0.539	-0.091	0.310	0.493	0.567	1.000
41 -RC-	-0.012	0.282	0.639	-0.073	0.513	-0.275	0.504	0.322
42 -CA-	0.221	-0.322	0.325	0.140	-0.093	-0.079	0.045	0.267
43 -SY-	0.397	-0.029	0.508	0.300	0.260	-0.370	0.131	0.067
44 -TO-	-0.626	0.767	-0.259	-0.574	0.719	-0.192	0.057	-0.168
45 -UA-	-0.345	0.500	0.577	-0.315	0.410	0.097	0.942	0.495
46 -CC-	0.315	-0.298	-0.278	0.196	-0.156	-0.245	-0.330	-0.415
47 -PH-	0.364	-0.572	-0.582	0.477	-0.809	0.333	-0.436	-0.342
48 -OR-	-0.357	0.520	0.539	-0.319	0.395	0.139	0.965	0.483
49 -WA-	-0.621	0.439	-0.212	-0.641	0.389	0.023	-0.285	0.051
50 -NA-	-0.425	0.584	0.749	-0.409	0.524	0.079	0.882	0.634
51 -AU-	0.525	-0.823	-0.553	0.507	-0.861	0.458	-0.443	-0.150
52 -SP-	-0.570	-0.869	0.518	-0.583	0.936	-0.266	0.592	0.264
53 -FN-	-0.086	0.352	0.706	-0.142	0.540	-0.229	0.587	0.376
54 -MN-	0.455	-0.835	-0.459	0.388	-0.843	0.436	-0.434	-0.055
55 -FP-	-0.331	0.554	0.530	-0.325	0.607	-0.173	0.754	0.354
56 -MP-	0.454	-0.810	-0.383	0.446	-0.794	0.143	-0.424	-0.130
57 -TN-	0.368	-0.457	0.330	0.230	-0.252	0.167	0.221	0.370
58 -TP-	-0.122	0.178	0.381	-0.119	0.245	-0.114	0.607	0.322
59 -AG-	-0.389	0.187	0.097	-0.270	0.063	-0.247	-0.125	-0.054
60 -TD-	-0.005	0.060	0.692	-0.074	0.164	-0.242	0.449	0.281
61 -EX-	0.283	-0.276	-0.115	0.305	-0.453	-0.397	-0.148	-0.686
62 -FK-	-0.547	0.728	0.451	-0.525	0.689	-0.169	0.761	-0.294
63 -MK-	0.492	-0.826	-0.504	0.451	-0.838	0.442	-0.416	-0.048
64 -TK-	-0.251	0.174	0.115	-0.261	0.113	0.193	0.600	0.291
65 -ES-	0.268	-0.389	-0.349	0.294	-0.667	0.075	-0.054	-0.498

CONTINUED - LOWER RIGHT HAND CORNER

	-RC-	-CA-	-SY-	-TO-	-UA-	-CC-	-PH-	-OR-
41 -RC-	1.000							
42 -CA-	0.631	1.000						
43 -SY-	0.686	0.251	1.000					
44 -TO-	0.096	-0.347	-0.169	1.000				
45 -UA-	0.620	0.230	0.111	0.085	1.000			
46 -CC-	-0.018	-0.025	0.285	0.048	-0.447	1.000		
47 -PH-	-0.826	-0.333	-0.529	-0.465	-0.486	-0.127	1.000	
48 -OR-	0.528	0.104	0.062	0.096	0.990	-0.439	-0.424	1.000
49 -WA-	-0.471	-0.490	-0.495	0.572	-0.315	-0.195	-0.024	-0.278
50 -NA-	0.458	0.035	0.124	0.021	0.881	-0.584	-0.441	0.893
51 -AU-	-0.603	0.145	-0.480	-0.591	-0.500	0.181	0.771	-0.487
52 -SP-	0.680	0.061	0.324	0.615	0.629	-0.171	-0.864	0.602
53 -FN-	0.983	0.597	0.636	0.075	0.706	-0.171	-0.804	0.619
54 -MN-	-0.544	0.234	-0.474	-0.600	-0.468	0.183	0.672	-0.468
55 -FP-	0.865	0.396	0.347	0.336	0.860	-0.148	-0.788	0.809
56 -MP-	-0.356	0.353	-0.315	-0.558	-0.412	0.387	0.528	-0.420
57 -TN-	0.557	0.917	0.236	-0.530	0.321	-0.007	-0.224	0.223
58 -TP-	0.767	0.628	0.214	0.072	0.730	0.045	-0.588	0.667
59 -AG-	-0.190	0.159	-0.401	-0.073	-0.045	-0.223	0.126	-0.060
60 -TD-	0.855	0.785	0.496	-0.263	0.631	-0.220	-0.549	0.530
61 -EX-	-0.185	-0.168	0.210	-0.342	-0.253	0.583	0.309	-0.217
62 -FK-	0.729	0.226	0.160	0.561	0.864	-0.224	-0.759	0.832
63 -MK-	-0.504	0.277	-0.471	-0.585	-0.442	0.185	0.678	-0.447
64 -TK-	0.476	0.552	-0.232	0.105	0.709	-0.118	-0.353	0.663
65 -ES-	-0.479	-0.263	-0.245	-0.412	-0.164	0.410	0.593	-0.092

