REGIONAL CHARACTERIZATION OF THE COPPER-NICKEL WATER QUALITY RESEARCH AREA

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CHAPTER II METHODS AND PROCEDURES

Literature Review: Methods and Procedures of Previous Water Quality Characterizations

INTRODUCTION

A brief review of the water quality study literature has revealed several methods of characterizing water quality. The purpose of this report is to describe three of these methods: simple water chemistry characterization, mass balance, and classification. Examples of each are given and advantages and disadvantages discussed. This report is based on a representative, rather than exhaustive, review of the literature.

Most of the water quality studies reviewed were carried out in the United States, although several areas in Europe and Canada were also represented. Literature on both impacted and nonimpacted areas was included. Impacted areas received direct point source discharges to water bodies of mining, industrial, and municipal wastes; nonpoint discharges from the same sources; and atmospheric deposition of pollutants. Nonimpacted areas received atmospheric deposition of pollutants, in small quantities only.

CHEMICAL CHARACTERIZATION

Chemical characterization of water is the first step in most water quality characterization reports. The reason that it is being considered separately here, is that a number of studies reviewed did not attempt to further analyze water quality data. These studies reported the data, and in some cases the effects ~~of~~ on aquatic organisms, but did not include additional comparisons, pathways of constituents, or future projections. Only mining and ore processing regions were represented by this type of study in the literature reviewed. Pollution sources were known or suspected in all cases, and high metal concentrations in water were assumed to be due to human activity, not natural sources.

The data collected for chemical characterization reports was, in most cases, water quality data only. Atmospheric and runoff inputs were not considered, and concentration of components in discharges were not monitored. Those studies which were concerned with the effects of water chemistry on biota included analysis of plant and animal tissues.

A goal of several chemical characterization studies was to establish baseline water chemistry data, in order to monitor future changes. Baseline monitoring was carried out above polluting discharges or on streams not receiving discharges.

New Lead Belt, Missouri

Several researchers have studied water quality in the New Lead Belt, an area of lead, zinc, copper, and silver mining and processing (Wixson et al. 1969, Jennett and Wixson 1972, Jennett et al. 19__). The objectives of the studies were to evaluate the extent and causes of pollution, and the effects of lead and other trace elements on water. Sampling sites were located on streams above mines and mills as control sites, and below the dischargers.

High metal concentrations were found to be present in stream water during periods of turbulent storm-water runoff. Washout of metals from the soil was the cause of this. The soil had been contaminated by airborne metal particles originating from a lead smelter. Another pollution effect discovered was the concentration of metals in algae. Algal mats proliferated in the streams because of milling effluents. During high flow periods the mats broke apart and carried metals further downstream.

Sudbury, Ontario

Atmospheric deposition of pollutants from a copper and nickel smelter near Sudbury, Ontario, has caused changes in lake chemistry. Lakes were monitored to assess the extent of area affected by deposition of pollutants, and to establish a baseline in order to monitor future changes (Gorham and Gordon 1960, Conroy et al. 1974, Conroy et al. 1975). Most water pollution problems in this area are due to atmospheric deposition, not direct discharge to the water.

Analyses of water samples revealed that lakes within five miles of Sudbury had high SO_4 concentrations and that lakes with high nickel and copper concentrations and low pH were located downwind of the smelter. Effects of lowered pH and elevated metal levels on aquatic biota were also studied. Acid lakes showed low diversity of zoobenthos and phytoplankton relative to nonacid lakes. Adverse affects on fish populations were also expected due to low pH and high metal concentrations.

Coeur d'Alene, Idaho

The Coeur d'Alene River and Lake and the Spokane River in Idaho make up a water system which has received mining and domestic wastes for over eighty years (Mink et al. 1971, Funk et al. 1975, Bauer 1974). Studies were carried out to determine the trace metal concentration of water and sediments, monitor movement of metals through the system, analyze the effects of mixing of the unimpacted North Branch and the impacted South Branch of the Coeur d'Alene River, and collect data for possible incorporation into future water quality models. Biological studies were also carried out to compare metal concentrations in water and sediments with concentrations in fish muscle and liver tissue, and to determine critical factors inhibiting recovery of benthic macroinvertebrate fauna. The Coeur d'Alene River was monitored on its two forks and below the confluence. A number of small lakes along the main stem of the river were also studied, as was Coeur d'Alene Lake.

Water quality of the main stem of the Coeur d'Alene River was found to be poor throughout its entire 32 mile length, primarily due to high zinc concentrations. High metal concentrations in sediments near the outlets of the lateral lakes and near the river inflow to Coeur d'Alene Lake were also found. In addition, groundwater samples showed high zinc and lead concentrations.

Advantages and Disadvantages

Chemical characterization of water is often only one step of a larger project. A study of biological uptake of metals, for example, requires first the water quality data. For these types of projects chemical characterization of water is adequate. On the other hand, a characterization of the water quality of an area may not be complete enough if only water chemistry data is collected. Sources and sinks of constituents in water are not necessarily apparent from water quality data. In obviously polluted areas such as those described above there is not much question about the source of pollutants; however, many areas receive smaller amounts of pollutants which are not as easily traced. In these areas atmospheric deposition sampling or evaluation of terrestrial characteristics of the drainage area may be required to produce a more complete picture of influences on water quality.

Comparison between water systems is possible using water chemistry data alone, however, by forming classes or groups of water bodies with similar attributes, comparison becomes easier. This is the object of classification systems, to be discussed later.

Mass Balance

Mass balance studies of water quality attempt to follow the movement of chemical constituents through water systems. Determining a mass balance may require collection of many types of data: precipitation, water and sediment chemistry; precipitation amount, streamflow, lake flushing rate, and groundwater flow; and characteristics of the drainage area, such as size, vegetation type, soil type, geology, and land use. In the literature reviewed, studies of this type were carried out in relatively unimpacted areas. Most pollution that did occur was from atmospheric deposition and nonpoint sources, rather than point discharges.

Hubbard Brook Experimental Forest, New Hampshire

The Hubbard Brook Experimental Forest in New Hampshire has been the site of a continuing mass balance study (Fisher et al. 1968, Likens et al. 1967).

The region has no nearby industrial or population centers. Three small watersheds were studied to determine the mass balance of Ca, Mg, Na, K, Cl, SO_4, NH_4, NO_3, H^+, HCO_3, Si, and Al. The objectives of the study were to determine the rates of movement of these chemicals through the watersheds, and relate the rates to the ecology of the forest and geochemistry of the watershed. Precipitation chemistry and amount of stream water chemistry and flow were determined. The bedrock of the three watersheds was known to be watertight, so groundwater was assumed not to influence stream chemistry or flow. Geology and vegetation type of the watersheds were known.

Results of the mass balance showed that output of Ca, Mg, and Na exceeded input, and that input of SO_4, NH_4, and NO_3 was greater than output. The ~~animal~~ annual atmospheric input of H^+ ions was found to be approximately equivalent to the total output of base metal ions in stream waters. Nitrate concentrations in streams showed a seasonal variation, with low levels in the summer and concentrations rising to reach peak values in early spring. Forest biota undoubtedly affected effluent nitrate levels.

Walker Branch Watershed, Tennessee

Cycling of trace metals has been studied in the Walker Branch Watershed near Oak Ridge, Tennessee (Andren et al. 1975). Objectives of the study were to derive a relationship between levels of trace elements in air, rain, and dry deposition; differentiate between natural and anthropogenic origins of trace elements; and study transport processes and input-~~output~~ output budgets of trace elements in the watershed.

The authors were prompted to perform this study by information in the literature indicating that elements are introduced into the atmosphere from fossil fuel burning power plants at rates equal to or greater than natural weathering rates, and that these elements are deposited to aquatic and terrestrial environments. Wet and dry deposition samples were collected, analyzed, and compared with stream water samples. Data on vegetation and soils were obtained from previous studies of the watershed.

The study revealed that Walker Branch Watershed efficiently retained Pb, Cd, and Cu, and less readily accumulated Cr, Mn, Zn, and Hg. The authors speculated that Pb and Cd entering the watershed were of anthropogenic origin (such as auto emissions), while Pb and Cd transported from the watershed were of geochemical origin. Ratios of Cu, Hg, and possibly Zn and Cd in the rain were found to be comparable to ratios in fly ash from coal fired electric plants. The presence of these elements in rain was tentatively attributed to three plants in the Oak Ridge vicinity.

Experimental Lakes Area, Ontario

During 1968 and 1969 forty ELA lakes in northwestern Ontario were studied, and mass balances of nitrogen and phosphorus were determined for four of these lakes (Armstrong and Schindler 1971). Concentrations of N and P were determined for precipitation, stream inflow, groundwater, lake water, and stream outflow. Precipitation volume, stream and groundwater flow, evapotranspiration rate and stream outflow were known.

The data indicated that all four lakes retained both nutrients. In two lakes the nutrients must have been lost to the sediments, because concentrations were not increased in the water column. The other two lakes probably received N and P from their sediments, as well as from external sources. Lake morphometry or ratio of sediment area to volume may have caused the differences between the two lake pairs. The lakes which lost nutrients to their sediments were much deeper, with greater ratios of sediment area to volume, than the lakes which received nutrients from their sediments.

Birkenes Watershed, Norway

Intensive studies have been carried out on ten small watersheds in southern Norway, where investigators were interested in the responses of watersheds to inputs of acid precipitation (Gjessing et al. 1976). The Birkenes Watershed, located in the area of Norway which receives the greatest deposition of acid precipitation, was reported on in detail. Chemistry and volume of precipitation and stream water were determined, and input and output of H^+, Na, K, Ca, Mg, Al, NH_4, NO_3, SO_4, and Cl then calculated.

Input of Cl, Na and SO_4 was found to be equal to output, indicating to the authors that supply to the watershed greatly exceeded the amount accumulated annually and needed for biological growth. Retention of K, NH_4, and NO_3 in the watershed occurred, probably due to biological uptake. Retention of H^+, which was also found, was most likely the cause of Ca, Mg, and Al loss from the watershed. Comparisons of the Birkenes Watershed mass balance data with data from other watersheds in Norway and North America revealed that major differences in chemical outputs were related to differences in geologic environments and acid precipitation loading.

Advantages and Disadvantages

Mass balance determinations provide more information about water systems than simple chemical characterizations. It is possible to determine the source of constituents in the water using a mass balance, and distinguish between internal sources and external sources. Whether a constituent leaves the watershed or water body, or remains can also be determined.

Knowing sources and sinks allows for better management of water bodies. A small watershed, such as Hubbard Brook Watershed, can be studied intensely and the information applied to larger systems. The effects of various land management practices, such as clearcutting, and effects of environmental pollutants on cycling of constituents, are possible to test in a small watershed (Borman and Likens 1967).

Mass balance determinations require the collection of a large amount of data, some of which may be difficult to obtain. A longer period of monitoring time is necessary for a mass balance than the other types of characterization, in order to take into account seasonal changes. Finally, it may not be possible to monitor all sources and sinks which may be important.

Classification Systems

Classification systems divide waters (usually lakes) into distinct groups, about which general statements can be made. The classification systems discussed here group lakes according to trophic state, ability to assimilate H^+; and land use, hydrologic and geologic characteristics of the watershed. Parameters required depend on classification type. Most classifications required water chemistry data and basin characteristic information. Biological parameters were also used in some cases. Classifications were carried out on both impacted and unimpacted water bodies.

Trophic Indices

The most common type of classification system found in the literature was the trophic state index. Hooper (1969) suggested four criteria of a useful trophic index:

1) discriminates between normal nutrient level fluctuations and more permanent changes;

2) has considerable sensitivity to levels of enrichments;

3) is a property or biological characteristic which is widespread among aquatic environments, but short-lived and sensitive to enrichment level changes; and

4) is suitable for long-term surveillance and monitoring by many generations of scientists.

Uttormark and Wall (1975) outlined differences in types of classes used in trophic indices. Some studies placed lakes in relative groups, with the study lakes classified only in relation to each other, not to an independent scale. Other studies classified lakes by numerical rank, by either a relative or an independent scale.

The National Eutrophication Survey (NES) reviewed two approaches to nutrient level determination, concentration and loading, as part of their effort to establish a phosphorus guideline or criterion to aid in avoidance of nuisance phytoplankton blooms (U.S.EPA 1974c). The concentration approach was used by various authors (Sakamoto 1966, Dillon and Rigler 1974) to relate total phosphorus concentration to chlorophyll a concentration. Based on this work, the NES developed a similar relationship using data from selected 1972 study lakes. The median total phosphorus value was plotted against the mean chlorophyll a concentration for lakes with an inorganic nitrogen to dissolved phosphorus ratio of 14 or greater. Phosphorus guidelines were then developed to coincide with the three trophic states.

Vollenweider (1968) made the first attempt to relate nutrient loading rate to lake trophic condition (U.S.EPA 1974c). He related total phosphorus loadings to the mean depth of lakes and empirically determined the loading rates corresponding to the three trophic conditions. Later he modified his relationship by plotting total phosphorus load against the ratio of mean depth to mean hydraulic retention time (Vollenweider 1973). The NES used Vollenweider's newest relationship to analyze the data for selected phosporus limited lakes. Vollenweider's concept held true when tested with survey data, with a few exceptions.

The NES determined that the loading rate concept was more useful for management of lake eutrophication than the concentration approach. It would be relatively easy, once sources of nutrients were determined, to determine he extent of phosphorus reduction from these sources that would be necessary to achieve the desired loading. A disadvantage of this approach is that in a lake with several entering streams carrying different nutrient loads, the loading rate for the entire lake may be acceptable ~~however~~ while loading rates for individual bays may not be acceptable.

Uttormark and Wall (1975) developed a lake condition index (LCI) for 1129 Wisconsin lakes using characteristics of existing classification systems that were appropriate. Parameters used were hypolimnetic dissolved oxygen, transparency, occurrence of fishkills, and use impairment (extent of macrophyte or algal growths). A range of numerical values for each parameter was assigned, with a total cumulative range of 0 to 23: the more undesirable characteristics a lake exhibited, the higher the LCI. These LCI values are not necessarily synonymous with trophic status, however, the authors did determine, with qualifications, a range of LCI values for five trophic states. A comparison of the LCI ranking of approximately 180 lakes with two other classification techniques showed the LCI results to be valid. The lake condition index ranking was developed on an independent scale, and may be applied to other lakes.

Carlson (1977) developed another numerical scale trophic state index (TSI). The advantage of a numerical scale over a nonmenclatural system, according to Carlson, is that a numerical scale is more sensitive to small trophic changes. A nomenclatural system suffers from a loss of information when lakes are lumped together into a few groups. Carlson based his scale on

Secchi disk values, with 0 corresponding to a Secchi disk depth of 64 m and 100 corresponding to a depth of 6.4 cm. The scale is related to algal biomass, because each doubling of algal biomass results in a halving of transparency. By regressing Secchi disk against chlorophyll a and total phosporus, Carlson was able to compute the TSI from these two parameters also. Thus, only one parameter is needed to determine a TSI for a lake, considered an advantage if data for only one parameter is available, or if data for one parameter is more desirable than data for the other parameters.

Carlson suggested that his trophic state index had several advantages. The TSI could be used for regional classification of all surface waters, including streams and rivers, and could be used as a predictive tool in lake management programs.

The NES developed a percentile ranking of the trophic status of 209 lakes in the northeast and north central U.S. (U.S.EPA 1974a). Parameters used to create the index were median total P, dissolved P, and inorganic N, mean chlorophyll a, mean Secchi disk depth, and minimum dissolved oxygen. To determine the Trophic Index Number (TIN) for a particular lake, the percentage of the total number of lakes which exceeded that lake in each parameter was determined. The TIN for the lake is the sum of the percentile ranks of all six parameters. A TIN of 0 to 594 was possible with this group of lakes. Very good trophic status was indicated by a TIN of 500 to 594, and mesotrophic lakes had a TIN of 420 to 499. Eutrophic conditions with occasional nuisance algal problems were found at 300 to 419 TIN, and below 300 nuisance conditions could be expected to occur more

This index system can be used for lakes not included in the original 209. An index developed from another data base would have a different Trophic Index Number range and the values would need to be interpreted differently.

Several disadvantages of the trophic index system were mentioned by the authors. Flushing rate of a lake is not accounted for by the TIN. A low TIN may seem to indicate that a lake has poor water quality, however, if the lake has a high flushing rate, this may not be true. The system was developed in the northeast and north central U.S., so application to other areas may not be valid. An advantage of the system is that it can be used to compare year to year changes of a lake.

Hydrologic Setting

One hundred fifty lakes in the north central U.S. were investigated by Winter (1977) in a first attempt to develop a general classification of the hydrologic settings of lakes. The purpose of the study was to classify lakes according to their interchange with atmospheric water, surface water and groundwater. Thirteen parameters were used in the study: precipitation-evaporation balance, streamflow in, streamflow out, ratio of drainage basin area to lake area, regional slope of the land surface, local relief of the lake's immediate drainage basin, relative altitude of the lake in the region, type of landform in which the lake is situated, mineralogy of the drift, texture of the drift (drift hydraulic conductivity), bedrock hydraulic conductivity , groundwater quality type, and groundwater total dissolved solids. A numerical value for each variable was assigned for each lake. The data were then analyzed using principal component analysis.

The most important factors to be considered in classifying hydrologic settings of lakes were found to be groundwater dissolved solids, precipitation-evaporation balance, streamflow inlet and outlet, and ratio of drainage basin area to lake area. Local relief and regional slope were the most important groundwater characteristics. Texture and drift of bedrock and lake depth were also found to be important variables.

A series of maps was developed showing the areal distribution of selected groups of variables, however, a single map showing lake types was not presented. It was concluded that a single map would be either too complex or too generalized, and somewhat misleading. Classification using all variables was thus not accomplished, and lakes could be compared based only on two variables at a time.

Hydrogeologic Regime

Sixty-three lakes in twelve states and provinces in the glaciated temperate zone of North America were studied for their hydrogeologic characteristics by Born et al. (1974). Objectives of the study were to:

1) Compile and summarize information about lakes for which hydrogeologic data was available.

2) Review and evaluate hydrogeologic aspects of lakes, with special emphasis on groundwater/surface-water relationships.

3) Specify critical hydrogeologic informational needs for evaluating lake environments, concluding with a tentative hydrogeologic classification

4) Demonstrate the applicability and utility of hydrogeologic information to lake management and development activities.

The authors did not collect data in the field, but rather used information available from the literature and from questionnaires sent to researchers. The hydrogeologic factors considered in the study were: 1) regime dominance (relative magnitude of groundwater in lake's water budget); 2) system efficiency (the rate aspects of groundwater/ lake interchange); and 3) position of a lake within a groundwater flow system.

A possible lake classification scheme based on the hydrogeologic factors was compiled by the authors. They divided regime dominance into groundwater dominated and surface water dominated lakes; system efficiency was judged either high or low; and position within the flow system was defined as discharge, recharge, flow-through or perched, for groundwater dominated lakes. The classification could not be considered workable, however, because of lack of data. System efficiency data, in particular, was lacking. The authors felt that groundwater/surface water relationship information is of importance to planning and management activities, and should be collected more systematically.

Land Use

The effects of geology, land use, and population density on phosphorus export from watersheds was studied by Dillon and Kirchner (1974). Thirty-four southern Ontario watersheds were considered, 26 on Canadian Shield bedrock (granitic igneous), 6 on sedimentary rock, and 2 on both types of bedrock. Dominant land use and population density were obtained from government maps and field observations. The authors' goal was to report the results of their own research and study the literature, in order to facilitate calculation of phosphorus loading to lakes.

Four groupings were created based on two rock types, igneous and sedimentary, and two land use types, forested and forest and pasture. Phosphorus export was found to be greatest from sedimentary forest and pasture watersheds. In order of decreasing phosphorus export, the other watersheds were: igneous forest and pasture, sedimentary forested, and igneous forested. It was determined that a change in land use from forested to forest and pasture in igneous watersheds would approximately double the total phosphorus export. Export from a sedimentary forested watershed was found to be almost twice that from an igneous forested watershed.

Comparison with the literature showed similar results for phosphorus export from other studies of forested and forest and pasture watersheds. Mean total phosporus export from sedimentary agricultural watersheds was reported in the literature to be double that from sedimentary forest and pasture watersheds. Other factors which affect phosphorus export include population density, the presence of lakes in the watershed, and slope of the watershed.

The National Eutrophication Survey also did a study relating drainage area characteristics to nutrient concentration in, and export from, streams (U.S.EPA 1974b). The 143 drainage areas used in the study were in the northeastern and north central U.S. Land use was determined from aerial photographs and land use maps; and categories covered were: forest, cleared-unproductive, agriculture, urban, wetland, and other (including barren, extractive, and open water).

Streams draining forested areas were found to have lower nutrient concentrations than streams draining agricultural areas. This was especially true for total phosphorus. The relationships between land use and nutrient export were less pronounced. Mean total phosphorus export from agricultural areas was only 2.7 times greater than that for forest watersheds. The greater average slope of the forested watersheds, which caused increased runoff, was considered to cause greater nutrient loss. If control plots had been used, where slope, soil type, and climatic conditions were similar, significantly lower nutrient export rates would have been expected from forested areas. Urban areas had high nutrient export also, probably due to increased runoff because of impervious surfaces.

Differences in phosphorus concentrations in streams in forested drainage areas were found between the northeastern and north central regions of the U.S. This was thought to be due to factors such as topography (particularly slope) and soil type. Differences in nitrogen concentrations were not as great. The relationship between nutrient runoff and soil type was not intensely studied; however, some effects were apparent. Streams draining areas with mostly basic soils had high nutrient concentrations, while acid-soil regions showed lower nutrient concentrations in streams.

Calcite Saturation Index

Calcite Saturation Index

Fifty lakes in the Sudbury, Ontario region were studied to assess the effects of atmospheric deposition of smelter pollution (Conroy et al. 1974). The lakes were classified by a calcite saturation index to predict lakes with low pH, lakes susceptible to pH depression, and lakes with sufficient buffering to provide protection against pH depression. Calcium ion concentration, alkalinity, and hydrogen ion concentration were used to compute the CSI for each lake. It was found that lakes with pH below 5 had no H^+ assimilation capacity. Lakes with high assimilation capacity were located in areas of calcareous surface material, usually glacial drift.

Advantages and Disadvantages

Hooper (1969) listed two purposes for classification schemes (eutrophication indices in this case), which, if accomplished, are advantages of this type of water quality characterization: 1) to provide adequate documentation of past changes, which must include the existance of agreed-upon categories and scale; and 2) to enable the present rate of change to be determined. A better understanding of the causes of rate changes could then be possible, and the necessary preventative and corrective action taken.

Categories and scales may, on the other hand, be subjective, or based on data from one area of the world, and therefore not usable for water bodies not part of the original study group. Data collected at one point in time to represent a lake's condition in general may also be a problem.

Classification systems based on only one or two parameters have the advantage of being fast and easy to use. Many lakes can be sampled and classified in a short period of time, making quick comparisons between lakes possible. Use of only a few parameters may prevent real understanding of a lake's condition, however.

Conclusion

The three water quality characterization methods discussed above, chemical characterization, mass balance, and classification, all have advantages and disadvantages. Which one is most useful depends on the characteristics of the water body studied and the questions of interest to the researcher. Determining a baseline to monitor future changes or examining effects of water chemistry on biological organisms may require only a chemical characterization of the water. If sources and sinks of constituents in water are of interest, a mass balance determination is necessary. Making comparisons between water bodies for management activities could require a classification based on the parameters of interest.

Degree and source of impacts which affect a water body may also determine which type of characterization is used. A mass balance may not be necessary if pollution sources are well known. Low concentrations of constituents in water may need to be traced by a detailed mass balance, on the other hand.

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Watershed Approach

Lake basins, river systems, and associated land possess unique characteristics which influence the quality of a region's water resources. While important, it is not enough to delineate the properties of each individual component; rather, the details from individual investigations must be synthesized into a holistic view of the region. It is for this reason that the watershed was chosen as the focal point for our data analysis efforts. As discrete hydrologic units, watersheds embody the various land-river-lake interactions which form the basis of a dynamic regional characterization. When one considers that northeastern Minnesota ~~posses~~ possesses a large number of lakes (often connected in chains), complex channel drainage patterns, such as the North and South Kawishiwi River, and a variety of land types from forest to wetlands, the need for and the logic of, a way to interrelate these factors becomes apparent. By developing information on these factors by watersheds, the hydrologic character of the study area has remained intact. The data which ~~has~~ have been gathered will enable us to detail differences within the study region, thereby allowing an assessment of the range of impacts on water resources that copper-nickel development would generate.

The Copper-Nickel Study Water Quality Research Area is comprised of the fourteen shaded watersheds on Figure 1. Hereafter this will be referred to as the "Research Area" or the "WQRA". The rectangular area outlined on Figure 1 is the official Copper-Nickel Study Area (known as the "Study Area"). Only characteristics of the Research Area will be discussed in this report.

Three distinct areas of land will be discussed in this report: watersheds, subwatersheds, and areas above stream stations. Watersheds were determined by the U.S. Geological Survey in St. Paul, Minnesota on 15 and 7½ minute topographic maps. Watershed boundaries were drawn based on the locations of stream sampling stations. The station farthest downstream on any stream has a name consisting of one or two letters and the number one (i.e. D-1, SR-1). Upstream stations have higher numbers, with the highest numbers assigned to headwater stations.

Subwatersheds were determined for those watersheds which contained more than one stream station (in the case of a one-station watershed, the entire watershed may also be referred to as a subwatershed). Subwatershed boundaries were drawn based on the locations of upstream stations.

The area "above" a particular station is the drainage area of that station. This may be one subwatershed, several subwatersheds, one watershed, or several watersheds. The area above station SR-5, for example, is subwatershed sr5; the area above SR-1 is the entire Stony River Watershed (subwatersheds sr1, sr2, sr3, sr4, and sr5). The area above a station is important when considering the effects of cultural, biological, and geologic factors on the water quality at that station.

Description of MLMIS Data

Land use, forest cover, soil and land form data displayed in maps and charts in the watershed descriptions were obtained from the Minnesota Land Management Information System (MLMIS). MLMIS is part of the Land Management Information Center of the Minnesota State Planning Agency, and has a goal to attempt to centralize and analyze data on Minnesota's resources (LMIC 1978). Cultural, resource, and political boundary information is stored on computer files by 40 acre parcel for every parcel in the state. A file of watershed and subwatershed boundaries was created for the Copper-Nickel Study using the boundaries drawn by the U.S.G.S. Maps of the four variables listed above were then created for the Research Area (see Maps 2, 3, 4, nd 5 in map pocket) as well as tables of statistics for areas above stations (see Appendix C).

Mapping variables by 40 acres parcels requires a degree of generalization. The data level which appears on the map for a particular parcel is the "dominant" level. For example, the land use data was interpreted from aerial photographs (MLMIS 1975). To transfer the information on a photo to information which could be mapped by 40 acres, a 40 acre grid was placed over the photo, and the dominant land use for each 40 acre parcel was coded. If a cell contained only two land use types, "water" and "cultivated," and water occupied 21 acres in the parcel, the entire parcel would appear as water on the land use map. If a cell contained eight land uses and a six acre lake made water the most widespread land use type, the entire parcel would again appear as water on the land use map. Thus, relatively small areas may be magnified as a result of the generalization required for this type of mapping.

Relatively large areas may not appear on the MLMIS maps due to generalization. If a 30 acre lake is located in two parcels (15 acres in each parcel) and "pasture" is the only other land use, pasture will be the dominant land use in both parcels. The lake will not show up on the land use map.

Although generalization exists in the MLMIS data, it is the most readily accessible, complete, and accurate set of data for variables which may affect water quality in the Research Area. The MLMIS data base was also heavily used by other disciplines of the Copper-Nickel Study.

Two sets of land use data have been used to describe the Research Area. The entire state of Minnesota was mapped for land use in 1969, and the Study Area was mapped again in 1977. As Figure 1 indicates, the Water Quality Research Area extends outside of the Copper-Nickel Study Area. Only eight watersheds are located entirely within the Study Area (Filson Creek, Keeley Creek, Unnamed Creek, Dunka River, Bear Island River, Embarrass River, Partridge River, St. Louis River), and these are described with 1977 land use data. The other six watersheds are discussed in terms of 1969 data. MLMIS staff interpreted data from aerial photos taken in 1968 and 1969 and the Copper-Nickel Study socioeconomic staff interpreted data from 1977 photos.

The two sets of land use data are not strictly comparable. A number of new categories were established in 1977 and interpretation of data levels was not consistent between the two years. Nine categories were identified in the Research Area in 1969: forested, cultivated, water, marsh, urban residential, extractive, pasture and open, urban and nonresidential or mixed residenial, and transportation. Eleven categories were identified in 1977: mineland, manufacturing-industrial, urban, rural residential, rural commercial, transportation, agriculture, forest, swamps/marshes/bogs, water, and open/vacant. The only categories which appear to be identical in both sets of data are water, extractive or mineland, and transportation. In 1977 ~~forested~~ black spruce bogs were included in the "swamps/marshes/bogs" category, while in 1969 forested bogs were included in the "forested" category. A much greater percentage of forest, therefore, appears in the 1969 data than in the 1977 data. Additional differences are identified in the individual watershed descriptions.

Forest cover data for the Research Area are from the U.S. Forest Service (MLMIS 1975). Data were interpreted by MLMIS staff, from 1971 and 1972 and aerial photographs, for 40 acre parcels which had at least ten percent forest cover of tree crowns. The MLMIS 1969 land use maps uses the same definition of forest. Four forest cover types have been identified in the Research Area, as well as unproductive and nonforested areas.

Seventeen soil associations were found in the Research Area. A soil association is a group of two or more soil series associated in a characteristic geographic pattern (ARDC 1974, MLMIS 1975). Soil series and associations are defined by profile, color, structure, consistency, sequence of horizons, conditions of relief and drainage, and origin and mode of formation (MLMIS 1975). The soils data, from the U.S. Soil Conservation Service in 1973, were interpreted for 160 acre cells.

Land form type is defined as the predominant land form for any soil association (MLMIS 1975). The data, collected in 1974, were interpreted by the U.S. Soil Conservation Service. Data sources were the Arrowhead Regional Development Commission (ARDC) and the U.S. Soil Conservation Service. Ten land form types exist in the Research Area.

Additional Descriptive Data

Other descriptive data for the watersheds were obtained as follows:

a. Lake morphometric data.

A_o (lake area) - standard planimetric procedures.

A_d (total lake drainage basin area) - standard planimetric procedures.

$\bar{Z}$ (mean depth) - V/A_o.

Zmax (maximum depth) - determined from bathymetric maps.

V (lake volume) - areas of depth contours were planimetered; water volume between contours was computed using the truncated cone method (Wetzel 1975); lake volume is the sum of the volume of all contour intervals.

Q (lake outlet discharge) - ten year average determined from historical data by the equation $0.9504 \text{ Log}_{10} X - 1.9586$, where $X = A_d$ (U.S. Forest Service, Ely, MN, John Ramquist, personal communication). Average for study period (March 1976 through February 1977) was determined by the equation $\text{Log } y = 1.04x + 5.15$, from data collected by the Copper-Nickel Study.

qs (areal water loading) - V/A_o.

ρ (flushing rate) - Q/V.

Stratification - determined from dissolved oxygen and temperature profiles.

b. Stream orders

Measured on U.S. Geological Survey topographic maps using the string method.

c. Flow characteristics

Flow data collected by U.S. Geological Survey, Grand Rapids, MN (U.S.G.S. 1977, 1978).

d. Physiographic areas

Interpreted from Physiographic Areas Map in Olcott and Siegel 1978.

e. Location of mines, stockpiles, and tailings basins

Direct Mining Land Use in the Regional Copper-Nickel Study Area, Map compiled by Copper-Nickel Study Socioeconomic staff, 1978.

f. Water use

Unpublished data, U.S. Geological Survey, St. Paul, MN, 1978, for years 1971 through 1976.

g. Discharges

Point discharges-data from NPDES permit files, Minnesota Pollution Control Agency, 1977, and from unpublished water use data, U.S. Geological Survey, St. Paul, MN, 1978.

Nonpoint discharges-data from Copper-Nickel Study Socioeconomic staff; University of Minnesota Mineral Resources Research Center (Tretheway 1974); Superior National Forest map, U.S. Forest Service, 1972.

Surface Water Quality Monitoring Program

The surface water quality of the Copper-Nickel Study region was monitored from March, 1976, through September, 1977. The program involved both lakes and streams; the locations of the sampling points are presented in Figure 2.

Thirty-two stream sites were chosen such that watershed outflow points, headwater areas, and points in between (for large systems) would be sampled. Sampling frequency varied from semi-monthly for the downstream sites (denoted "primary" in Figure 2) to monthly and, in two cases, quarterly for the upstream sites (denoted "secondary" and "tertiary," respectively, in Figure 2). Tables giving the exact location of sampling sites in the watershed, and diagrams depicting their terrestrial characteristics can be found in Appendix A.

Stream gaging stations were established by the U.S. Geological Survey at each of the stream water quality sites. At a minimum, gage height was measured each time a water quality sample was taken; at eleven sites continuous flow recorders were operating. See Appendix A for a listing of the types of stream gaging station established in the region.

The distribution of lake sampling sites (see Figure 2) was similar to that for streams; that is, headwaters as well as downstream lakes were sampled. In most cases, each lake had a single sampling site, but for six of the larger lakes, more than one site ~~were~~ was established (see Appendix A for exact locations). Sampling frequency for seven lakes (denoted "primary" in Figure 2) was quarterly; for the remaining 19 lakes (denoted "survey" in Figure 2) the frequency was semi-annually.

The physical and chemical parameters mesured during the program are listed in Table 1. After the first year of sampling the entire program, as outlined above, was reviewed and appropriate modifications were made concerning the number of stream and lake sites, sampling frequency, and parameters. Case by case discussions of these modifications are not needed here for the rationale and implications of the modifications will be evident in subsequent sections of this report.

Details on sample collection procedures, field laboratory procedures, sample handling and shipment, and recordkeeping can be found in Appendix A.

CHAPTER III

RESULTS

Watershed Descriptions

DESCRIPTION OF ~~STUDY~~ RESEARCH AREA

Introduction

The Water Quality ~~Study~~ Research Area (~~Study~~ Research Area) is 4738 square kilometers in size and is made up of 14 watersheds (Table 2). The Laurentian Divide splits the area; water north of the Divide flows to the Rainy River, and south of the Divide to Lake Superior. Superior National Forest occupies much of the ~~Study~~ Research Area, and the Boundary Waters Canoe Area (BWCA) dips into the area in the north.

Topography of the ~~Study~~ Research Area is rolling to very hilly (Olcott and Siegel 1978). The altitude generally reflects a southwesterly trend with the lowest area at the St. Louis River near Aurora in the southwest. Highest elevations occur in the east-central area in the Embarrass Mountains. Total relief is about 640 feet.

Geology and Land Form

Bedrock underlying the ~~Study~~ Research Area is mainly the Duluth Complex, igneous rocks from Late Precambrian time (Weiblen and Morey 1975). The Duluth Complex intrudes and overlays the older metamorphosed sedimentary rocks of the Mesabi Iron Range sequence (Morey 1972b). Under this sequence is Giants Range Granite which is exposed in the Embarrass Mountains (Olcott and Siegel 1978). North of the Embarrass Mountains bedrock is mainly granite and metamorphosed sedimentary and volcanic rocks of Early Precambrian age. Small sections of the eastern part of the ~~Study~~ Research Area are underlain by volcanic bedrock of the North Shore Volcanic Group (Sims 1970).

The Duluth Complex is irregularly mineralized at its contact with older units. This mineralized zone, which dips 30 to 60 degrees in a southeasterly direction (Phinney 1972), is where taconite mining takes place and where copper and nickel sulfides occur. The contact follows generally the northern boundaries of the Partridge River, Dunka River, and Unnamed Creek watersheds. Extractive areas on the land use map (Map 2) show the location of mineral resources along the contact.

Land form characteristics of the ~~Study~~ Research Area (Map 5 and Figure 3) are due in great part to advances of the Rainy Lobe of the Laurentian ice sheet, during the St. Croix and Antomba phases of Wisconsin Glaciation (Olcott and Siegel 1978). The oldest surficial deposits in the ~~Study~~ Research Area are drumlins deposited during the St. Croix phase. The southermost part of ~~Study~~ Research Area encompasses part of the Toimi Drumlin Field. Many bogs occupy the poorly-drained low spots between drumlins.

When the Rainy Lobe retreated north, it left glaciofluvial deposits of sand and gravel in bedrock valleys, such as the Dunka and Embarrass River basins (Olcott and Siegel 1978). The Dunka River Basin may have been a preglacial tributary to the Embarrass River. Both river valleys are now considered to be part of sand plain physiographic area by the U.S. Geological Survey (USGS)(Olcott and Siegel 1978), and the Embarrass valley has some of the thickest surface deposits of the entire ~~Study~~ Research Area.

A second advance, during the Antomba phase of glaciation, truncated the northern edge of the Toimi Drumlin Field and left a thin sheet of till over the bedrock to the north (note the "shallow to bedrock" area across the entire northern part of the ~~Study~~ Research Area on Map 5)(Olcott and Siegel 1978). The extent to which the ice sheet advanced is marked by terminal and recessional moraines (presumably the northern edge of the "moraine and drumlin areas" category on Map 5). Final retreat of the Rainy Lobe deposited additional outwash material.

The southwestern part of the ~~Study~~ Research Area was covered by a third glacial advance, the St. Louis sub lobe of the Des Moines Lobe (Olcott and Siegel 1978). This ice sheet covered the area south of the Embarrass Mountains and the western edge of the Toimi Drumlin Field (Wright 1972). A layer of till was deposited over older Rainy Lobe deposits. The "eskers and outwash" area in subwatersheds s11 and p1 (Map 5) is a result of this glaciation.

<u>Land Use and Forest Cover</u>

More than 89 percent of the ~~Study~~ Research Area is forested (MLMIS 1969) (Map 2 and Figure 2; Appendix B has land use type definitions). Water, the second most abundant "land" use, occupies seven percent of the ~~Study~~ Research Area. All large lakes appear on the land use map, but of the rivers in the ~~Study~~ Research Area only part of the Kawishiwi system is visible. Most of the farming activity (only 1.2 percent of the ~~Study~~ Research Area), indicated by the "cultivated" and "pasture and open" categories, occurs in the western region, especially in subwatersheds e1 and w1. Urban areas are also more common in the west. The ~~Study~~ Research Area is sparsely settled, indicated by the less than one percent of urban land use. ~~Data used to compile land use statistics were collected in 1968 and 1969, however, and the amount of residential land has since increased (Copper-Nickel Study Socioeconomic staff, personal communication)~~.

Forest cover type shows a distinct pattern in the ~~Study~~ Research Area, as can be seen on Map 3 (also Figure 3). Almost all the pine in the area is concentrated in the northeast while spruce and fir are mainly in the southwestern third of the ~~Study~~ Research Area. Together the two conifer categories account for ~~fifty~~ 50 percent of the forest. Aspen and birch, the largest single category of forest cover, fall in another ~~forty~~ 40 percent of the ~~Study~~ Research Area, in the northwest, southwest, and farthest northeast corner. Nonforested areas correspond with lakes, bogs, mineland, and urban areas.

<u>Soils</u>

The pattern of soil associations in the Study Area can be seen on Map 5 (also Figure 3). Appendix B gives detailed descriptions of the soil series which make up each soil association. The relationship between land form type and soil association type is also indicated in Appendix B .

The most widespread soil association in the Study Area is Mesaba-Barto undulating. It covers 35 percent of the area, corresponding to some of the "shallow to bedrock" landform area (Map 5), mainly in the north. South of this is a large area of the Tivola-Unnamed-Cloquet undulating to steep ~~indifferentiated~~ undifferentiated association which is an esker and outwash area. The predominant peat bog soil type, Mooselake nearly level, is concentrated in the Toimi Drumlin Field and scattered throughout much of the ~~Study~~ Research Area, becoming less concentrated to the north. The drumlins themselves appear to be composed mainly of the Newfound-Newfound wet undulating association.

GENERAL HYDROLOGICAL CHARACTERISTICS OF THE ~~REGION~~ RESEARCH AREA

The purpose of this section is to present only that flow information with direct implications for surface water quality. For a detailed hydrological discussion the reader is referred to the Hydrology Regional Characterization Report.

The significance of flow conditions to water quality lies in the role of water as a transport medium. An appreciation of the spatial and temporal variability of this medium is therefore essential to proper interpretation of water quality data.

Spatial Variability

Figure 4 presents a plot of total discharge (Q) versus drainage area (Ad) during the period March 1, 1976, through February 28, 1977, for 18 stream stations. The data for eleven of the stations were obtained with on-site continuous flow recorders; data for the remaining seven stations were compiled from periodic discharge measurements, gage heights at time of water quality sample collection, and correlations and hydrographic comparisons with the nearest continuous flow recorder. All data were compiled by the USGS. As the graph readily shows, a watershed's annual discharge was highly correlated to its drainage area; the regression equation is also seen to be applicable to a wide range of drainage areas. This equation was used to estimate the annual discharge for the period March 1, 1976, through February 28, 1977, at the remaining stream stations where adequate discharge data were lacking. After these values were calculated, the discharges for all stream stations were standardized by converting cubic meters of discharge to centimeters of runoff.

The formula was:

$$R = \frac{100Q}{Ad}$$

where R = centimeters of runoff
Q = annual discharge in cubic meters
Ad = drainage area in square meters
100 = meter to centimeter conversion factor

These results are presented in Figure 5.

Spatial variability in the amount of runoff delivered at each site is evident, ranging from a low of 11 cm downstream from Colby Lake (P-1) to a high of 24 cm in the headwater areas of the Stony River system (SR-4). The median value for the region was 17 cm.

Temporal Variability

Plots of daily mean discharge (m^3/sec) versus time for the eleven continuous record stations are presented in Appendix B. Two of these (Filson Creek and the South Kawishiwi River at K-7) are reproduced in Figure 6. Temporal variability in flow is obvious at both stations. The hydrograph can be conveniently divided into two sections: peak flow and base flow. Each of these can in turn be refined with peak flow periods consisting of spring runoff and storm events; baseflow can be observed under ice and ice-free conditions. The 1976-1977 period was unusual in that record peak flows were observed early in 1976, whereas record low flows were observed throughout the latter half of that year and during the first three quarters of 1977. Of particular interest is the total lack of spring runoff in 1977. The extended drought partially disrupted the water quality monitoring program. Table 3 lists those stations that were not sampled because they either were dry or were frozen to the bottom.