CONTINUED - LOWER RIGHT HAND CORNER

		-WA-	-NA-	-AU-	-SP-	-FN-	-MN-	-FP-	-MP-
49	-WA-	1.000							
50	-NA-	-0.062	1.000						
51	-AU-	-0.170	-0.563	1.000					
52	-SP-	0.151	0.648	-0.873	1.000				
53	-FN-	-0.426	0.582	-0.634	0.723	1.000			
54	-MN-	-0.115	-0.534	0.973	-0.856	-0.575	1.000		
55	-FP-	-0.321	0.656	-0.673	0.791	0.876	-0.627	1.000	
56	-MP-	-0.324	-0.552	0.864	-0.782	-0.446	0.878	-0.432	1.000
57	-TN-	-0.601	0.113	0.278	-0.051	0.545	0.372	0.351	0.394
58	-TP-	-0.530	0.429	-0.280	0.455	0.730	-0.222	0.875	0.059
59	-AG-	0.211	0.140	0.175	0.062	-0.141	0.135	-0.131	0.188
60	-TD-	-0.563	0.477	-0.316	0.422	0.888	-0.231	0.701	-0.138
61	-EX-	-0.479	-0.317	0.256	-0.310	-0.236	0.164	-0.259	0.326
62	-FK-	-0.108	0.693	-0.721	0.857	0.766	-0.677	0.961	-0.540
63	-MK-	-0.191	-0.543	0.987	-0.828	-0.540	0.988	-0.584	0.891
64	-TK-	-0.318	0.393	-0.015	0.340	0.490	0.042	0.703	0.130
65	-ES-	-0.380	-0.264	0.575	-0.529	-0.495	0.489	-0.374	0.515

CONTINUED - LOWER RIGHT HAND CORNER

		-TN-	-TP-	-AG-	-TD-	-EX-	-FK-	-MK-	-TK-
57	-TN-	1.000							
58	-TP-	0.601	1.000						
59	-AG-	-0.021	-0.044	1.000					
60	-TD-	0.770	0.702	0.002	1.000				
61	-EX-	-0.100	-0.111	0.098	-0.082	1.000			
62	-FK-	0.174	0.774	-0.046	0.571	-0.302	1.000		
63	-MK-	0.399	-0.167	0.174	-0.204	0.196	-0.642	1.000	
64	-TK-	0.599	0.849	0.102	0.554	-0.209	0.699	0.099	1.000
65	-ES-	-0.060	-0.137	0.099	-0.273	0.829	-0.362	0.514	0.009

CONTINUED - LOWER RIGHT HAND CORNER

		-ES-
65	-ES-	1.000

APPENDIX C

EXTRAPOLATION OF AGRICULTURAL LOADINGS TO ENTIRE GREAT LAKES BASIN

APPENDIX C

Extrapolation of Agricultural Loadings to the Entire Great Lakes Basin

The PLUARG program had as one of its primary objectives the identification of the major pollutant generating land use areas in the Great Lakes Basin. The material presented in this appendix was prepared for the Task C Summary Report of the Synthesis and Extrapolation Work Group, as a general extrapolation which could be used by PLUARG.

Since the bulk of the data collected in the PLUARG studies on the effect of agriculture has been through the Canadian Agricultural Watersheds Studies, and since agriculture is the most extensive land use in the Lake Erie Basin it was logical that the results of these studies should be applied to the Great Lakes Basin as a whole to attempt to identify those agricultural areas with the greatest potential to generate Great Lakes pollutants. Before this could be done, it was necessary to establish the appropriateness of extrapolation equations for areas outside the Canadian Great Lakes Basins.

The most compatible data with which to verify loading predictions for the Great Lakes Basin, based on the PLUARG agricultural watershed studies, was that available through other PLUARG studies. Most of the sub-basins monitored by PLUARG were, however, of mixed (rather than agricultural) land use. A search of available data indicated 20 primarily rural sub-basins which appeared suitable for comparisons of loadings of suspended solids and total phosphorus, and 11 for total nitrogen, provided that adjustments were made for the contributions of other major land uses. These adjustments were made by applying mean unit area loads for urban and forested land in these sub-basins and then assuming the balance of the measured load was the result of agricultural land uses. The sub-basins which were used were independent (loadings do not have to be found by difference) tributary catchments of the PLUARG pilot watersheds.

Since the extrapolation attempt required a base data year for comparing the variables, the calendar years 1975 and 1976 were selected for this approach. The data presented in the preceeding sections of this report, however, were for the two year period May 1975 to April 1977. The equations used in this section were therefore obtained from the Agricultural Watershed Study Integrators who were preparing 1976 data extrapolation attempts for the Grand and Saugeen Rivers. These sources are referenced below where appropriate.

Suspended sediment from rural watersheds

Suspended sediment (suspended solids) data were highly variable throughout the watershed studies. An attempt at extrapolation for agricultural land based on simple linear regression on soil texture and row-crop density, based on the relatively uniform size and stream characteristics of the 11 Canadian Agricultural Watersheds (van Vleit, Wall and Dickinson, 1978), has been examined. Table C-1 shows these results together with estimates of loads from urban and forested lands. The data for this verification attempt were obtained from the preliminary Summary Pilot Watershed Reports of the PLUARG studies involved, and by personal communication with project leaders.

TABLE C-1 COMPARISON OF MEASURED AND PREDICTED ANNUAL LOADS OF SUSPENDED SEDIMENTS

Site[1]	Year	Predicted load (tonnes/yr)[2]			Total Unit Area Loads (Kg/ha/yr)		Stream Discharge
		Agr.	Urban	Forest	Measured	Predicted	(cm/yr)
GR-6	1976	6358	384	166	145	180	48
GR-13	1976	1196	795	668	69	33	42
GR-14	1976	14110	775	304	409	196	53
SR-4	1976	4129	333	379	138	73	61
SR-5	1976	0	249	240	191	20	59
G-1	1975-76	392	25	101	65	104	42
G-2	1975-76	701	108	82	162	165	43
G-3	1975-76	1329	1367	82	655	299	43
G-4	1975-76	511	58	20	232	305	36
G-5	1975-76	224	701	165	457	129	36
G-6	1975-76	587	37	64	189	166	63
G-7	1975-76	698	0	30	399	258	63
G-8	1975-76	6426	6886	1224	27	194	45
B-2[3]	1975	668	0	0	3376	709	29
B-6[3]	1975	464	36	1	5599	702	26
B-2[3]	1976	668	0	0	528	709	12
B-6[3]	1976	464	36	1	641	702	10
MR	1976	623	279	1	486	421	25
M-5[3]	1975-76	1773	0	11	44	350	38
M-5[3]	1976-77	1773	0	11	51	350	11

[1] GR is Grand River; SR is Saugeen River; G is Genessee River; B is Black Creek; MR is Menomonee River station 463001; M is Mill Creek.