Figure 6 illustrates another important concept--watershed response rate. Filson Creek was one of the smaller watersheds studied (27 km^2); the South Kawishiwi River at K-7 is typical of the larger systems studied (1474 km^2). Being smaller, the Filson Creek system responded more quickly to runoff and storm events. Event peaks were better defined and preceded corresponding peaks in the South Kawishiwi River. An example can be seen during March, 1977. The runoff curve peaked and was descending in Filson Creek while the South Kawishiwi was only beginning to respond. Other examples can be seen in August and September, 1977. It is possible, in Filson Creek, to discern watershed responses to individual storm events; the South Kawishiwi response curves are much less distinct. The significance of these differences in response times lies in the ability of a small, responsive tributary to deliver a mass of water (and with it its chemical load) to a main channel before the larger system can respond with its mass of diluting water.

This lag time in responses enhances the importance of what might normally be considered an insignificant contribution of chemical mass by a tributary to its main channel. More will be said on this in subsequent sections of this report.

Stream Orders

Stream orders were determined for the watersheds in the ~~Study~~ Research Area. The results are tabulated in Appendix B.

Dams

The locations of dams in the ~~Study~~ Research Area are presented in Appendix B.

WATERSHED DESCRIPTIONS

Kawishiwi River Watershed

Watershed area		1346 km^2
Percentage of ~~Study~~ Research Area	28.4	
Subwatershed areas	k7	236
	k6	655
	k5	262
	k4	66
	k3	64
	k1	63
Stream stations	K-7	South Kawishiwi River
	K-6	North Kawishiwi River
	K-5	South Kawishiwi River
	K-4	White Iron Lake Outlet
	K-3	Garden Lake Outlet
	K-1	Fall Lake Outlet
Lake stations	LBH-1	Birch Lake
	LBH-2	"
	LBH-3	"
	LBH-4	"
	LGO-1	Gabbro Lake
	LGO-2	Gabbro Lake
	LWI-1	White Iron Lake
	LWI-2	White Iron Lake
	LA-1	August Lake
	LA-2	August Lake
	LCW	Clearwater Lake
	LO-1	Lake One
	LTL-1	Turtle Lake
	LF-1	Fall Lake

The Kawishiwi River Watershed is the largest watershed in the ~~Study~~ Research Area, occupying over one quarter of the region, and is hydrologically unique (Figure 1). Subwatershed k6 is a large headwaters area almost entirely within the BWCA and removed from most human influences. The remaining five Kawishiwi subwatersheds all receive water from other watersheds, some of which are impacted by mining and urban discharges. The Kawishiwi River splits below station K-6; the north branch flows west into subwatershed k3; the south branch flows southwest through subwatersheds k7, k5, and k4 before rejoining the north branch in subwatershed k3. The watershed stretches from the easternmost part of the ~~Study~~ Research Area to the western boundary. Stream station K-1 is the outlet for the entire area north of the Laurentian Divide.

The Kawishiwi River flows through a number of large lakes, two of which (White Iron and Birch) were monitored at lake stations. Characteristics of all the monitored lakes in the watershed are shown in Table 4.

Land use in the Kawishiwi Watershed is mainly forest (Map 2 and Figure 7) (MLMIS 1969). A large percentage of the watershed relative to the ~~Study~~ Research Area is water. Pine is the predominant tree type and occupies a broad band in the eastern and central part of the watershed (Map 3). This area accounts for 42 percent of the pine in the entire ~~Study~~ Research Area (MLMIS 19~~6~~72). Aspen and birch are located in the eastern and western regions of the watershed.

Soils in the watershed are almost entirely Mesaba-Barto undulating to hilly (Map 4). Note on Map 5 that this corresponds to most of the "shallow to bedrock" land form area. Only two areas in the watershed have different land form types. The western end of subwatershed k5 and the southern end of subwatershed k7 are mainly outwash areas.

Table 5 lists water users and point discharge sources in the Kawishiwi Watershed. Possible nonpoint sources of water pollution include the city of Ely; storm sewer discharge to Shagawa River, road salt (28 tons used during 1975-1976 winter); village of Winton storm sewer discharge; rural residences; roads and highways; and campgrounds and resorts. Rural residences, campgrounds, and resorts are users of small amounts of water which are not listed in Table 5 .

Isabella River Watershed

Watershed area		883 km^2
Percentage of ~~Study~~ Research Area	18.6	
Subwatershed areas	i1	751
	Little Isabella	132
Stream stations	I-1	Isabella River
Lake stations	none	

The Isabella River Watershed is a large watershed on the eastern edge of the ~~Study~~ Research Area (Figure 1). Most of the watershed is within the Superior National Forest and the northern edge is within the BWCA. The southeastern boundary is formed by the Laurentian Divide. Nearly 4.5 percent of the watershed is water (MLMIS 1969) (Map 2 and Figure 8). The Isabella River flows out of the watershed and joins the Kawishiwi River in subwatershed k7 after flowing through Bald Eagle and Gabbro lakes.

Most of the forested area in the watershed is pine (Map 3). This accounts for over 45 percent of the pine in the ~~Study~~ Research Area (MLMIS 19~~6~~72). Spruce, fir, aspen, and birch occupy small areas in the east and south of the watershed.

The Isabella Watershed is split nearly in half between "shallow to bedrock" and "eskers and outwash" land form areas (Map 5) with "shallow to bedrock" to the north. Peat bogs scattered throughout the watershed take up 11 percent of the area. Map 4 and Figure ~~2~~ 9 show soil type distribution.

No water use or point discharge data ~~is~~ are available for the Isabella Watershed; however, possible nonpoint discharge sources and users of small amounts of water include campgrounds and resorts, roads and highways, village of Isabella, other small towns, and rural residences.

Filson Creek Watershed

Watershed area		27 km^2
Percentage of ~~Study~~ Research Area	0.6	
Subwatershed areas	f1	27
Stream stations	F-1	Filson Creek
Lake stations	none	

Filson Creek Watershed is small and was monitored by one stream station (F-1). Filson Creek flows into the Kawishiwi River in subwatershed k7 (Figure 1). Two small lakes in the watershed account for ~~two~~ just over one percent of the total area (MLMIS 1977) A high percentage (86) of the area is forested and 12 percent is swamp, marsh or bog (Figure 9). The 1969 land use data showed 98 percent forest and ~~no to~~ marsh (Map 2). This does not indicate a change in land use, but rather a change in classification. Black spruce bog, considered "forest" in 1969, was classified as "swamp, marsh or bog" in 1977. ~~Study Area.~~ Filson Creek Watershed is on the Western edge of the pine forest area (Map 3) and has only 38 percent pine, a much lower percentage than the Isabella Watershed. Aspen and birch comprise most of the forest.

Only two land form types are found in Filson Creek Watershed, "shallow to bedrock" and bogs (Map 5). There are likewise only two soil associations found here, Mesaba-Barto undulating to hilly and Mooselake nearly level (Map 4).

Water use and point discharge data ~~is~~ are not available for Filson Creek Watershed. The only sources of water pollution appear to be highway 181 and logging roads.

Keeley Creek Watershed

Watershed area		29 km^2
Percentage of ~~Study~~ Research Area	0.6	
Subwatershed areas	kc1	29
Stream stations	KC-1	Keeley Creek
Lake stations	none	

Keeley Creek Watershed, located just south of Filson Creek Watershed, is quite similar to Filson (Figure 1). The watershed is small and the creek flows into Birch Lake in the Kawishiwi system and subwatershed k5. ~~Map 2~~ Eighty-eight percent of the watershed is forest, seven percent swamp, marsh or bog, and four percent is open or vacant (Figure 10)(MLMIS 1977). In 1969 no open land was present in the watershed (Map 2), which may indicate recent logging activity.

Pine forest occupies the eastern one quarter of the watershed (Map 3). There is some spruce and fir to the west, but aspen and birch are the predominant tree types. Like Filson Creek Watershed, Keeley has only two land form types, "shallow to bedrock" and bog, and two soil types (Maps 4 and 5).

Keeley Creek Watershed contains no large water users or dischargers covered by permits. A possible nonpoint source of pollution is Minnesota highway 1.

Stony River Watershed

Watershed area		632 km^2
Percentage of ~~Study~~ Research Area	13.3	
Subwatershed areas	sr5	125
	sr4	161
	sr3	180
	sr2	101
	sr1	65
Stream stations	SR-5	Greenwood River
	SR-4	Stony River
	SR-3	Slate Lake Outlet
	SR-2	Stony River
	SR-1	Stony River
Lake stations	LGD-2	Greenwood Lake
	LSD-1	Sand Lake
	LSM-1	South McDougal Lake
	LST-1	Slate Lake

The Stony River Watershed is a relatively large watershed which forms part of the southern boundary of the ~~Study~~ Research Area (Figure 1). On the west the Laurentian Divide constitutes about half of the watershed boundary. The Stony River, which flows into Birch Lake, was monitored at four places, and one tributary (Greenwood River) was also monitored. There are quite a few lakes in the watershed, especially in the central area. Four lakes were monitored, and their characteristics are shown in Table 6.

Most of the Stony River Watershed is forested, according to Map 2 and Figure 1 (MLMIS 1969). Spruce and fir are the predominant tree types (Map 3), and occupy nearly half of the forested area. The watershed has about 29 percent of all the spruce and fir in the ~~Study~~ Research Area (MLMIS 196~~2~~7). In the northern section of the watershed the spruce-fir forest is replaced by a mixture of pine and aspen-birch forest.

The Stony River Watershed has a wide range of soil types (Map 4) and land form types (Map 5). It contains nearly 25 percent of the peat bog in the ~~Study~~ Research Area (MLMIS 1974). About one third of the watershed is covered with bogs and peat soils. The "shallow to bedrock" land form area dips into the northern end of the watershed in subwatershed sr1. South of this is a broad band of outwash area interspersed with bogs. Subwatersheds sr4 and sr5 in the south have a mixture of land forms but are mainly drumlin and bog areas.

Water use and point discharge information is not available for the Stony River Watershed; however, nonpoint sources of water pollution may include campgrounds and resorts, roads and highways, and rural residences. Campgrounds, resorts, and residences are also users of small amounts of water.

Unnamed Creek Watershed

Watershed area		11 km^2
Percentage of ~~Study~~ Research Area	0.2	
Subwatershed areas	bb1	11
Stream stations	BB-1	Unnamed Creek
Lake Stations	none	

Unnamed Creek Watershed is the smallest watershed in the ~~Study~~ Research Area and is one of the most heavily mined (MLMIS ~~1969~~ 1977). Station BB-1 monitored Unnamed Creek at its mouth on Bob Bay of Birch Lake (Figure 1). The amount of mineland in the watershed increased between 1969 and 1977. In 1969 17 percent of the watershed was "extractive" land use and two percent "pasture and open" (open land often surrounds mines)(Map 2). Twenty seven percent "mineland" was found in 1977, and 26 percent "open/vacant" (Figure 12). Erie Mining Company has an open pit mine along the entire northwest edge of the watershed on the contact (MEQB 1978). Stockpiles along the southeast edge of the pit take up additional land. The forested area which is mainly aspen and birch (Map 3), decreased from 81 to 44 percent of the watershed from 1969 to 1977, leaving Unnamed Creek with the smallest forest percentage of all the watersheds. The soil types and land form maps (Maps 4 and 5) show that nearly three quarters of Unnamed Creek Watershed has a thin soil cover over the bedrock, and another 13 percent is ~~peat~~ bog. The mining area is also visible on these maps.

Water users and point dischargers in Unnamed Creek Watershed are listed in Table 7. Seepage from stockpiles is a nonpoint source of water pollution not included in the table.

Dunka River Watershed

Watershed area		128 km^2
Percentage of ~~Study~~ Research Area	2.7	
Subwatershed areas	d2 d1	44 84
Stream stations	D-2 D-1	Dunka River Dunka River
Lake stations	none	

The Dunka River Watershed is located south of Unnamed Creek Watershed (Figure 1). The eastern and southern boundaries are formed by the Laurentian Divide, and the contact runs along part of the northern edge. Sampling station D-1 is located somewhat above the mouth of the Dunka River at Birch Lake, so the watershed does not extend to the end of the river. ~~Six~~ Twelve percent of the watershed is mining land ~~(Map 2 and~~ (Figure 13), (MLMIS 1977), compared to 6 percent in 1969 (Map 2).

About one third of Reserve Mining Company's Peter Mitchell Open Pit Mine is located in subwatershed d1 along the contact. Surrounding the pit are stockpiles (MEQB 1978). The percentage of open land increased from three to 14 percent from 1969 to 1977.

The southern part of the watershed has no mining and is more heavily forested. Subwatershed d2 is 70 percent forest, compared to 48 percent forest in subwatershed d1 (MLMIS 1977). Aspen and birch ~~forest is~~ are most widespread, with some spruce-fir forest interspersed (Map 3). ~~A relatively high percentage of "unproductive" land corresponds with some of the large bog areas in the watershed (Map 5)~~. Over 30 percent of subwatershed d2 is peat bog (MLMIS 1974), and over 20 percent of the entire watershed is bog ~~(MLMIS 1974)~~ (Map 5). The soil type associated with these bogs is Mooselake nearly level (Map 4). "Shallow to bedrock" is the largest land form area in the watershed.

Mining companies are the major water users and dischargers in Dunka River Watershed (Table 8). Stockpile seepage, mining roads, and public highways are nonpoint sources of water pollution.

<u>Bear Island River Watershed</u>

Watershed area		177 km^2
Percentage of ~~Study~~ Research Area	3.7	
Subwatershed areas	bi1	177
Stream stations	BI-1	Bear Island River
Lake stations	LBI-1 LBI-2 LPH-1	Bear Island Lake " Perch Lake

Bear Island River Watershed is on the western edge of the ~~Study~~ Research Area (Figure 1). The river flows northeast into White Iron Lake in the

Kawishiwi Watershed. The Watershed has 0.91 percent rural residential land (MLMIS 1977) (Appendix B), a larger ~~the highest~~ percentage than most ~~of any~~ watersheds in the Research Area. Scattered residences, many located near lakes, appear to account for this. Lakes occupy ~~nine~~ eight percent of the watershed (Figure 14). Two lakes were monitored and their characteristics appear in Table 9. Aspen and birch are the predominant tree types (Map 3). Conifers take up less than 20 percent of the watershed, a low percentage for the Study Area. Most of the watershed has "shallow to bedrock" land form (Map 5) and two soil types: Mesaba-Barto undulating to hilly and Conic-Insula indulating to hilly (Map 4). Peat bog occupies about 15 percent of the area. An increase in the amount of open land in the watershed appears to have occurred since 1969. Five percent open and vacant land was found in 1977, compared to one percent pasture and open in 1969 (Map 2).

Bear Island River Watershed has no large water users or point dischargers. Nonpoint sources may include rural residences and roads and highways.

Shagawa River Watershed

Watershed area		256 km^2
Percentage of ~~Study~~ Research Area	5.4	
Subwatershed areas	sh1	256
Stream stations	SH-1	Shagawa Lake Outlet
Lake stations	none	

The Shagawa River Watershed forms the northwest corner of the ~~Study~~ Research Area (Figure 1). It is unique because of its high percentages of urban land and area occupied by water (Figure 15) (MLMIS 1969). Twenty percent of the watershed area is water, due mainly to Shagawa and Burntside lakes, two of the largest lakes in the ~~Study~~ Research Area. Urban areas surround the lakes and the town of Ely is located beside Shagawa Lake (Map 2). Shagawa Watershed has 23 percent of the urban residential land and 28 percent of the urban and nonresidential or mixed residential land in the ~~Study~~ Research Area (the ~~Study~~ Research Area has only 0.54 and 0.29 percent of these land use types, respectively) (MLMIS 1969).

Over three-quarters of the forest in the watershed is aspen and birch (Map 3). This is the highest percentage of any watershed in the ~~Study~~ Research Area. Like other watersheds in the northern part of the ~~Study~~ Research Area, Shagawa is characterized by "shallow to bedrock" land form (Map 5). The watershed has Conic-Insula indulating to hilly soils in this area, however, which is unusual. The ~~Study~~ Research Area as a whole has only five percent of this soil type, and the Shagawa River Watershed has 61 percent of the total (MLMIS 1973).

Table 10 shows the two large water users and dischargers in the Shagawa River Watershed. Nonpoint sources and users of small amounts of water in the area include the city of Ely: storm sewer discharge to Shagawa Lake, road salt (28 tons used during 1975-1976 winter); campgrounds and resorts; roads and highways; rural residences; and the abandoned Pioneer Mine pit.

Rainy River Drainage

Area above K-1	3489 km^2
Percentage of ~~Study~~ Research Area	73.6

The preceding sections have dealt with the individual watersheds in the ~~Study~~ Research Area which are north of the Laurentian Divide and part of the Rainy River Drainage (Figure 1). Since the water from this entire region leaves the ~~Study~~ Research Area at one point (stream station K-1), it is appropriate to consider the region as a whole.

The Kawishiwi River collects water from all the other watersheds north of the Divide. As mentioned earlier, only subwatershed k6 of the Kawishiwi System does not receive input from other watersheds. Because of the variation between sets of biological, cultural, and geological factors from watershed to watershed, a wide range of water chemistry types can be expected to enter the Kawishiwi.

The area north of the Divide is predominantly forested (Map 2 and Figure 16) (MLMIS 1969). About one third of the forest is pine, however; this accounts for 98 percent of the pine in the ~~Study~~ Research Area (MLMIS 1972). Map 3 clearly shows where the pine in the region is concentrated. A disproportionate amount of the water in the ~~Study~~ Research Area (91 percent) also is located north of the Divide (MLMIS 1969). Mining areas take up only 0.3 percent of the region, which accounts for 23 percent of the mining land use in the ~~Study~~ Research Area (MLMIS 1969).

The northern half of the area north of the Divide consists almost entirely of "shallow to bedrock" land form type (Map 5). To the south other land forms become more prevalent, especially eskers and outwash areas and bogs. The Mesaba-Barto undulating to hilly soil association is most common (Map 4).

Embarrass River Watershed

Watershed area		229 km^2
Percentage of ~~Study~~ Research Area	4.8	
Subwatershed areas	e1 e2	46 183
Stream stations	E-2 E-1	Embarrass River "
Lake stations	none	

The Embarrass River Watershed is located on the western edge of the ~~Study~~ Research Area with the Laurentian Divide as its northern border and the Embarrass Mountains as its southern border (Figure 1). The river flows in a south-westerly direction out of the watershed and joins the St. Louis River outside of the ~~Study~~ Research Area.

The town of Babbitt is located in the eastern end of the watershed, and accounts for the 4.5 percent urban land use in Subwatershed e2 (Appendix B), the highest percentage of ~~all~~ subwatersheds in the research area (MLMIS 1977). Rural residential land occupies 1.3 percent of Subwatershed e2. Nearly four percent of the Embarrass Watershed is agricultural land (Figure 17), which is more than any other watershed.

The forest (63 percent of the watershed) is mainly aspen-birch, with 27 percent spruce-fir, and only two percent pine (Map 3).

Peat bogs are the major land form type in the Embarrass Watershed, according to Map 5, and take up one third of the watershed. Two types of peat soils form the bogs (Map 4). The "shallow to bedrock" area corresponds to the Embarrass Mountains, and the outwash plain and sandy moraine area is part of the thick glaciofluvial deposits resulting from the retreat of the Rainy Lobe of the Laurentian ice sheet (Olcott and Siegel 1978).

Water users and dischargers in the Embarrass Watershed are listed in Table 11. In addition, there may be nonpoint discharges from these sources: Village of Babbitt: storm sewer discharges, road sale (20 tons used during 1975-1976 winter); rural residences; and roads and highways.

Partridge River Watershed

Watershed area		404 km^2
Percentage of ~~Study~~ research Area	8.5	
Subwatershed areas	p5	32
	p4	48
	p3	47
	p2	137
	p1	71
	Second Creek	69
Stream stations	P-5	Partridge River
	P-4	South Branch Partridge River
	P-3	Colvin Creek
	P-2	Partridge River
	P-1	Partridge River
Lake stations	LCY-1	Colby Lake
	LCY-2	Colby Lake
	LBG-1	Big Lake

The Partridge River Watershed is defined on the north by the contact and the Embarrass Mountains and on the east by the Laurentian Divide (Figure 1). Two lakes in the watershed were monitored and their characteristics and are shown in Table 12. Mining along the contact occurs in four of the six subwatersheds and mineland occupies nearly ~~nine~~ 19 percent of the watershed area (MLMIS 1977) ~~(Map 2 and~~ (Figure 18). Second Creek Subwatershed, with ~~34~~ 61 percent extractive land, has proportionally more mining land than any other subwatershed (MLMIS ~~1969~~ 1977). Open pit mines belonging to Erie Mining Company and Pittsburgh Pacific Mining Company, a large tailings basin, and many stockpiles are located in the subwatershed (MEQB 1978). Subwatershed p5 contains most of Reserve Mining Company's Peter Mitchell Open Pit and is ~~25~~ 46 percent mining land (MEQB 1978, MLMIS ~~1969~~ 1977).

Mineland occupies about twice as much land now as it did in 1969 in the Partridge River Watershed (Map 2). The entire watershed contained nine percent extractive land in 1969, Second Creek Subwatershed contained 34 percent and Subwatershed p5 contained 25 percent. The amount of open land has also increased dramatically, possibly in association with mining activity.

Forest cover is limited in the watershed because of the large amounts of mining and open land. Subwatershed p5 has only 20 percent forest and Second Creek Subwatershed only 29 percent. Forest type is predominantly aspen and birch. Conifers, mainly spruce and fir, account for about one third of the forest area (Map 3).

Map 5 shows a wide range of land forms existing in the watershed. The northeast, outside of the mining areas, is characterized by thinly-covered bedrock. Moraine and drumlin areas take up most of the southern section with many bogs. The USGS classifies this section as "shallow bedrock-moraine area" (Olcott and Siegel 1978), a slightly different interpretation. To the west, again excluding mineland, is an area of eskers and outwash. Map 4 shows the soil types associated with these land forms.

The Partridge River Watershed has a large number of point and nonpoint pollution sources. Table 13 lists point sources and water users. Abandoned and exhausted mines may be nonpoint sources, and Table 14 lists these in the watershed. Stockpiles surrounding the mines may also be nonpoint sources. Other possible nonpoint sources include the village of Hoyt Lakes: storm sewer discharge to Colby Lake and Whitewater Lake, road salt (5 tons used during 1975-1976 winter); roads and highways; campgrounds and resorts; and rural residences. Small amounts of water are used by campgrounds, resorts, and rural residences.

Although six subwatersheds make up the Partridge Watershed, stream water was monitored in only five subwatersheds. Second Creek enters the

Partridge River downstream of Station P-1, thus the effects of characteristics of Second Creek Subwatershed on water quality were not revealed, except in a diluted form at station SL-1 on the St. Louis River.

St. Louis River Watershed

Watershed area		350 km^2
Percentage of ~~Study~~ Research Area	7.4	
Subwatershed areas	sl3	157
	sl2	86
	sl1	107
Stream stations	SL-3	Seven Beaver Lake Outlet
	SL-2	St. Louis River
	SL-1	"
Lake stations	LSB-1	Seven Beaver Lake
	LSB-2	"
	LPN-1	Pine Lake
	LL-1	Long Lake

The St. Louis River drains the entire region south of the Laurentian Divide in the ~~Study~~ Research Area; however, most tributaries join the river downstream of the Copper-Nickel monitoring stations. Only the Partridge River flows into the St. Louis within the boundaries of the ~~Study~~ Research Area (Figure 1). The St. Louis River Watershed is long and narrow with the Laurentian Divide as its eastern boundary and the northern edge of the Toimi Drumlin Field generally forming its southern boundary (Olcott and Siegel 1978). Three lakes in the watershed were monitored; their characteristics are given in Table 15. Forest is the predominant land use ~~(Map 2 and~~ (Figure 19), consisting of mostly spruce and fir in the east and aspen and birch in the west (Map 3).

The most striking feature of the St. Louis Watershed is the large amount of bog, best seen on the land form map (Map 5). Subwatersheds s12 and s13 are both more than 50 percent bog-covered (MLMIS 1974). This area is defined by the USGS as the Seven Beaver-Sand Lake wetland area (Olcott and Siegel 1978). Most of the remainder of the watershed is moraine and drumlin area (MLMIS 1974), although the USGS considers part of this area to also include shallow to bedrock physiography (Olcott and Siegel 1978). Soils in the watershed are primarily Newfound-Newfound wet undulating and peat soils (Map 4).

The St. Louis River Watershed has no large water users or point dischargers. Nonpoint dischargers and users of small amounts of water include campgrounds and resorts, rural residences, and roads and highways.

The area upstream of station SL-1 includes both the St. Louis and Partridge watersheds, since the Partridge River enters the St. Louis River in subwatershed s11. Characteristics for the area above SL-1 are listed in Appendix C.

<u>Whiteface River Watershed</u>

Watershed area		148 km^2
Percentage of ~~Study~~ Research Area	3.1	
Subwatershed areas	wf1 wf2	24 124
Stream stations	WF-1 WF-2	Shiver Creek Whiteface River
Lake stations	none	

The Whiteface River Watershed forms two extensions on the southern edge of the ~~Study~~ Research Area (Figure 1). Shiver Creek, monitored at station WF-1, and the Whiteface River, monitored at station WF-2, both flow into Whiteface Reservoir south of the ~~Study~~ Research Area. The Whiteface River continues out of the reservoir and eventually joins the St. Louis River.

The watershed is entirely within the Toimi Drumlin Field and has numerous small bogs between the drumlins (Map 5 and Figure 20). Most of the forested area [99 percent of the watershed (MLMIS 1969)] is aspen and birch, interspersed with spruce and fir (Maps 2 and 3). Map 4 shows the soil types in the watershed.

A campground on Cadotte Lake, rural residences, and roads may use and discharge small amounts of water within the Watershed. No large users or dischargers requiring permits are found in Whiteface Watershed.

<u>Water Hen Creek Watershed</u>

Watershed area		118 km^2
Percentage of ~~Study~~ Research Area	2.5	
Subwatershed areas	w1	118
Stream stations	W-1	
Lake stations	none	

Water Hen Creek Watershed forms the third extension on the southern edge of the ~~Study~~ Research Area (Figure 1). The creek flows northwest after leaving the ~~Study~~ Research Area and into the St. Louis River. A greater percentage of this watershed is taken up by pasture, open, and cultivated land than any other watershed (Map 2 and Figure 21) (MLMIS 1969). As in other watersheds in the southwestern part of the ~~Study~~ Research Area, most of the forest is aspen and birch with spruce and fir second most prevalent (Map 3). Part of Water Hen Creek Watershed is within the Toimi Drumlin Field; however, the western section consists of mainly moraine (Olcott and Siegel 1978)(Map 5).

The watershed has only nonpoint sources of water pollution and small water users, such as roads and rural residences.

Lake Superior Drainage

Total area south of Laurentian Divide	1249 km^2
Percentage of ~~Study~~ Research Area	26.4

Five watersheds, which account for 20 percent of the ~~Study~~ Research Area, are located south of the Laurentian Divide in the Lake Superior Drainage (Figure 1). Although the St. Louis River drains the entire area, only the Partridge River joins the St. Louis within the boundaries of the ~~Study~~ Research Area. Most of the extractive land use (77 percent) in the ~~Study~~ Research Area occurs south of the Divide, since the contact runs through much of the Partridge River Watershed (MLMIS 1969). Cultivated land, less than 0.2 percent of the Study Area, falls predominantly (92 percent) within the Lake Superior Drainage. Pasture and open land is also more common south of the Divide (MLMIS 1969).

The area south of the Divide is mostly forested (Map 2 and Figure 22), but has a different forest type composition than the area north of the Divide (Map 3). Whereas the northern area is 37 percent pine forest, the southern area is only two percent pine. Aspen-birch forest is most common, with spruce and fir occupying the next largest region.

Land form south of the Laurentian Divide is also different from that north of the Divide (Map 5). Sixty-six percent of the moraine and drumlin area is in the south, and only six percent of the "shallow to bedrock" area (MLMIS 1974). Bogs take up 32 percent of the Lake Superior Drainage. Small bogs are located between the drumlins and the large Seven Beaver-Sand Lake wetland area is found in the St. Louis River Watershed (Olcott and Siegel 1978). Soil types associated with the land form types are shown on Map 4.

Lakes Outside of ~~Study~~ Research Area

Seven lakes were monitored which are not within any of the designated watersheds. Their locations can be seen on Figure 1. Characteristics of the drainage areas of these lakes will not be included here; however, characteristics of the lakes themselves are listed in Table 16.

SURFACE WATER QUALITY

This section presents summary statistics for lake and stream water quality. Four major parameter groups are considered. The first consists of general water quality parameters such as major cations and anions, color, and conductivity; the second includes parameters relating to acid buffering capacity; the third consists of major nutrients; and the fourth includes major and trace metals. Only summary statistics are presented; all interpretations and discussions are dealt with in Chapter IV-Discussion.

Data are presented in the form of Box Plots (McGill et al. 1978), a display technique that illustrates range, median, and quantities (Figure ~~4~~ 23); and, when appropriate, bar diagrams.

For each parameter under the four general groupings, summaries are given for individual stream stations only. ~~the region based on stream data, and the region based on lake data.~~ Summaries for individual lake stations are not warranted because lake sampling frequency was low and for many stations less than five data points exist.

Except for pH, dissolved oxygen, and specific conductivity, determinations that were conducted on-site or at a field laboratory, chemical analyses were performed by the laboratories of the USGS in Denver and the Minnesota State Department of Health. Data on analytical variability and quality assurance are presented in the Data Quality Assurance Technical Report.

GENERAL WATER QUALITY

Figure ~~23~~ 4 is a bar diagram of median major cation and anion concentrations expressed as milliequivalents per liter; median silica concentrations are expressed as milli~~meter~~moles per liter.

Ideally it is expected that the sum of cations equal the sum of anions; in practice this rarely occurs. The inequalities observed in Figure ~~23~~ 4 suggest that additional ionic species existed that were locally important, but that were not measured. Analytical variability, which tends to increase with increasing concentrations, may also contribute to such inequalities. The lack of exact agreement between cations and anions does not, however, reduce the usefulness of Figure ~~23~~ 4, for the diagram does illustrate spatial variability in the proportions of the major ionic species that govern general water quality.

Box plots for these parameters plus color, specific conductivity, and total organic carbon (TOC) are presented in Figure 25.

BUFFERING PARAMETERS

Box plots for pH, alkalinity, and sulfate are presented in Figure 26.

NUTRIENTS

Box plots for total phosphorus and total nitrogen are presented in Figure 27. Summary data for lake chlorophyll *a* and secchi disk are given in Table 17.

METALS

Figure 28 presents box plots for total iron, copper, nickel, lead, zinc, ~~and~~ cadmium, manganese, cobalt, mercury, arsenic and aluminum.

Arsenic and mercury were analyzed for because of their known toxicities. Less than detectable concentrations were common across the region, but as Figure 28 ~~Table 18~~ illustrates, measurable concentrations of the two metals were observed throughout the Research ~~Study~~ Area. The maximum mercury value, 0.6 μg/ℓ, was measured at K-1; the maximum median values 0.1 μg/ℓ, was observed at BI-1; the minimum median value, 0.01 μg/ℓ, was observed at K-7. For arsenic the maximum value was 100 μg/ℓ at E-1; the range in median values was 0.5 μg/ℓ at BB-1 to 1.7 μg/ℓ at both W-1 and WF-2.

Miscellaneous Parameters

Box plots for the remaining parameters measured during the study are presented in Appendix D.

CHAPTER IV
DISCUSSION

SURFACE WATER QUALITY

The box plots presented in Chapter III are useful for visualizing the distributional characteristics of the data sets. However, additional data analysis techniques were needed to obtain a clearer picture of regional water quality. Before proceeding with a discussion of the results of these effects a brief description of the principal methods employed is warranted.

Parameter Correlations

To investigate the inter-relationships of parameters, linear regressions were generated. As much of the data showed skewed distributions, regressions were made on log transformed data sets in addition to the nontransformed ones; the more significant correlation of the two was then selected. When a relationship seemed especially helpful for water quality the regression equation for the best fitting straight line through the scatter plot was obtained.

Spatial Variability

A series of analysis steps were used to establish spatial trends in water quality. The first step consisted of reviewing the ~~survey~~ summary statistics and resulted in tentative spatial groupings of stream stations based on median concentrations. These tentative groupings were then strengthened by the application of the multiple range test (an analysis of variance technique). Three definite groupings of stream stations resulted which were then tested using univariate analysis of variance. To evaluate differences between groups, on a multivariate basis, discriminant analysis was employed. This technique determines a classification function to distinguish between the three spatial groups and then applies the function to each observation to determine if it is correctly classified. If the observation is not correctly classified, the function determines which group it seems to belong to. As a result of this analysis it was possible to identify statistically difficult water quality areas in the ~~Study~~ Research Area.

Flow Dependency

An analysis of the inter-relationships between flow conditions and water chemistry yielded an understanding of the sources of the chemical constituents found in water and of the temporal variability in chemical mass transport.

The possibilities for the relationship between the chemical concentrations of a parameter and flow conditions in the streem are numerous, but the range can be divided into five convenient categories: simple inversive dependence; partially inversive-partially independent; complete independence; partial independence-partial direct dependence; simple direct dependence. These cases are illustrated in Figure 29 and are numbered 1, 2, 3, 4, and 5, respectively. Included in Figure 29 are the corresponding mass vs. flow, concentration vs. time, and mass vs. time relationships for the five concentrations vs. flow cases.

Case 1--This relationship would be observed at a monitoring site if there were a constant source of mass upstream. When flow increased due to precipitation, concentration would be seen to decrease as a direct function of dilution. This case assumes that the diluting water contains no additional mass.

Case 2--Here, additional mass is being contributed by the atmosphere resulting in only partial dilution of the mass from the upstream source.

Case 3--There is no constant upstream source of mass. The atmosphere is ~~the~~ a major mass source, and therefore the circumstances observed in the stream are controlled by atmospheric and meteorological processes. For all practical purposes concentration is constant over time.

Case 4--In this case atmospheric and meteorological processes are still important but now there is additional and intermittant mass release within the watershed. Watershed washoff or accelerated weathering with increasing precipitation are examples of this phenomenon.

Case 5--This is an extension of Case 4 with internal watershed release of mass accounting for a greater percentage of the total mass source.

To expect a given stream to fit one of these five cases exactly for all parameters is unrealistic, simply because of the differences in sources of chemical mass and variability in water quality. In evaluating flow dependency of parameters in the ~~Study~~ Research Area plots of the type illustrated in Figure 29 were generated for each of the eleven stream stations for which continuous flow, and calculated mass, data were available. It is reasonable to assume that the relationships between flow and quality defined by the eleven stations are representative of regional atmospheric-watershed interactions.

Watershed Mass Export Rate

To further develop and quantify these atmospheric-watershed interactions, mass export rates for the major parameters at the eleven stream stations used in the above analysis were determined. The results were compared to regional atmospheric deposition rates for the same parameters determined from four bulk precipitation collectors. If the watershed export rate is lower than atmospheric input rate, watershed retention of that parameter is suggested. If the input-export rates are equal simple mass balance is observed implying an atmospheric source of the material. On the other hand, if the export rate exceeds the input rate one can assume that the watershed itself is contributing mass in addition to the atmosphere.

Water Quality Indices

For two parameter groups--nutrients and buffering--lake water quality indices were calculated. The indices are based on theoretical consideration of trophic state and buffering capacity and allow the lakes in the ~~Study~~ Research Area to be directly compared.

The results of the above data analyses for the four parameter groups now follow.

GENERAL WATER QUALITY

Parameter Correlations

Table ~~17~~ 18 lists those linear correlations found to be significant in lakes and streams at a 95 percent level or greater ($p \leq 0.05$) for specific conductance, color, total organic carbon, calcium, and magnesium. While these correlations should not be interpreted as establishing direct cause and effect relationships, they do suggest associations between parameters which in turn are helpful to an understanding of the interactions of chemical species in natural waters. A case in point is color. It is widely known that dissolved and suspended organics as well as inorganics can contribute to a water's color. It was therefore not surprising to find such parameter correlations with color in the ~~Study~~ Research Area. What was interesting to note, however, were the specific parameters involved. A wide variety of inorganic and organic parameters were measured during the Study, yet only iron and organic carbon and nitrogen were seen to be the compounds most closely associated with color (see Figures 30 and 31). The correlations by themselves do not allow one to say that iron and organic carbon and nitrogen caused the color, but they do suggest a significant association between those organic and inorganic compounds and the color of the water. This distinction may seem subtle, but is is nevertheless essential to keep in mind. At best, correlations can only imply causality, they cannot prove it.

Specific conductivity is a measure of a water's ability to conduct electrical current, which in turn is due to the presence of charged ionic species. Total dissolved solids (filterable residue), which were correlated with conductivity (see Figure 32), are often regarded as a measure of weathering processes. In igneous basins characterized by insoluble rock, one would expect weathering to occur slowly and be reflected in low total dissolved solids and conductivity levels; this was indeed observed in the Research Area. However, it should be noted that the atmosphere may also be a source of ionic species, particularly bicarbonate ions.

The usefulness of conductivity measurements can be enhanced by regressing them against a series of specific ion concentrations. Predictive equations can be obtained to yield estimates of specific ion concentrations from simple conductivity measurements. Two examples are calcium and magnesium, which are shown in Table 18 to be highly correlated with conductivity, and which, not coincidentally, were the most prevalent ionic species measured in the region.

Calcium, as will be discussed later, is also a principal factor in buffering systems. Increasing calcium concentrations were found to be associated with increasing pH values, and in lakes, with increasing alkalinity levels.

Spatial Variability

Following a review of the summary statistics and application of the multiple range test (an analysis of variance technique) three definite spatial groupings of stream stations were recognized, based on median concentrations during the Study period.

They were:

Group A: P-1, SL-1, BB-1

Group B: P-2, E-1, D-1

Group C: all other stream stations

For the major cations and anions as well as for color and TOC, concentrations were highest in Group A and lowest in Group C. Additional analysis of variance was applied to test for the significance of the differences between the groups. The results are presented in Table ~~18~~ 19.

Clearly, the three groups were significantly different from each other, with the one exception being sodium in Groups A and B. As the watershed descriptions indicated, modifications to the natural environment have occurred in the Unnamed Creek and Partridge systems. The data support the hypothesis that the elevated levels of the chemical constituents noted above are the result of these alterations in the watersheds. The inclusion of SL-1 in Group A is due to the dominance of that station's water quality by the Partridge River system which discharges into the St. Louis River just above SL-1.

For example, in testing for significance of differences in mean calcium concentrations between SL-1 and SL-2, and between SL-1 and P-1, no difference was noted between the latter pair, whereas the concentration at SL-1 was ~~seemed to be~~ significantly higher than that at SL-2 ($p<0.005$).

The watershed descriptions also note the existence of industrial and/or municipal dischargers and development in the Dunka and Embarrass watersheds.

The data analyses conducted here verify that significantly higher than background concentrations exist at these stations, but the data also clearly demonstrate that the levels are significantly below those in SL-1, P-1, and BB-1.

Comparisons were also made across the region to ascertain if there were spatial differences in data variability. While universal relationships were not observed the general trends were:

1) stations with higher mean concentrations also exhibited greater variability in water quality

2) smaller drainage areas showed greater water quality variability than did larger drainage areas.

Representative data for these observations are presented in Table ~~19~~ 20.

Spatial variability in the lakes was less easier to statistically test because of small data sets. Analysis of variance, however, generally delineated the following relative relationships between lakes for nine general water quality parameters:

- Calcium: Tofte>Colby, Wynne>all others
- Magnesium: Slate, Colby, Wynne>most others>Perch, One, Triangle, One
- Potassium: Colby>most others>Wynne
- Sodium: no distinct groupings
- Chloride: Colby>most others>Clearwater
- Silica: Gabbro, Wynne>most others>Tofte, Clearwater
- Conductivity: Colby, Tofte, Wynne>all others
- Color: So. McDougal>most others>Clearwater, Tofte
- TOC: Colby, Sand, Wynne, Long, Whiteface, So. McDougal, Greenwood, Seven Beaver>all others

It is cautioned that these groupings are based on relatively few data and only suggest spatial trends. They are not definitive as the stream analyses were, thereby limiting their usefulness.

Flow Dependency

The results of flow dependency analysis for the general water quality parameters are presented in Table 21. The numbers listed refer to the cases diagrammed earlier in Figure 29; letter codes explain variations observed during the analysis.

For all practical purposes, concentrations of these elements were independent of flow; notable exceptions were calcium and sodium in the Partridge River at P-1 and calcium in the St. Louis system where distinct, partial dilutional effects were observed.

First flush phenomena were common across the region. These occur when flood waves (from spring runoff or storm events) in moving down channels, push more highly mineralized water already in the channels ahead of them.

The distinct dilutional effects noted in the Partridge and St. Louis rivers illustrate well the inter-relationship between atmosphere and watershed sources of material. As already noted, the concentration of major cations and anions in these two systems were significantly higher than any other area, except Unnamed Creek. During runoff and storm events, the mass contribution via the atmosphere was small compared to that already in the watershed from natural and anthropogenic sources, so the net observed effect was dilution by the event water. In the other watersheds where metal concentrations were not so large, the influence of atmospheric inputs was greater, and in fact was the dominant process in determining the observed water quality.

In two instances (for potassium at Isabella and sodium at Kawishiwi, K-5) there were indications that concentrations were increasing with flow. This would be expected in watersheds subject to accelerated weathering processed, or possessing widespread nonpoint sources of materials. It is not possible at this time to identify the precise mechanisms that were operating in the Isabella and South Kawishiwi rivers. In any case, the variations were slight, and atmospheric processes were still seen to be the dominant ones.

Watershed Mass Export

Figure 33 presents bar diagrams for watershed mass export rates for calcium, magnesium, sodium, and chloride. As described earlier these diagrams provide an additional way to visualize air-water interactions. Primarily, the Dunka, Partridge, and St. Louis river systems exported more material per unit drainage area than the other watersheds. Internal watershed sources of calcium and magnesium were noted throughout the region; on the other hand, watershed retention of sodium and chloride were indicated by all watersheds except the St. Louis and Dunka.

BUFFERING PARAMETER

The parameters of primary concern were lake and stream pH, alkalinity, and sulfate.

Parameter Correlations

Table 22 lists those linear correlations found to be significant at the 95 percent level or greater ($p \leq 0.05$).

Alkalinity, defined as the capacity of a solution to neutralize acid, is predominantly due to the presence of anions or molecular species of weak acids which are not fully dissociated above pH 4.5 (Hem 1970). Under most conditions encountered in aquatic environments, these dissolved species are bicarbonate and carbonate ions, although, theoretically, any ion that reacts with strong aid can contribute to alkalinity. Figure 34 illustrates the pH-alkalinity relationship demonstrated by the alkalinity-bicarbonate correlation. As bicarbonate is an inorganic carbon containing compound, it was not surprising to find dissolved inorganic carbon (DIC) correlated with alkalinity.