[2] Predicted loads for small, primarily rural, sub-basins using regression of 1976 Canadian Agricultural Watershed unit-area loads on soil clay content and row crops as follows:

Total suspended sediments (kg/ha/yr) = -281 + 13.6(%Clay) + 8.3(% Row Crops) and a representative "best estimate" of 1000 kg/ha/yr and 30 kg/ha/yr for urban and forested land respectively.

[3] The loads for 1975 and 1976 in Black Creek and 75-76 and 76-77 in Mill Creek have been separated as both years had unusual runoff conditions.

The extrapolation based on soil and row-crop data may be reasonable for estimating inputs from agricultural fields where stream border conditions are similar to those found in the Canadian Agriculture Watersheds. It should be noted that management of land bordering a stream is critical to the sediment yields and may, in part, account for the unexplained variations seen in table C-1. Furthermore, since the prediction method does not include a flow variable, the discrepancy found between predicted and measured loads in the Black Creek Watershed can be partly explained by the occurrence of a 100 year frequency storm in 1975, and the unusually low runoff which occurred in 1976.

It must be concluded that this approach to extrapolation of sediment loadings requires further refinement. The sites with the highest predicted loadings were usually the sites with the highest monitored loads, but there was poor agreement in terms of magnitude of these loads. Despite this problem, discussion with PLUARG Task C Synthesis and Extrapolation Work Group members indicated a concern for the identification of the highest potential contributing areas, since suspended solids (sediment) is a significant parameter for Great Lakes Water Quality. Figure C-1 was developed from the equation used in table C-1. The data for the Canadian side of the basin were obtained in the same way as that described in section 5.2 of the main report. The soil clay content data for the U.S. side were found by utilizing the soil association maps of the U.S. Task B report (PLUARG Task B, 1976) and estimating mean clay contents for each soil series. These mean clay contents were obtained from the soil clay content descriptor included at the soil family name level for each soil series obtainable from published listings (SCS, 1977) and applying the mean clay content listed for definition purposes for each of these family names (SCS, 1975). Estimates were then made of the mean soil association clay content by averaging the dominant two or three soil series in each association, and applying these values to the estimated distribution of each association in each U.S. Great Lakes County. The county was the unit of area description used as the most detailed U.S. census data were available only on this basis. Row-crop density for each county was obtained from the 1976 U.S. census of agriculture data base (USDC, 1976; Doneth, 1975).

The suspended sediment loads obtained from the equation of table C-1 were weighted according to the percentage of the area of each county, or each sub-basin, in farm land. The resulting distribution of estimated agricultural loadings of suspended sediment is shown in figure C-2.

Phosphorus from rural watersheds

The Agricultural Watershed Studies Phosphorus Integration effort (Miller and Spires, 1978) found that about 85% of the variability in unit area loadings of total P in 1976 was accounted for by a second order equation based on the clay content of the soil and the proportion of land area in wide space row-crops, - similar to that discussed in section 5.2 of this report. Using this equation to estimate loadings from agricultural land, together with mean loadings of 2.0 kg/ha/yr and 0.1 kg/ha/yr respectively from urban and forested land areas, allowed the prediction of total phosphorus loadings, presented in table C-2, for the selected sub-basins of the PLUARG pilot watersheds.

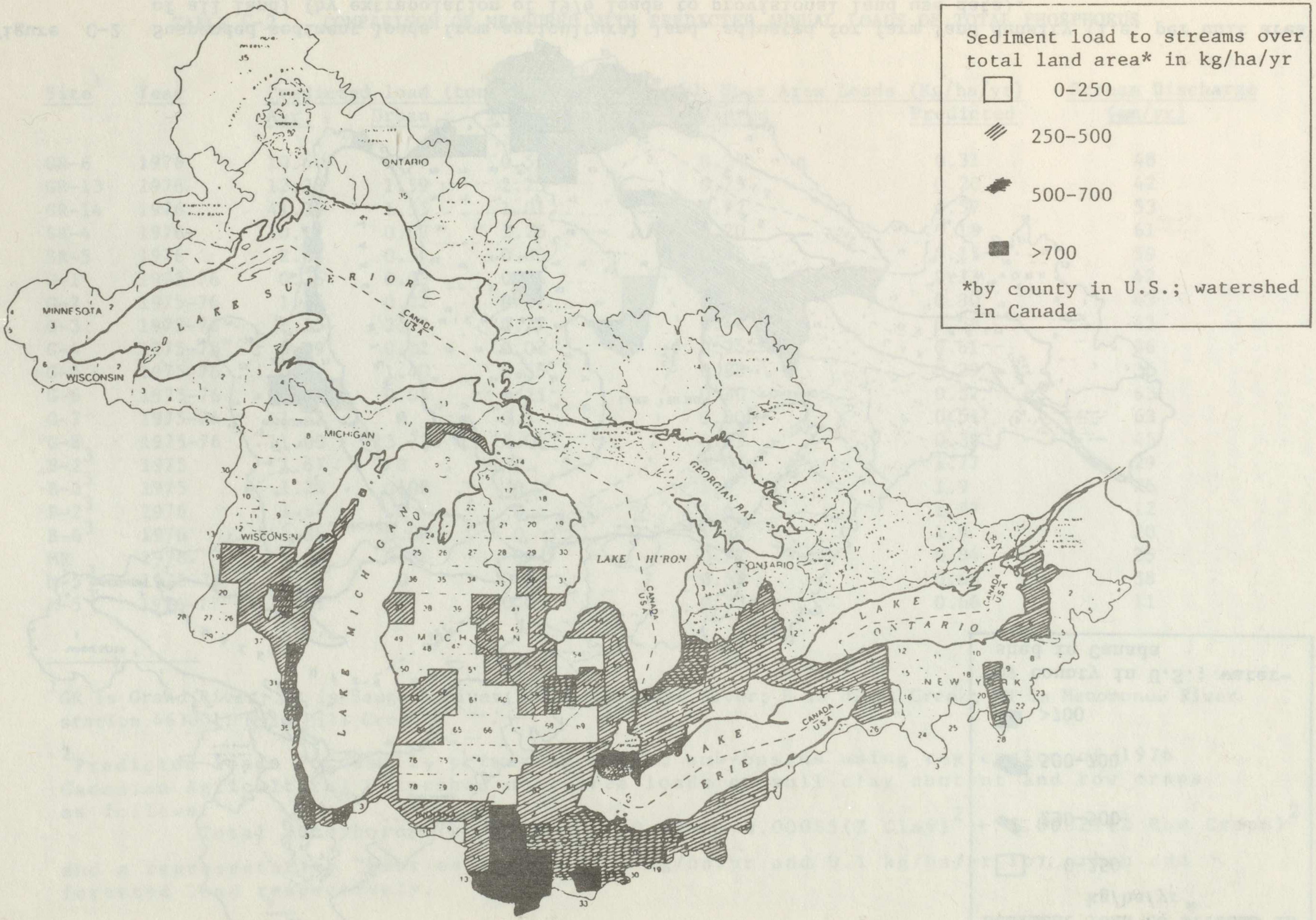

Figure C-1 Locations of agricultural land having unit area loads as indicated of suspended sediment (by extrapolation of 1976 loads to provisional land use data).

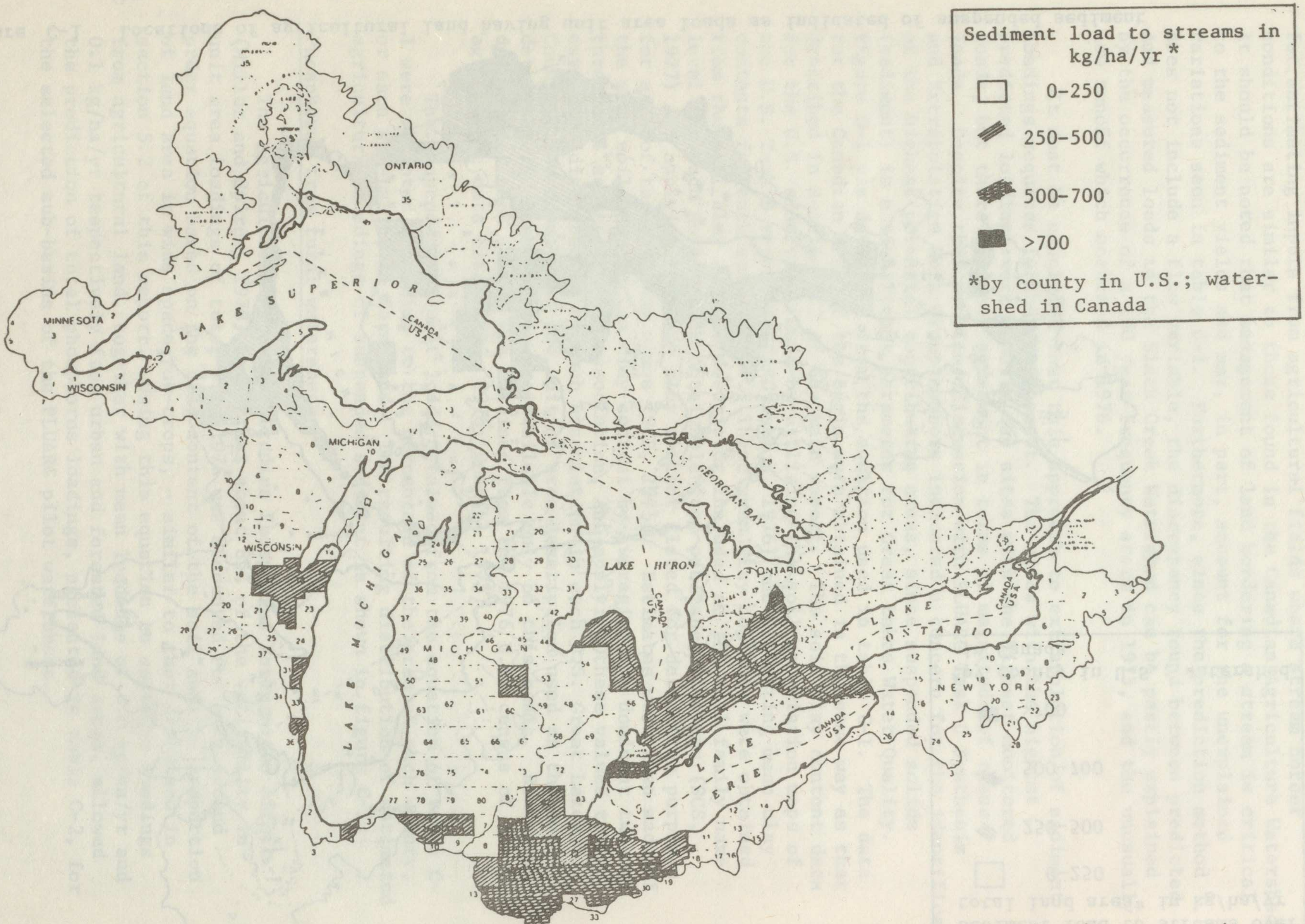

Figure C-2 Suspended sediment loads from agricultural land, adjusted for farm land density (i.e. per unit area of all land) (by extrapolation of 1976 loads to provisional land use data).