In addition to the expected correlations with the buffering related parameters (alkalinity, calcium, bicarbonate), pH was also associated with a variety of metals, especially in lakes.

Spatial Variability

A review of the summary statistics and the application of analyses of variance produced the same spatial groupings of stream stations as discussed in the preceding section. Table 23 presents the levels of significance of group differences. The stations exhibiting the highest pH values and greatest buffering capacity were BB-1, SL-1, and P-1.

Comparisons made across the region to ascertain spatial differences in data variability produced these general findings:

1) Stations having the higher pH, alkalinity, sulfate, and bicarbonate values did not necessarily exhibit greater data variability.

2) Headwater areas could not be distinguished from downstream areas on the basis of data variability.

The analysis of variance techniques used above are helpful for determining statistical differences between groups on a univariate basis. To assess group differences and variability on a multivariate basis, discriminant analysis was employed. The results using sulfate, pH, and alkalinity as the discriminating variables are given below:

		PREDICTED GROUPING		
		A	B	C
ACTUAL GROUPING	A	89%	7%	4%
	B	18%	48%	34%
	C	0%	6%	94%

These results clearly indicate that the stream stations in Groups A and C are well classified, and do indeed behave as two distinct groups with respect to the three parameters. The stream stations in Group B, on the other hand, are less defineable as a group; at times some stations appear more like those in Group C; and at other times they appear more like Group A stations. The stream station that exhibited the greatest variability in temporal grouping was D-1, followed by E-1.

Analysis of variance generally delineated the following relative relationships between lakes for pH, alkalinity, bicarbonate, dissolved inorganic carbon, and sulfate:

pH: Tofte>most others>Seven Beaver

Alkalinity: Tofte, Wynne>most others>Greenwood

Bicarbonate: Tofte, Wynne>most others>Perch, Turtle

DIC: Tofte>most others>Clearwater

Sulfate: Colby>Wynne, Birch>most others>Slate, Bear Island

Little more can be said about spatial variability of these parameters in lakes beyond these relative relationships.

The lowest pH values measured were 4.7 and 4.8 at Filson Creek and Keeley Creek, respectively, and occurred during February, 1977. At the time of sampling, flows in the streams were minimal due to drought and freezing conditions. When faced with low flow conditions the sampling team was instructed to take measurements and samples of whatever water was present, but to note well the sampling conditions. In the two cases above, measurements were made of what appeared to be small amounts of meltwater, surrounded by ice; the waters were not flowing. Therefore, these measurements were more a representation of precipitation pH than of ambient stream pH.

This example illustrates a significant point about the ability of a watershed under winter conditions to store chemical constituents which, with melting, ~~will~~ can be released as a slug. So even though the median pH values in Filson and Keeley creeks were 6.1 and 6.2, respectively, it is possible for sudden pH reductions to occur at runoff periods, possessing a short-term stress on the system. This is similar to the first flush phenomena discussed earlier.

In reviewing the stream summary statistics for pH, it was seen that head-water areas of given streams had lower median pH values than their mouths. Examples are the St. Louis River with median pH's of 6.6, 7.2, and 7.6 at SL-3, SL-2, and SL-1, respectively; and the Stony River with median pH's of 6.7, 6.8, 7.0, 7.2, and 7.2 for SR-5 through SR-1, respectively. The significances of these differences lies in the fact that for every 0.3 unit drop in pH, hydrogen ion concentration doubles.

Temporal variability in lake pH is linked to biological activity in the lakes. Values are at a maximum in productive lakes during peak phyto-plankton growth periods (mid to late summer) and are at their minimum during the winter. The pH maxima are due to photosynthetic utilization of carbon dioxide in the water with resulting reduction the amount of weak acids that would otherwise be formed.

Flow Dependency

The results of flow dependency analysis for alkalinity and sulfate are presented in Table ~~23~~ 24.

For the majority of the region complex, yet distinct, dilutional effects were observed for alkalinity. The degree of dilution, however, suggested that some alkalinity was being contributed by the atmosphere in addition to that provided by the watershed. For Shagawa, Bear Island, and the Kawishiwi at K-6 and K-7, watershed contribution of alkalinity was not observed and the atmosphere appeared the only source. In these areas concentrations were constant over time for all practical purposes.

Flow dependency of sulfate was dominated by atmospheric processes in the northern and eastern portions of the region. In Filson, Dunka, Partridge, Bear Island, and St. Louis rivers dilutional effects were observed, indicating watershed sources of sulfate, in addition to that being provided via the atmosphere.

Watershed Mass Export

Figure 26 presents bar diagrams for watershed mass export rates for alkalinity and sulfate air-water interactions, and the presence or absence of watershed sources of material are indicated.

Filson Creek, followed closely by Bear Island and Partridge, had the lowest alkalinity export rate, indicating that it is the least buffered. The St. Louis Watershed with an alkalinity export rate of 70 kg/ha/yr was the best buffered. Without atmospheric loading data, however, it is not possible to comment on the relative significance of atmospheric versus watershed sources of alkalinity.

Definite spatial groups are clearly indicated in sulfate export. Partridge, St. Louis, and Dunka exported far more sulfate per unit area than was deposited from atmospheric sources, adding considerable strength to the conclusion that alternations in the natural state of watersheds accelerate mass export. The data suggest that sulfide bearing rock have been exposed to oxidative processes through excavative activities with subsequent release of sulfate to the aquatic environment. In the other watersheds the export rate was nearly equal to the atmospheric loading rate; there were no indications of sulfate release from internal watershed sources. In fact there may have been some sulfate retention by the watersheds, but given the analytical variability of sulfate determinations the validity of this observation is uncertain.

Calcite Saturation Index

Calcite saturation indices (CSI) were calculated for all study lakes. The index provides a measure of a lakes ability to assimilate hydrogen ions (Conroy et al. 1974). The formula is:

$$CSI = -Log_{10}(IAP) + Log_{10}(K_{CaCO_3})$$

$$IAP = \frac{(Ca)(K_2)(ALK)}{40{,}000\,(H)}$$

where,
Ca = mg/l   H = eq/l
Alk = eq/l K_2 = 2nd dissociation constant, carbonic acid

Lakes with an index less than 3.0 are considered well buffered; lakes with an index between 3.0 and 5.0 are poorly buffered with the suggestion that acidification may already be occurring; an index over 5.0 indicates lakes with little or no buffering ability and it is likely that severe acidification has already occurred. The CSI's for the 26 study lakes are given in Table 25. Tofte Lake is seen to be nearly saturated with respect to calcium carbonate,and, therefore, very well buffered. The poorly buffered lakes are, with one exception, all headwater lakes. This can be explained by remembering that buffering is a function not only of atmospheric processes, but also of watershed geology. Headwater lakes, such as Greenwood, have smaller drainage areas than downstream lakes, such as Birch. The chemistry of headwater lakes, therefore, often reflects that of precipitation, with watershed contributions to lake chemistry assuming secondary importance. To be sure there are exceptions to this; Tofte Lake is a prime example. In general though, it was observed that as one proceeded from headwater to downstream lakes, the ability of the lakes to assimilate hydrogen ions improved. This trend was better defined after CSI's were calculated for an additional 30 lakes located in the Boundary Waters Canoe Area (BWCA). Data on the lakes were obtained from the U.S. Forest Service (USFS) in Duluth; results are presented in Table ~~25~~ 26. Fifty percent of the lakes were found to be poorly buffered, and with few exceptions they represented headwater lakes. By comparison, all of the well-buffered lakes were downstream lakes. From this analysis it can be concluded that the headwater areas of the region are not generally well-buffered and would have limited abilities to assimilate additional acid loading.

NUTRIENT PARAMETERS

The parameters of primary concern were lake and stream phosphorus and total nitrogen.

Parameter Correlations

Table ~~26~~ 27 lists those linear correlations found to be significant at the 95 percent level or greater ($p \leq 0.05$).

The availability of nutrients, particularly phosphorus, in lakes is a prime factor influencing eutrophic processes in general, and phytoplankton productivity in particular. Because of this the correlations between total phosphorus, bioproductivity, and lake trophic state were studied in greater detail. These equations are useful because they allow estimates of productivity and trophic state to be derived from relatively easily obtained physical and chemical data. Figure ~~27~~ 36 presents the relationship between median total phosphorus and summer (1976) lake chlorophyll *a* concentrations.

Chlorophyll *a* is a direct measure of primary productivity; the summer values were chosen for the regression because productivity is at its maximum then. Chlorophyll *a* determinations, however, are subject to wide variability. This is due in part to the distinct yet complex series of algal bloams, involving the three major phytoplanktonic families (Diatomaceae, Chlorophyceae, and Cyanophyceae), that occur in lakes from early to late summer.

Also contributing to the scatter in Figure ~~27~~ 36 is the fact that the number of phosphorus data points ranged from only 2 to 6 per lake. Despite these limitations, a clear relationship is indicated. Attempts to relate median total phosphorus to phytoplankton cell counts and standard units were not successful.

Two stronger, and more useful, relationships were found when summer chlorophyll a and median total phosphorus were each regressed against the inverse median secchi disk value. These are presented in Figure 37 and 38, respectively. Secchi disk values, which are a measure of water transparency, are easy to obtain, and when used in conjunction with the regression equations given yield reasonably good estimates of the other two parameters. Of particular interest in Figure 37 are the four lakes that do not fit the relationship. These lakes were among the most colored of those studied, and they illustrate well a major limitation to using secchi disk readings to estimate primary productivity. In highly colored waters there is a tendency for productivity estimates to be underestimated. Similarly, it is seen in Figure 38 that in particularly transparent waters secchi disk readings can lead to an overestimation of phosphorus levels, although the deviations from linearity are not as great. Therefore, while one can certainly conclude that distinct and useful associations exist between these three parameters, it is also important to recognize the limitations of the associations and that in particular, these are tendencies for the associations to weaken in very colored and very transparent waters. For additional discussion of the inter-relationships of these parameters, the reader is referred to Working Paper #23, National Eutrophication Survey (EPA, 1974).

An attempt was made to relate median total phosphorus values to vernal total phosphorus values, as the latter are often used as the best estimate of available phosphorus for the upcoming phytoplankton growing season. Unfortunately, there were few vernal phosphorus data available; from the 13 data points that were used, it appeared that median total phosphorus concentration was 70 percent of the vernal phosphorus value. The variability associated with this relationship, however, was ±20%, thereby limiting its usefulness.

Spatial Variability

A review of the summary statistics produced spatial groupings of stream standards that corresponded to Groups A, B, and C discussed earlier. Table 28 ~~27~~ presents the levels of significance of group differences as a result of analysis of variance.

Although the greatest individual ~~single~~ phosphorus values were observed at BB-1 (2100 μg/ℓ) and E-1 (413 μg/ℓ), in general the Group C stations had higher overall phosphorus values. The greatest single total nitrogen value was observed at D-1 (14.0 mg/ℓ). The tendency for Group A and B stations to have significantly higher nitrogen values may be explained in part by the use of explosives, consisting of a fertilizer-kerosene mixture, by the taconite industry. Nitrogenous residues are known to exist following explosions, thereby contributing to nonpoint source runoff of this nutrient.

Comparisons made across the region to ascertain spatial differences in data variability found that:

1) Phosphorus values were more variable than nitrogen values.
2) No clear trends existed between headwater and downstream stations.
3) No clear trends existed between small watersheds and large watersheds.
4) While observed, it was not consistantly found that stations with higher mean concentrations exhibited greater variability.

A multivariate assessment, through discriminant analysis, of how distinct Groups A, B, and C were from each other revealed that discrimination between groups was rather weak; see below:

		PREDICTED GROUPING		
		A	B	C
ACTUAL GROUPING	A	52%	11%	37%
	B	15%	43%	42%
	C	19%	8%	73%

The discriminating variables used were total phosphorus, total nitrogen, Kjeldahl-N, $NO_2 + NO_3$, color, dissolved oxygen and nonfilterable residue.

What this analysis shows is that while significant univariate group differences may exist (as shown in Table 28), these differences become less clear when assessments are made in terms of multiple nutrient parameters. The Shagawa system would be better placed in Group A rather than Group C; systems exhibiting high variability were Filson, Dunka, and Embarrass. These results could have been anticipated by a review of the univariate analysis of variance (Table 28). In that analysis Group C was shown to have significantly higher concentrations of total phosphorus yet significantly lower concentrations of total nitrogen than Groups A and B. It is easy to understand, then, why group differences would weaken when considered by a classification function that purposefully employs multiple variables.

Analysis of variance of the lake data indicated no relative spatial distinctions between lakes for total nitrogen and phosphorus; temporal variability in nutrient levels probably accounted for this.

Flow Dependency

Table 27 presents the results of flow dependency analysis for total nitrogen and total phosphorus. The relationships of concentration to flow were quite straightforward; for all practical purposes nitrogen and phosphorus concentrations were independent of flow, implying atmospheric dominance of the relationship. The only unusual observation was for nitrogen in the Dunka Watershed.

In a plot of concentration versus flow, two distinct data distributions, representing two different concentration levels were observed; the slopes of the lines through each distribution, however, were equal. The higher concentrations (1.9 mg/ℓ) occurred during the winter of 1976-1977 and during the drought period of 1977; the low concentrations (1.0 mg/ℓ) represented periods of runoff, storm events, and average baseflow during 1976 and 1977. While flow independence was still suggested by each distribution, this circumstance does provide an illustration of the complications that can arrive when trying to deduce general flow relationships over all conditions in dynamic systems.

Watershed Mass Export

Figure ~~30~~ 39 presents a bar diagram for watershed mass export rates of phosphorus. Watershed retention of phosphorus is indicated; the regional rate of 0.04 kg/ha/yr is what is expected for forested, igneous basins Dillon and Rigler (1975).

Trophic State Indices

Trophic state indices (TSI) using total phosphorus and secchi disk values were calculated for the study lakes according to the equations developed by Carlson (1977):

$$TSI\ (SD) = 10\ (6 - \frac{\ln SD}{\ln 2})$$

$$TSI\ (TP) = 10\ (6 - \frac{\ln \frac{48}{TP}}{\ln 2})$$

As a guide, for given index values, lakes can be categorized as follows:

CATEGORY	INDEX
Oligotrophic	20 ± 5
Oligo-Mesotrophic	30 ± 5
Mesotrophic	40 ± 5
Meso-Eutrophic	50 ± 5
Eutrophic	60 ± 5

The results for the 26 study lakes are presented in Table ~~29~~ 30. By the definitions given above, seven of twenty-six can be considered eutrophic; and additional sixteen can be considered meso-eutrophic. The lease productive lake was Tofte; the most productive was South McDougal. The eutrophic lakes were all headwater lakes and for the most part were shallow and surrounded by extensive bog and marsh areas.

Theoretically, the index values calculated by using phosphorus and secchi disk data should be equal. This is not the case for most of the lakes and is due in large part to the tendency of the secchi disk index to be biased high and low for highly colored and highly transparent lakes, rexpectively. Examples of this can be seen with Clearwater (highly transparent) and Seven Beaver (highly colored).

Nitrogen:Phosphorus Ratios

Nitrogen:Phosphorus ratios can be used to evaluate lake nutrient limitations. Lakes with N:P ratios ≥ 14 are phosphorus limited; ratios <14 indicate nitrogen limitation. In general, only highly eutrophic lakes exhibit nitrogen limitation. For the 26 study lakes the median ratios ranged from 14 to 60; 50 percent of the lakes had median N:P ratios greater than 25. The lakes approaching nitrogen limitation were Fall, Greenwood, One, and Long; the most phosphorus limited lake was Colby.

METALS

Parameter Correlations

Correlations found to be significant in lakes and streams at a 95 percent level or greater ($p \leq 0.05$) for copper, nickel, cadmium, zinc, lead, and iron are presented in Table 31. Several relationships warrant particular note:

1) Lower pH levels were associated with higher copper concentrations.

2) Increased copper concentrations were accompanied by increased nickel concentrations.

3) The patterns of occurrences of the toxic trace metals--cadmium, lead, and mercury--were directly related.

4) Iron was directly associated with color, but inversely related to dissolved oxygen.

5) Suspended and dissolved solids were consistently associated with trace metals in lakes.

6) In general, many more parameter correlations were observed in lakes rather than streams; this may be due to the function of lakes as chemical sinks, and to the fact that water quality in lakes was less variable than stream water quality.

Spatial Variability

Figure 40 presents median major and trace metal concentrations, expressed as μmoles/ℓ, for the individual stream stations.

The diagrams illustrate spatial differences not only in terms of total metal, but also in terms of the relative proportions of the individual elements.

The results of univariate analysis of variance to test the significance of univariate group differences are presented in Table 32. The groups correspond to those previously referred to as A (P-1, SL-1, BB-1), B (D-1, E-1, P-2), and C (all others). Of particular interest was the group relationships for iron. For most other parameters Group A stations were significantly higher; in the case of iron, these stations were among the lowest despite the occurrence of taconite operations in the watersheds. Mass transport distance, the existence of upstream lakes operating as sinks and oxidative conditions resulting in the precipitation of ferric iron were all important factors in determining observed iron concentrations in downstream portions of watersheds. As already discussed, the St. Louis system's water chemistry is dominated by the Partridge River watershed. P-2 represented the Partridge River at its inflow to Colby Lake, while P-1 represented the river immediately downstream from the lake. Since P-2 had significantly greater iron concentrations than P-1 ($p<0.005$) this suggests that Colby Lake is an efficient sink for iron. That mass transport distance is also an important factor can be demonstrated in the Unnamed Creek watershed. Iron concentrations as high as 1.9 mg/ℓ were observed in water seeping from taconite waste rock stockpiles (EM-8) located in the headwaters of the watershed. By contrast, the maximum iron concentration observed at BB-1, the outflow point of the watershed, was only 0.4 mg/ℓ; the approximate distance from EM-8 to BB-1 is 3.3 km. Finally, iron concentrations were shown to be inversely related to the dissolved oxygen content of the water (Table 31).

A notable exception to the stated stream groupings in Table 32 involved copper at Filson Creek (F-1). This station had significantly higher concentrations than any other stream site. Internal loading is believed to be the cause, but sufficient data to prove this are lacking.

Comparisons were made across the region to delineate spatial differences in data variability. There were no apparent trends in variability based either on watershed size or relative concentration. Some parameters, such as zinc and cadmium, were more variable than others, such as copper and nickel, but this is more a function of analytical conditions rather than natural variability.

Discriminant analysis verified group classifications, but also indicated that substantial variability within and between groups existed. Stream sites exhibiting the greatest degree of group variability were D-1, P-1, SL-1, P-3, and E-2.

The relative concentration relationships between lakes for six metals, determined by analysis of variance, are given below:

Copper: Colby>most others>Triangle, Long, Turtle

Nickel: no distinct groupings

Cadmium: no distinct groupings

Zinc: Clearwater>most others>Tofte, Bear Island, Bearhead, Triangle

Lead: Greenwood, So. McDougal>most others>Triangle

Iron: Seven Beaver, So. McDougal>most others>Tofte, Clearwater, Triangle

Flow Dependency

The results of flow dependency analyses are presented in Table 32; numbers refer to cases illustrated earlier (Figure 23).

Although nearly all metal concentrations were independent of flow, the analysis revealed that both first flush, and, to a lesser degree, accelerated watershed washoff, were not uncommon occurrences. In four instances mass increased with flow at a rate greater than would be expected on the basis of atmospheric inputs alone. These were zinc in the Kawishiwi River at K-5 and K-6, and lead in the Kawishiwi River at K-6 and in the Isabella River. These observations, especially those for lead, are unusual and at present lack adequate explanation.

Watershed Mass Export

Bar diagrams for watershed mass export compared to atmospheric mass input are presented in Figure 41 for iron, aluminum, copper, nickel, cadmium, zinc, lead, and arsenic. There were only two indications of other than atmospheric controls of the export processes. These occurred for copper in the Filson Creek and Dunka River watersheds.

The lack of similar occurrences for the St. Louis or Partridge are likely due to copper retention by Colby Lake.

The lack of adequate atmospheric loading data for iron and aluminum prevented an assessment of the significance of atmospheric contributions of the elements to the watersheds. The greatest export rate for both elements was observed in Filson Creek. Iron rates across the region were more variable than those for aluminum. This observation is not unexpected in light of the taconite operations occurring in selected watersheds, and the already discussed complex transport processes for iron; aluminum has not been shown to have distinct spatial trends in the region, so it is logical to expect little variability in export rates.

Copper:Nickel Ratios

Copper:nickel ratios can be used to evaluate the sources of the elements and their relative behavior in aquatic systems under a variety of conditions. Under natural conditions elemental ratios in water would not be expected to change greatly. In undisturbed areas where water chemistry is dominated ~~deviated~~ by atmospheric processes, elemental ratios often reflect those in precipitation. Where weathering processes are ~~of~~ important, ratios can indicate selective release rates ~~ratios~~. Finally, when two elements have different chemistries, such as copper and nickel, ratios can identify selective uptake and deposition processes, especially at environmental interfaces (i.e. water-sediment).

Copper:nickel ratios in streams ranged from 0.01 to 10.5, with the median being 1.1. In general, the median value represents undisturbed, forested portions of the watersheds. Where substantial industrial or cultural disturbances have occurred, the ratios have decreased due to selective increases in nickel. This is no better illustrated than in Unnamed Creek where the median ratio was 0.03.

Copper Complexing Capacity

A special study was undertaken to evaluate the ability of chemical constituents in lake waters to form complexes with copper. This has ~~had~~ particular significance to biological systems, for copper is a well known acute and chronic toxicant.

The analytical technique used was a modification of that originally developed by Chau et al. (1974). Details on the methodology can be found in the Complexing Capacity Technical Report. The results of the study are summarized below.

The twenty-six study lakes were sampled for complexing capacity between June 14, 1976, and March 1, 1977. Those designated "primary" were sampled in late June, late August, mid-October, and late February; those designated "survey" were sampled in July and October.

Multiple regression analysis was used to attempt to relate the observed changes in complexing capacity to changes observed in other water quality parameters. In this way it was hoped to develop a simple predictive tool for determining complexing capacity. A large number of parameters representing various physical and chemical characteristics were considered as independent variables; complexing capacity was, of course, the dependent variable. Morphometric characteristics included: drainage area, surface area, volume, mean depth, flushing rate, and the ratio of drainage area to surface area. Other parameters investigated were: total organic carbon (TOC), color, pH, specific conductivity, water temperature, dissolved organic carbon (DOC), and secchi disk.

Due to the large number independent variables considered, two guidelines were adhered to during the model building. First, no model was to include two parameters that measured essentially the same characteristic. For example, no model was to include both TOC and DOC, or both color and secchi disk. Second, no model was to include more than five independent variables.

The results of the complexing capacity determinations showed definite temporal variability; minimums occurred in early summer and maximums occurred during the fall. Between lake variability at any given time was great, however.

No model could be developed that adequately described all lakes at all times. Analysis, therefore, concentrated on individual sampling periods, beginning first with the headwater lakes where associations would be strongest.

Modeling was most successful for the early summer period. The model is:

$$CC = -1.87 + 0.052(TOC) + 0.007(color) + 0.345(pH)$$

where CC = complexing capacity, μ moles Cu/l
TOC is in mg/l
Color is in pt-co units

The r^2 value is 0.90 of the three independent variables; color, and TOC were the more important. The correlation between complexing capacity and TOC was 0.85 and was 0.79 between complexing capacity and color. There was also evidence of significant correlations between complexing capacity and drainage area ($r = 0.68$), flushing rate ($r = 0.64$), and mean depth ($r = -0.65$). However, correlations between these parameters and TOC and color are rather strong, and they do not make significant contributions to the model after TOC and color have been included. On the other hand, pH had a much weaker association with complexing capacity than TOC and color, but it also is relatively independent of them. Therefore, in the model it accounts for a portion of the variance that TOC and color do not.

When downstream lakes were included in the analysis, the following model was developed:

$$CC = -1.95 + 0.058(TOC) + 0.006(color) + 0.360(pH)$$
$$r^2 = 0.78$$

Note that the regression coefficients in this model are nearly identical to those in the model for headwater lakes. The relationships between complexing capacity, TOC, and color for all lakes during early summer are presented in Figures 42, 43, and 44.

These relationships did not hold for the fall and winter sampling periods, and adequate models could not be developed. However, it was possible to model the magnitude of change from the maximum in the fall to the minimum in the summer. In general, lakes with the lower complexing capacity values in the summer exhibited the greater increase by fall. The model is:

$$\text{Change in CC} = 2.24 - 0.76(\text{summer cc})$$
$$r^2 = 0.76$$

(see Figure 45)

This change was found to be associated with changes in TOC and color. The model expressing this is:

$$\text{Change in CC} = 1.87 - 0.096(\text{TOC change}) + 0.032(\text{color change})$$
$$r^2 = 0.78$$

WATER QUALITY RESEARCH AREA COMPARED TO OTHER REGIONS

The literature was reviewed and data were compiled on the concentrations of buffering, nutrient, and metal parameters in other parts of the world. The results are presented in Appendix E; although the review was not comprehensive it did allow Cu-Ni generated data to be put into perspective. These are listed and commented on below.

1) In general, the waters of northeastern Minnesota are dilute. This observation was not unexpected for two reasons. First, igneous basins, such as those in northeastern Minnesota, are characterized by hard, relatively insoluble rock. Weathering processes would be slow and mass contributions by the basin itself would be expected to be low. In these cases surface water chemistry is often highly related to precipitation chemistry. Second, anthropogenic sources of pollution and general watershed disturbances in the region are limited; the effects of those that do exist are more localized than regional. As was noted earlier, those watersheds exhibiting the greater concentrations of chemical constituents were, in nearly every case, those subjected to anthropogenic manipulations (mining, residential areas). By comparison, concentrations of most parameters in other regions (noted in Appendix E) where basins were of more sedimentary nature and where cultural influences are more prevalent were substantially elevated. A notable exception was iron. Concentrations in northeastern Minnesota were higher than many of the other areas reviewed, reflecting, presumably, the presence of taconite deposits and mining activities.

Armstrong and Shindler (1971) list other dilute surface water areas. These include northern Ontario, the Adirondack Mountains in New York, New England, Chile and Argentina, Western Ireland and portions of Scotland, England, the USSR, Sweden, and Kenya.

2) Cu-Ni generated data are consistent with those recently generated for the area by other agencies.

Water quality data for northeastern Minnesota have been gathered by the U.S. Forest Service, Minnesota Pollution Control Agency, the U.S. Environmental Protection Agency, and the U.S. Geological Survey. In most cases data are for sites other than those sampled for this study; the data base is also less than that of the Cu-Ni Study. However, the data from all sources were seen to be in general agreement.

Some data sets were more variable than others, but in general median or mean values were comparable. This is encouraging for it enhances the overall confidence in the Cu-Ni data base and supports the conclusion that observations reported for the Water Quality Research Area were representative of northeastern Minnesota as a whole.

3) The water quality of northeastern Minnesota is comparable to other portions of the Canadian Shield.

The Canadian Shield is a 1.8 million square mile region of Precambrian rock. Most of this bedrock lies in Canada, but it also extends into northeastern Minnesota, northern Wisconsin, and the upper penninsula of Michigan. A review of data generated in Canada on the northern portions of the Canadian Shield showed general agreement with Cu-Ni data. This was particularly true for pH, phosphorus, and the major cations and anions. On the other hand, medium iron and sulfate concentrations in the Cu-Ni area were higher than Canadian portions of the shield; this was due to the inclusion of data from mining areas in the Cu-Ni data set. If these data are deleted, agreement between the two portions of the Shield improves. The major reference was Armstrong and Shindler (1971).

4) Within Minnesota the trend is for increasing concentrations of nearly all constituents as one travels from northeast to southwest.

This trend is clearly evident in the data reported in Appendix E, many of the reasons for this have already been mentioned. In summary, they are related to:

- increased urbanization in the southern portions of the state, resulting in greater contributions of such chemicals as trace metals and nutrients to surface waters via point and nonpoint sources.

- increased agricultural activity in the southern areas accounting for increased sediment, nitrogen, and phosphorus levels in surface waters from nonpoint sources.

- the existence of more sedimentary drainage basins in the southwest rather than igneous. Shield basins in the northeast resulting in overall increased weathering of mass from the former basins.

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APPENDIX A

SURFACE WATER QUALITY MONITORING PROGRAM

Appendix A. 1. Locations of stream water quality monitoring stations.

Station Name[a]	Cu-Ni Designation	USGS Number	Latitude-Longitude		Accessible By
Kawishiwi at Fall Lake outlet	K-1	05127250	47-58-05	91-43-20	canoe,snowmobile
Shagawa bl Shagawa Lake	K-2	05127230	47-55-09	91-50-08	auto
Kawishiwi ab dam nr Winton	K-3	05127000	47-56-05	91-45-50	auto
Kawishiwi bl White Iron Lake	K-4	05126620	47-54-13	91-45-15	auto
Kawishiwi ab White Iron Lake	K-5	05126210	47-50-31	91-47-56	canoe,snowmobile
Kawishiwi nr Fernberg Tower	K-6	05124480	47-55-22	91-32-06	plane
Kawishiwi at gage	K-7	05125000	47-50-24	91-41-43	short walk
Filson nr mouth	F-1	05124994	47-50-25	91-40-52	walk
Bear Island at State Hwy. 1	BI-1	05126500	47-49-56	91-50-12	auto
Isabella ab Bald Eagle Lake	I-1	05124500	47-48-00	91-31-15	plane
Keeley at mouth	KC-1	05125040	47-46-04	91-45-04	auto,snowmobile
Unnamed at Bob Bay	BB-1	05125730	47-43-28	91-48-50	walk,snowmobile
Stony at mouth	SR-1	05125650	47-44-18	91-46-11	auto
Stony at F.S. Rd. 424	SR-2	05125550	47-41-39	91-45-38	auto
Stony bl Slate Lake	SR-3	05125500	47-41-10	91-38-20	auto
Stony ab McDougal Lakes	SR-4	05125400	47-38-05	91-31-19	auto,snowmobile
Greenwood bl Greenwood Lake	SR-5	05125450	47-35-17	91-36-51	auto,snowmobile
Dunka at mouth	D-1	05126000	47-41-55	91-52-05	auto

Appendix A.1. (Contd.)

Station Name[a]	Cu-Ni Designation	USGS Number	Latitude-Longitude		Accessible By
Dunka at AMAX test shaft	D-2	05125950	47-38-56	91-50-56	auto,walk
Embarrass at Embarrass	E-1	04017000	47-39-24	92-11-51	auto
Embarrass at F.S. Rd. 104	E-2	04016900	47-40-33	92-03-15	auto
Partridge nr Aurora	P-1	04015490	47-31-13	92-11-27	auto
Partridge at Allen	P-2	04015471	47-30-51	92-05-42	auto
Colvin at F.S. Rd. 420	P-3	04015461	47-31-47	91-59-53	auto
So. Br. Partridge at FS Rd 113	P-4	04015455	47-33-59	91-56-32	auto
Partridge at Erie Rd.	P-5	04015447	47-37-10	91-55-31	auto
St. Louis nr Aurora	SL-1	04016500	47-29-30	92-14-20	auto
St. Louis at F.S. Rd. 133	SL-2	04015438	47-28-51	92-02-23	auto
St. Louis bl Seven Beaver Lake	SL-3	04015430	47-29-29	91-50-44	auto
Water Hen Creek	W-1	----	47-19-22	92-17-40	auto
Shiver Creek	WF-1	----	47-22-20	92-03-27	auto
Whiteface River	WF-2	----	47-19-24	92-05-00	walk,snowmobile

[a]Abbreviations used: ab = above, bl = below, nr = near, F.S. = U.S. Forest Service

Appendix A.2 Stream Water Quality

Station Drawings

LEGEND FOR WATER QUALITY STATION DRAWINGS

- STAFF GAGE
- WATER QUALITY SAMPLING SITES
- BEDROCK
- ROCKS
- BOULDERS
- RAPIDS
- RIFFLE
- BEAVER DAM
- WOOD DAM
- DOCK
- BRIDGE
- CULVERT
- RAILROAD
- LOW GRASS
- TALL GRASS
- LOW - TALL GRASS
- BRUSH
- CATTAILS
- CEDAR
- WILLOWS
- ALDERS
- LOW ALDERS
- ASPEN
- ASH
- PINE OR CONIFERS
- BIRCH
- GRAVEL OR SAND
- USGS GAGE SHELTER
- CABIN OR HOUSE
- CAMPGROUND
- BOAT LANDING

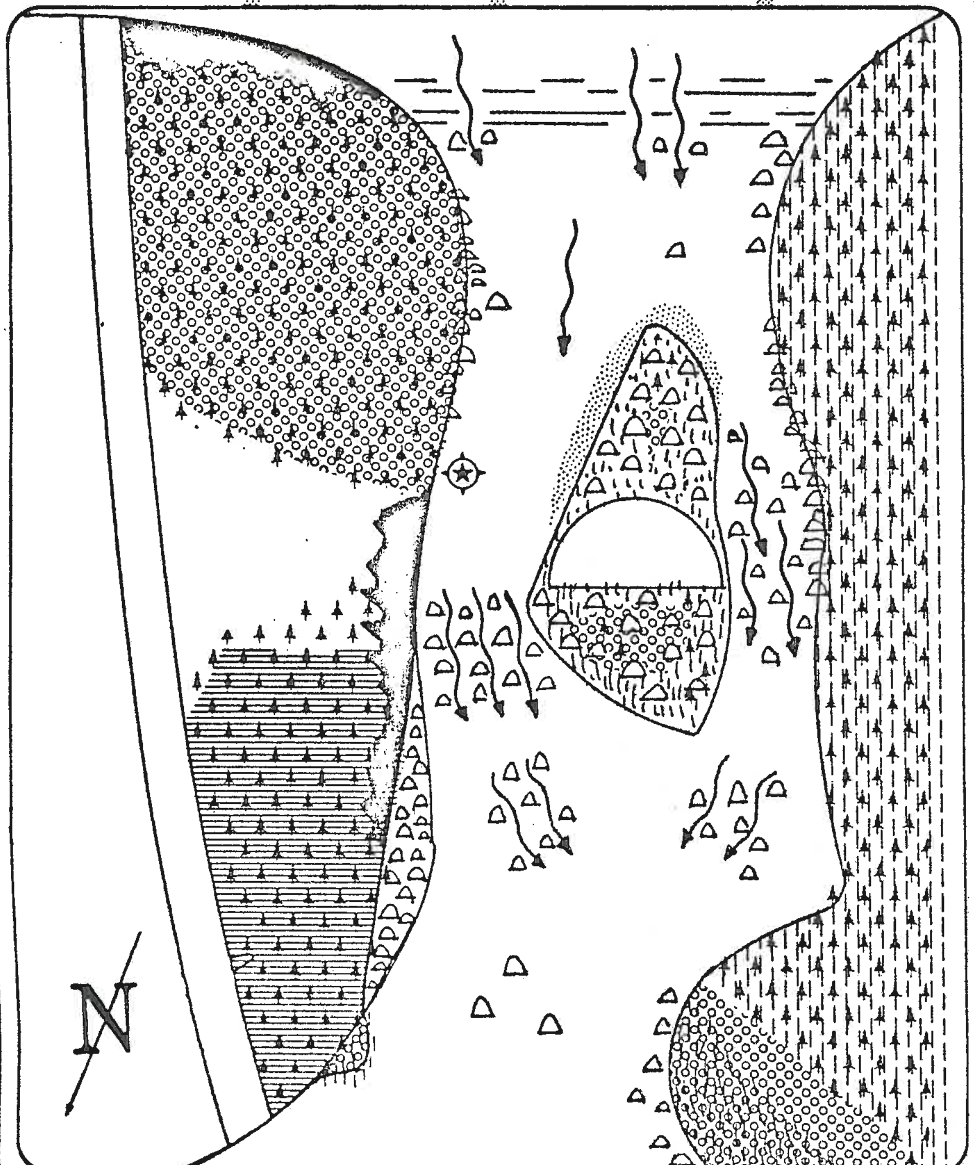
WINDING ARROW IN WATER INDICATES DIRECTION OF FLOW

NUMBER IN WATER INDICATES APPROXIMATE DEPTH AT THAT POINT DURING SUMMER STABLE FLOW CONDITIONS

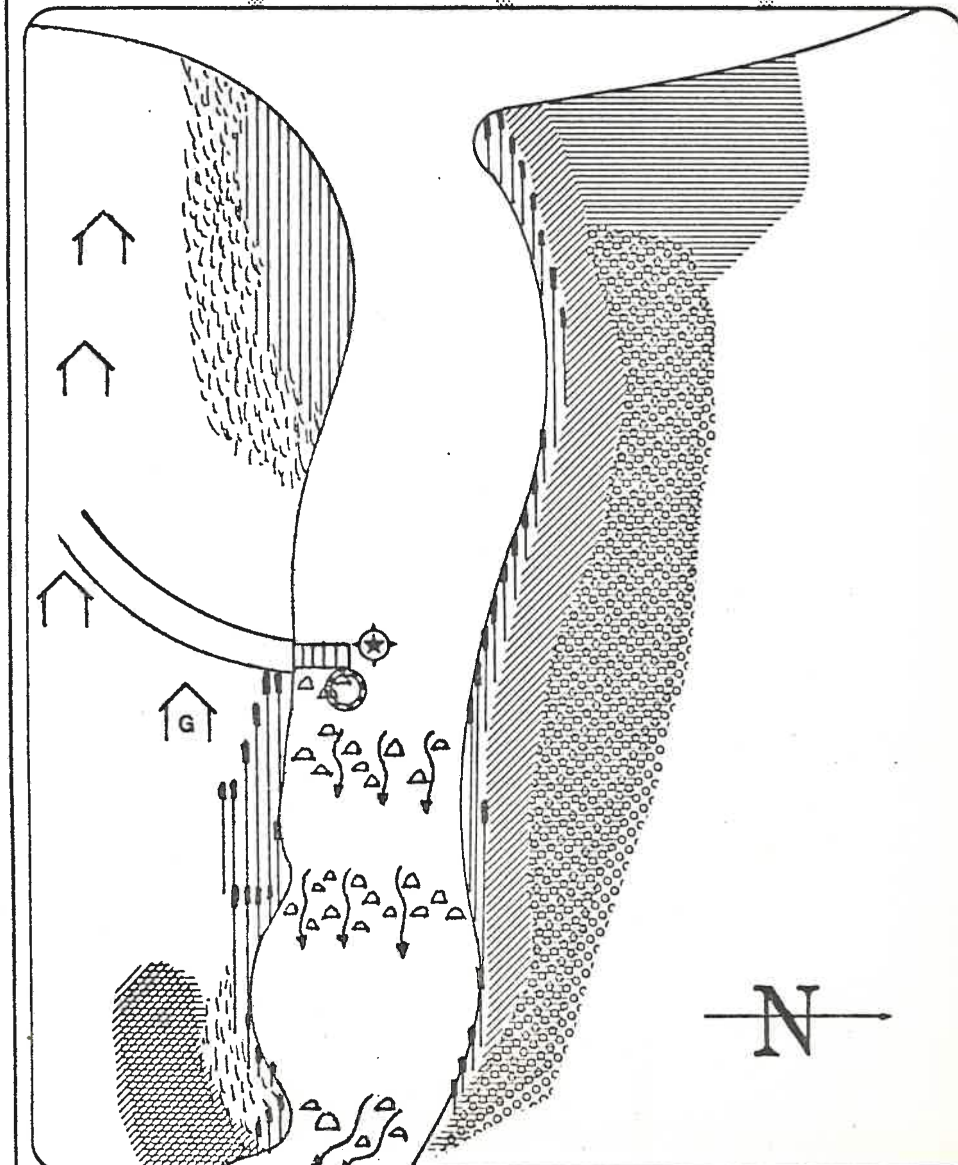
ST. INDICATES STEEP

H.W.- HIGH WATER SAMPLE SITE
L.W.- LOW WATER SAMPLE SITE

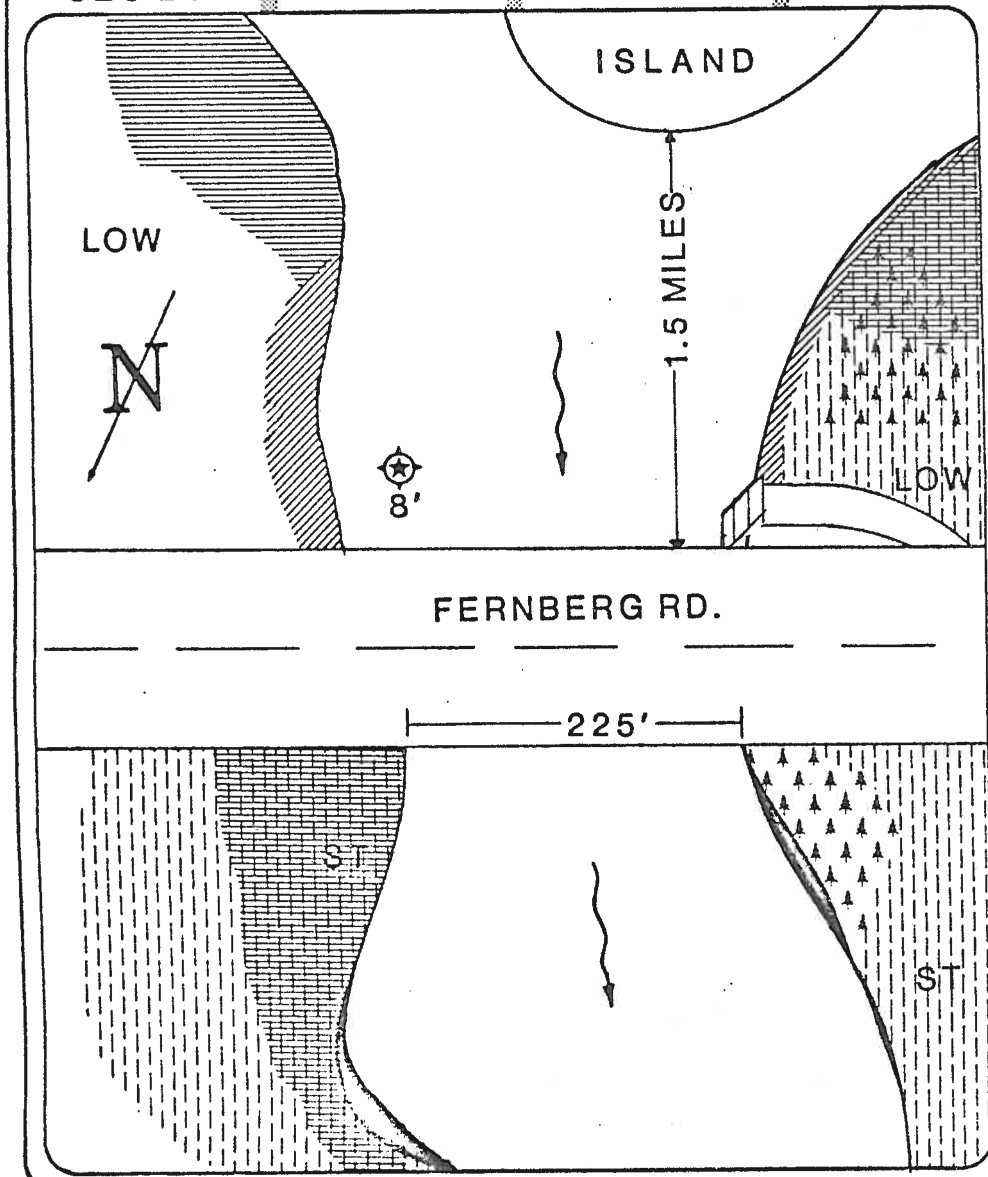
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
KAWISHIWI AT OUTLET FALL LAKE 63N 11W SEC 3	05127250	PRIMARY	K-1



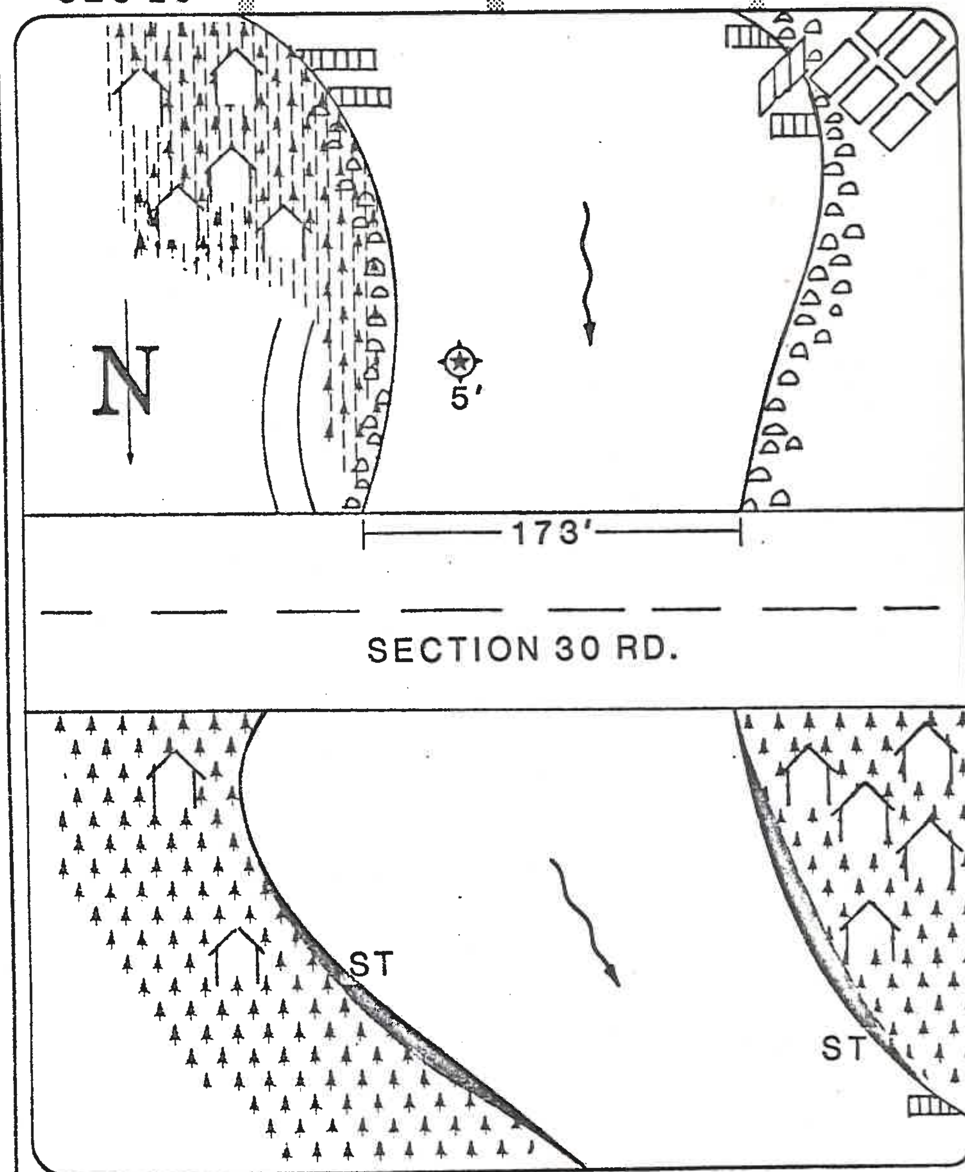
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
SHAGAWA BL SHAGAWA LAKE 63N 12W SEC 26	05127230	SECONDARY	K-2



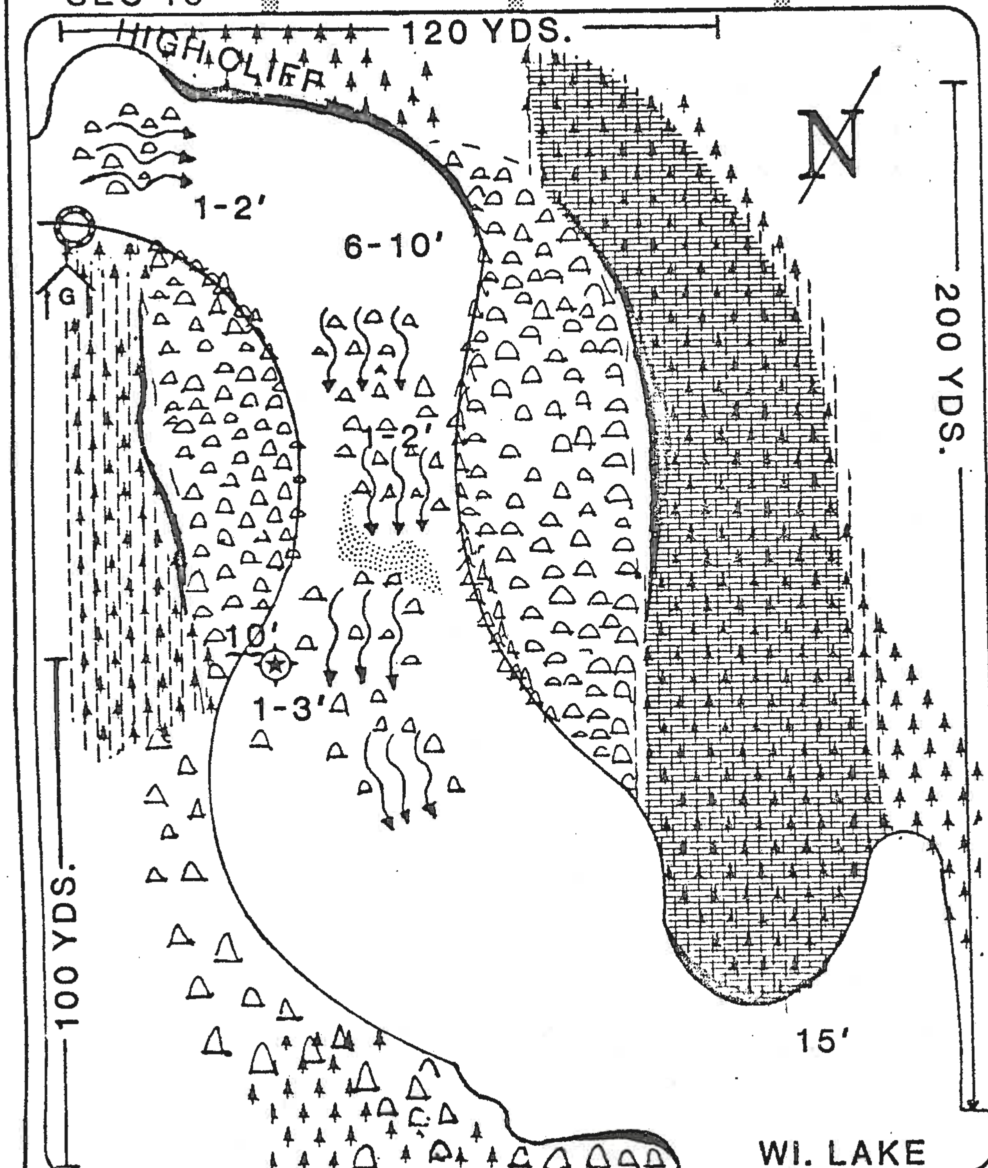
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
KAWISHIWI ABOVE DAM NR WINTON 63N 11W SEC 20	05127000	SECONDARY	K-3



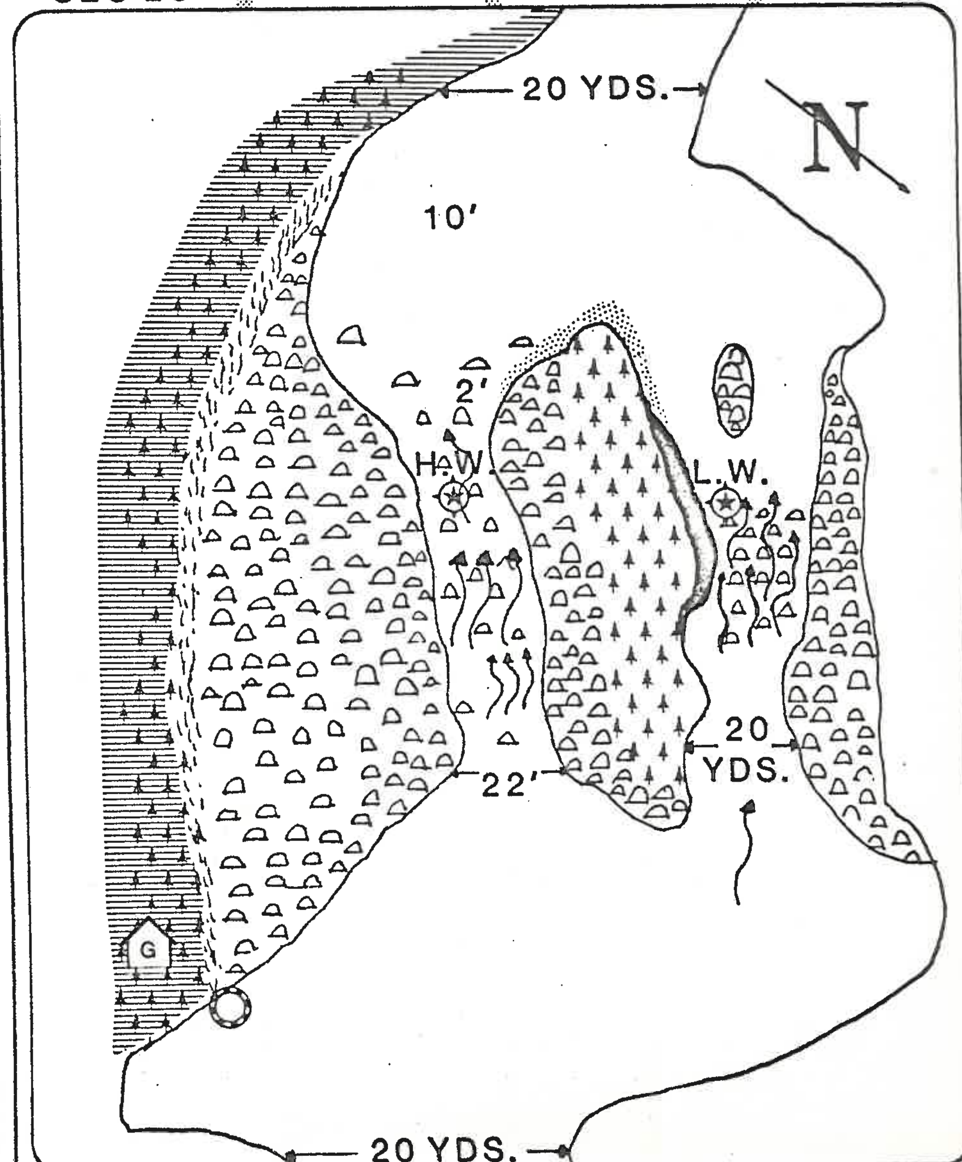
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
KAWISHIWI BL WHITE IRON LAKE 63N 11W SEC 29	05126620	SECONDARY	K-4



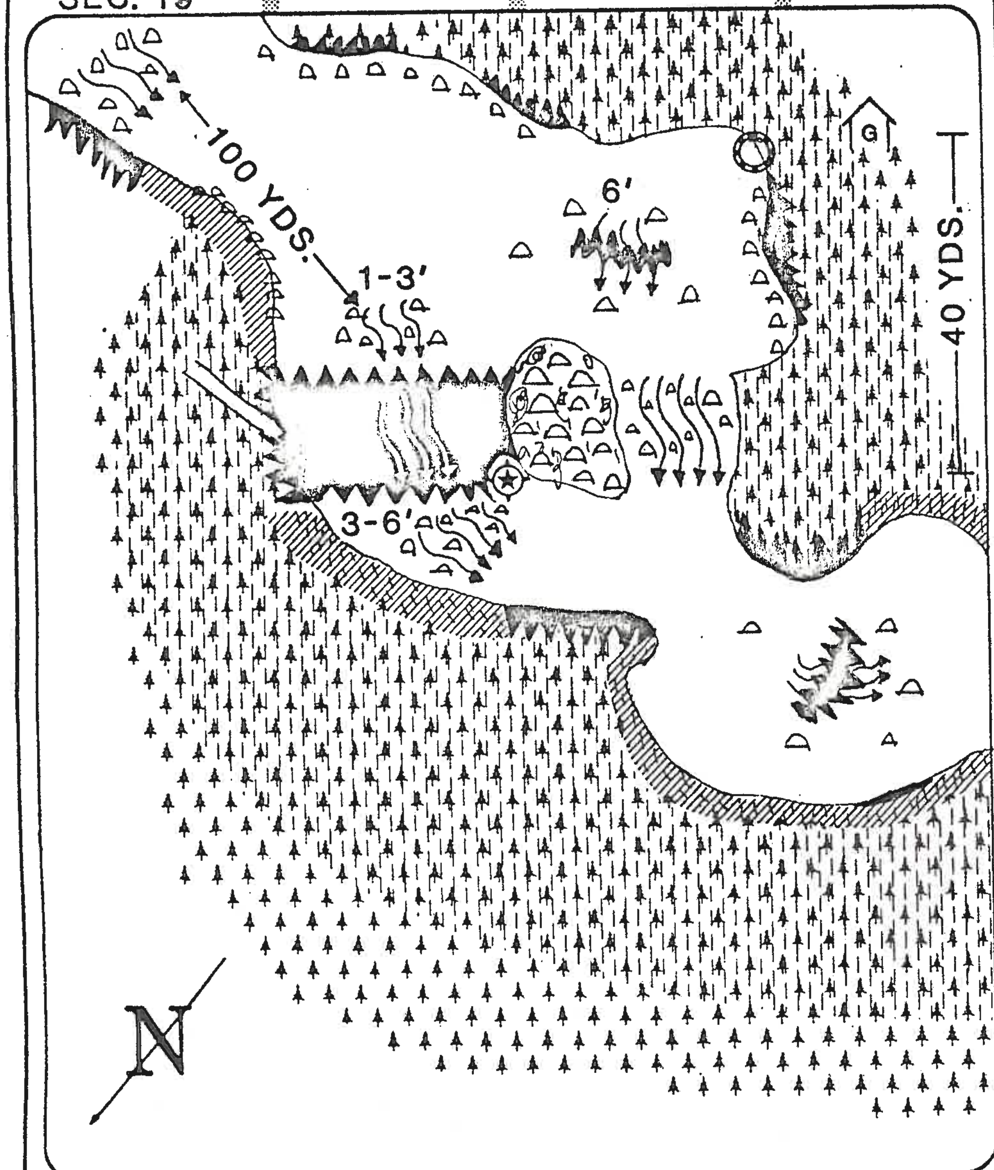
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
KAWISHIWI AB WHITE IRON LAKE 62N 11W SEC 19	05126210	PRIMARY	K-5



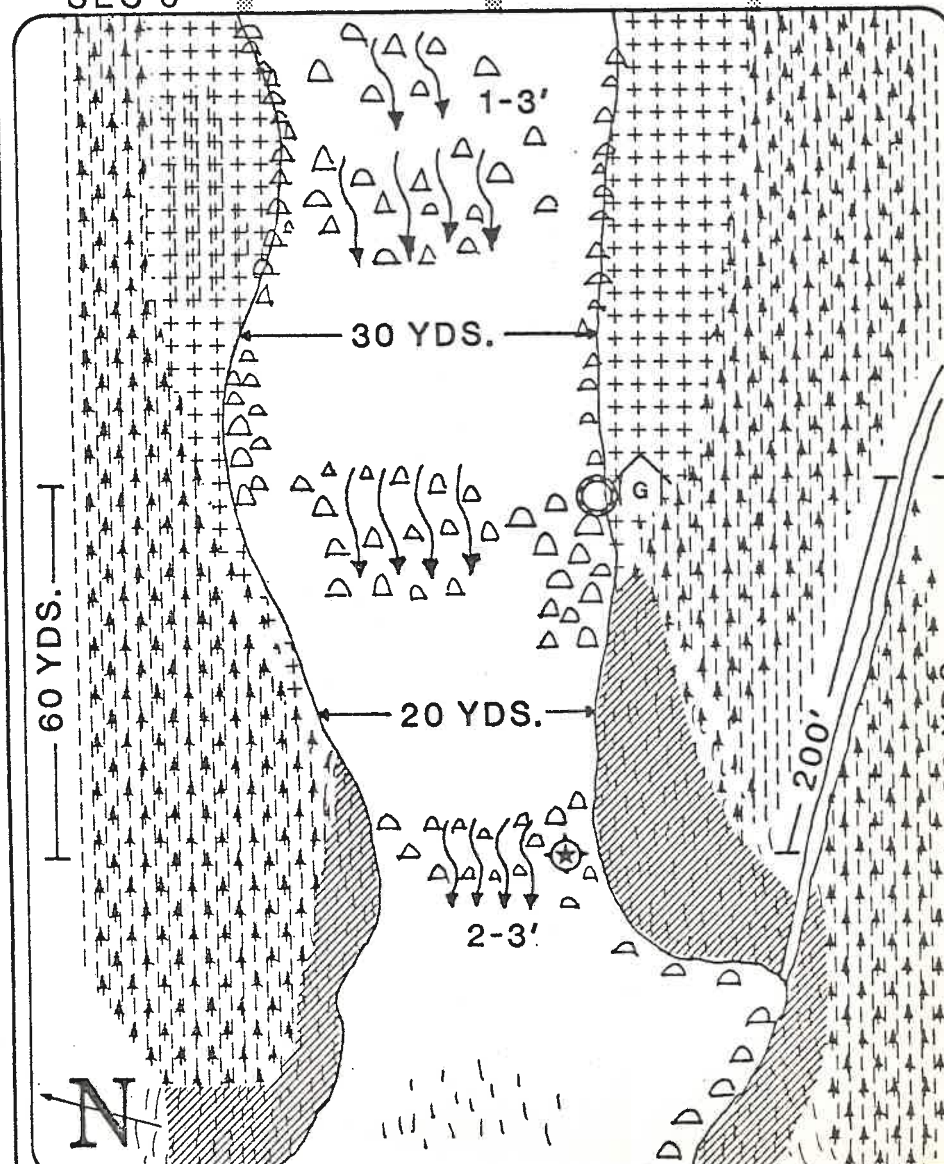
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
KAWISHIWI AT GAGE 62N 11W SEC 23	05125000	PRIMARY	K-7



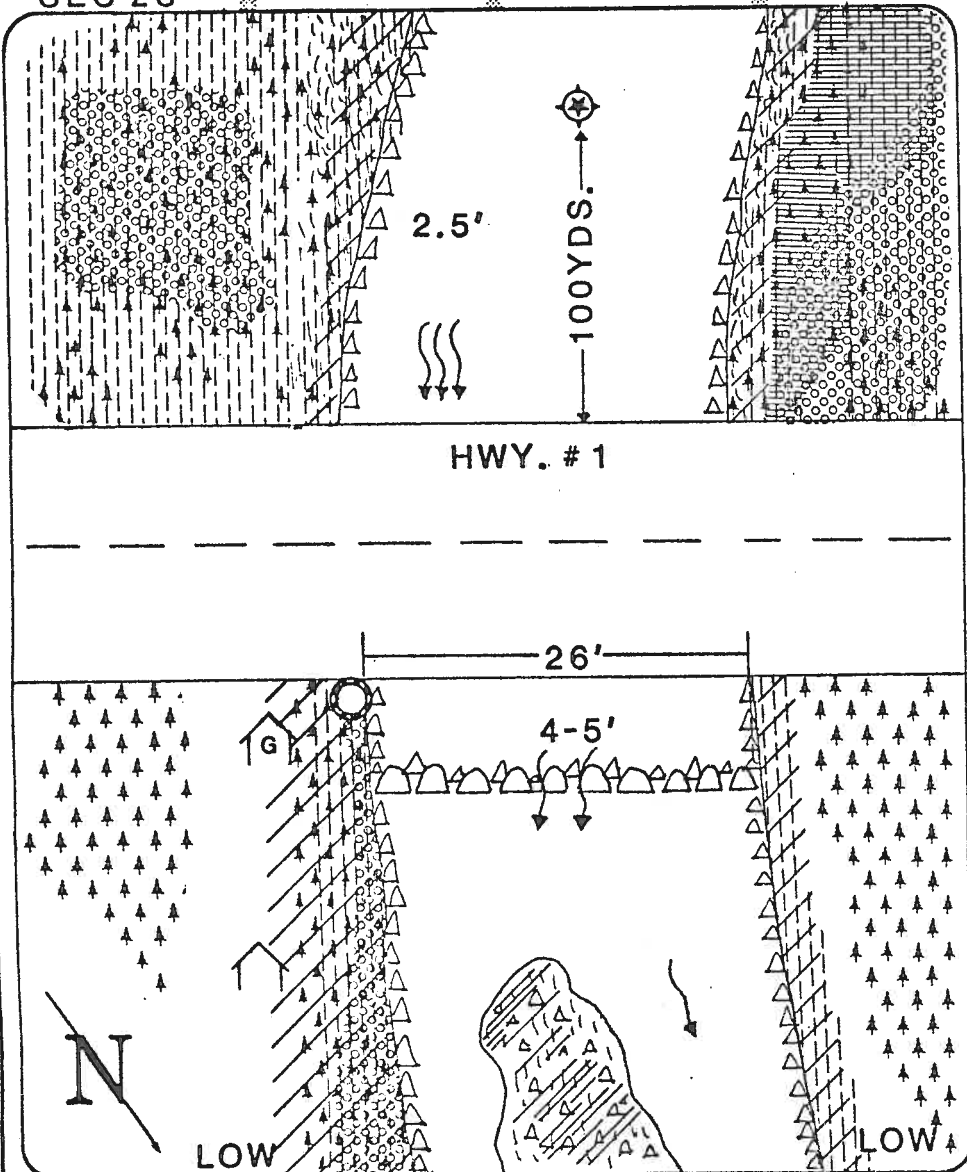
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
KAWISHIWI AB DAM NR FENBERG TOWER 63N 9W SEC. 19	05124480	PRIMARY	K-6



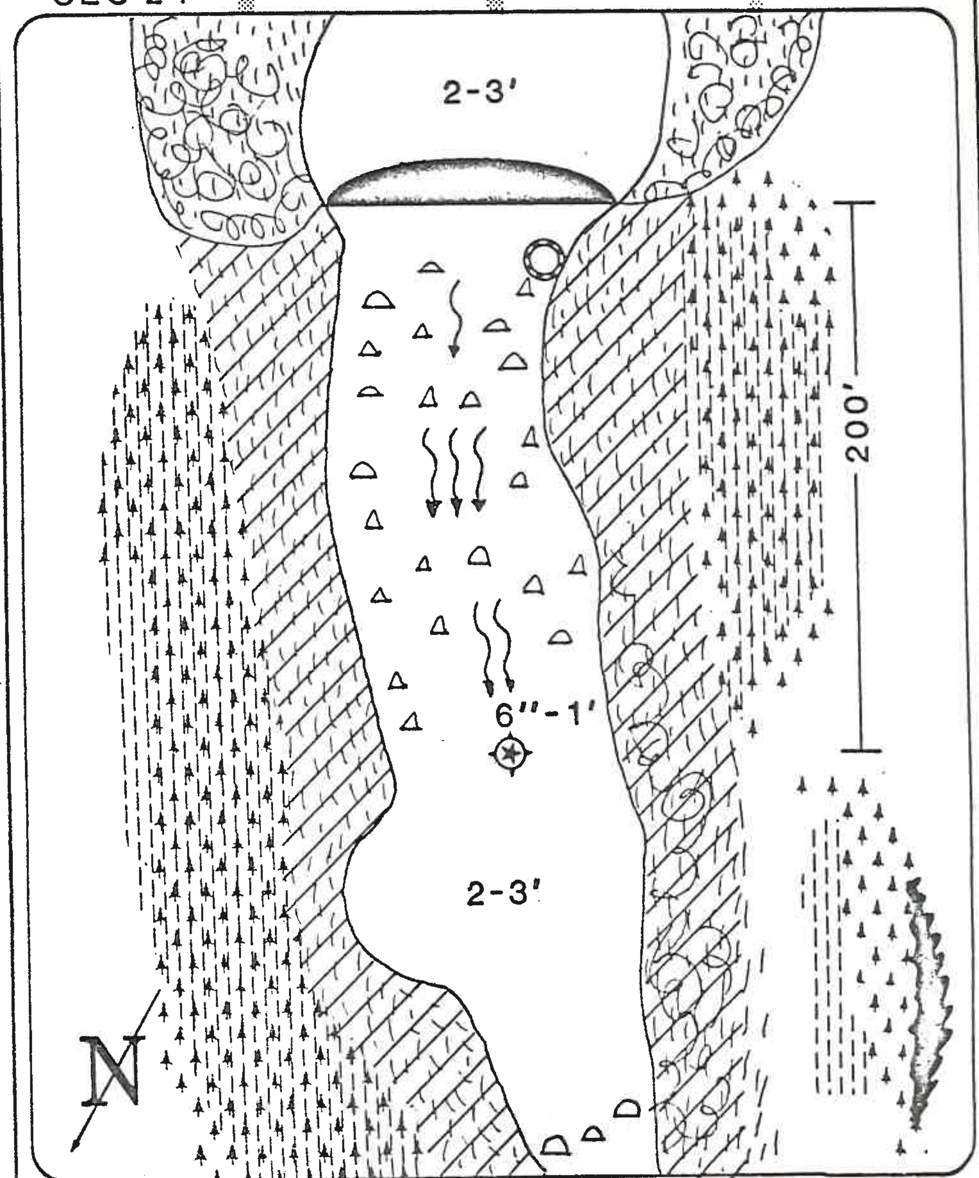
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
ISABELLA AB BALD EAGLE 61N 9W SEC 6	05124500	PRIMARY	I-1



STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
BEAR ISLAND AT STATE HWY. 1 62N 12W SEC 23	05126500	SECONDARY	BI-1



STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
FILSON NR MOUTH 62N 11W SEC 24	05124994	SECONDARY	F-1



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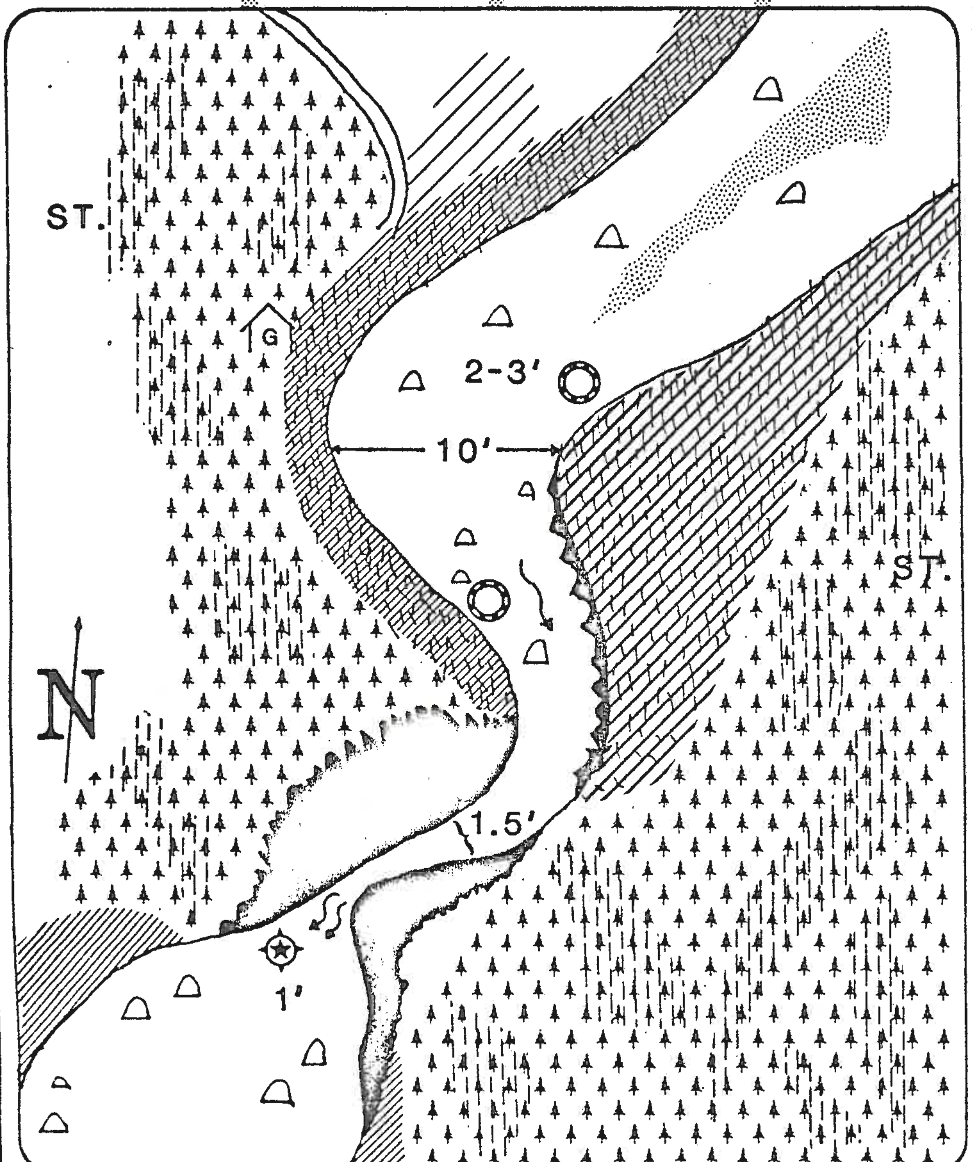
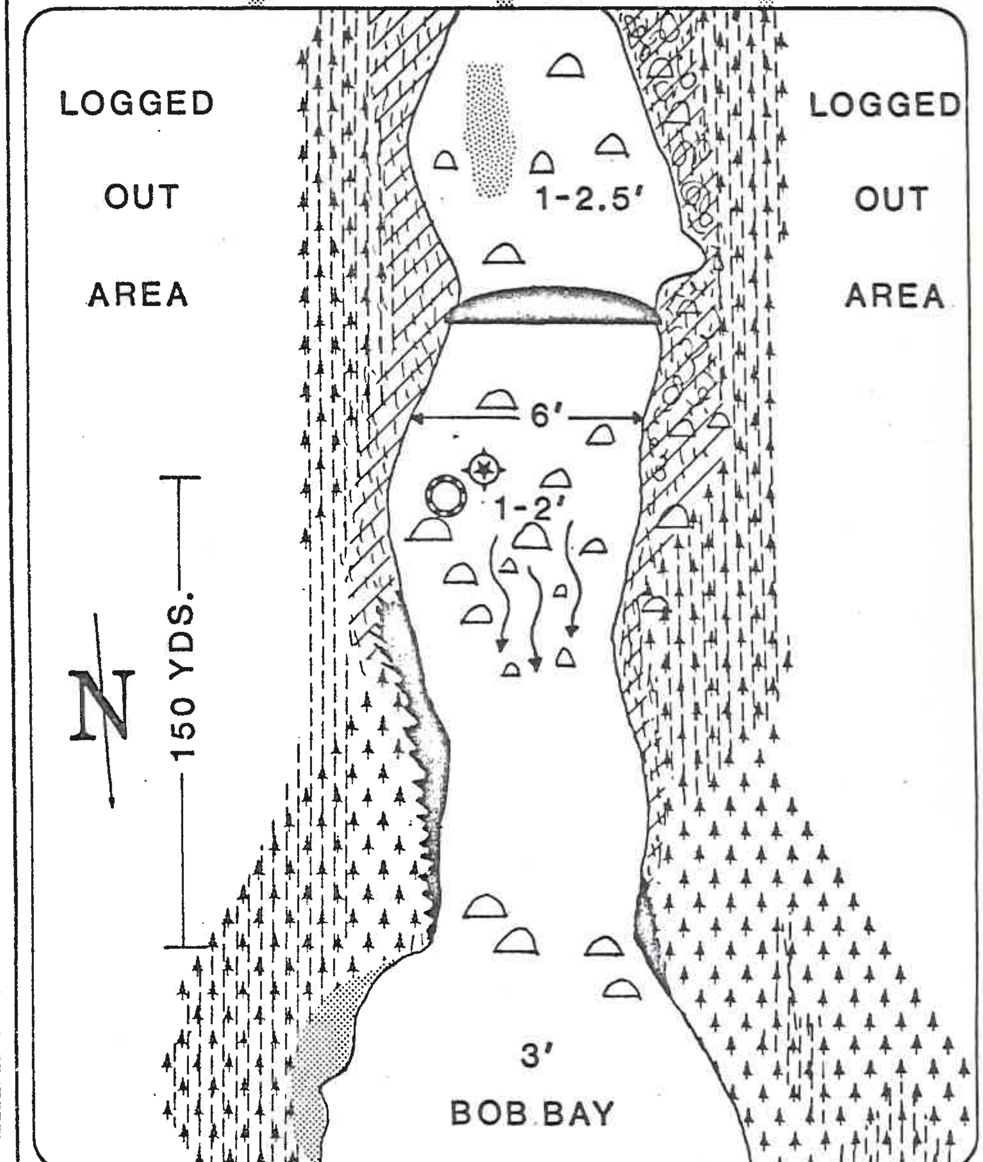
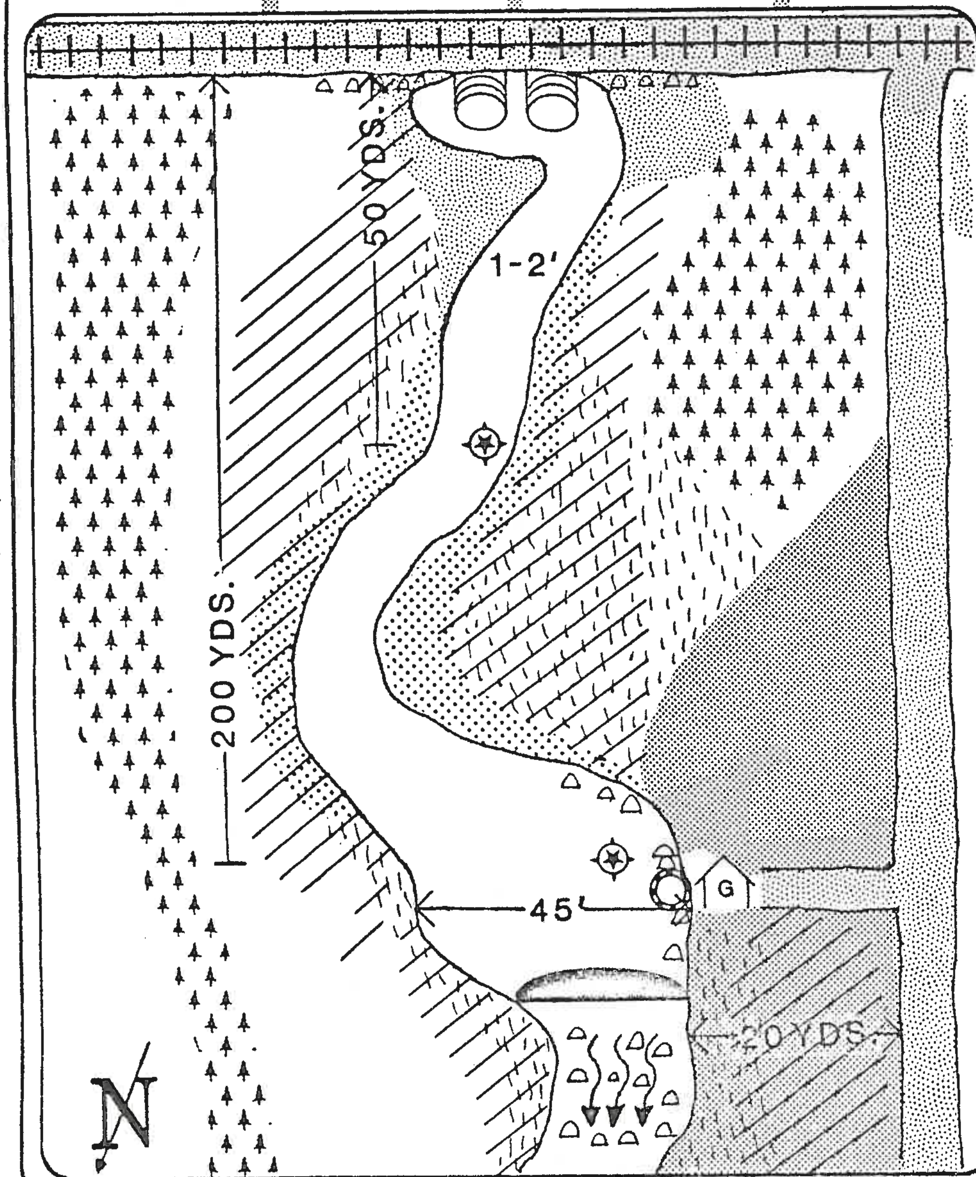


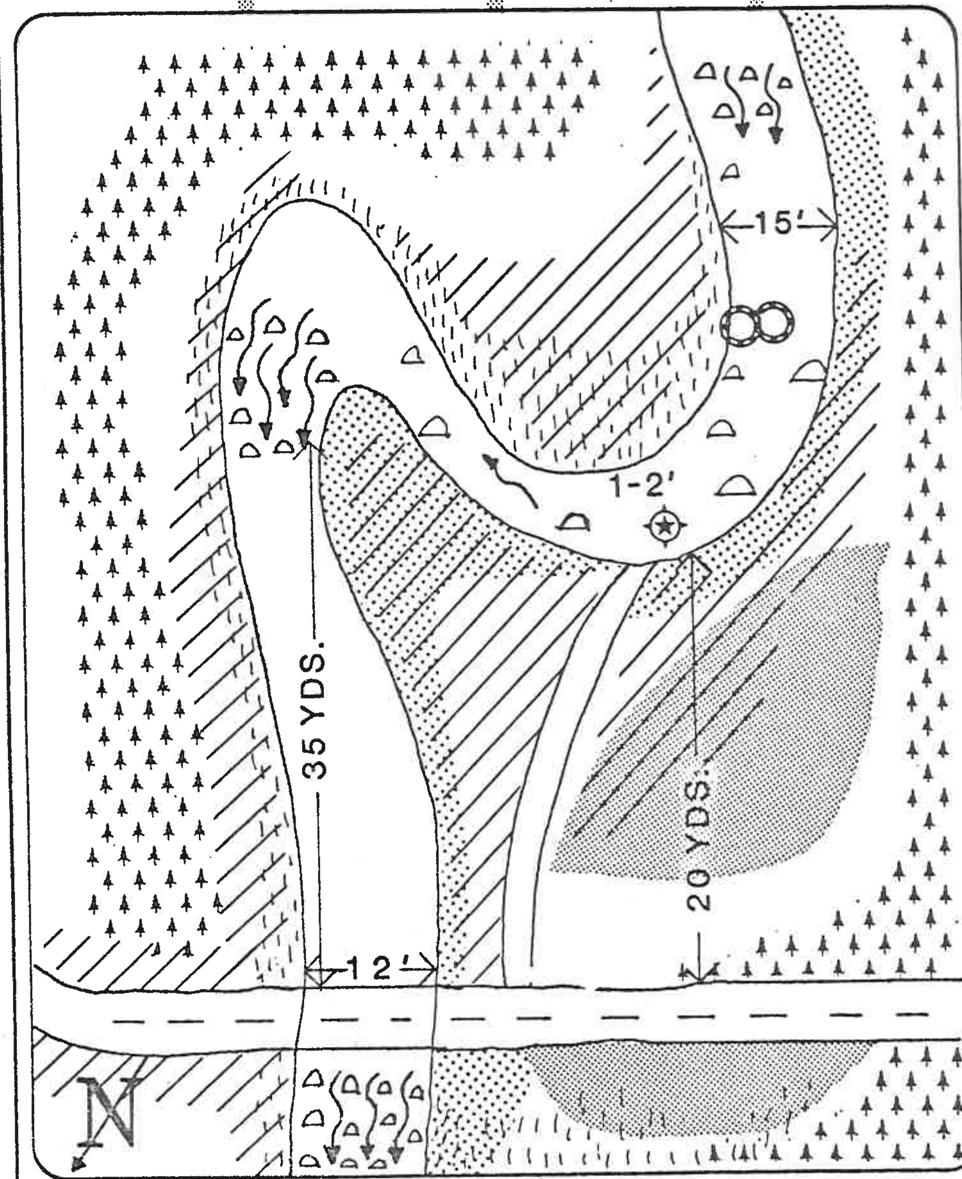
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
UNNAMED AT BOB BAY 61N 12W SEC 36	05125730	SECONDARY	BB-1