TABLE C-2 COMPARISON OF MEASURED WITH PREDICTED ANNUAL LOADS OF TOTAL PHOSPHORUS

Site[1]	Year	Predicted load (tonnes/yr)[2]			Total Unit Area Loads (Kg/ha/yr)		Stream Discharge
		Agr.	Urban	Forest	Measured	Predicted	(cm/yr)
GR-6	1976	10.6	0.77	0.55	0.37	0.31	48
GR-13	1976	12.28	1.59	2.23	0.25	0.20	42
GR-14	1976	41.39	1.55	1.01	0.77	0.57	53
SR-4	1976	10.17	0.67	1.26	0.20	0.18	61
SR-5	1976	2.84	0.5	0.80	0.28	0.17	59
G-1	1975-76	0.76	0.05	0.34	0.10	0.23	42
G-2	1975-76	1.15	0.22	0.27	0.11	0.30	43
G-3	1975-76	2.35	2.73	0.27	0.44	0.58	43
G-4	1975-76	0.99	0.12	0.07	0.35	0.61	36
G-5	1975-76	0.51	1.40	0.55	0.38	0.29	36
G-6	1975-76	1.04	0.08	0.21	0.30	0.32	63
G-7	1975-76	1.32	0	0.1	0.60	0.51	63
G-8	1975-76	11.03	13.77	4.08	0.15	0.39	45
B-2[3]	1975	1.67	0	0	9.07	1.77	29
B-6[3]	1975	1.28	0.08	0	6.9	1.9	26
B-2[3]	1976	1.67	0	0	1.6	1.77	12
B-6[3]	1976	1.28	0.08	0	1.42	1.9	10
MR	1976	1.25	0.56	0	0.72	0.84	25
M-5[3]	1975-76	3.31	0	0.04	0.58	0.66	38
M-5[3]	1976-77	3.31	0	0.04	0.33	0.66	11

[1]GR is Grand River; SR is Saugeen River; G is Genessee River; B is Black Creek; MR is Menomonee River station 463001; M is Mill Creek.

[2]Predicted loads for small, primarily rural, sub-basins using regression of 1976 Canadian Agricultural Watershed unit-area loads on soil clay content and row crops as follows:

$$\text{Total phosphorus (kg/ha/yr)} = -0.094 + 0.00085(\%\ \text{Clay})^2 + 0.00021(\%\ \text{Row Crops})^2$$

and a representative "best estimate" of 2 kg/ha/yr and 0.1 kg/ha/yr for urban and forested land respectively.

[3]The loads for 1975 and 1976 in Black Creek and for 75-76 and 76-77 in Mill Creek have been separated as both years had unusual runoff conditions.

In some cases, the extrapolation model does not predict the variability in the measured load exactly, probably because of the higher clay content of many of the U.S. Lake Erie basin soils compared to the soils of the Canadian part of the basin. This necessitated extrapolation outside the range of the original agricultural data set. The extreme variability in flow conditions observed in two years of data at some of the U.S. Task C study sites created added difficulties. Nevertheless, the unit-area load extrapolation procedure does appear to give an effective separation of "high" (greater than 1.5 kg/ha/yr), "medium" (0.5 to 1.5 kg/ha/yr) and "low" (less than 0.5 kg/ha/yr) yielding rural areas, despite the lack of a flow variable in the equation.

The extrapolation of total phosphorus from agricultural land takes into account an average effect of livestock. Modelling procedures in the Canadian Agricultural Watersheds Studies (Robinson and Draper, 1978) have found that livestock contribute an average of approximately 0.15 kg of phosphorus per animal unit per year. However, since livestock density was not a statistically significant determinant of total P loading to the streams in the Agricultural Watersheds studied, extrapolation of livestock effects must be handled as a separate procedure in order to estimate their probable impact. Livestock units and phosphorus production in manure were, however, statistically significant in explaining variability in dissolved phosphorus loadings (see section 4.2.3.2 of this report). However, since concentrations of dissolved phosphorus are known to change markedly during stream transport, and since the extent of these changes cannot be predicted, estimation of lake loadings from upstream input is impossible. Extrapolation of dissolved phosphorus loadings was therefore not attempted.

Figure C-3 shows the extrapolated loadings of total phosphorus in the Great Lakes basin from agriculture based on areas where soils with high clay content and predominantly row-crop culture occured together. The data sources for this figure were the same as those for figure C-1 discussed above. These values were also weighted by farm-land density, and the results shown in figure C-4. Figure C-5 shows an estimation of livestock contributions to phosphorus loadings of streams draining to the Great Lakes. These load values should not be added to the loads shown on the previous map, as a variety of livestock densities were present in the base sites on which the first extrapolation of total phosphorus was made. Rather, the livestock loads should be used to indicate where actual loads are probably higher or lower than those shown by the first extrapolation. However, the livestock loadings are small enough that they bring about few changes to the expected average agricultural loadings.

Nitrogen from rural watersheds

Table C-3 presents the results of an extrapolation of total nitrogen loadings from the agricultural watershed studies based on 1976 results (Neilson, Culley and Cameron, 1978). Representative urban and forested land inputs of nitrogen used in this table were 10 kg/ha/yr and 2 kg/ha/yr respectively. Since not all PLUARG studies have included nitrogen (this parameter being deemed by PLUARG as one of secondary significance), it was not possible to obtain loadings for as many representative U.S.