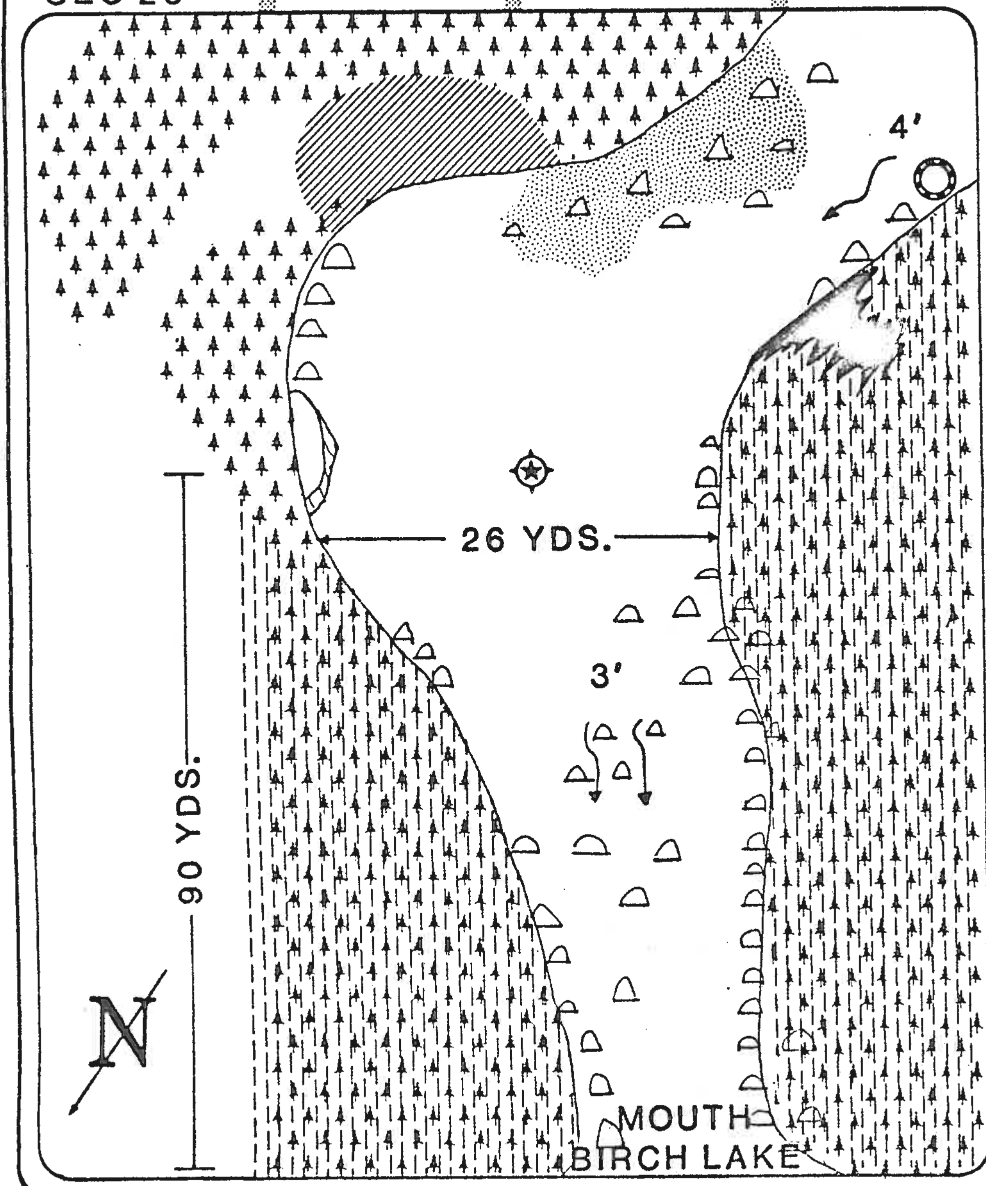
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
DUNKA AT MOUTH 60N 12W SEC 4	05126000	PRIMARY	D-1



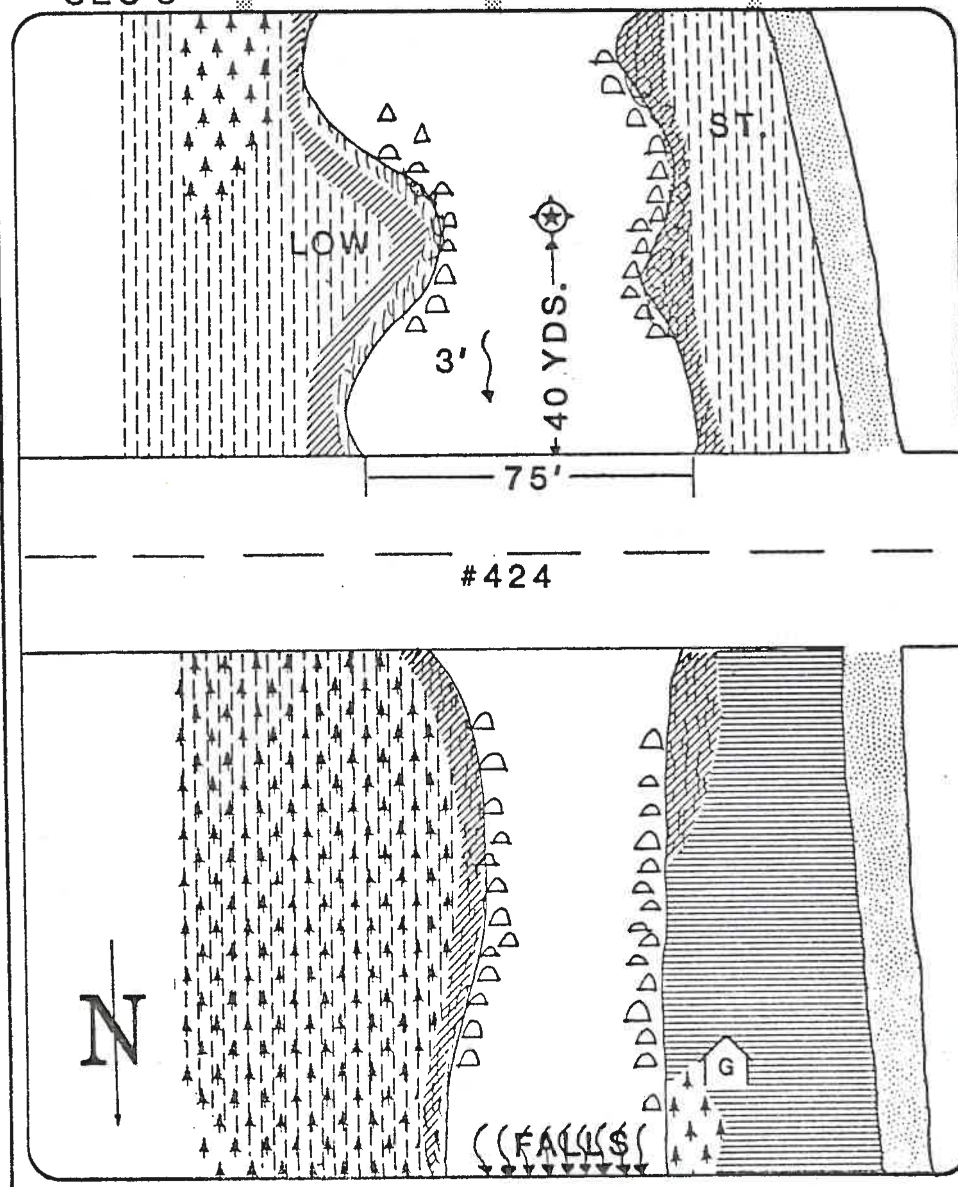
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
DUNKA AT AMAX TEST SHAFT 60N 12W SEC 27	05125950	TERTIARY	D-2



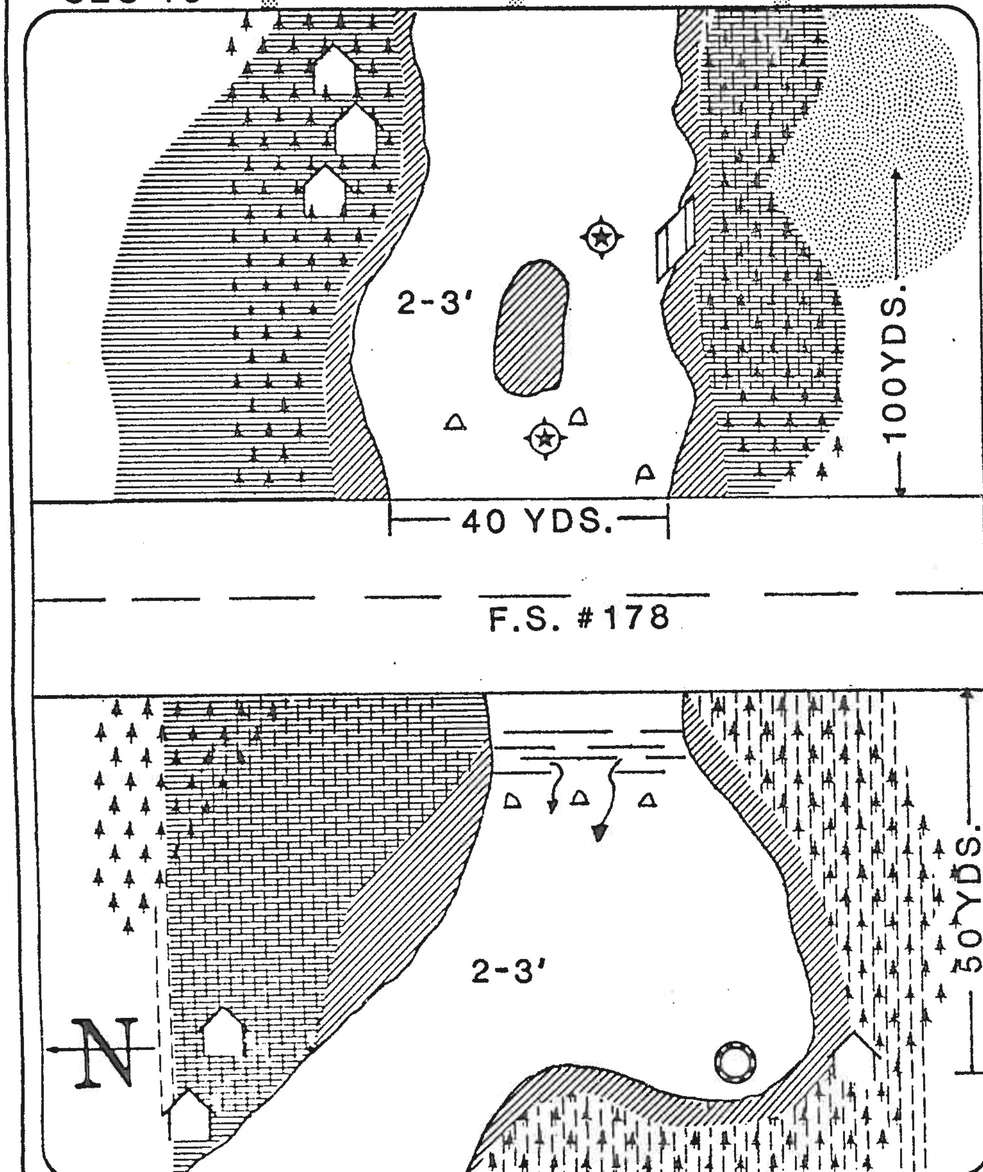
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
STONY AT MOUTH 61N 11W SEC 29	05125650	PRIMARY	SR-1



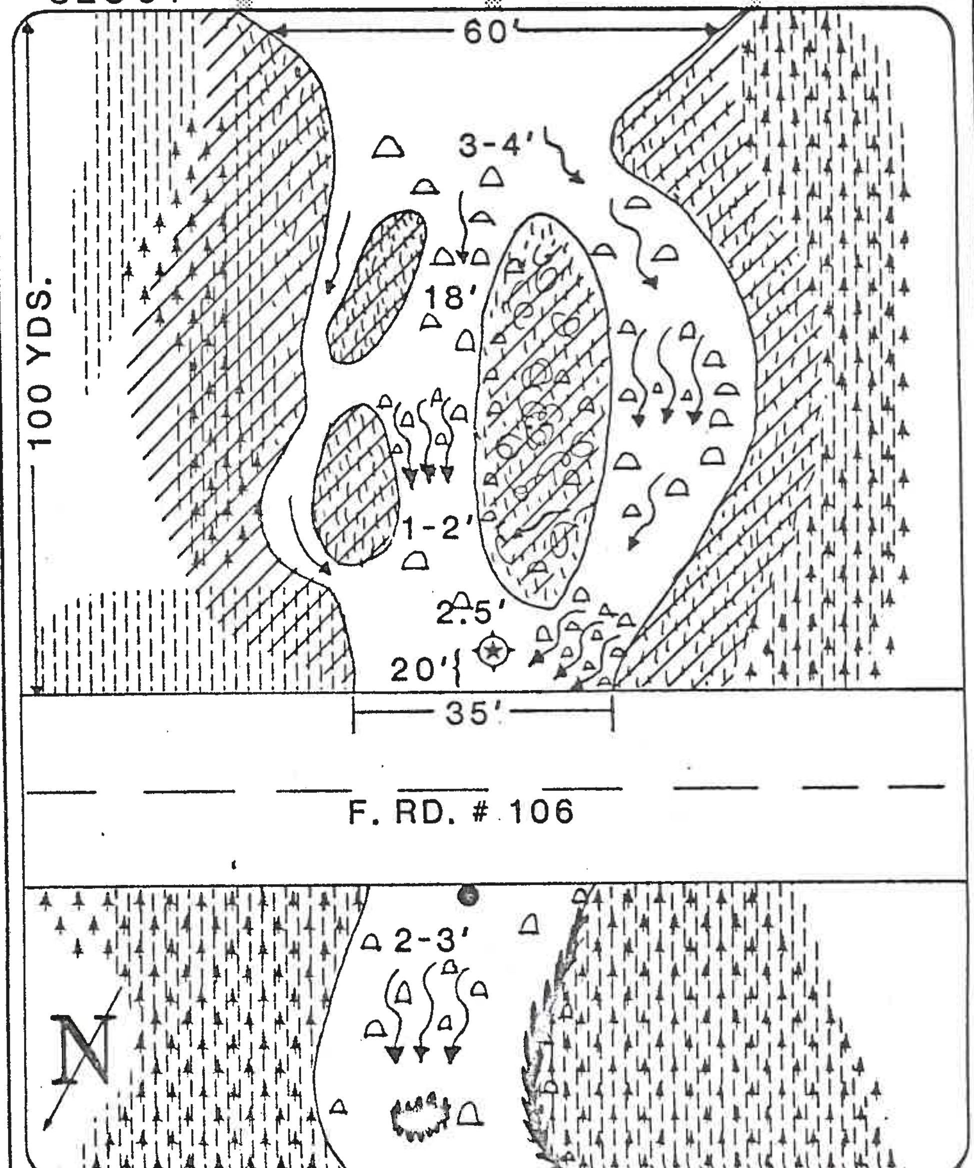
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
STONY AT F.S. RD. 424 60N 11W SEC 8	05125550	SECONDARY	SR-2



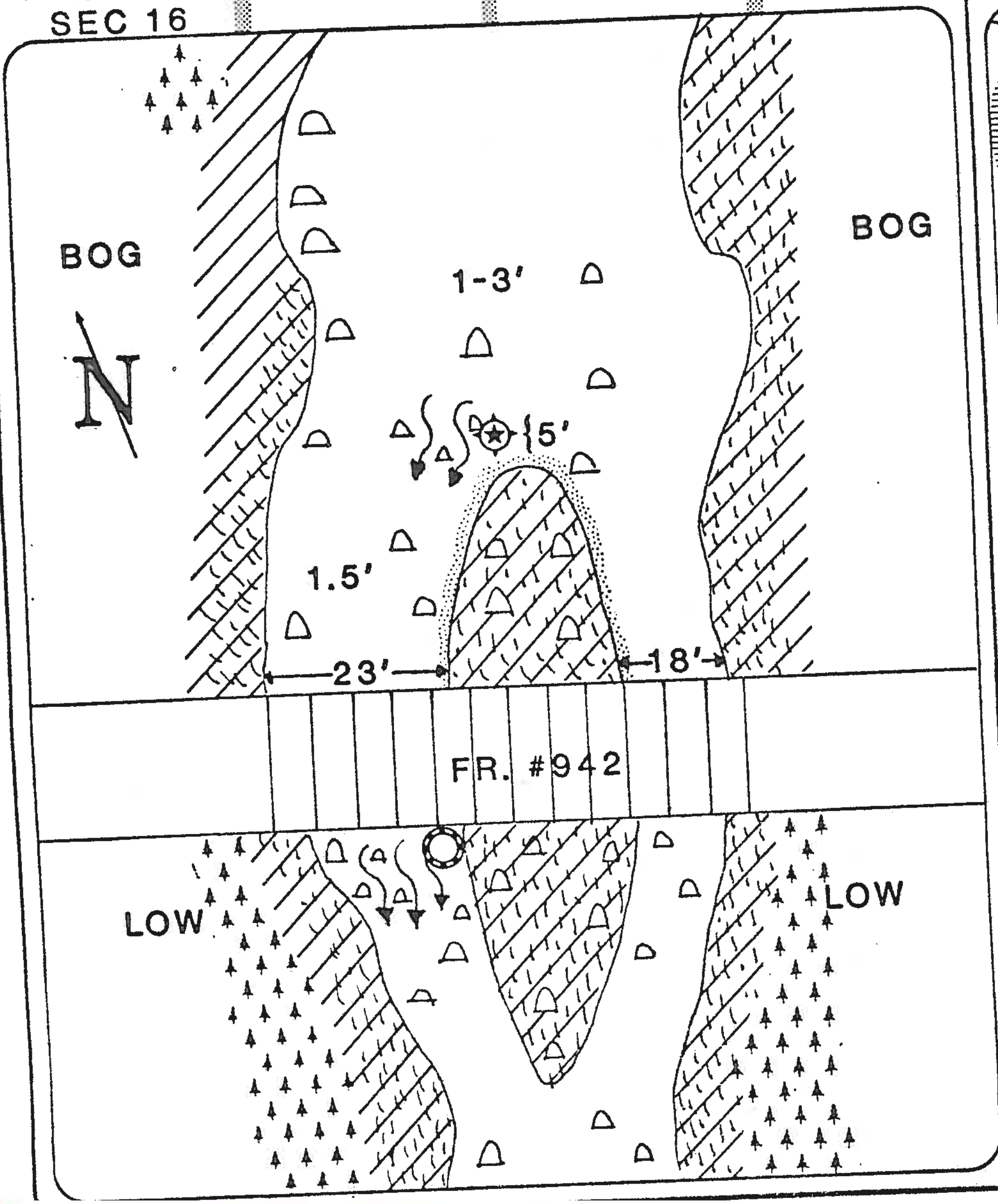
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
STONY BL STATE LAKE 60N 10W SEC 16	05125500	SECONDARY	SR-3



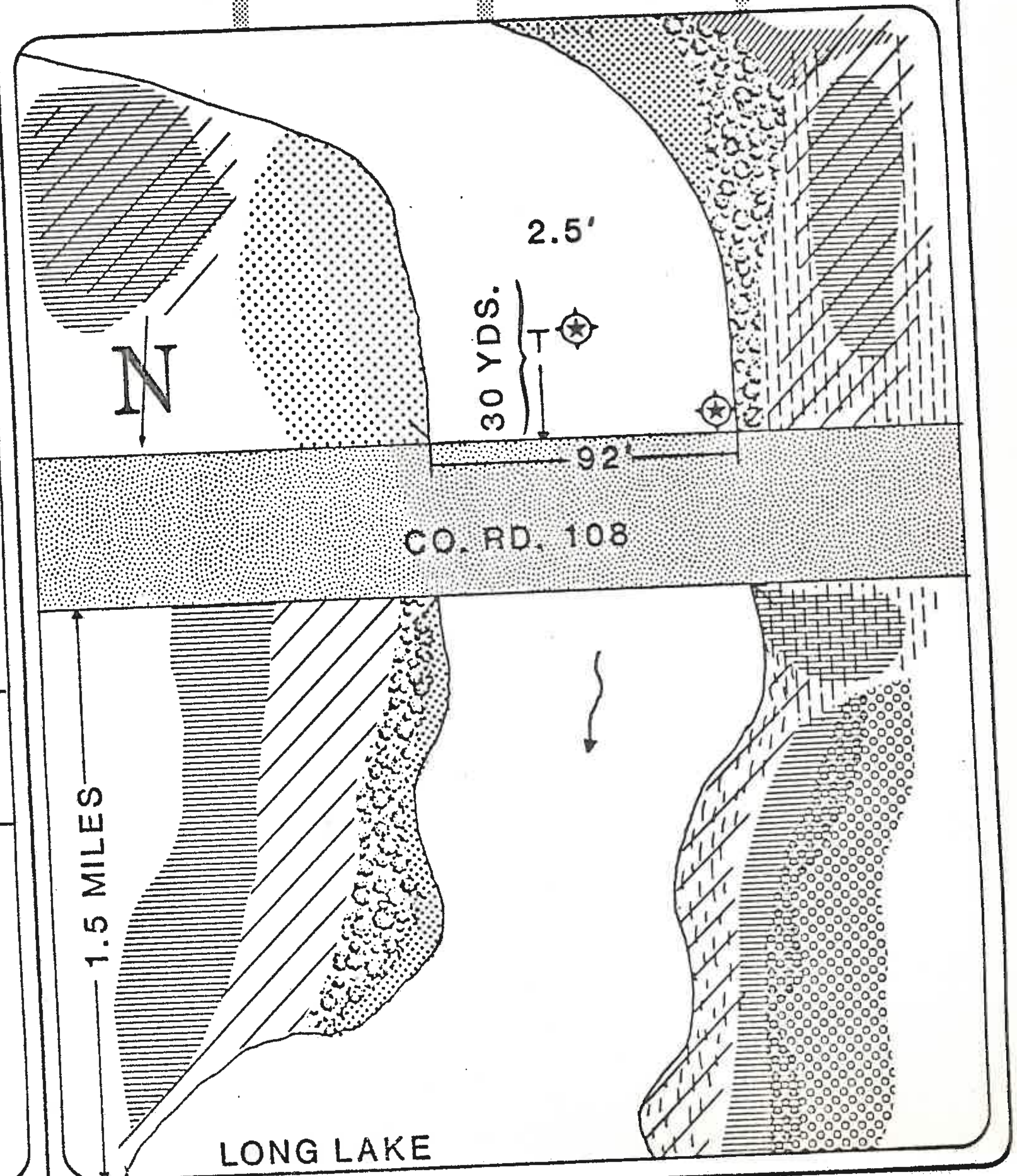
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
STONY AB MC DOUGAL LAKES 60W 9W SEC 31	05125400	SECONDARY	SR-4



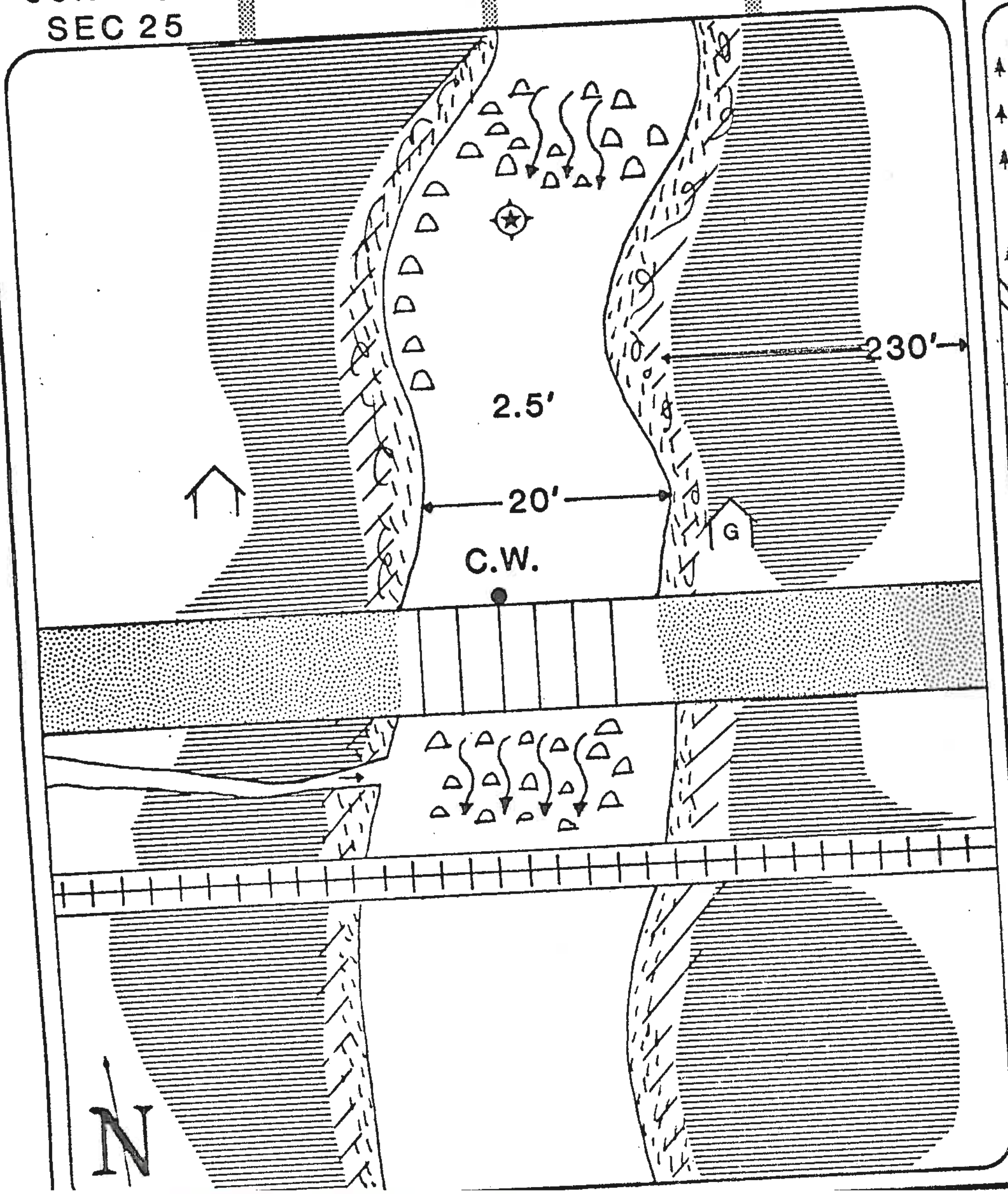
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
GREENWOOD BL LAKE GREENWOOD 59W 10W SEC 16	05125450	SECONDARY	SR-5



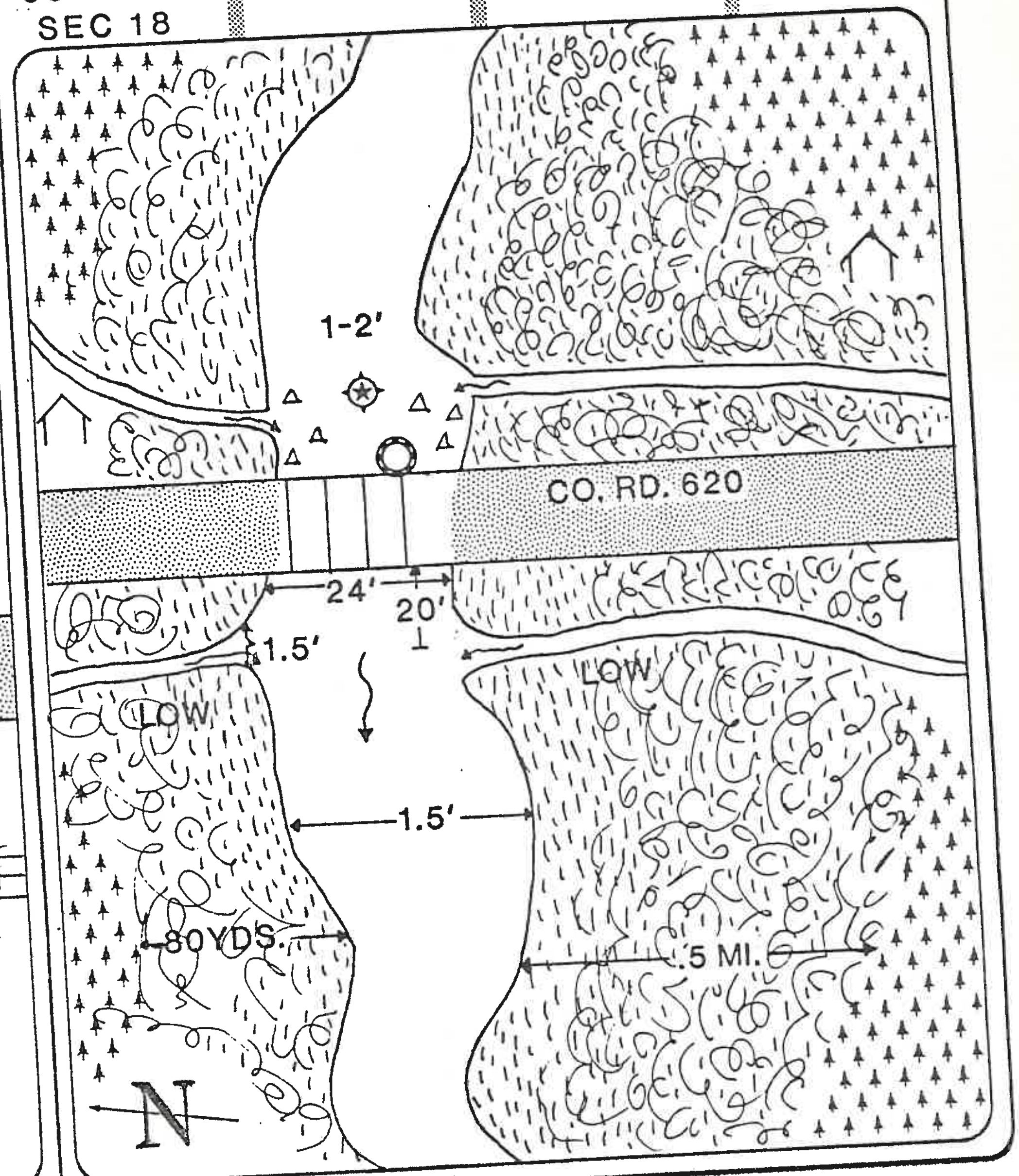
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
			W-1



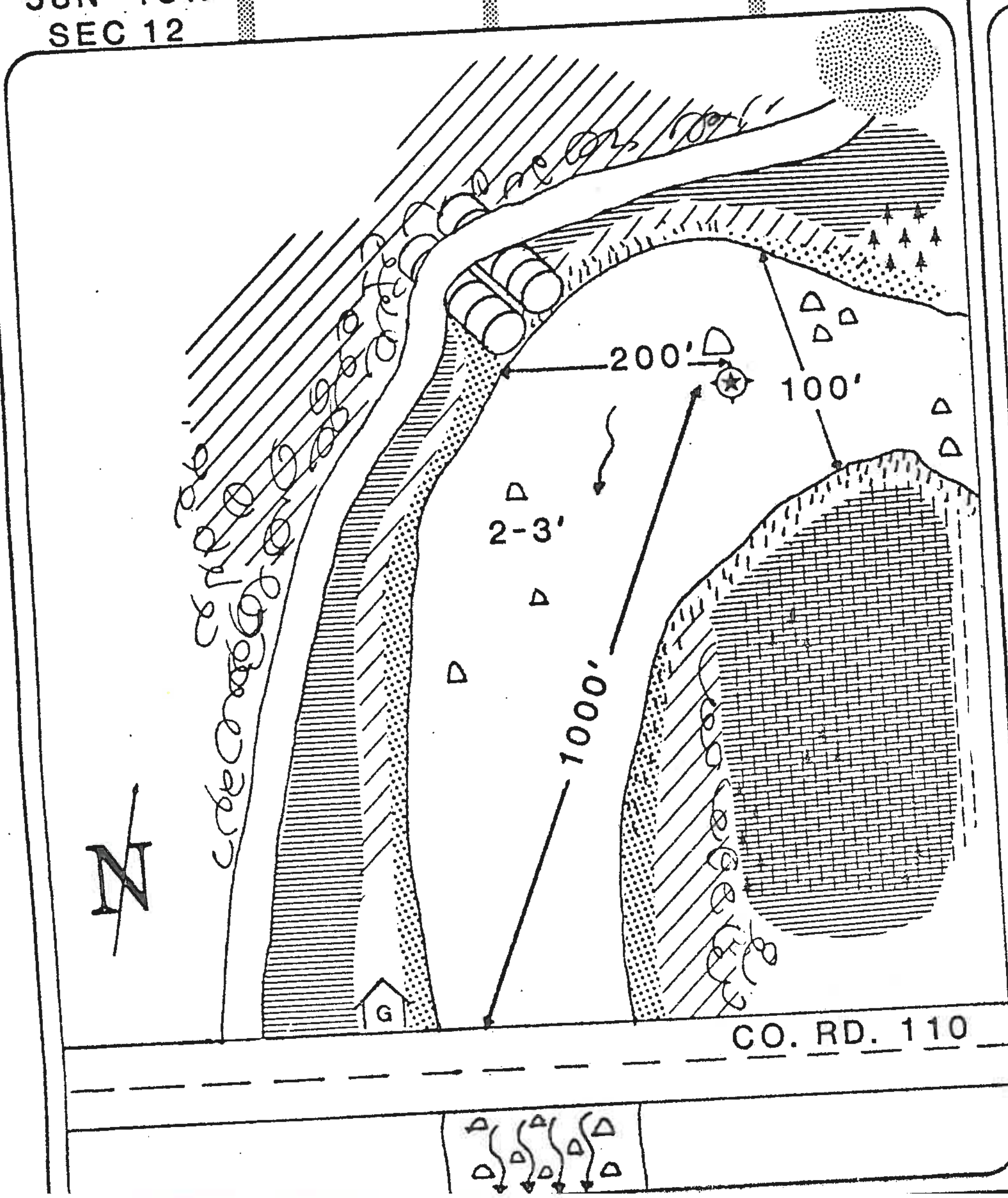
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
EMBARRASS AT EMBARRASS 60N 15W SEC 25	04017000	SECONDARY	E-1



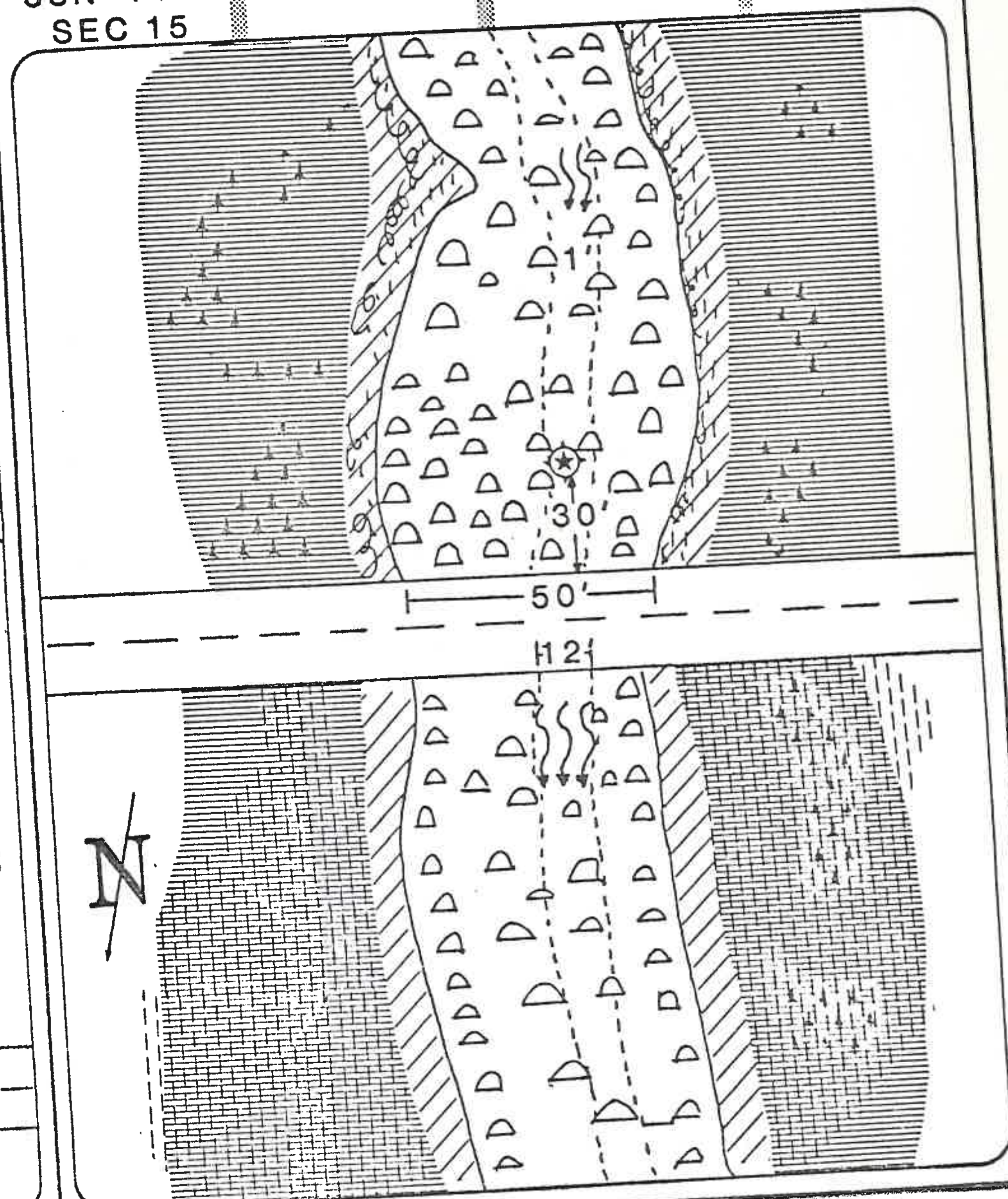
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
EMBARRASS AT F. S. RD. 104 60N 13W SEC 18	04016900	SECONDARY	E-2



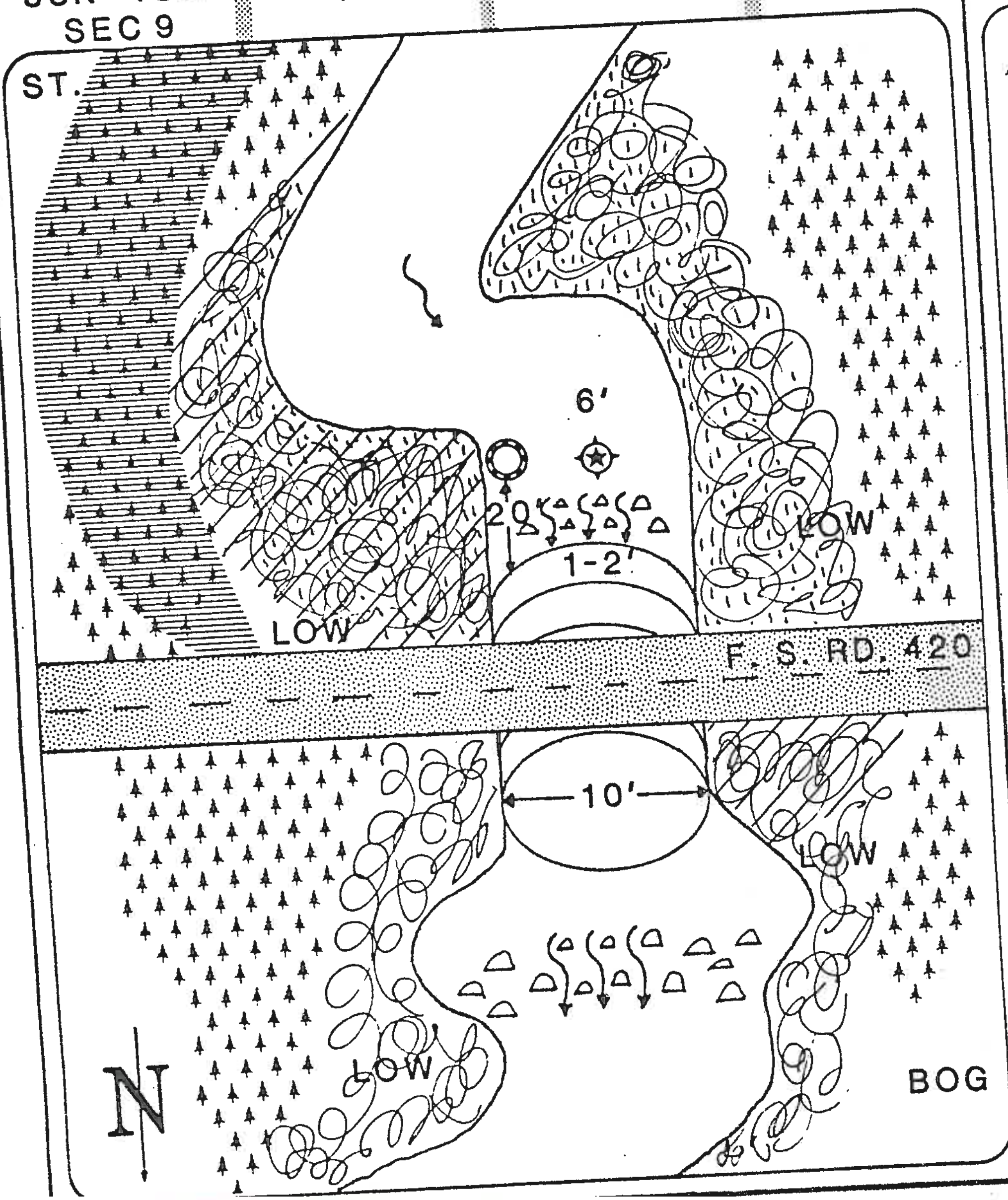
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
PARTRIDGE NR AURORA 58N 15W SEC 12	04015490	PRIMARY	P-1



STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
PARTRIDGE AT ALLEN 58N 14W SEC 15	04015471	SECONDARY	P-2



STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
COLVIN AT F. S. RD. 420 58N 13W SEC 9	04015461	SECONDARY	P-3