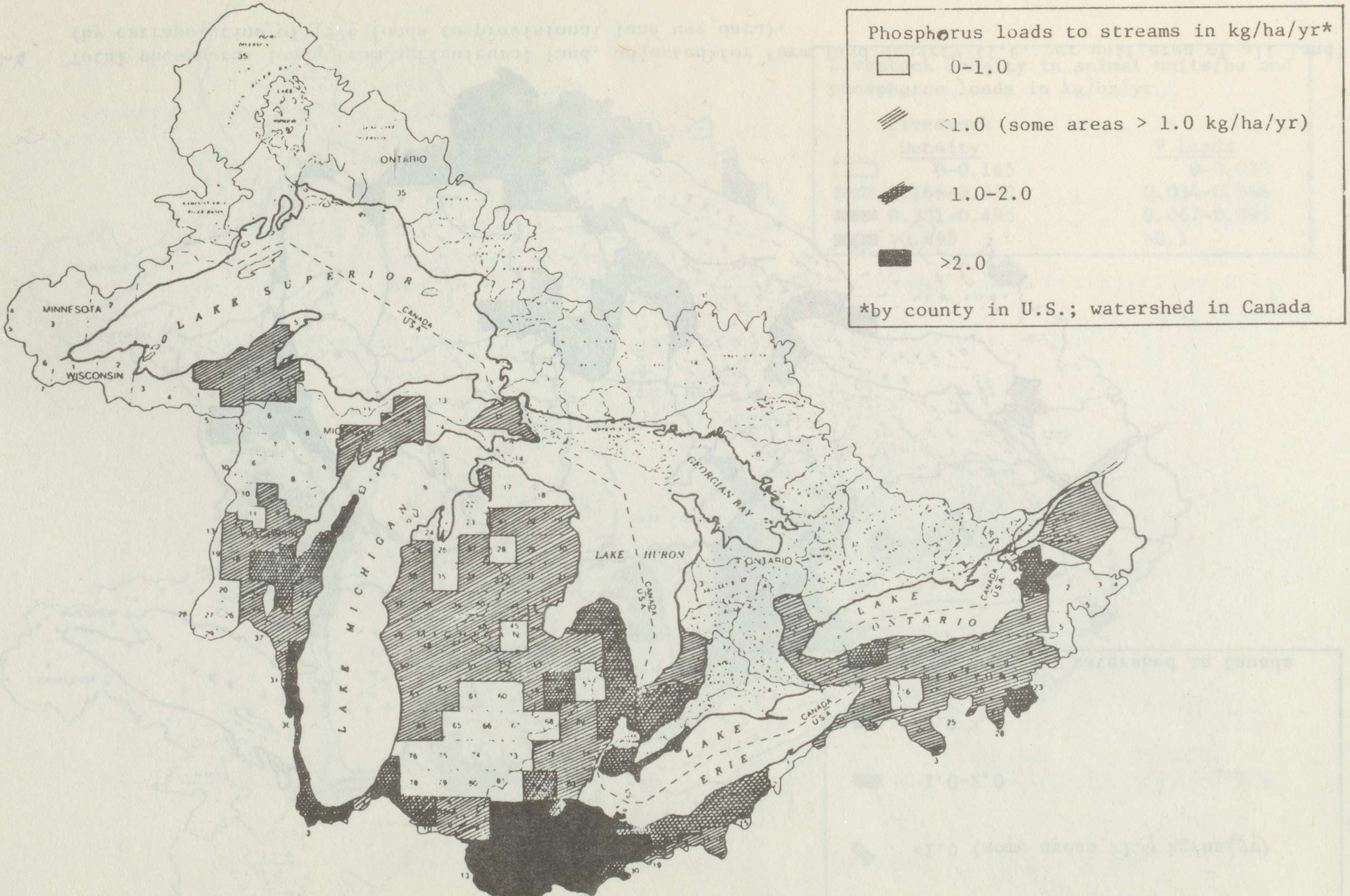

Figure C-3 Locations of agricultural land having unit area loads as indicated of total phosphorus (by extrapolation of 1976 loads to provisional land use data).

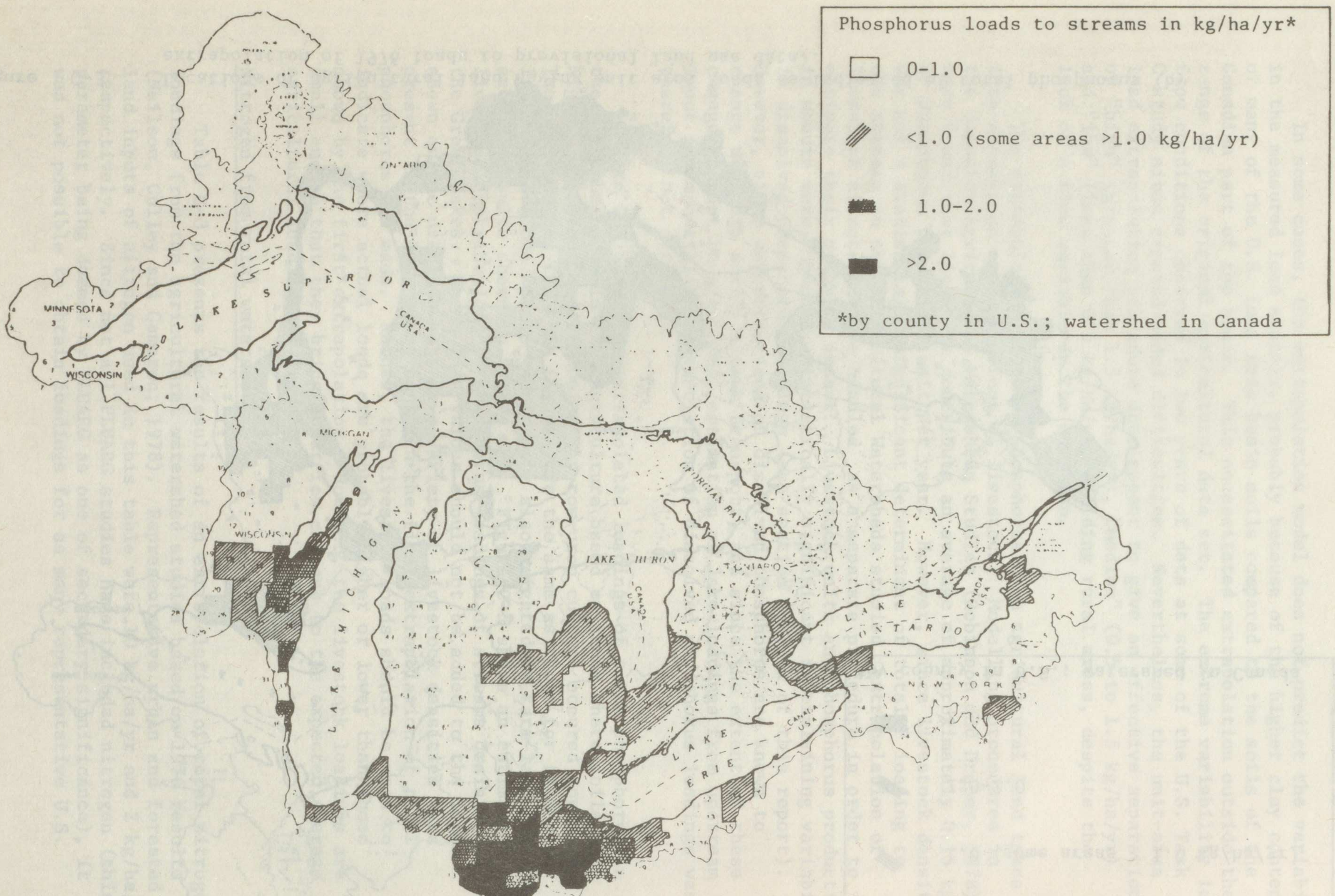

Figure C-4 Total phosphorus loads from agricultural land, adjusted for farm land density (i.e. per unit area of all land) (by extrapolation of 1976 loads to provisional land use data).