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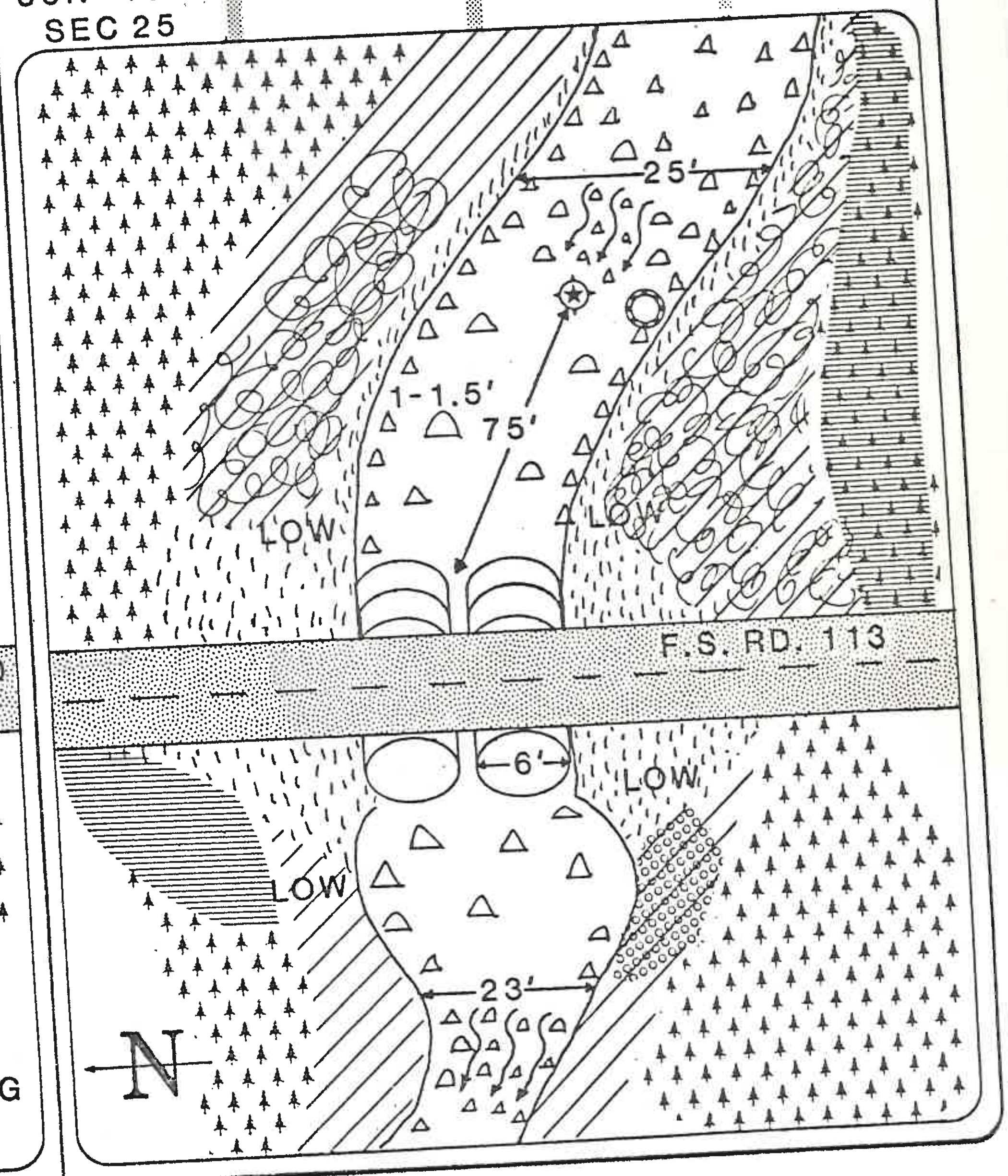
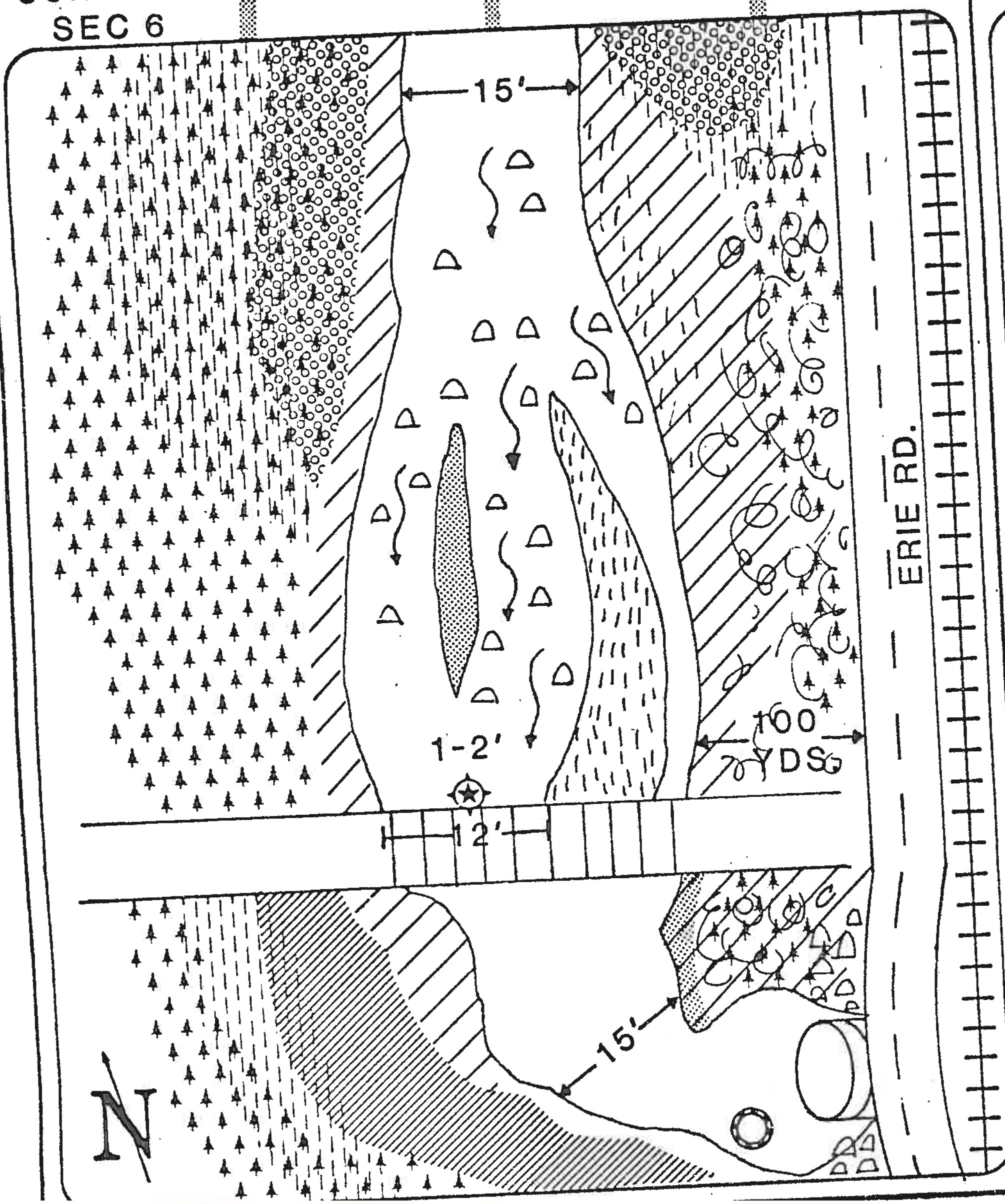
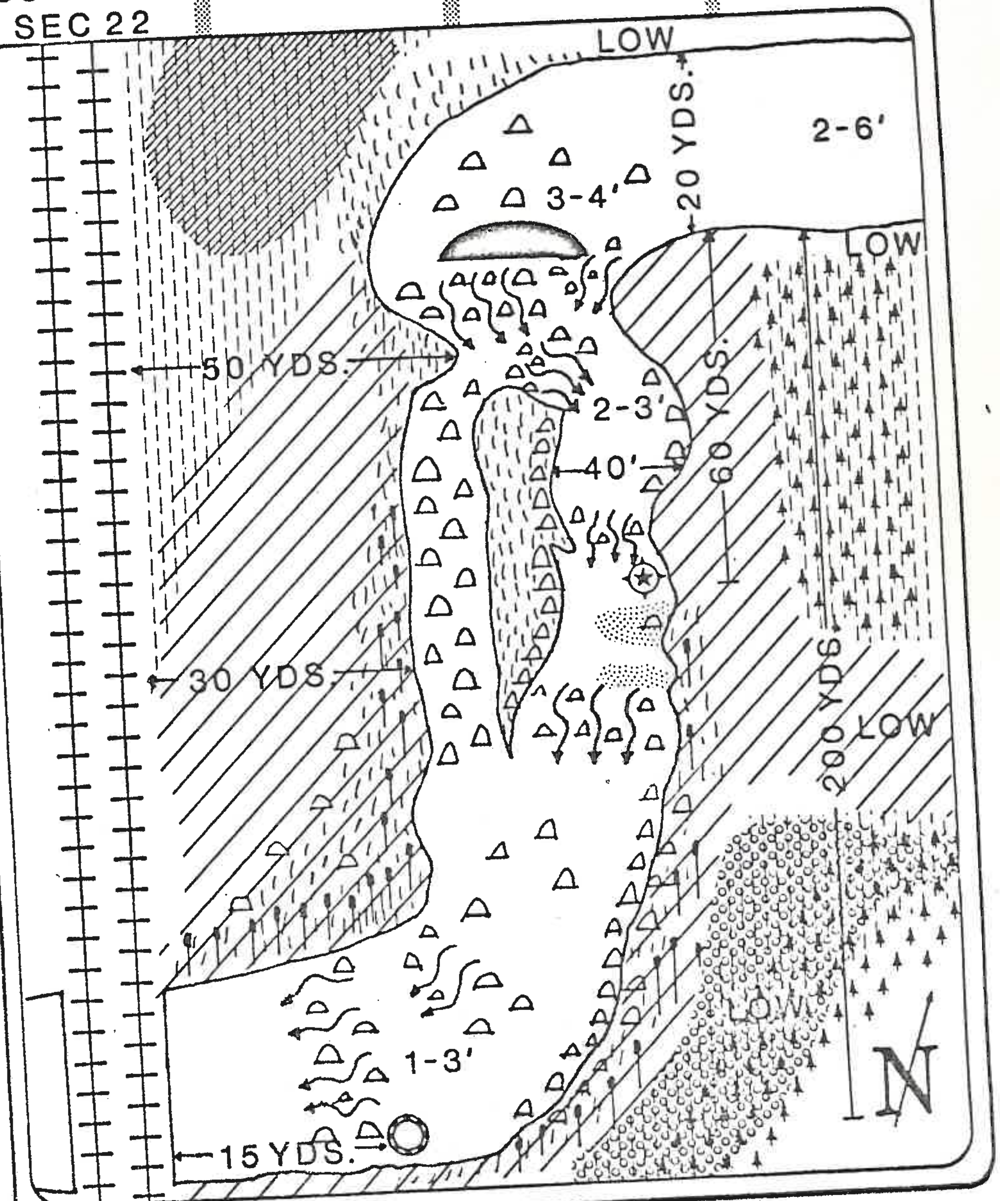
SO. BRANCH PARTRIDGE FS RD. 113 59N 13W SEC 25	04015455	SECONDARY	P-4



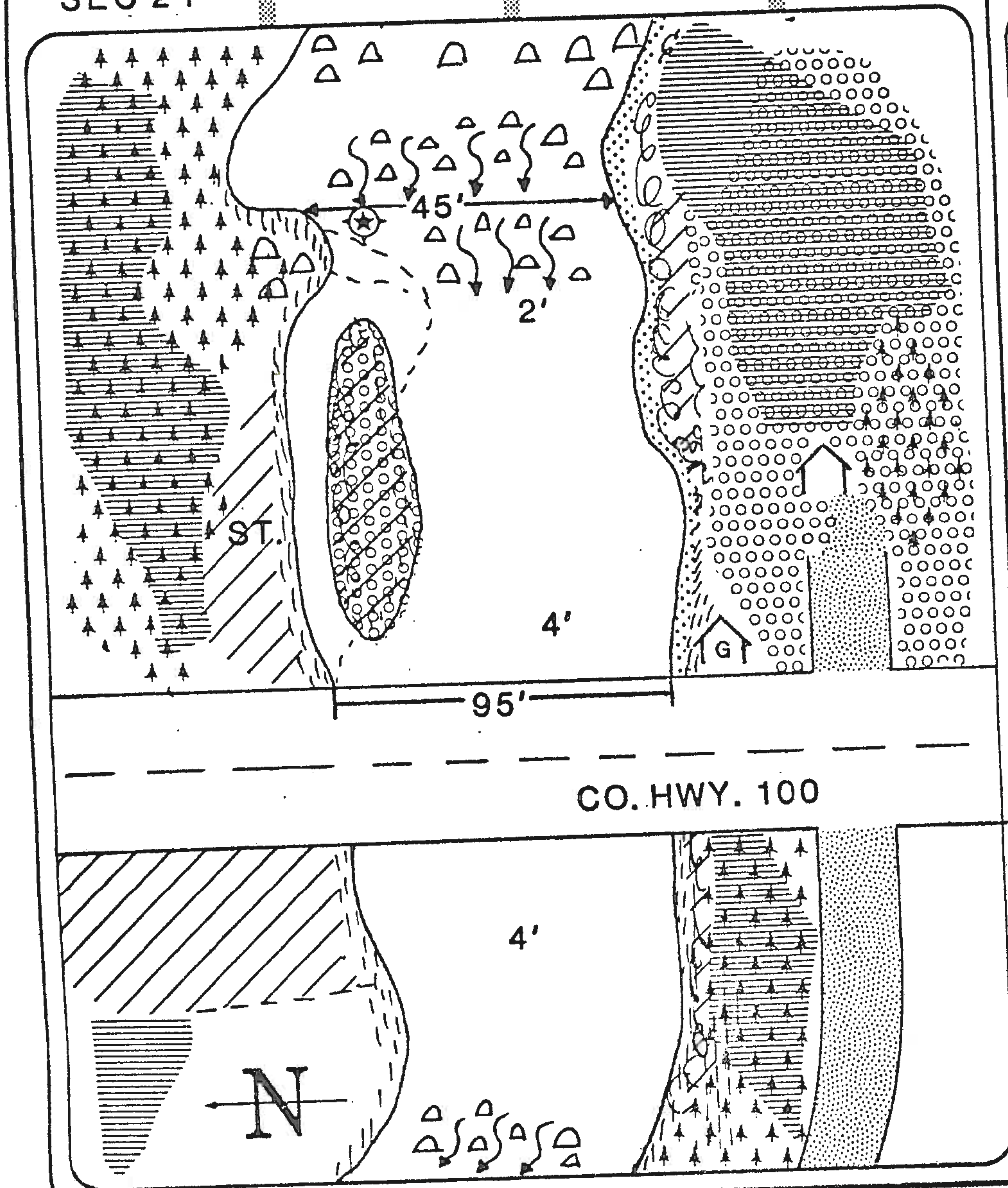
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
PARTRIDGE AT ERIE RD. 59N 12W SEC 6	04015447	TERTIARY	P-5



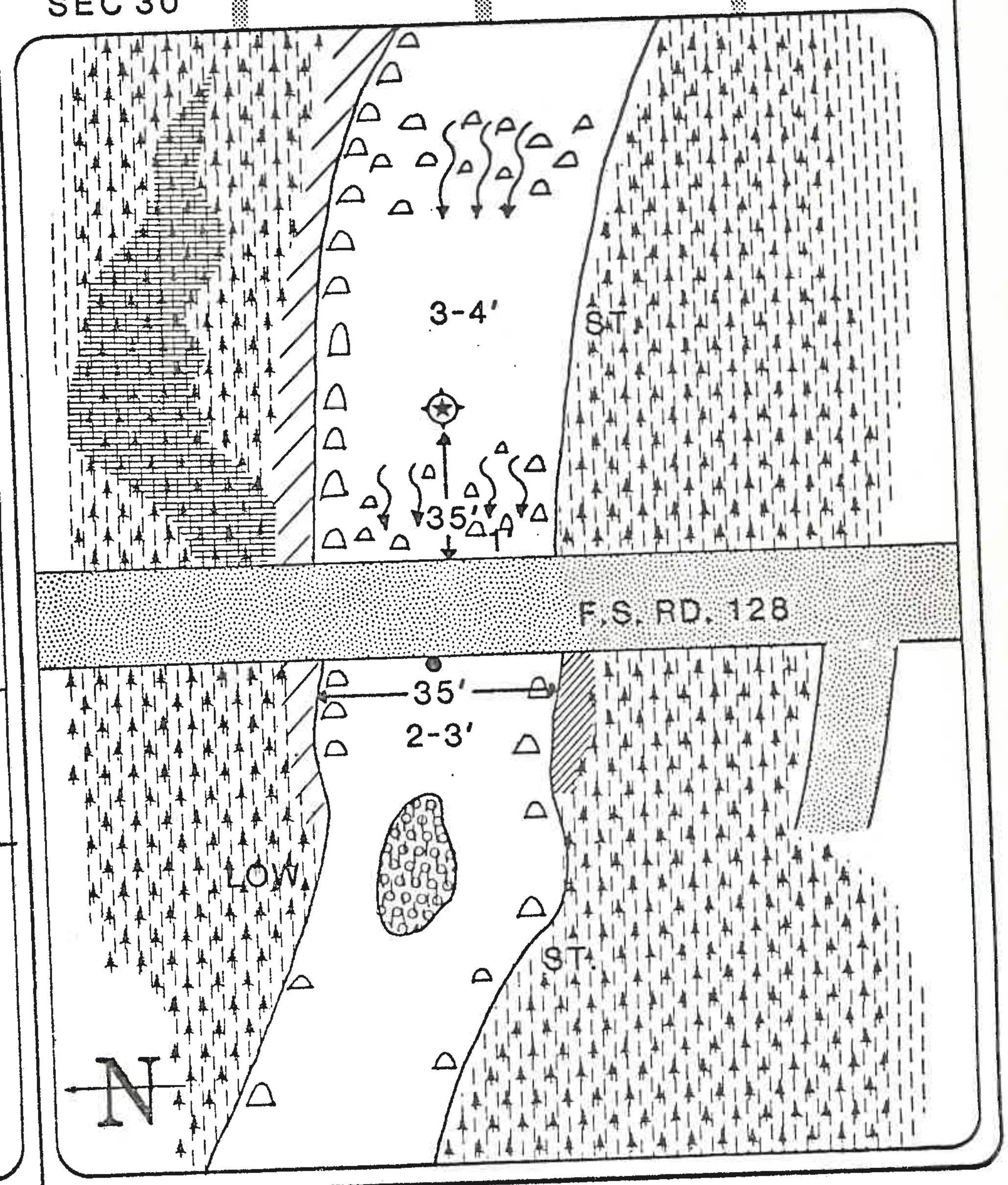
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
ST. LOUIS BL SEVEN BEAVER LAKE 58N 12W SEC 22	04015430	SECONDARY	SL-3



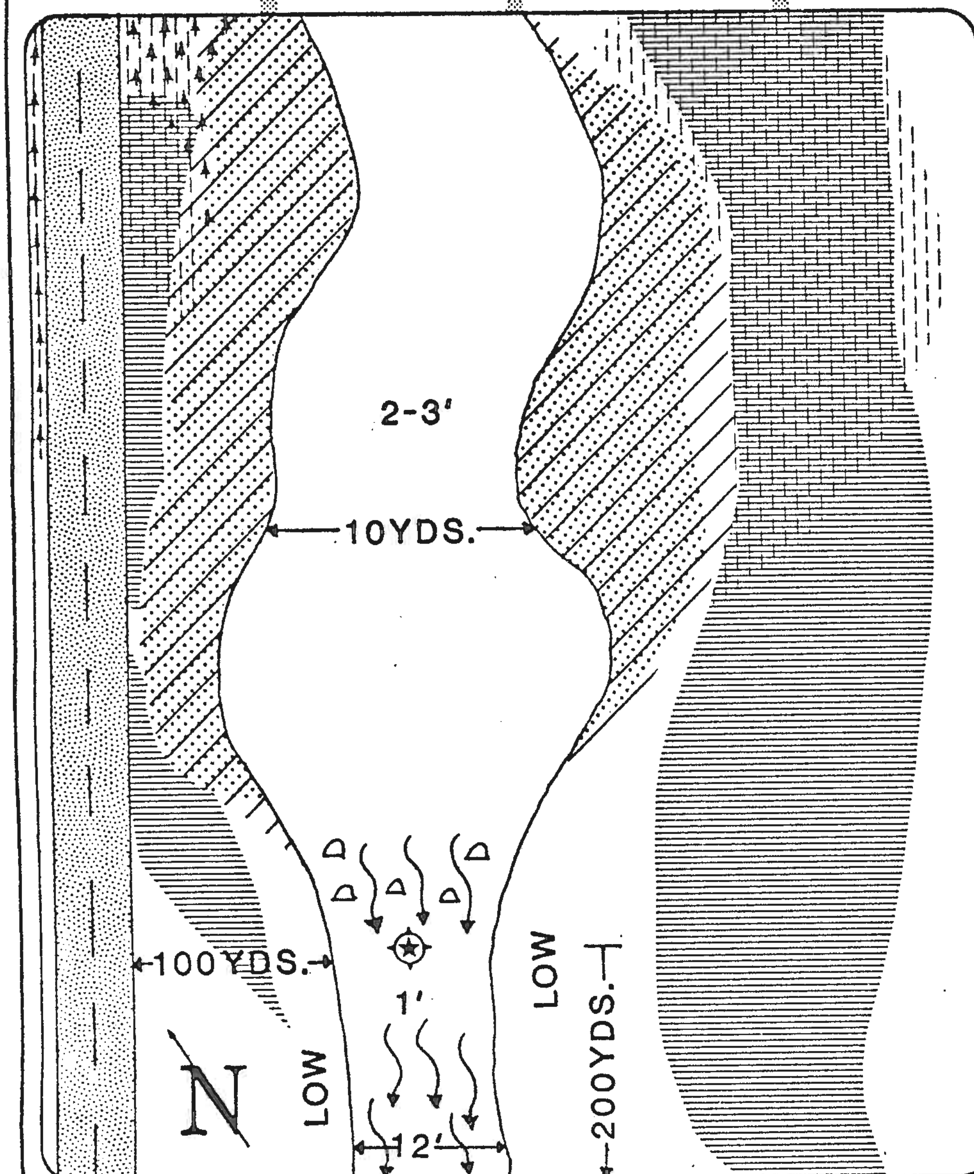
STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
ST. LOUIS NR AURORA 58N 15W SEC 21	04016500	PRIMARY	SL-1



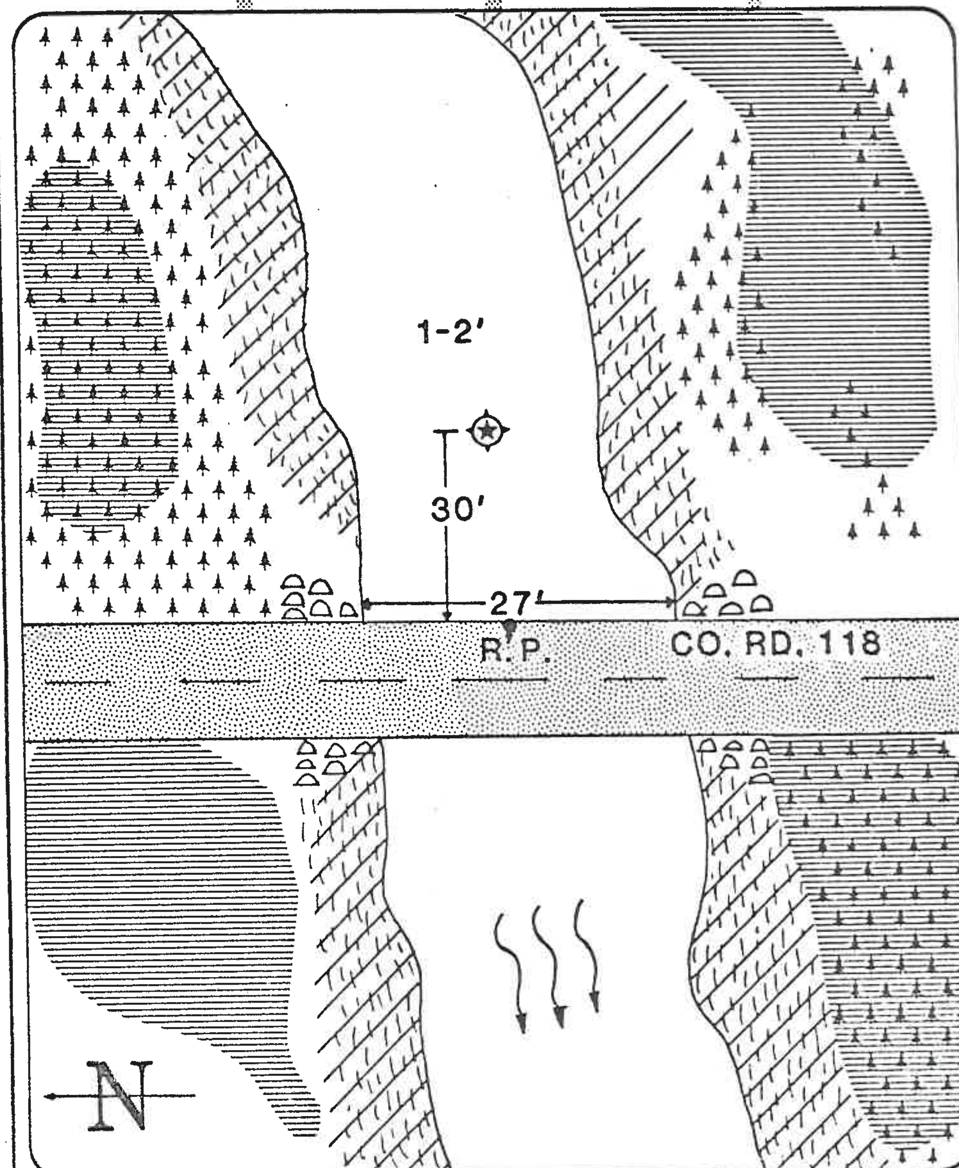
STATION NAME	USGS NUMBER	CLASSIFICATION	-NI DESIGNATION
ST. LOUIS AT F. S. RD. 133 58N 13W SEC 30	04015438	SECONDARY	SL-2



STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
			WF-1



STATION NAME	USGS NUMBER	CLASSIFICATION	CU-NI DESIGNATION
			WF-2



Appendix A.3. Stream gaging stations.

STATION	USGS NO.	TYPE OF GAGING STATION, OR FLOW OBTAINED BY[a]	EQUIPMENT READ BY FIELD CREWS[a]	AGENCY OR FIRM	HISTORICAL RECORD
K-1	05127250	Computed, flow at K-2 & K-3 lake level gaged	RP in lake	USGS	None
K-2	05127230	CR, manometer	manometer, recorder, OS	USGS	1967-P
K-3	05127000	hydroelectric plant	OS above and below dam	MP&L	1906-P
K-4	05126620	not gaged	RP from bridge indicates level of White Iron Lake	---	None
K-5	05126210	CR, manometer	manometer, recorder, OS	USGS	1975-P
K-6	05124480	CR, manometer	manometer, OS	USGS	1966-P
K-7	05125000	CR, stilling well	recorder, ET, OS	USGS USFS	1952-1961,P[b] 1967-1976
F-1	05124990	CR, manometer	manometer, recorder, OS	USGS	1974-P
BI-1	05126500	CR, stilling well	recorder, FT, OS	USGS	1953-1962[c]
I-1	05124500	CR, stilling well	recorder, FT, ET, OS	USGS USFS	1953-1961,P[b] 1967-1976
KC-1	05125040	PM	OS	USGS	None
BB-1	05125730	CR, stilling well	water level recorder, OS	USGS	None
SR-1	05125650	Computed until July, 1976, (SR-2 plus Nira & Denley Creeks) PM after July, 1976	OS after July, 1976	USGS	None
SR-2	05125550	CR, manometer	manometer, recorder, OS	USGS	1975-P
SR-3	05125500	CR, stilling well[d]	recorder, ET, FT, OS	USGS	1953-1964
SR-4	05125400	PM	RP	USGS	None
SR-5	05125450	PM	OS	USGS	None
D-1	05126000	CR, stilling well	recorder, ET, OS	USGS	1952-1962[c]

Appendix A.3. (Contd.)

STATION	USGS NO.	TYPE OF GAGING STATION, OR FLOW OBTAINED BY[a]	EQUIPMENT READ BY FIELD CREWS[a]	AGENCY OR FIRM	HISTORICAL RECORD
D-2		PM	OS	AMAX	None
E-1	04017000	CR, stilling well[d]	recorder, ET, FT, CG, OS	USGS	1943-1964
E-2	04016900	PM	OS	USGS	None
near P-1	04016000	CR, stilling well	recorder, WW	USGS	1942-P
Second Cr.	04015500	CR, manometer	recorder, ET, OS	USGS	1955-P
P-1	04015490	computed 04016000; minus 04015500	----	USGS	None
P-2	04015471	not gaged	RP from bridge	----	None
near P-2	----	PM, 2½ mi. downstream from P-2	OS	USFS	1975-P
P-3	04015461	PM	OS	USGS	None
P-4	04015455	PM[e]	OS	USGS	None
P-5	04015447	PM	OS	AMAX	None
SL-1	04016500	CR, stilling well	recorder, FT, ET, WW	USGS	1942-P
SL-2	04015438	PM	RP	USGS	None
SL-3	04015430	PM	OS	USGS	None

[a]Abbreviations used: CR = continuous-record; PM = periodic measurements; RP = reference point; OS = outside staff; ET = electric tape; FT = float tape; WW = wire weight; CG = chain gage
[b]Reoperated by USGS as of July, 1976.
[c]Reactivated by USGS at beginning of Cu-Ni Study.
[d]Continuous record obtained but not worked up, discharge at time of sampling only is supplied by USGS.
[e]Continuous recording gage (manometer, digital recorder) established at this station June 23, 1977, by USGS at request of AMAX.

Appendix A.4 LAKE SAMPLING STATION IDENTIFICATION

LAKE SAMPLING STATIONS	Cu-Ni SYMBOL	USGS ID LATITUDE-LONGITUDE	STATE ID# (DNR)
Primary Lakes			
Birch 1	LBH-1	474657091455801	69301
Birch 2	LBH-2	474427091480202	69302
Birch 3	LBH-3	474408091521803	69303
Birch 4	LBH-4	474409091544504	69304
Gabbro 1	LGO-1	475122091355901	3870101
Gabbro 2	LGO-2	475043091345002	3870102
White Iron 1	LWI-1	475329091464201	69401
White Iron 2	LWI-2	475118091485002	69402
Colby 1	LCY-1	473134092094501	6924901
Colby 2	LCY-2	473150092081602	6924902
Seven Beaver 1	LSB-1	473007091492101	69201
Seven Beaver 2	SLB-2	472954091475802	69202
August 1	LA-1	474545091361501	3869101
August 2	LA-2	474543091364902	3869102
Whiteface Res 1	LWF-1	471930092084501	6937501

Appendix A.4. (Contd.)

LAKE SAMPLING STATIONS	Cu-Ni SYMBOL	USGS ID LATITUDE-LONGITUDE	STATE ID# (DNR)
Survey Lakes			
Tofte	LTF-1	475755091342001	3872401
Triangle	LTG-1	475624091332701	3871501
Clearwater	LCW-1	475240091310601	3863801
One	LO-1	475507091293301	3860501
Fall	LF-1	475649091443201	3881101
Turtle	LTL-1	475113091331301	3870401
Greenwood	LGD-2	473039091382602	3865602
Sand	LSD-1	473455091402001	3873501
Slate	LST-1	474146091372901	3866601
South McDougal	LSM-1	473655091331601	3865901
Bass	LBS-1	475737091511801	696301
Bear Island	LBI-1	474634091573001	6911501
Bear Island	LBI-2	474624091594402	6911502
Perch	LPH-1	474542091545501	695801
Bearhead	LBD-1	474648092051201	6925401
Pine	LPN-1	472730091474001	69101
Long	LL-1	472749091511701	694401
Big	LBG-1	473151091511701	695001
Wynne	LW-1	473313092164801	6943401
Cloquet	LCT-1	472611091291901	3853901

Underlined stations sampled in 1977.

Appendix A.5. Field Procedures and Handling

Field Procedures

Lake and stream sampling was carried out by staff stationed in Ely. Two people took field measurements, processed samples in the field laboratory, and prepared samples for shipment. They also maintained and calibrated field and lab equipment and carried out the routine quality assurance procedures.

Most stream sampling stations were accessable by automobile (Appendices A.1. and A.2.), although some required a short walk, or the use of a canoe or snowmobile. Two stations in the BWCA were reached by U.S. Forest Service planes.

Lake samples were taken from a 14-foot aluminum fishing boat powered by a 10 horsepower outboard motor, a 17-foot aluminum square stern canoe with a 4 horsepower motor, or from the pontoon of a U.S. Forest Service float plane. A boat and motor were borrowed from the EPA Shagawa Lake Project in Ely on a few occasions.

Sample bottles were labeled the day before use. U.S.G.S. bottles were labeled with station location, date, time, and bottle designation. Minnesota Department of Health (MDH) bottles were labeled with the Copper-Nickel station symbol, date, and time. U.S.G.S. bottles were teflon, glass, or polypropylene. The teflon and glass bottles were cleaned and reused, and the polypropylene bottles were disposed of after one use. All MDH bottles were glass or high density polypropylene; both were cleaned and reused.

Stream Field Procedures

A chest type cooler was picked up at the U.S. Forest Service office in Ely. All other bottles, instruments, and sampling equipment were already in the vehicle. Sampling equipment and bottles were carried in two rigid plastic backpacks worn by the samplers.

At each station the sampling procedure was as follows:

1) One person (sampler) put on waders and gloves while the other person (recorder) organized preservatives and wrote the date and time on bottles. During winter months samples were taken through natural openings in the ice if possible. If a natural opening did not exist, an ice chisel was used to cut a hole, and a plastic strainer was used to remove the ice chips from the hole. Samples were taken below the surface of the ice.

2) Sampler waded into the stream with conductivity bridge, conductivity cell, and thermometer; and facing upstream took the measurements.

3) Recorder calibrated the pH meter and handed this meter to the sampler to determine pH.

4) Two samples were taken for Winkler analysis of dissolved oxygen. A clear plastic cylinder with large rubber stoppers to close each end was used to take these samples. One stopper was holed and fitted with a rubber hose. The sample was taken by removing the stoppers, immersing the sampler vertically, turning it horizontally to allow the water to run through cylinder to eliminate all bubbles. The stoppers were inserted and the sampler carried ashore. The end of the hose was inserted into the bottom of the DO bottle, the top stopper loosened, and the bottle allowed to fill to overflowing. Samples were fixed with Hach dry chemicals supplied premeasured in plastic "pillows".

5) Sample bottles were then filled by the sampler, who faced upstream and sampled the main part of the current. Most bottles were rinsed three times before the sample was taken. Bottles were immersed neck down into the stream, then turned upward to fill, brought out of the water, and capped. U.S.G.S. teflon bottles for trace metals were uncapped, filled, and recapped all under water. MDH bottles for the total trace metal samples (high density polypropylene) were rinsed three times and uncapped and recapped above the surface.

6) Preservatives were added to the bottles as required (U.S.G.S. trace metal samples were preserved under hood at field lab). Both U.S.G.S. and MDH supplied all preservatives used in their respective samples. U.S.G.S. preservatives were contained in sealed glass ampules; and MDH preservatives were supplied in small polyethylene bottles. Parafilm was used to seal the space between the MDH bottle neck and cap.

7) A change from lab to in-field filtration of trace metals was initiated when responsibility for analysis was transferred from U.S.G.S. to MDH. The procedure used was as follows:

a) An assembled and cleaned aseptic filtration unit (filter holder with swinex top and receiving flask) with bottle in place was supplied by MDH in a plastic bag. The cap for the bottle was supplied in a separate plastic bag.

b) Filtration apparatus was placed into plastic holder on the end of an L-shaped piece of plastic pipe and locked bayonet style. A hand pump was connected to the unit with a five-foot piece of plastic tubing.

c) The apparatus and holder were immersed in the stream and vacuum applied with the pump. The bottle was filled about four-fifths full and vacuum released before removing the apparatus from the stream.

d) The apparatus was removed from the holder and the Swinex top removed. The HNO_3 preservative was added to the sample, the cap screwed on the ... from the base of the unit.

e) The dissolved metals bottle was labeled and placed inside the bag in which the cap was supplied.

f) Filtering apparatus was returned to plastic bag.

g) The same sample was used for the dissolved organic carbon, calcium, and magnesium analyses. When these parameters were to be analyzed but the dissolved trace metals were not, the filtering unit required a less vigorous cleaning procedure which was performed by the field crew. The filtering apparatus with filter in place was rinsed once with ten percent HNO_3, and three times with USFS ~~DO~~ deionized water before the bottle, supplied by MDH, was inserted.

8) All sample bottles were placed in the ice chest.

9) U.S.G.S. water level staffs and other water level recorders were read.

10) Information required for the field notebook was completed.

Lake Field Procedures

The water sampling bottle (Kemmerer) was cleaned for trace metals by rinsing once with 0.2 percent nitric acid followed by three rinses with distilled, deionized water. The dissolved oxygen (DO) meter was Winkler calibrated and the batteries charged if necessary.

At each station the sampling procedure was as follows:

1) The DO meter was turned on 15 minutes before it was to be used to allow it to equilibrate.

2) If sampling from a boat or canoe, the motor was turned off and the craft allowed to drift a distance before anchoring. The motor was raised out of the water unless the temperature was below freezing.

3) The eight liter, nonmetallic Kemmerer was opened and lowered into the water to "soak."

4) General information such as time, weather, and station identification was recorded in the field notebook.

5) The DO meter, probe, and stirrer were assembled, the red line and zero checked, and the measurements taken at one meter intervals starting at the surface. One person operated the meter and handled the probe ~~leds~~ leads while the other recorded values on the profile data sheet.

6) A surface water sample was taken with the Kemmerer. A polyvinyl chloride (PVC) tube, which was mounted to the outside of the ice chest, was slipped over a vertical PVC rod mounted to the top of the ice chest. This served to hold the Kemmerer upright while withdrawing water. Sample bottles were rinsed, filled, and preservatives added. Bottles were filled by depressing the Kemmerer valve with the mouth of the bottle. This eliminated the need for opening the valve with the fingers. One Kemmerer fill normally provided enough water to fill all required bottles.

A filtered sample for MDH analyzed dissolved trace metals was obtained from the Kemmerer by attaching a short length (5 to 8 cm) of tygon tubing between the valve and the aseptic filtration unit, locking open the valve, and pumping a sample through with the hand pump. The tubing was prepared and cleaned by MDH. The rest of the procedure and equipment used was the same as described for stream sampling, above.

7) Mid-depth sample was taken if scheduled.

8) Bottom sample was taken if scheduled.

9) Samples were stored in an ice chest and chilled with freezable ice packs.

10) Secchi disk reading was taken. This was measured on the shaded side of the boat by averaging the depth at which it disappeared when lowered and the depth at which it reappeared when raised.

11) Biological samples were taken (see Aquatic Biology Lakes Operation Manual).

12) Gear was stowed for move to next station or to shore. DO meter was not turned off it proceeding to another station.

Field Lab Procedures

Samples were brought to the field lab the same day they were collected, for processing, shipment, or temporary storage. The USFS deionized water was used for routine rinsing and U.S.G.S. deionized water was used for critical rinsing, such as the trace ~~supplied by U.S.G.S. central~~ metal samples. The U.S.G.S. deionized water was supplied by ~~the~~ U.S.G.S. central labs and its quality was known, USFS deionized water was distilled at the USFS lab in Ely and deionized at the Copper-Nickel field lab. Millipore 0.45 um filters constructed of inert mixtures of cellulose acetate and cellulose nitrate were used for all filtering except for the U.S.G.S. suspended and dissolved organic carbon samples. A silver filter was used for this filtration.

The field lab procedures were as follows:

1) Conductivity and pH were measured, if this was not done in the field.

2) Complexing capacity samples were marked with pH and stored overnight in a refrigerator.

3) Winkler dissolved oxygen samples were titrated using .0375 N phenylarsine oxide (PAO). The sample for the special parameters, dissolved organic and inorganic carbon, was filtered in a standard vacuum flask, filter holder, and 300 ml reservoir funnel. The filtering apparatus, with 0.45 micron filter in place, was rinsed three times with USFS deionized water. About 25 ml of the sample was given three rinses with the filtrate and then filled one half full with filtrate and frozen. The frozen samples were subsequently transported to the University of Minnesota. The filtration apparatus was washed in detergent, rinsed three times with tap water, then three times with USFS deionized water, and placed on a towel to dry.

4) Radiochemistry samples and U.S.G.S. trace metal samples, when these and the nonmetal parameter samples were being sent to separate labs, were stored in a refrigerator for a period of several days to several weeks before being shipped. Otherwise, all samples were shipped the day they were collected (U.S. Mail to U.S.G.S.) or the following morning (bus to MDH) in five-gallon, insulated, cylinder-like, plastic coolers (Gott). These coolers accommodated four refreezable cool packs with a sample to be analyzed for primary parameters, and three cool packs with either a sample to be analyzed for primary and secondary parameters or one to be analyzed for primary, secondary, and tertiary parameters.

5) U.S.G.S. or MDH laboratory forms, U.S.G.S. chain of custody forms and seals, and shipping labels were filled out. Laboratory forms were placed inside sealable plastic bags and sent along with the respective samples.

6) The reagent pack taken into the field was inventoried and resupplied s necessary.

7) Bottles were labeled for the next day sampling.

The procedures outlined below were required for samples sent to U.S.G.S.:

8) Filtering of U.S.G.S. samples was carried out as follows: a 0.45 um filter was placed on the filter holder, wetted with USFS deionized water, and clamped to a "rinsing" flask. Three rinses of USFS deionized water (about 200 ml) and about 25 ml of sample were swirled around the funnel and drawn through. The filter holder was removed and placed on a second flask which had been rinsed three times with USFS deionized water. Two hundred and seventy ml of sample were then filtered; 20 ml were used to rinse the bottle which had previously been rinsed with USFS deionized water, then the remainder of the filtrate was poured in. One ml of HNO_3 was added to samples requiring acidification. The filter holder and the two flasks were washed with detergent and rinsed three times with both tap and USFS deionized water.

9) The U.S.G.S. suspended and dissolved organic carbon samples were filtered using a silver filter. The collection bottle (300 ml BOD bottle) filtering apparatus, graduated cylinder, and forceps were rinsed with potassium dichromate, tap water (three times) and USFS deionized water (three times). Between 75 and 100 ml of the sample were poured into the graduated cylinder and the volume recorded. The 0.45 um silver filtrate was placed on the holder and wetted with USFS deionized water. About 10 ml of sample were swirled in the funnel, drawn through the filter, and discarded. This was repeated with another 10 ml. The remaining sample was filtered and the filtrate poured into a glass bottle and labeled DOC. The original sample bottle and graduated cylinder were rinsed three times with USFS deionized water. Each time the rinse water was poured into the funnel and filtered. Finally, the sides of the funnel were rinsed three times with USFS deionized water and this was ~~drwn~~ down through. The silver filter was removed, folded in half using the cleaned forceps, and placed into a plastic petri dish. The volume filtered and the designation "SOC" were added to the label on the petri dish. The petri dish was placed in a sealable plastic bag labeled the same way.

10) The filtration for dissolved trace metals was carried out in a laminar flow hood to minimize contamination from dust. Millipore aseptic filtration units were used to filter the water, and an exhaustive routine of rinsing and cleaning was carried out to minimize contamination. (It should be noted that despite

these efforts, the dissolved metals data indicated a contamination problem, the source of which was never determined.) Details of the filtering procedure are outlined below.

a) Disposable plastic gloves and other protective gear was put on and the counter top of the hood was wiped with 10 percent HNO_3.

b) RA-teflon (total metals sampled) was acidified with 2 ml of ultrapure HNO_3 from a U.S.G.S. supplied glass ampule.

c) Filtration unit was removed from its storage container containing one percent HNO_3 and assembled.

d) The unit, without a filter, was rinsed with 50 ml of ten percent HNO_3 three times. The acid was swirled in the top half, drawn through, swirled in bottom half, and discarded.

e) The same procedure was repeated using USFS deionized water.

f) A 0.45 um filter was wetted with U.S.G.S. deionized water and inserted into the unit.

g) The rinsing procedure (d) was repeated using 0.2 percent HNO_3.

h) The rinsing procedure (d) was repeated using U.S.G.S. deionized water.

i) When a filter blank was run, 50 ml of U.S.G.S. deionized water was filtered, poured into a clean teflon bottle, and used to rinse the bottle. An additional 250 ml of U.S.G.S. deionized water was filtered and poured into the bottle. One such filter blank (labeled FBA) was prepared each day samples were filtered.

j) The rinsing procedure (d) was repeated using 50 ml of sample. This filtrate was used to rinse a clean teflon bottle before being discarded. An additional 250 ml of sample were drawn through and poured into the teflon bottle which was labeled "FA". The sample (and filter blank if run) was acidified with one ml of ultrapure HNO_3 from a glass ampule supplied by U.S.G.S.

k) The filter was removed and the unit cleaned by rinsing (d) with 50 ml of ten percent HNO_3. The separate halfs were then replaced into their respective one percent HNO_3 baths.

l) The teflon bottle containing the unused sample was emptied and cleaned with three 10 percent HNO_3 rinses followed by three USFS deionized water rinses. This bottle was then used for another sample.

Sample Handling and Shipment

During the warm months samples were placed in a cold water bath in an ice chest for transport back to the field lab. Samples destined for U.S.G.S. labs were mailed at the end of the day collected. Travel time for U.S.G.S. bound samples, while normally two or three days, upon occasion took as long as two weeks.

After three days in transit samples could not be expected to arrive in a cool state. The uncertainties and problems associated with the transport of samples to U.S.G.S. was a major factor which prompted the switch from U.S.G.S. to MDH analysis. Maximum U.S. Environmental Protection Agency (USEPA) recommended sample holding times for certain critical parameters were always exceeded when samples were sent to U.S.G.S.

MDH destined samples were stored overnight in a refrigerator and shipped by bus the next day. These samples reached MDH within 30 hours of the time they were taken and were always 4°C or cooler upon arrival.

Record Keeping and Data Transmission

All field notes and data were recorded in hard-bound books designed for the Study. Information included in the field notebooks was general information, type of samples collected, dissolved oxygen, temperature profile, pH, and conductivity readings. The field notebooks are on file at the Copper-Nickel Study office.

Sample log forms were sent with the samples to the University of Minnesota, Minneapolis; U.S.G.S., and MDH.

Sample chain of custody was maintained between Ely and U.S.G.S. labs by the application of a self-adhesive label from the lid to the body of the shipping cooler. The lid could not be removed without tearing the label. A chain of custody form was sent in each cooler to U.S.G.S. The U.S.G.S. receiving person indicated on this form whether the label was intact upon arrival, and returned it in the cooler to Ely. MDH recorded whether or not the label was intact in their own records. A chain of custody procedure was also used when BOD and fecal coliform samples were delivered by the field crew to the SERCO lab in Ely.

APPENDIX B

MISCELLANEOUS WATERSHED INFORMATION

Appendix B.1. 1969 land use category descriptions.
(SOURCE: Minnesota Land Management Information System. 1975. Arrowhead Region data manual. Center for Urban and Regional Affairs, Univ. of Minn. Manual #3030.)

DATA LEVEL	DESCRIPTION
1	Forested - A forty in which there is at least a ten percent crown cover of deciduous or coniferous trees.
2	Cultivated - A forty in which dominant land use appears (on aerial photographs) to consist of recently tilled or harvested land.
3	Water - A forty in which permanent open water is the dominant surface feature.
4	Marsh - A forty in which the dominant land use consists of nonforested, vegetated areas which are permanently wet.
5	Urban Residential - A forty containing five or more residential buildings (seasonal and permanent homes, resorts, mobile homes, etc.) and no commercial buildings.
6	Extractive - A forty in which the dominant land use consists of the extraction of minerals and includes such features and facilities as mines, tailings, gravel pits, quarries, crusheries, and storage facilities.
7	Pasture and Open - A forty in which the dominant land use consists of pasture land or land not used for any other identifiable purpose.
8	Urban and Nonresidential or Mixed Residential - A forty containing at least one commercial, industrial, or institutional development. Examples: schools, factories, hospitals, nurseries, cemeteries, golf courses, gun clubs, athletic fields, organized recreational facilities, business districts, churches, filling stations, government buildings, warehouses, storage tanks, grain elevators, military installations, sewage disposal facilities, fish rearing areas, radio and television stations, drive-in theaters, state and county garages, prisons, motels, nursing homes, and junk yards.
9	Transportation - A forty in which the dominant land use consists of facilities for the conveyance of people and/or materials. Examples: airports, railroad yards, highway interchanges, rights-of-way.

APPENDIX B2

Land Use Classifications and Criteria for 1977 Land Use Mapping
(Source: Regional Copper-Nickel Socio-economic staff)

1.0 MINELAND

Any land used or occupied by any phase of the mining process or any facility controlled by the mining industry. The following mineland uses will be classified:

1.1-pits
1.2-waste dumps/lean-ore piles
1.3-tailings basins/ponds
1.4-processing plants/buildings (including on-site offices, storage facilities, garages, etc.)/other surface structures associated with underground mining
1.5-lots/yards fenced in vacant land roads; railroads surrounding these uses

Exclusions:

-mining company-owned railroads
-mining company-owned roads (outside of pits)
-any unused, vacant land which may be owned or controlled by the mining companies which is not clearly dominated by the mining process

2.0 MANUFACTURING-INDUSTRIAL

Any land used or occupied by industry (other than mining) including:

-manufacturing/processing plants
-at-plant office buildings
-large warehouse/storage facilities
-gravel pits
-other

and excluding:

-any unused or vacant land owned or controlled by industrial concerns which is not clearly dominated by manufacturing/industrial use
-any private roads
-any private railroads

3.0 URBAN

Any built-up areas within a municipality which include residences, social and community services (built up areas outside of the municipal limits will be absorbed into one or several other classifications).

APPENDIX B2 (Contd.)

4.0 <u>RURAL RESIDENTIAL</u>

Any residence and land <u>immediately</u> adjacent to it which lies outside a defined Urban area <u>including</u>:

- -year-round residences
- -temporary or seasonal residences
- -trailer homes
- -farmsteads
- -clusters of residences outside municipal limits

5.0 <u>RURAL COMMERCIAL</u>

Any structure or land laying outside a defined Urban area which is used or occupied for commercial purposes <u>including</u>:

- -resorts
- -stores
- -gas stations
- -bars
- -others

6.0 <u>TRANSPORTATION</u>

Any land occupied by facilities which transport people and/or materials. The following transportation uses will be classified:

6.1-rights of way for both functional and abandoned railroads
6.2-rights of way for roads and highways
6.3-airports
6.4-associated loading/unloading facilities

7.0 <u>AGRICULTURE</u>

Any land primarily used for the production of food or to support livestock <u>including</u>:

- -cultivated fields
- -grazed pastureland
- -orchards
- -outbuildings (barns, silos, sheds, etc.)
- -large home gardens

and <u>excluding</u>:

- -inhabited farmhouses and their yards
- -unused fields or pastures

APPENDIX B.2 (Contd.)

8.0 FOREST

Excluding:

-black spruce bogs

9.0 SWAMPS/MARSHES/BOGS

Any vegetated land which is permanently wet and which has not been otherwise classified (as mineland for example) <u>including</u>:

-black spruce bogs

10.0 WATER

Any land which is covered by water <u>including</u>:

-lakes
-streams
-artificial lakes such as found in old pits, reservoirs, etc.

and <u>excluding</u>:

-ponded water within tailing basins

12.0 OPEN/VACANT

Any open, vacant, or unused land (even when this open land is clearly associated with adjacent land that has a specific use, such as an unused field next to a cultivated field) <u>including</u>:

-clearcut timber land which is not obviously replanted
-unused fields or pastures
-other unclassifiable lands

and <u>exluding</u>:

-forested land
-swamp/marsh/bog
-water

Appendix B.3.. Soil association and soil series descriptions.

Table B.3.1. Soil association descriptions
(SOURCE: Arrowhead Regional Development Commission. 1974. General soil map of Arrowhead Region map key; Minnesota Land Management Information System. 1975. Arrowhead Region data manual. Center for Urban and Regional Affairs, Univ. of Minn. Manual #3030.

DATA LEVEL	DESCRIPTION[a]	PROPORTION OF MAJOR SOILS(%)	PREDOMINANT SLOPE(%)	LOCAL RELIEF(ft)	LAND FORM
2	Dusler-Duluth nearly level association		0-2	0-3	Ground Moraine
	A) Dusler-Aeric Glossaqualfs, fine-loamy, mixed	50			
	B) Duluth, Glossic Eutroboralfs, fine-loamy, mixed	20			
	C) Minor soils[b]	30			
4	Ahmeek-Ronneby undulating association		0-12	5-25	Moraines & Drumlin Areas
	A) Ahmeek, Typic Fragiochrepts, coarse-loamy, mixed	65			
	B) Ronneby, Aeric Fragiaqualfs, coarse-loamy, mixed	15			
	C) Minor soils	20			
5	Newfound-Newfound (wet) undulating association		0-12	5-25	Moraines & Drumlin Areas
	A) Newfound, Typic Fragiochrepts, coarse-loamy, mixed	65			
	B) Newfound (wet), Aeric Fragiaqualfs, coarse-loamy, mixed	15			
	C) Minor soils	20			
6	Unnamed-Toivola undulating association		0-12	3-6	Outwash Plains
	A) Unnamed, Typic Haplorthods, coarse-loamy over sandy skeletal	75			
	B) Toivola, Typic Udorthents, sandy skeletal, mixed	15			
	C) Minor soils	10			

Table B.3.1. (contd.)

DATA LEVEL	DESCRIPTION[a]	PROPORTION OF MAJOR SOILS(%)	PREDOMINANT SLOPE(%)	LOCAL RELIEF(ft)	LAND FORM
7	Toivola-Unnamed-Cloquet undulating to steep undifferentiated association		0-35	20-50	Eskers & Outwash Areas
	A) Toivola, Typic Udorthents, sandy-skeletal, mixed	60			
	B) Unnamed, Typic Haplorthods, coarse-loamy over sandy skeletal, mixed	15			
	C) Cloquet, Typic Dystrochrepts, coarse-loamy over sandy or sandy skeletal, mixed	15			
	D) Minor soils	10			
8	Mesaba-Barto undulating to hilly association		2-25	20-75	Shallow to Bedrock
	A) Mesaba, Typic Dystrochrepts, coarse-loamy, mixed	45			
	B) Barto, Lithic Dystrochrepts, loamy, mixed	40			
	C) Quetico, Lithic Dystrochrepts, loamy, mixed	5			
	D) Minor soils	10			
9	Conic-Insula undulating to hilly association		2-25	20-75	Shallow to Bedrock
	A) Conic, Typic Fragiochrepts, coarse-loamy, mixed	45			
	B) Insula, Lithic Dystrochrepts, loamy, mixed	35			
	C) Quetico, Lithic Dystrochrepts, loamy, mixed	10			
	D) Minor soils				
17	Nebish-Mooselake-Shooker hilly association		12-25	5-40	Moraine
	A) Nebish, Typic Eutroboralfs, fine-loamy, mixed	50			
	B) Mooselake, Typic Borohemists, euic	30			
	C) Shooker, Aeric Ochraqualfs, fine-loamy, mixed	5			
	D) Minor soils	15			

Table B.3.1. (contd.)

DATA LEVEL	DESCRIPTION[a]	PROPORTION OF MAJOR SOILS(%)	PREDOMINANT SLOPE(%)	LOCAL RELIEF(ft)	LAND FORM
25	Cormant-Shawano nearly level association		0-2	0-10	Glacial Lake Plain
	A) Cormant, Mollic Psammaquent, mixed	65			
	B) Shawano, Typic Udipsamments, mixed	20			
	C) Minor soils	15			
26	Menahga-Cutfoot undulating association		0-12	0-30	Outwash Plains & Sandy Moraine
	A) Menahga-Typic Udipsamments, mixed	60			
	B) Cutfoot, Alfic Udipsamments, mixed	30			
	C) Minor soils	10			
35	Mesaba-Barto undulating association		0-6	5-10	Shallow to Bedrock
	A) Mesaba, Typic Dystrochrepts, coarse-loamy, mixed	45			
	B) Barto, Lithic Dystrochrepts, loamy, mixed	40			
	C) Quetico, Lithic Dystrochrepts, loamy, mixed	5			
	D) Minor soils	10			
41	Cloquet-Emmert undulating association		0-12	2-12	Outwash Plain
	A) Cloquet, Typic Dystrochrepts, coarse-loamy over sandy or sandy skeletal	75			
	B) Emmert, Typic Udorthents, sandy skeletal, mixed	15			
	C) Minor soils	10			
49	Unnamed-Hibbing nearly level association		0-2	5-10	Ground Moraine
	A) Unnamed, Aquic Eutroboralfs, fine, mixed	60			
	B) Hibbing, Typic Eutroboralfs, fine, mixed	30			
	C) Minor soils	10			

Table B.3.1. (contd.)

DATA LEVEL	DESCRIPTION[a]	PROPORTION OF MAJOR SOILS(%)	PREDOMINANT SLOPE(%)	LOCAL RELIEF(ft)	LAND FORM
50	Hibbing-Unnamed undulating association		0-12	10-30	Moraines
	A) Hibbing, Typic Eutroboralfs, fine, mixed	60			
	B) Unnamed, Aquic Eutroboralfs, fine, mixed	30			
	C) Minor soils	10			
57	Greenwood nearly level association		0-1	0-2	Bogs
	A) Greenwood, Typic Borohemists, dysic	65			
	B) Minor soils	35			
58	Mooselake nearly level association		0-1	0-2	Bogs
	A) Mooselake, Typic Borohemists, euic	65			
	B) Minor soils	35			
59	Waskish-Lobo nearly level association			0-2	Raised Bogs
	A) Waskish, Typic Spagnofibrist, dysic	50			
	B) Lobo, Hemic Spagnofibrist, dysic	35			
	C) Minor soils	15			
60	Mine				
62	Water				

[a]Detailed descriptions of soil series follow this table.
[b]Minor soils differ from major soils in degree of wetness, texture, or other significant soil characteristics.

Appendix B.3. (contd.)

Table B.3.2. Detailed soil series descriptions.
(SOURCE: ARDC 1974)

2A	This series consists of nearly level, somewhat poor and poorly drained soils formed in loam or clay loam till. These soils are on concave slopes on moraines. Native vegetation is forest. The surface layer is very dark gray silt loam about 11 inches thick. The subsurface layer is gray fine sandy loam about 4 inches thick. The subsoil is reddish brown, loam about 40 inches thick. The underlying material is reddish brown loam. Permeability is slow. The available water capacity is high and organic matter content is high. The availability of phosphorus is low, and of potassium is low. The major limitation to use is wetness.
2B	This series consists of nearly level to rolling, well to moderately well drained soils formed in loam or clay loam till. These soils are on convex slopes and moraines. Native vegetation is forest. The surface layer is very dark brown silt loam about 2 inches thick. The subsurface layer is dark reddish brown silt loam or very fine sandy loam about 11 inches thick. The subsoil is dark reddish brown, firm loam about 53 inches thick. The underlying material is dark reddish brown loam. Permeability is slow. The available water capacity is high and organic matter content is low. The availability of phosphorus is low, and of potassium is low. Most areas of soils are used for forest. The major limitation to use is the hazard of erosion on steep slopes.
4A	This series consists of nearly level to steep, well and moderately well drained soils formed in sandy loam till. These soils are on moraines and broad drumlins. Native vegetation is forest. The surface. layer is very dark brown silt loam about 2 inches thick. The subsoil is dark brown, very friable, fine sandy loam about 14 inches thick in the upper part. The lower part is reddish brown firm sandy loam about 44 inches thick. The underlying material is reddish brown fine sandy loam. Permeability is moderately slow. The available water capacity is low and organic matter content is low. The availability of phosphorus is moderate, and of potassium is moderate. These soils have very dense lower subsoils and underlying material. Gobbles are common throughout the profile.
4B	This series consists of slightly concave and nearly level, somewhat poorly drained soils formed in sandy loam till. These soils are on the base of slopes and level ground moraines. Native vegetation is forest. The surface layer is black silt loam about 4 inches thick. The subsurface layer is grayish brown silt loam about 7 inches thick. The subsoil is reddish brown sandy loam about 47 inches thick. The underlying material is dark reddish brown fine sandy loam. Permeability is moderately slow. The available water capacity is low and organic matter content is medium. The availability of phosphorus potassium is low. Subsoil is very dense. Most areas are used for forest and pasture. The major limitation to use is the hazard of wetness.

Table B.3.2. (contd.)

5A	This series consists of gently sloping to steep well drained soils formed in more than 40 inches of brownish, medium and strongly acid gravelly sandy loam over bedrock. At depths of 14 to 28 inches there occurs a well developed fragipan ranging in thickness from 10 to 35 inches or more. Percent of coarse fragment typically is 25 to 35 percent. The fragipan restricts root penetration. The terrain is sloping to hilly and is located in the Laurentian Shield country of northeastern Minnesota.
5B	This series consists of slightly concave and nearly level, somewhat poorly and poorly drained soils formed in sandy loam glacial till under a mixed deciduous-coniferous forest. Typically they have black loam surface horizons; mottled dark brown and brown loam subsurface horizons; mottled dark brown sandy loam subsoil horizons and dark brown sandy loam underlying material. A fragipan typically begins at 18 inches. Slopes are less than 2 percent. Most areas are forested.
6A,7B	This series consists of deep excessively drained soils formed in loamy material over stratified sand and gravel under deciduous and coniferous forest on plane and convex slopes of outwash plains, eskers, and kames. Typically they have black, sandy loam surface layers 1 inch thick; dark grayish brown, sandy loam subsurface layers 2 inches thick; dark reddish brown and reddish brown, sandy loam subsoil 12 inches thick; and yellowish brown, gravelly very coarse sand underlying material. Slopes range from 1 to 60 percent. Most areas are forested.
6B,7A	This series consists of nearly level to very steep, excessively drained soils formed in outwash material. These soils are on outwash eskers and ice-contact glacial deposits. Native vegetation was forest. The surface layer is dark reddish brown decomposed plant remains about 2 inches thick. The subsurface layer is gray very gravelly coarse sandy loam about 5 inches thick. The subsoil is strong brown, gravelly loamy sand about 10 inches thick. The underlying material is brown very gravelly coarse sand. Permeability is very rapid. The available water capacity is very low and organic matter content is low. These soils contain many cobbles and boulders.
7C	This series consists of nearly level to steep, excessively drained soils formed in 1 to 2 feet of loamy material over stratified sand and gravel. These soils are on plane and convex slopes of outwash plains, eskers and kames. Native vegetation was forest. In a representative profile the surface layer is black sandy loam about 1 inch thick. The subsoil is dark brown, very friable, sandy loam about 13 inches thick. The underlying material is reddish brown gravelly coarse sand. Permeability is moderate in the upper part of the profile and very rapid in the lower part of the profile. The available water capacity is low and organic matter content is low. The availability of phosphorus is low, and of potassium is low.

Table B.3.2. (contd.)

8A, 35A	This series consists of gently sloping to steep well drained soils formed in 20 to 40 inches of dark brown, medium acid, gravelly sandy loam glacial till that is underlain by bedrock. The dominant bedrock is gabbro and granite. Surface stones typically occupy less than 5 percent of surface and varies locally to 30 percent. Subsurface coarse fragment content typically is 25 percent. These soils occur on sloping to hilly terrain in the Laurentian Shield country of northeastern Minnesota.
8B, 35B	This series consists of gently sloping to steep well drained soils formed in 8 to 20 inches of brownish and reddish gravelly coarse sandy loam, glacial till underlain by bedrock. Coarse fragment content typically is about 20 percent. Soils are subject to seasonal drouthiness. These soils occur on sloping to hilly terrain in the Laurentian Shield country of northeastern Minnesota.
8C, 9C, 35C	This series consists of somewhat excessively drained soils formed in 4 to 8 inches of dark brown and strong brown, strongly and very strongly acid loam over bedrock. Bedrock outcroppings are common. The terrain is broken, irregular and sloping to hilly. These soils occur within the Laurentian Shield country of northeastern Minnesota.
9A	This series consists of gently sloping to steep well drained soils formed in 20 to 40 inches of brownish medium to very strongly acid, gravelly sandy loam glacial till that is underlain by bedrock. Occurring at depths of 10 to 24 inches is a 5 to 16 inch thick fragipan. These soils occur in the Laurentian Shield country of northeastern Minnesota.
9B	This series consists of gently sloping to steep well drained soils formed in 8 to 20 inches of dark yellowish brown to dark brown, medium to strongly acid, gravelly sandy loam glacial till that is underlain by bedrock. Coarse fragments occupy about 25 percent of the soil material. These soils occur within the Laurentian Shield country of northeastern Minnesota.
17A	This series consists of gently sloping to very steep, well drained soils formed in glacial till. These soils are on convex areas of ground and terminal moraines. Native vegetation was forest. In a representative profile, the surface layer is very dark gray loam about 3 inches thick. The subsurface layer is grayish brown sandy loam about 6 inches thick. The subsoil is dark yellowish brown to light olive brown, firm clay loam. The underlying material is light olive brown loam. The permeability is moderate to moderately slow. The organic matter content is low. The reaction is neutral. The inherent fertility is moderate.

Table B.3.2. (contd.)

17B,58A	These are medium to slightly acid deep very poorly drained organic soils. They consist of moderately decomposed dark reddish brown woody materials throughout most of the layers from 12 to 51 inches. Normally these soils occupy bogs ranging from 10 to more than 600 acres in size. White cedar, tamarack, black spruce and in places black ash are the major trees growing on these soils. Some areas are nearly treeless and have chiefly lowland brush. These soils have a high inherent fertility.
17C	This series consists of nearly level, poorly drained soils formed in calcareous till. The native vegetation is mixed coniferous and deciduous forests. In a representative profile the surface layer is black or grayish brown sandy loam or loam about 12 inches thick. The subsoil horizon is grayish brown loam to clay loam about 24 inches thick. The underlying material is grayish brown loam. Permeability is moderate to moderately rapid. Moderate available water capacity. Inherent fertility is moderate. The reaction is neutral.
25A	This series consists of nearly level, poorly drained soils formed in lake laid sands. These soils are in 3 to 15 acre irregularly shaped slightly depressional areas. Native vegetation was forest. In a representative profile the surface layer is black loamy fine sand about 6 inches thick. The underlying material is light brownish gray fine sand. The permeability is rapid. The available water capacity and inherent fertility are low. The organic matter content is medium. The surface reaction is neutral.
25B	This series consists of excessively drained, sandy, nearly level to sloping soils that formed in glacial outwash. They are rapidly permeable with low available water capacity.
26A	This series consists of deep excessively drained soils formed in glacial outwash under coniferous forest on outwash plains and valley trains. Typically they have black and very dark grayish brown loamy coarse sand 4 inches thick; dark brown, dark yellowish brown and brown coarse sand subsoils 20 inches thick; and pale brown coarse sand underlying material. Slopes range from 0 to 12 percent. Most areas are forested, a few cropped or pastured.
26B	This series consists of deep excessively drained soils formed in sandy outwash under coniferous and deciduous forest on smooth and pitted plains. Typically they have organic layers 2 inches thick; very dark gray and dark grayish brown loamy sand surface layers 2 to 4 inches thick; dark brown loamy sand subsurface layers 10 inches thick; layered brown and yellowish brown coarse sand and dark brown loamy coarse sand subsoil 27 inches thick; and pale brown or brown sand or coarse sand underlying material. Slopes are 0 to 35 percent. The main use is for forestry.

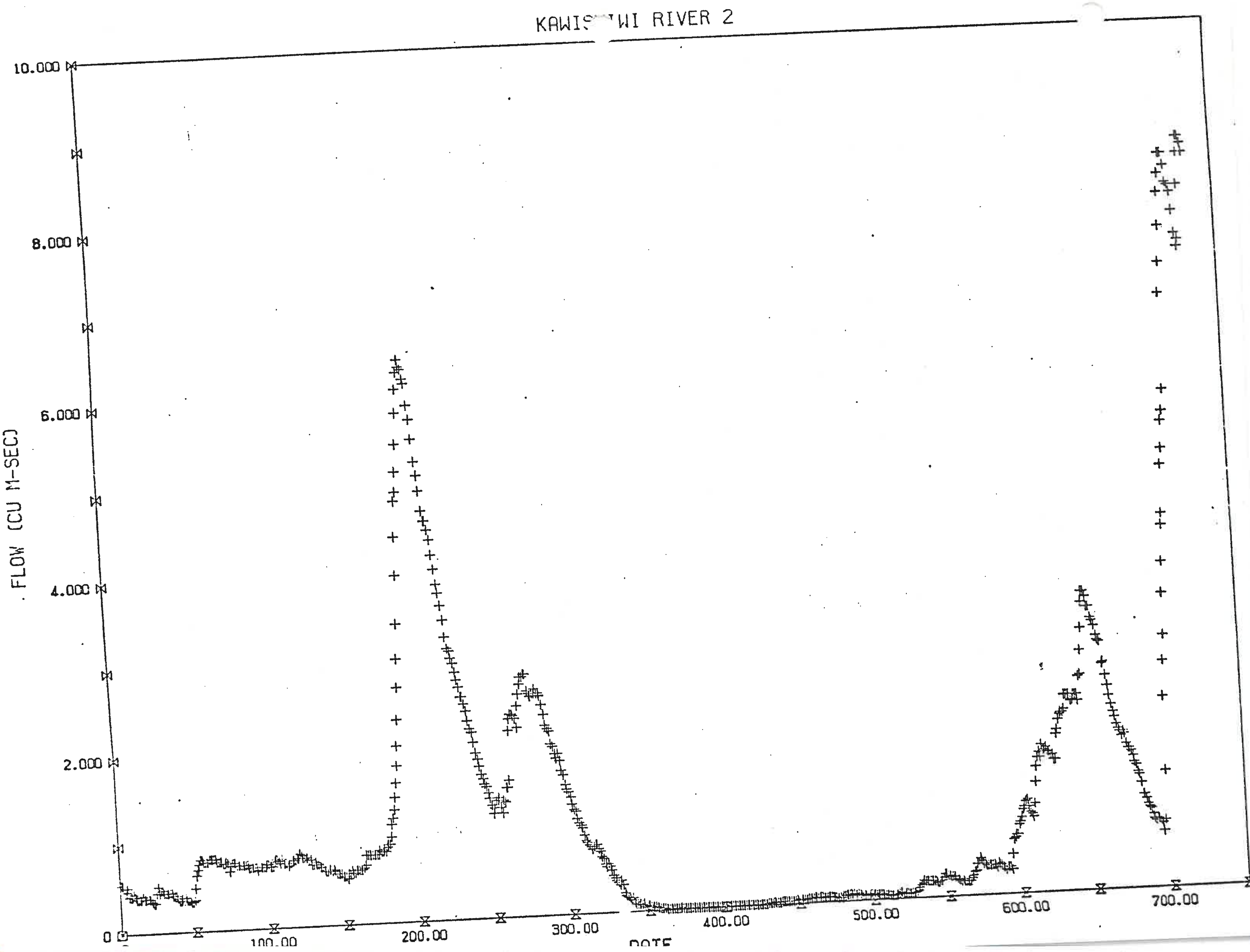
Table B.3.2. (contd.)

41A	This series consists of nearly level to hilly, excessively drained soils formed in reddish brown sand. These soils are on outwash plains and lake beaches. Native vegetation is forest. The surface layer is about 1 inch thick. The subsurface layer is reddish gray loamy sand about 1 inch thick. The subsoil is reddish brown, loamy sand and sand about 21 inches thick. The underlying material is light reddish brown fine sand. Permeability is rapid to very rapid. The available water capacity is low and organic matter content is low. The availability of phosphorus is low and ot potassium is low. Most areas are used for forest, a few areas are used for cultivated crops. The major limitation to use is the hazard of drought.
41B	This series consists of nearly level and gently sloping, somewhat excessively drained soils formed in sandy glacial outwash. These soils are on outwash plains. Native vegetation is forest. In a representative profile the surface layer is black sandy loam about 2 inches thick. The subsoil is dark brown, very friable, sandy loam about 13 inches thick. The underlying material is reddish brown sand. Permeability is moderate in the upper and rapid in the lower part of the profile. The available water capacity and organic matter content is low. The availability of phosphorus and potassium is low. Most areas soils are used for forest; and forage after clearing. The major limitation to use is drought.
49A,50B	This series consists of deep somewhat poorly and poorly drained soils formed in reddish brown clayey glacial till under a deciduous and coniferous forest on nearly level till plains and good moraine. Typically they have grayish brown loam surface layers 9 inches thick; reddish brown clay subsoil layers 25 inches thick; reddish brown silty clay underlying material. Slopes range from 0 to 2 percent.
49B,50A	This series consists of nearly level to hilly, well and moderately well drained soils formed in reddish brown clayey material. These soils are on moraines and lake plains. Native vegetation is forest. The surface layer is dark gray loam about 2 inches thick. The subsurface layer is grayish brown loam about 6 inches thick. The subsoil is reddish brown clay about 26 inches thick. The underlying material is reddish brown clay; permeability is slow. The available water capacity is moderate and organic matter content is low. The availability of phosphorus is low and potassium is low.
57A	These are extremely to very strongly acid deep organic soils. They consist of moderately decomposed dark brown or dark reddish brown herbaceous material throughout most of the layers from 12 to 51 inches. Normally these soils occupy bogs ranging from 10 to more than 600 acres in size. Black spruce along with a few tamarack are the major trees growing on these soils. The permeability is moderate to moderately rapid. The available water capacity is very high.

Table B.3.2. (contd.)

59A	These soils are extremely acid, deep organic soils. They consist of slightly decomposed, reddish brown sphagnum fibers throughout most of the upper 5 feet. Normally they occupy areas within large bogs that have slightly convex surfaces. Mapped areas are usually circular or oblong and range from about 100 to more than 600 acres in size. Black spruce along with a few tamarack are the major trees growing on these soils.
59B	These are extremely acid, deep organic soils. They consist of slightly decomposed reddish brown sphagnum material throughout the upper three to four feet. Below this is moderately decomposed, dark reddish brown herbaceous material. These soils occur in relatively narrow bands around the outer edge of large raised bogs and in circular or oblong areas in small bogs.

Appendix B.4. Daily Mean Discharge vs Time, 11 Stream Stations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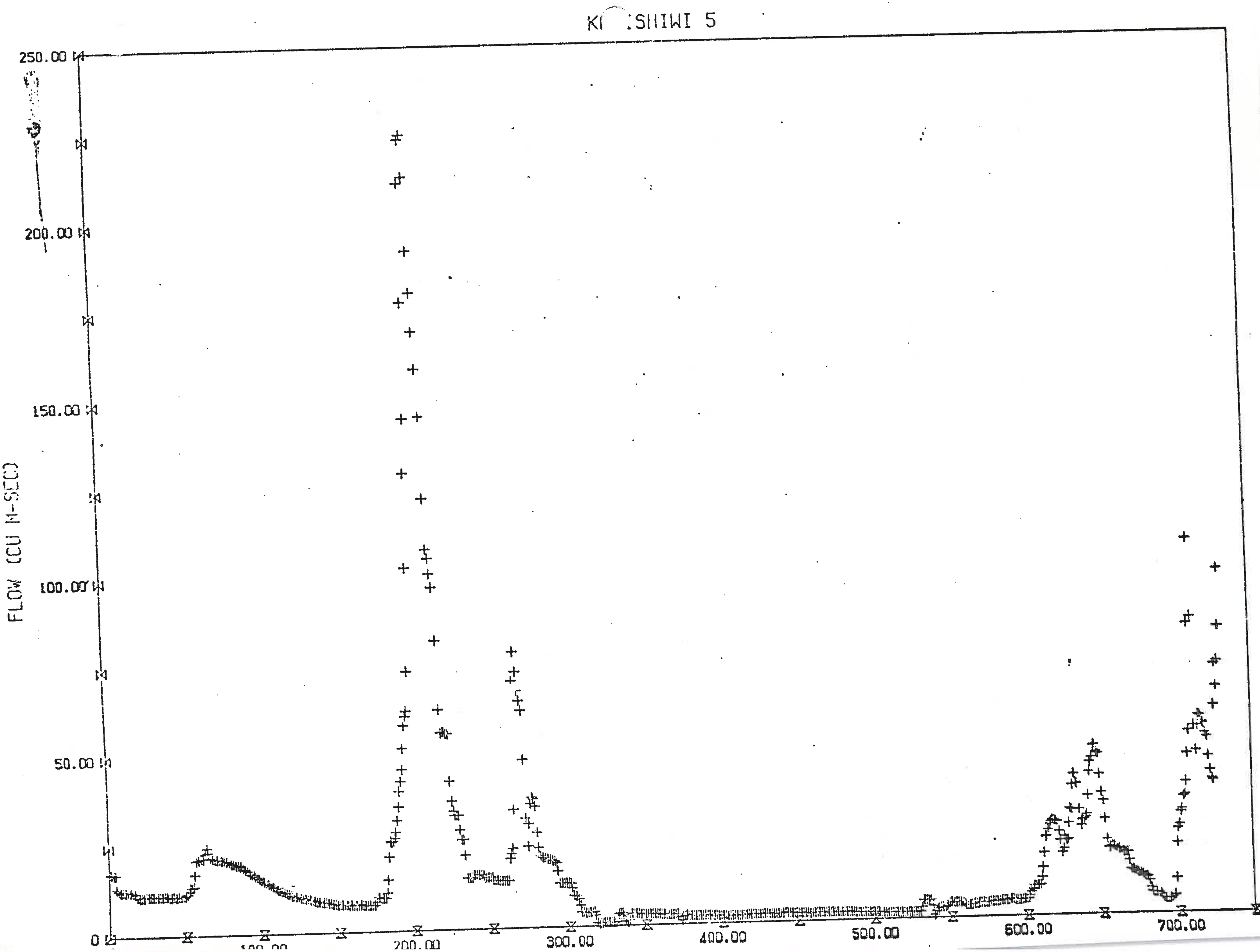
FLOW (CU M-SEC)
10.000
8.000
6.000
4.000
2.000
0
100.00
200.00
300.00
400.00
500.00
600.00
700.00
DATE


KI :SHIWI 5
FLOW (CU M-SEC)
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150.00
100.00
50.00
0
200.00
300.00
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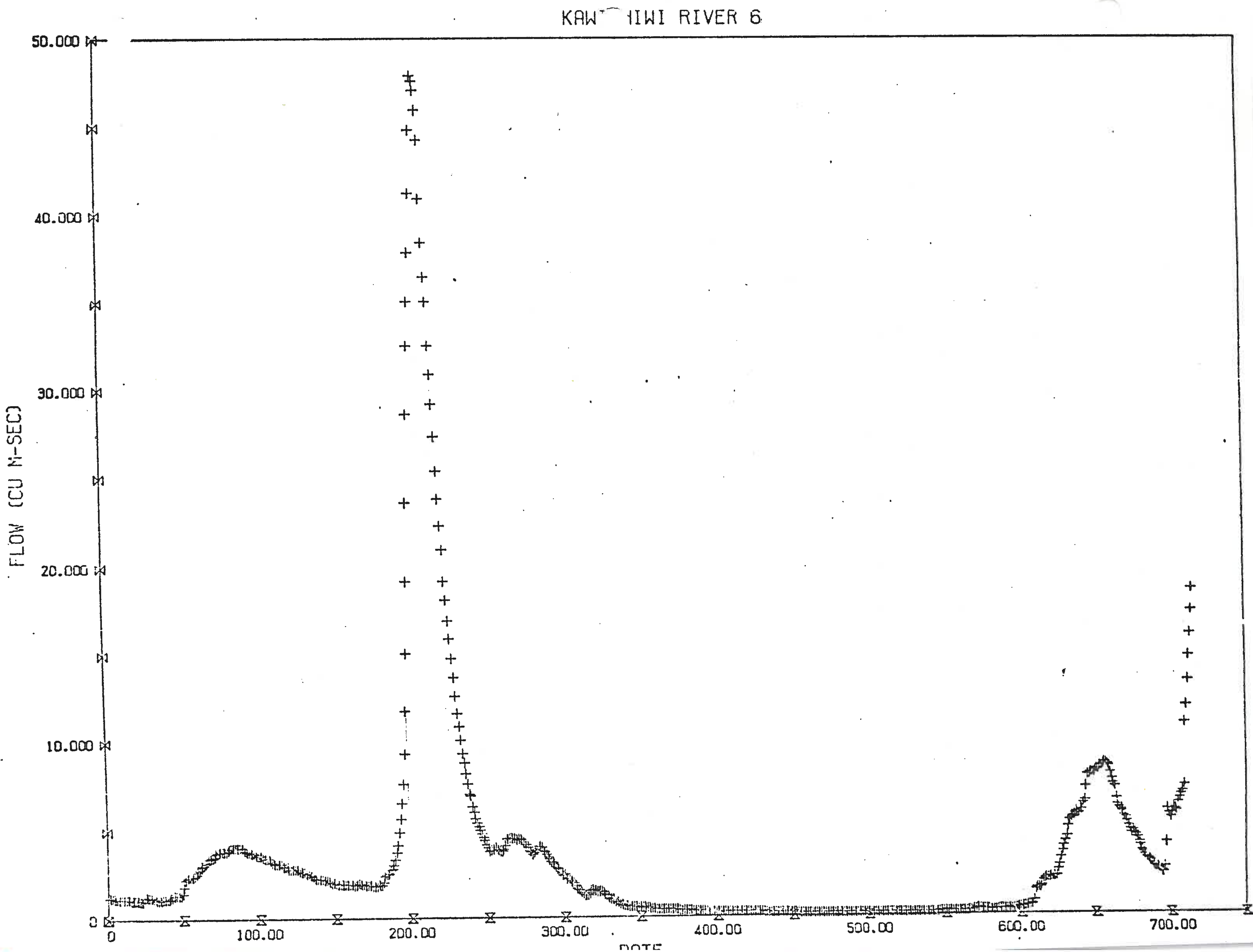
500.00
600.00
700.00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FLOW (CU M-SEC)
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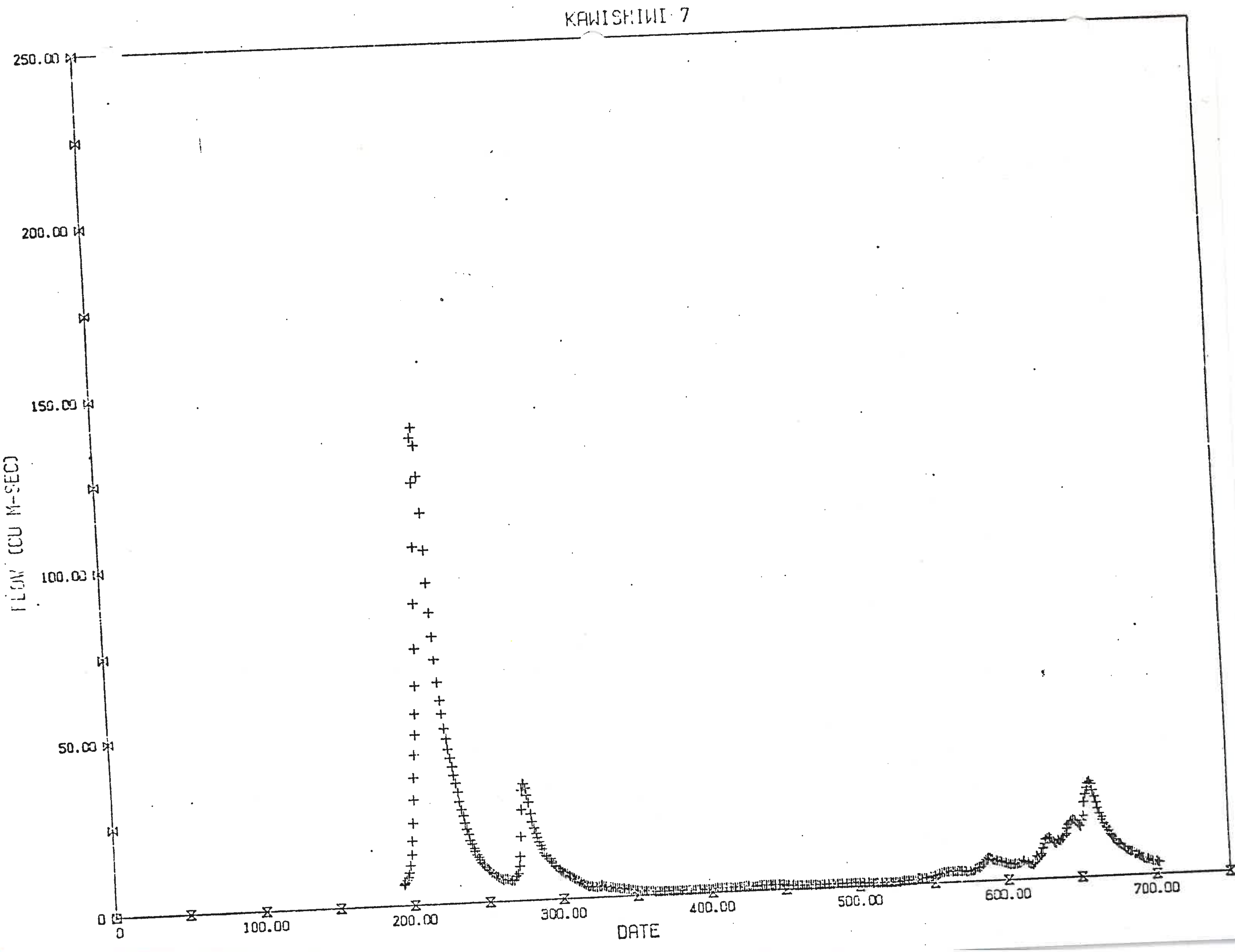
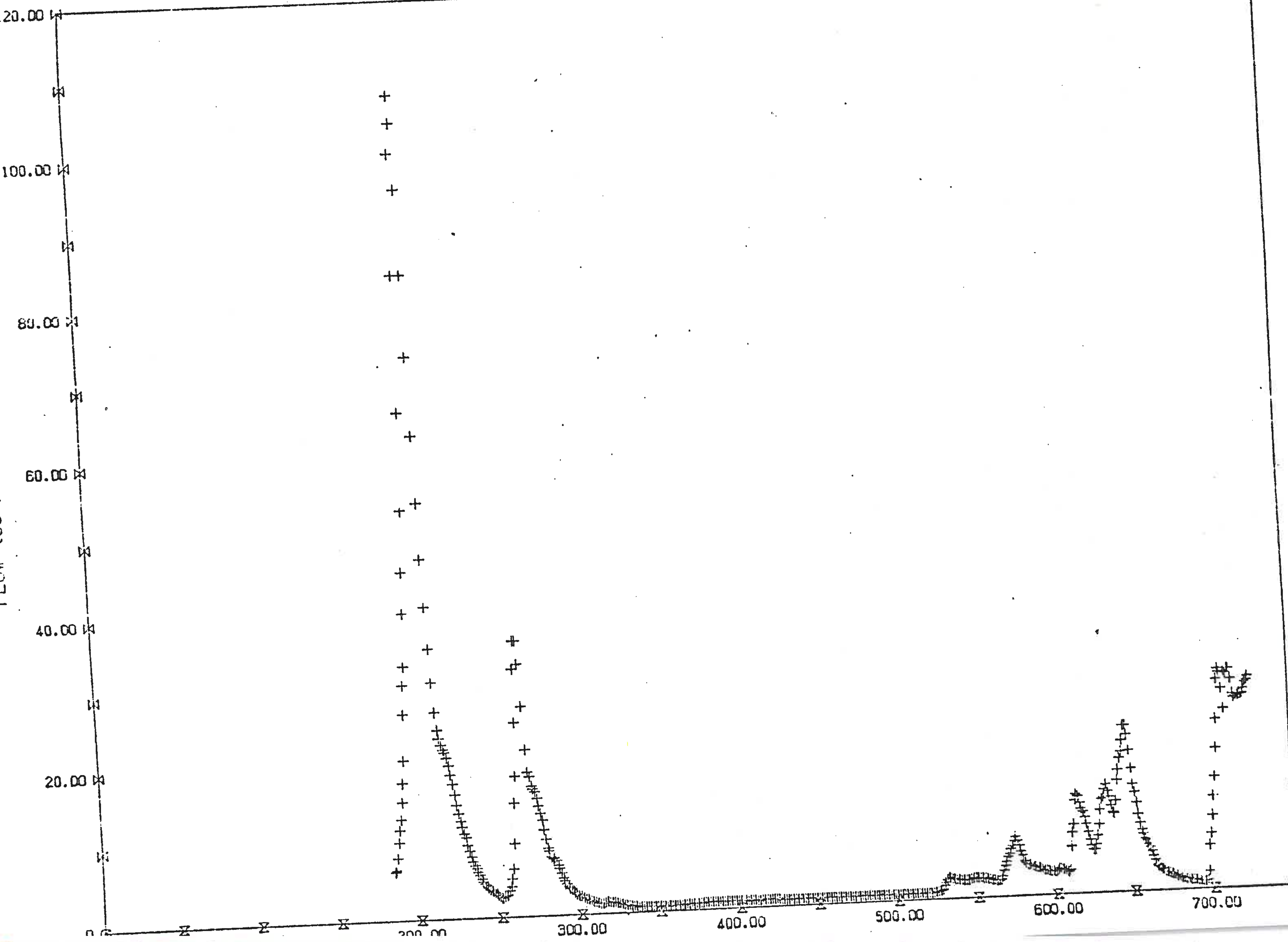
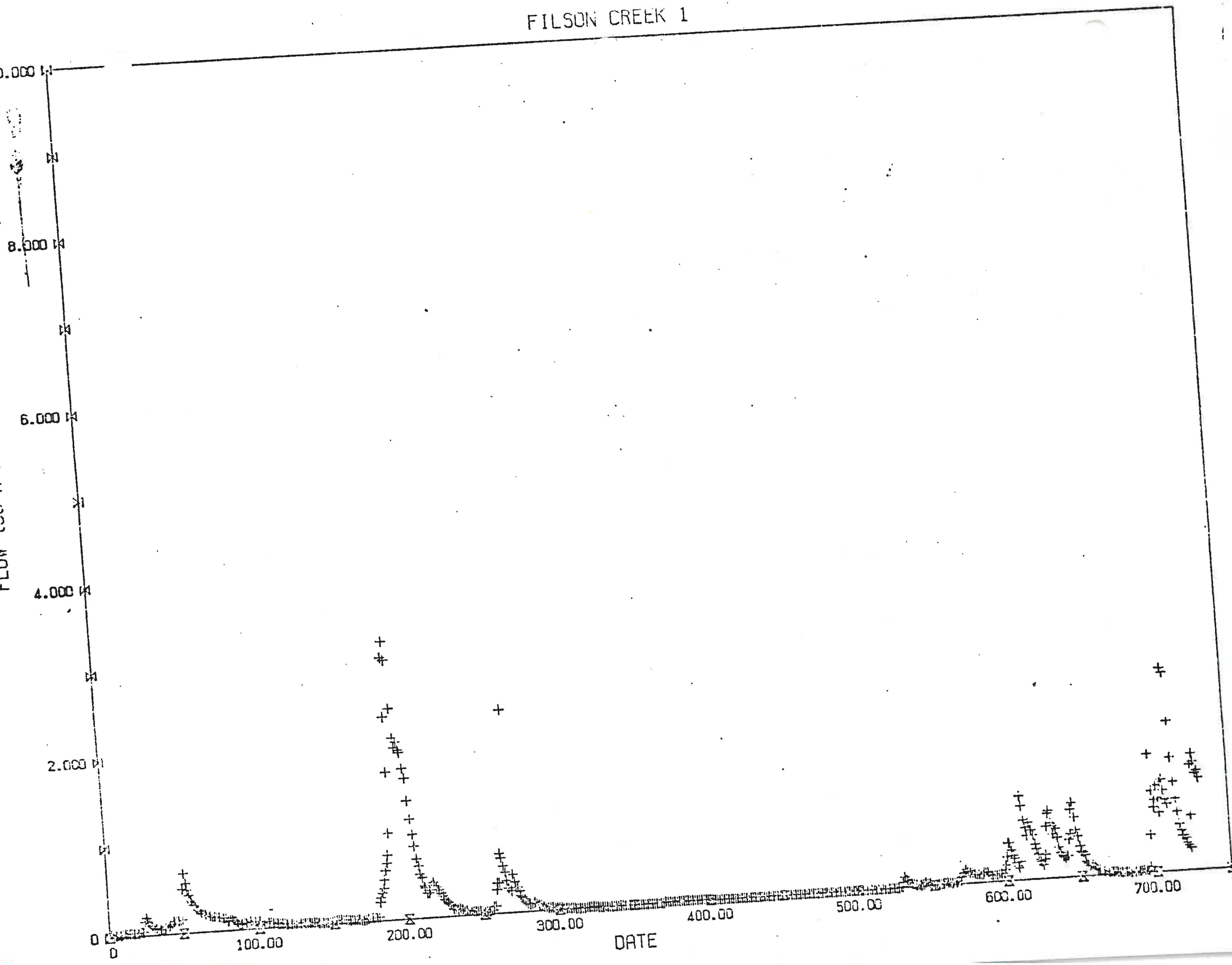
40.000
30.000
20.000
10.000
0
0
100.00
200.00
300.00
400.00
500.00
600.00
700.00