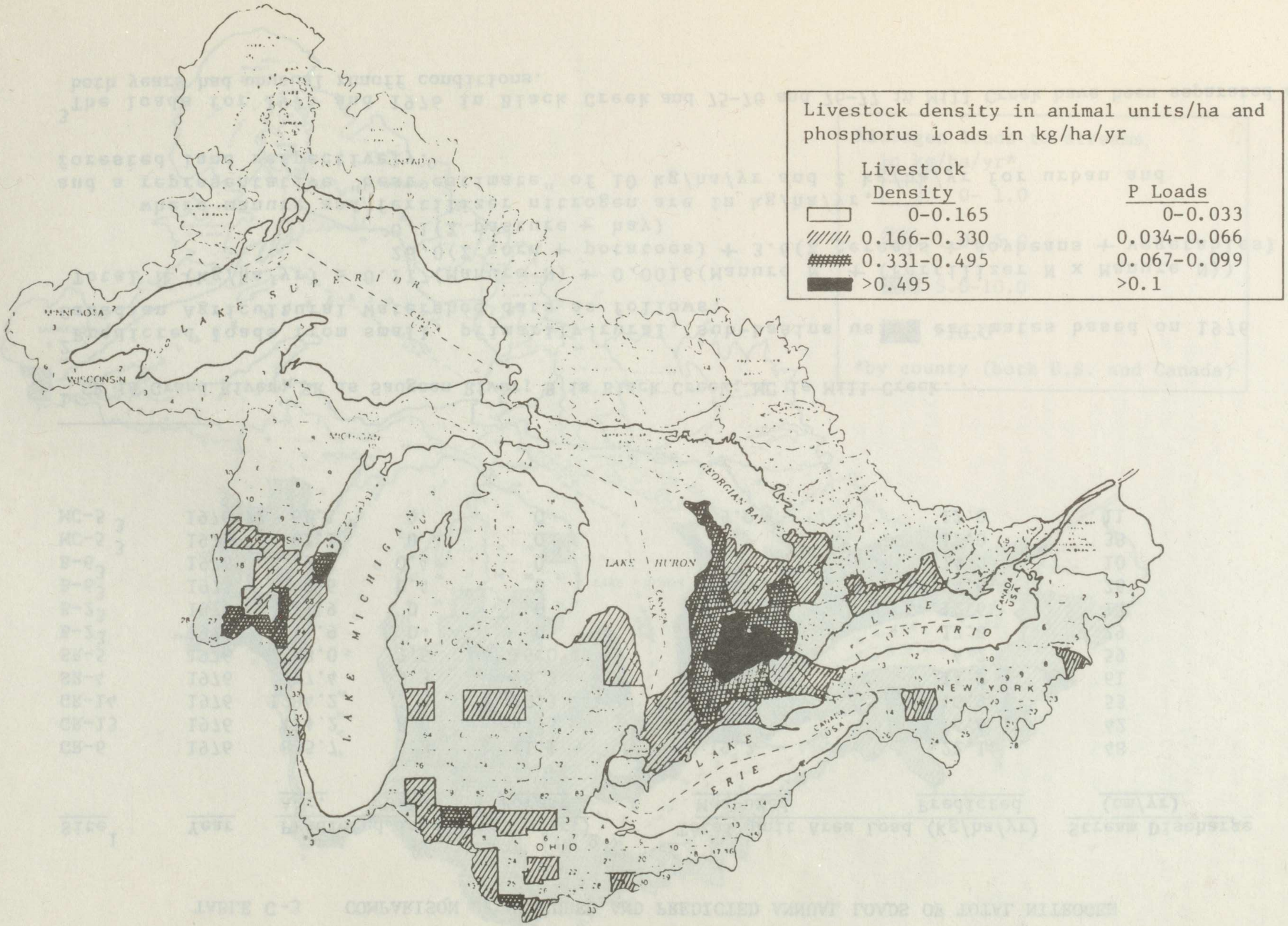

Figure C-5 Livestock density and estimated total phosphorus loads from livestock per unit area of all land (by extrapolation to provisional land use data).

TABLE C-3 COMPARISON OF MEASURED AND PREDICTED ANNUAL LOADS OF TOTAL NITROGEN

Site[1]	Year	Predicted load (tonnes/yr.)[2]			Total Unit Area Load (Kg/ha/yr)		Stream Discharge
		Agr.	Urban	Forest	Measured	Predicted	(cm/yr)
GR-6	1976	835.7	3.3	11.1	19.2	22.1	48
GR-13	1976	474.2	8.0	44.5	5.6	6.6	42
GR-14	1976	1284.2	7.8	20.3	13.1	16.9	53
SR-4	1976	717.4	3.3	25.3	9.5	11.2	61
SR-5	1976	88.0	2.5	16.0	6.1	4.2	59
B-2[3]	1975	11.9	0	0	16.3	12.6	29
B-2[3]	1976	11.9	0	0	7.1	12.6	12
B-6[3]	1975	9.6	0.4	0	9.1	14.0	26
B-6[3]	1976	9.6	0.4	0	2.4	14.0	10
MC-5[3]	1975-76	61.1	0	0	9.7	12.0	38
MC-5[3]	1976-77	61.1	0	0	5.0	12.0	11

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[1] GR is Grand River; SR is Saugeen River; B is Black Creek; MC is Mill Creek.

[2] Predicted loads from small, primarily rural, sub-basins using estimates based on 1976 Canadian Agricultural Watershed data as follows:

$$\text{Total N (kg/ha/yr)} = 0.117(\text{Manure N}) + 0.0016(\text{Manure N}^2 + (\text{Fertilizer N} \times \text{Manure N}))$$
$$26.0(\%\ \text{corn} + \text{potatoes}) + 3.6(\%\ \text{cereals} + \text{soybeans} + \text{vegetables})$$
$$0.1(\%\ \text{pasture} + \text{hay})$$

where manure and fertilizer nitrogen are in kg/ha/yr, and a representative "best estimate" of 10 kg/ha/yr and 2 kg/ha/yr for urban and forested land respectively.

[3] The loads for 1975 and 1976 in Black Creek and 75-76 and 76-77 in Mill Creek have been separated as both years had unusual runoff conditions.

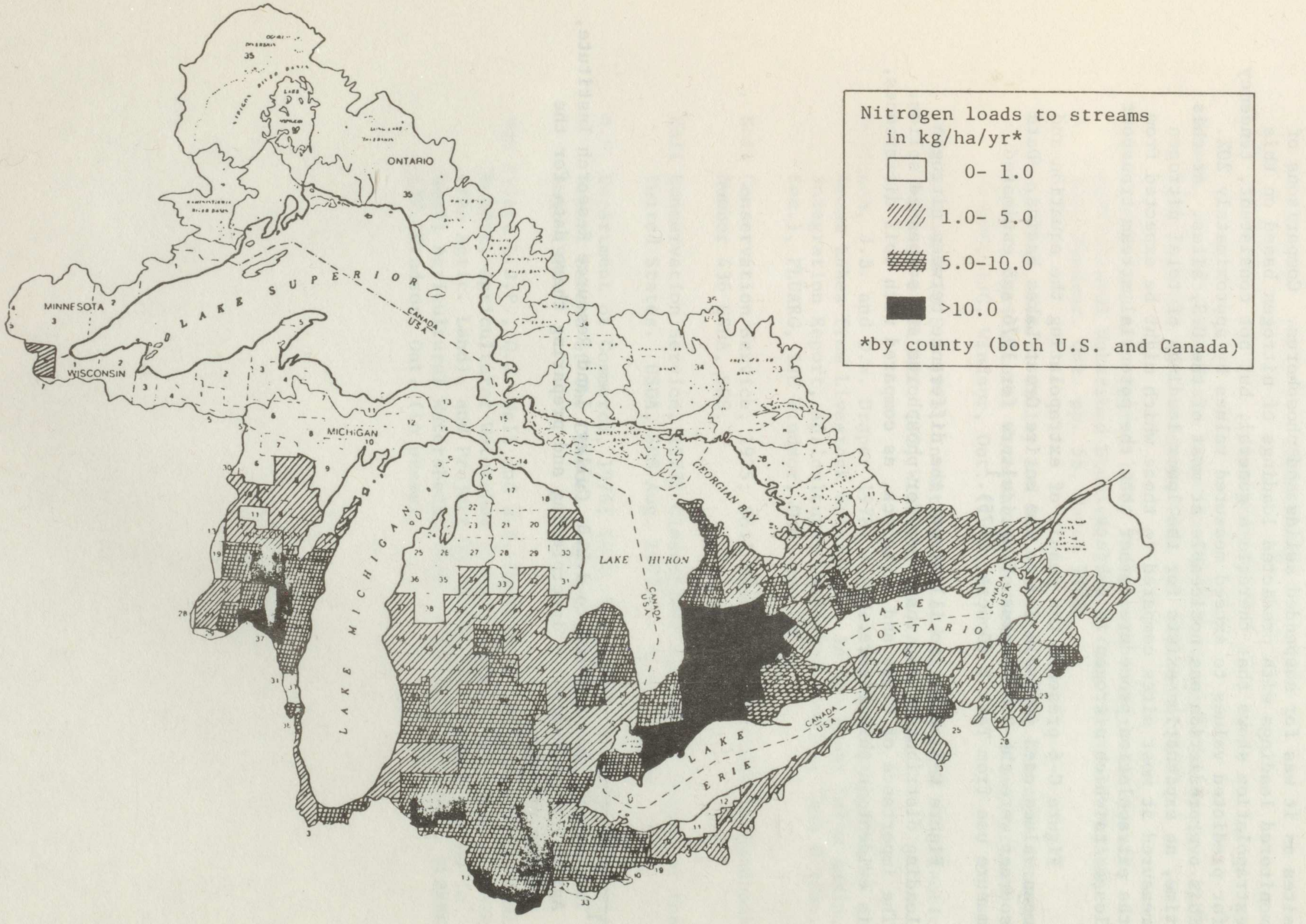

Figure C-6 Total nitrogen loads from agricultural land, adjusted for farm land density (i.e. per unit area of all land) (by extrapolation of 1976 loads to provisional land use data).

sites as it was for suspended solids and phosphorus. Comparisons of monitored loadings with predicted loadings of nitrogen based on this extrapolation shows that there is a general, but not consistent, tendency for predicted values to exceed measured values by approximately 20%. This overprediction was noticeable at most of the U.S. sites. At this time, no explanation exists for the lower loadings of total nitrogen measured at most sites compared to those which might be expected from the extrapolation procedure, other than the potential stream transport losses to which nitrogen is subject.

Figure C-6 presents the result of extrapolating the equation and mean values used in Table C-3 to the entire Great Lakes basins. Data sources were the U.S. census of agriculture for 1976 and estimated manure use from Task B (Doneth, 1975).[1]

Figure C-6 serves to illustrate the difference between nitrogen loading distribution and that seen for phosphorus and suspended solids. The importance of crops and livestock, as compared with soil differences, is evident in this figure.

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[1]The authors are indebted to J.L.B. Culley, Land Resource Research Institute, Agriculture Canada, for interpreting and preparing these data for the mapping process.

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(Appendix C)

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