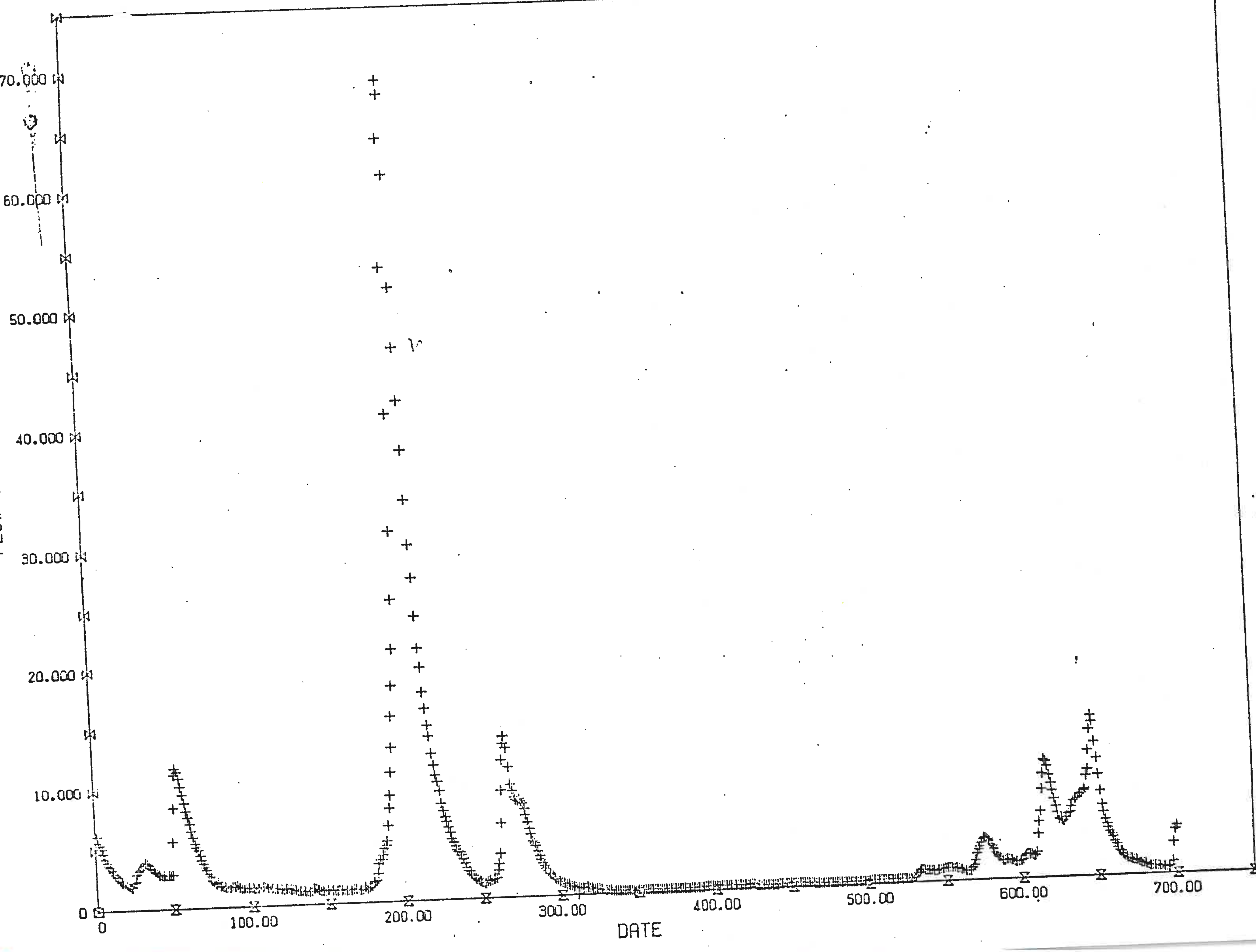

KAWISHIWI 7
250.00
200.00
150.00
100.00
50.00
0
FLOW (CU M-SEC)
0
100.00
200.00
300.00
400.00
500.00
600.00
700.00
DATE

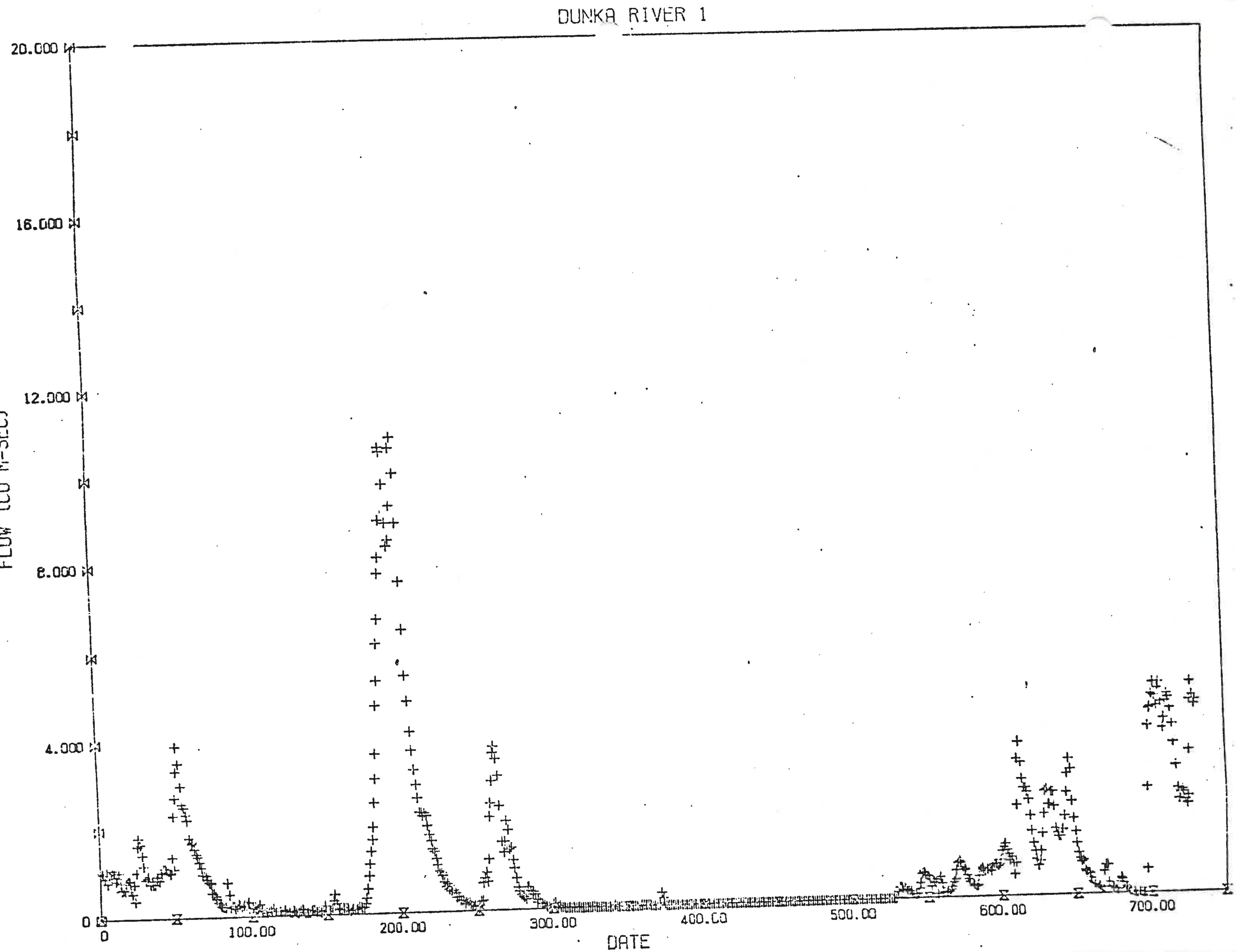
ISABELL RIVER 1




FILSON CREEK 1
0.000
8.000
6.000
4.000
2.000
0
0
100.00
200.00
300.00
400.00
500.00
600.00
700.00
DATE

STONY RIVER 2

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FLOW (CU M-SEC)
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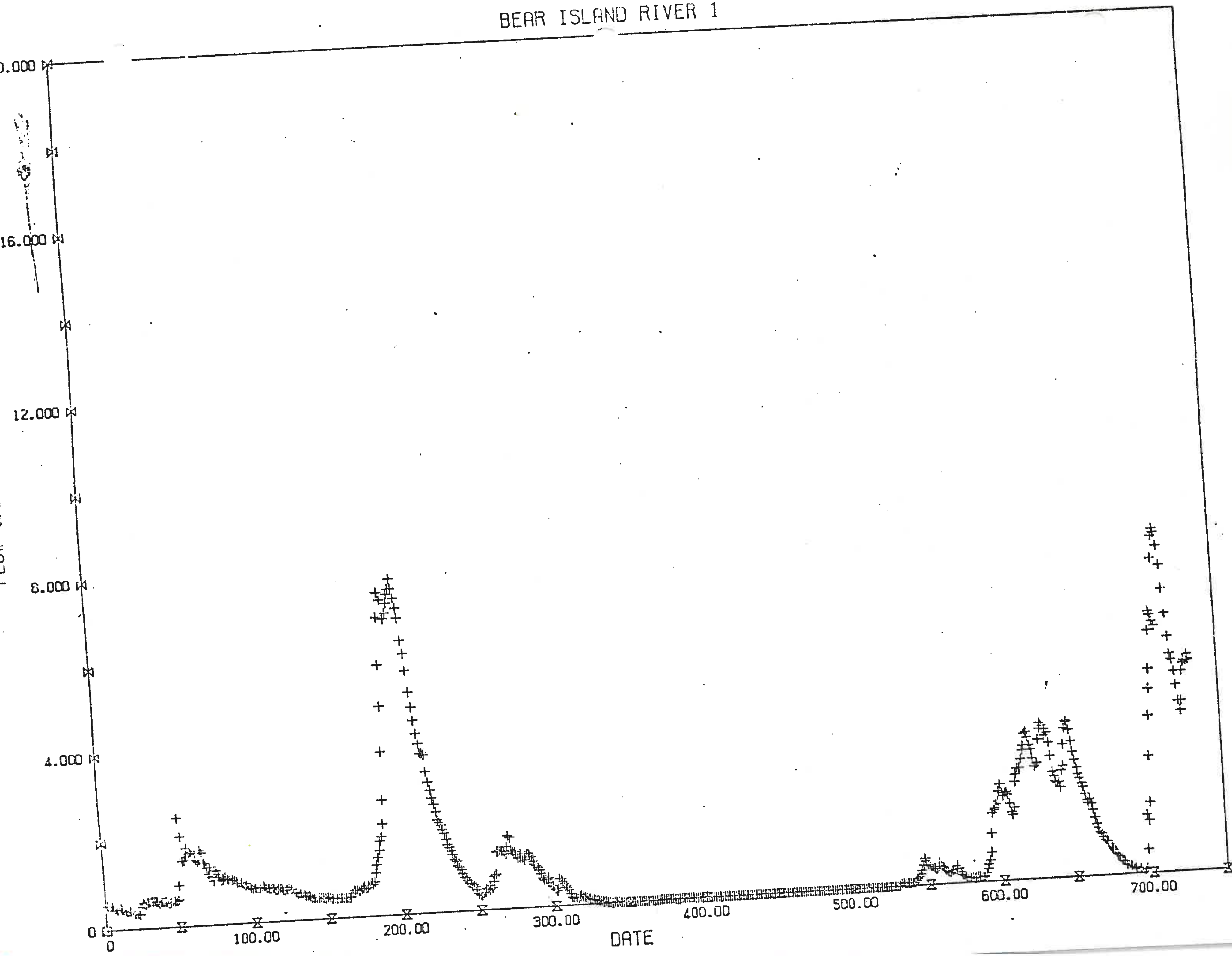
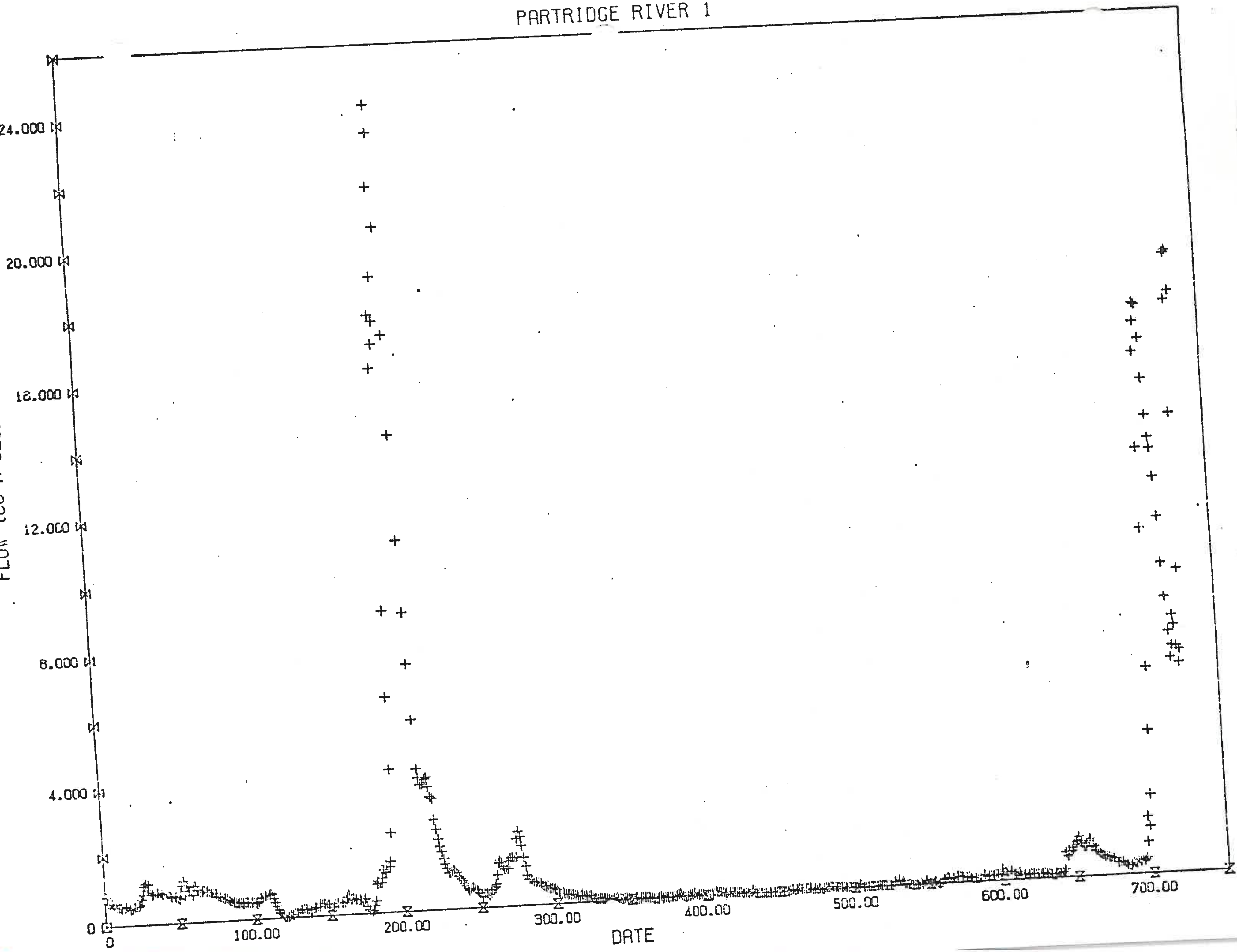
16.000
12.000
8.000
4.000
0
0
100.00
200.00
300.00
400.00
500.00
600.00
700.00
DATE

BEAR ISLAND RIVER 1




PARTRIDGE RIVER 1
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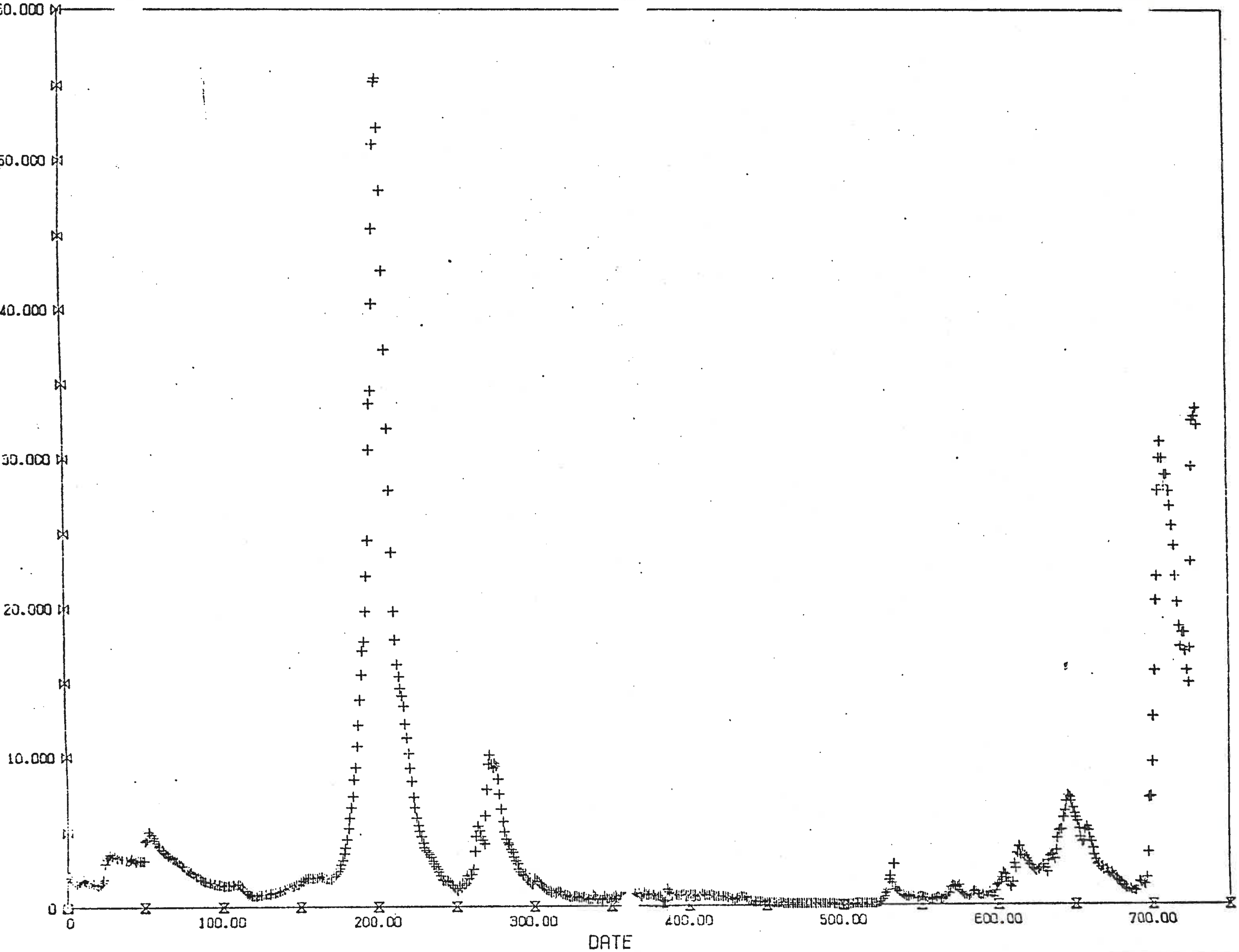
20.000
16.000
12.000
8.000
4.000
0
0
100.00
200.00
300.00
400.00
500.00
600.00
700.00
DATE

ST. LOUIS RIVER 1



Appendix B.5. Stream orders and lengths in Water Quality Research Area.

WATERSHED	ORDER AND LENGTH (km^2) 1st	2nd	3rd	4th	5th	TOTAL
Kawishiwi River						
Isabella River	207	150	118	50	19	544
Filson Creek	14	.2				14
Keeley Creek	11	7				18
Stony River	105	81	53	39.7		279
Unnamed Creek	2.8					2.8
Dunka River	34.5	16	12.8			63
Bear Island River	33	21	23.3			77
Shagawa River	60	49	23.6	3		136
Total North of Laurentian Divide						
Embarrass River	40	13	23			76
Partridge River	81.1	57	14	31		183
St. Louis River	38	14.4	64	6.7		123
Whiteface River	51.7	4.3	26			82
Water Hen Creek	32.5	17.3	17.3	3.8		71
Total South of Laurentian Divide	243	106	144	41		535
Total Water Quality Research Area						

Appendix B.6. Dams in the Water Quality Research Area.

NAME	WATERSHED	HYDRAULIC HEIGHT M	YEAR CONSTRUCTED
Gabbro Lake #1	Kawishiwi	4.0	1927
Gabbro Lake #2	Kawishiwi	2.1	1924
Birch Lake	Kawishiwi	2.4	1923
Fall Lake	Kawishiwi	1.2	1959
Winton Dam (Garden Lake)	Kawishiwi	12.5	1923
No. Kawishiwi River	Kawishiwi	.9	----
Lower Sand Lake	Stony	.6	----
McDougal Lake	Stony	2.4	1941
Slate Lake	Stony	.9	----
Stony River	Stony	1.5	----
Bear Island Lake	Bear Island	1.8	1920
Bear Island River	Bear Island	1.8	----
Shagawa Lake	Shagawa	4.9	----
Wynne Lake	Embarrass	3.7	1944
St. Louis River	St. Louis	1.5	----

Appendix B.7. Classification of lakes and streams in the Water Quality Research Area.

Table B.7.1. MPCA classification of lakes.

WATERS	LOCATION	USE CLASS
Intrastate Waters (WPC 24)		
Rainy River Watershed		
Burntside	T63, R12-13	1B, 2A, 3B
Clark	T63, R14	1B, 2B
Clearwater[a]	T62, R9-10	1B, 2B
Crab	T63, R13-14	1B, 2A, 3B
Dry	T63, R12	1B, 2A, 3B
High	T63-64, R12	1B, 2A, 3B
Jasper	T65, R5	1B, 2A, 3B
Johnson	T67-68, R17-18	1B, 2A, 3B
Djibway	T68, R9-10	1B, 2A, 3B
Snowbank	T63-64, R9	1B, 2A, 3B
Tofte[a]	T63-64, R10	1B, 2A, 3B
All other lakes in BWCA		1B, 2B
St. Louis River Watershed		
Colby[a]	T58, R14	1B, 2B, 3B
Interstate Waters (WPC 25)		
Rainy River Watershed		
Birch[a]	T64-65, R8-9	1B, 2B
Fall[a]	T63-64, R11-12	1B, 2B
Newton	R63-64, R11	1B, 2B
St. Louis River Watershed		
Seven Beaver[a]	T58, R11-12	2B, 3A

[a]Lakes sampled by Copper-Nickel Study.

Appendix B.7. (contd.)

Table B.7.2. DNR fisheries lake classifications.

LAKE NAME	DNR FISHERIES CLASSIFICATION[a]
Primary Lakes	
Birch	SW - W
Gabbro	SW - W
White Iron	SW - W
Colby	C - W
Seven Beaver	SW - W
August	SW - W
Whiteface Reservoir	SW - W
Survey Lakes	
Tofte	T
Triangle	Unclassified
Clearwater	RF - GF
One	SW - W
Fall	SW - W
Turtle	RF - GF
Greenwood	SW - W
Sand	SW - W
Slate	SW - W
South McDougal	SW - W
Bass	C
Bear Island	SW - W
Perch	C
Bearhead	SW - W
Pine	SW - W
Long	RF - GF - NP
Big	C - W
Wynne	SW - W
Cloquet	RF - GF

[a] SW-W = Soft-water walleye
GF = Game fish
NP = Northern pike
C-W = Centrarchid-walleye
T = Managed for stream trout
RF = Rough fish

Appendix B.7. (contd.)

Table B.7.3. MPCA classification of streams.

WATERS	LOCATION	USE CLASS
Intrastate Waters (WPC24)		
Rainy River Watershed		
August Creek	T61-62,R10	2B
Bear Creek	T63,R15	2B
Dunka River	T59-60,R12	2B
Grassy Creek	T61,R13-14	1B,2A,3B
Greenwood River	T59,R10	2B
Gustafson (Armstrong) Creek	T63-63,R12-13	2B
Harris Lake Creek	T61,R10	1B,2A,3B
Hil Creek	T60,R8-9	1B,2A,3B
Little Isabella River (excluding trout waters)	T59-60-61-62,R8-9	2B
Little Isabella River	T59-60,R8	1B,2A,3B
Longstorff Creek	T62-63,R12	1B,2A,3B
Mike Kelly Creek	T60,R11	1B,2A,3B
Mitawan Creek	T60-61,R8-9	1B,2A,3B
Pike River	T59-60-61, R15-16	2B
Purvis Creek	T62,R13	1B,2A,3B
Section Thirty Creek	T63,R11-12	1B,2A,3B
Snake River	T61,R9	1B,2B
Sphagnum Creek	T60-61,R9	1B,2A,3B
Stony River	T58-59-60,R9-10-11	2B
East Two Rivers	T61-62,R14-15	1B,2A,3B
West Two Rivers Tributary	T61,R15	1B,2A,3B
Victor Creek	T60,R9	1B,2A,3B
Weiss Creek	T59-60,R9	1B,2A,3B
All other streams in BWCA		1B,2B
St. Louis River Watershed		
First (Mud) Creek	T58-59,R15	2A,3B
Banner Brook	T58,R13	1B,2A,3B
Berry Creek	T55-56,12-13	1B,2A,3B
Cloquet River	T51 to 55,R12 to 18	2B
Cloquet River, West Branch	T55-56,12-13	2B
Cranberry Creek	T58,R13	2C
Embarrass River	T59-60,R13-14-15	2B
Whiteface River (Hornby Junction Ck)	T55-56,R13	1B,2A,3B
Indian Creek	T55-56,R12	1B,2A,3B
Langley River (Not the tributary of the Dunka River)	T56,R10-11	2B
Little Langley River	T55-56,R10-11	2B
Mud Creek, Little	T57,R11	1B,2A,3B
Mud Hen Creek	T56,R17	2B
Murphy Creek	T56-57,R11	1B,2A,3B
Paleface River	T54-55,R16-17	2B
Partridge River	T58,R13-14-15	2B
Stephens (Stevens)(Second)Creek	T58-59,R15	2A,3B
Sullivans Creek	T56-57,R10-11	1B,2A,3B

Table B.7.3. (contd.)

WATERS	LOCATION	USE CLASS
St. Louis River Watershed (contd.)		
Trappers Creek	T56,R11	2C
Water Hen Creek	T56,R15-16	2B
South Branch Water Hen Creek	T56-57,R14-15	2B
Whiteface River	T52-53-54,R17-18-19	2B
Wolf Creek	T56,R12,13	2B
Wyman Creek	T58-59,R14	1B,2A,3B
Interstate Waters (WPC 25)		
Rainy River Watershed		
Kawishiwi River	source to Fall Lake	1B,2B,3B
St. Louis River Watershed		
St. Louis River	Seven Beaver Lake outlet to Cloquet	2B,3B
St. Louis River	Cloquet to Clough Island	2C,3B

All intrastate waters not specifically named are classified as 2B,2C,3B,3C,4A, and B5 and 6.
All interstate waters not specifically named are classified as 2C,3C,4A and B, 5 and 6.

Underlined streams were sampled by Copper-Nickel Study.

Appendix B.7. (contd.)

Table B.7.4. Minnesota and USEPA surface Water Quality Standards.[a]

MINNESOTA					USEPA[b]
Class 1. Domestic Consumption	1A	1B	1C	1D	
Total coliform organisms MPN	1	10	200	S	---
Turbidity value NTU	5	S	S	--	---
Color value pt-co	15	S	S	--	7.5
Threshold odor number TON	3	S	S	--	---
Methylene blue active substance	0.5	S	S	--	---
Arsenic	0.01	S	S	0.05	0.05
Chlorides	250	S	S	--	---
Copper	1	S	S	--	1
Carbon chloroform extract	0.2	S	S	--	---
Cyanides	0.01	S	S	0.2	---
Fluorides	1.5	S	S	S	---
Iron	0.3	S	S	--	0.3
Manganese	0.05	S	S	--	0.05
Nitrates	45	S	S	--	0.01
Phenol	0.001	S	S	--	0.001
Sulfates	250	S	S	--	---
Total dissolved solids	500	S	S	--	---
Zinc	5	S	S	--	5
Barium	1	S	S	S	1
Cadmium	0.01	S	S	S	0.01
Chromium (Hexavalent)	0.05	S	S	S	0.05
Lead	0.05	S	S	S	0.05
Selenium	0.01	S	S	S	0.01
Silver	0.05	S	S	S	0.05
Radioactive material	S	S	S	S	---
Class 2. Fisheries and Recreation	2A	2B	2C	--	
Dissolved oxygen	7or6	6or5	5or4		5
Temperature °F	C	S	S		C
Ammonia	0.2	1	1.5		0.02 AL
Chlorides	50	---	---		0.002 to 0.01
Chromium	0.02	0.05	S		0.1
Copper	0.01,C	S	S		C
Cyanides	0.02	S	S		0.005
Oil	0.5	S	10,C		C
pH value standard units	6.5-8.5	6.5-9.0	S		6.5-9.0
Phenols	0.01,C	S	S		0.001
Turbidity value NTU	10	25	S		C
Color value pt-co	30pc	---	---		---
Fecal coliform organisms MPN	200MPN	S	S		200
Radioactive materials PCJ/L	C	S	S		---

Table B.7.4. (contd.)

MINNESOTA					USEPA[b]
Class 3. Industrial Consumption	3A	3B	3C	---	
Chlorides	50	100	250		---
Hardness	50	250	500		variable
pH standard units	6.5-8.5	6.0-9.0	S		---
Fecal coliform organisms MPN	200	S	S		---
Class 4. Agriculture & Wildlife	4A	4B	---	---	
Bicarbonates meq/L	5	---			---
Boron	0.5	---			0.75
pH standard units	6.0-8.5	6.0-9.0			---
Specific conductance μs	1000	---			---
Fecal coliform organisms MPN	200	---			---
Sulfates	10	---			---
Radioactive materials PCI/L	C	C			---
Unspecified toxic substances	---	C			---
Total dissolved salts	700	1000			---
Sodium	C	---			---
Class 5. Navigation & Waste Disposal	5A	---	---	---	
Fecal coliform organiams MPN	200	---			
pH standard units	6.0-9.0	---			
Hydrogen sulfide	0.02	---			
Class 6. Other Uses	---	---	---	---	

No specific standards assigned to this class, but Agency reserves right to "impose any standards necessary for the protection of this class."

Table B.7.4. (contd.)

Parameters in various classes for which Minnesota has no standard but EPA does.

	STANDARD	CLASS
Alkalinity	20	Aquatic life
Arsenic	0.1	Aquatic life
Cadmium	0.0004 to 0.012[d]	Aquatic life
Iron	1.0	Aquatic life
Lead	C	Aquatic life
Mercury	0.002	Domestic use
	0.00005	Aquatic life
Nickel	C	Aquatic life
pH standard units	5-9	Domestic use
Selenium	C	Aquatic life
Chlorides and Sulfates	250	Domestic use
Sulfide-Hydrogen sulfide	0.002 H_2S	Aquatic life
Beryllium	0.011 to 1.1[d]	Aquatic life
	0.1 to 0.5[e]	Agriculture
Zinc	C	Aquatic life

[a]Units in mg/L unless noted otherwise.
[b]USEPA standards for pesticides and those that apply to marine organisms are not included.
[c]Narrative standard.
[d]Standard varies with hardness of water and sensitivity of organisms.
[e]Standard varies with type of soil.

S = Same value as in previous column.
-- = No standard or no class.

Appendix B.8. Lake stratification definitions.
(SOURCE: Ruttner, F. 1952. Fundamentals of limnology. Univ. of Toronto Press, Toronto and Buffalo, 195 pp)

Four types of lakes, based on stratification, were found among the monitored lakes in the Study Area.

1) Lakes which do not stratify.

2) Monomictic lakes: lakes which have only one period of circulation during a year. Tofte Lake was the only monomictic lake monitored.

3) Dimictic lakes: lakes which have two turnovers per year, in spring and fall. These lakes have been further classified as:

   a) strongly dimictic: lakes characterized by well-defined thermal and oxygen profiles.
   b) weakly dimictic: lakes which have less well-defined thermal and oxygen profiles. Hypolimnetic waters do not become anoxic.

APPENDIX C

MLMIS STATISTICS FOR WATERSHEDS

Appendix C.1. 1969 Land Use in Water Quality Research Area. (In Percent)
(Source: Minnesota Land Management Information System)

LAND USE[a] / Region / Area(km^2)	RESEARCH AREA (4738)	KAWISHIWI WATERSHED (1346)	LITTLE ISABELLA SUBWATERSHED (132)	ABOVE[b] I-1 (883)	ABOVE SR-5 (125)	ABOVE SR-4 (161)	ABOVE SR-3 (466)	ABOVE SR-2 (567)	ABOVE[b] SR-1 (632)
Forested	89.36	84.62	95.54	94.85	95.35	98.48	94.92	95.52	95.86
Cultivated	.18	.04	0	0	0	0	0	0	0
Water	7.02	13.07	2.29	4.46	4.65	1.20	4.04	3.54	3.28
Marsh	.53	.62	.12	.15	0	.22	.77	.71	.66
Urban Residential	.54	.86	.24	.15	0	0	.24	.20	.18
Extractive	1.02	.05	0	0	0	0	0	0	0
Pasture & Open	1.05	.44	1.20	.31	0	0	0	0	0
Urban & Nonresidential or Mixed Residential	.28	.25	.48	.07	0	.11	.03	.03	.03
Transportation	.02	.05	.12	.02	0	0	0	0	0

Appendix C.1. (contd.)

LAND USE[a] / Region / Area(km^2)	ABOVE[b] SH-1 (256)	ABOVE K-7 (1474)	ABOVE K-6 (655)	ABOVE K-5 (2536)	ABOVE K-4 (2779)	ABOVE K-3 (3170)	ABOVE[c] K-1 (3489)	ABOVE WF-1 (24)	ABOVE WF-2 (124)	WHITEFACE WATERSHED (148)	ABOVE[b] W-1 (118)	SOUTH OF LAURENTIAN DIVIDE (1249)
Forested	75.67	91.70	89.03	91.56	90.94	90.60	89.10	97.28	98.84	98.60	87.03	90.01
Cultivated	0	0	0	.02	.02	.02	.02	0	0	0	1.93	.62
Water	19.60	7.54	10.60	6.79	7.21	7.53	8.69	0	.90	.76	.55	2.40
Marsh	.06	.38	.34	.54	.54	.54	.49	0	0	0	0	.65
Urban Residential	2.25	.08	.02	.24	.38	.41	.62	0	.13	.11	0	.30
Extractive	0	0	0	.38	.35	.34	.31	0	0	0	0	2.97
Pasture & Open	.97	.26	0	.38	.44	.42	.50	2.72	.13	.54	10.48	2.60
Urban & Nonresidential or Mixed Residential	1.46	.04	0	.08	.10	.10	.25	0	0	0	0	.37
Transportation	0	.01	0	.01	.03	.03	.02	0	0	0	0	0

[a]See Appendix B for land use category definitions.
[b]Constitutes entire watershed.
[c]Constitutes area north of Laurentian Divide.

Appendix C.2. 1977 Land Use in Water Quality Research Area. (In Percent)
(Source: Minnesota Land Management Information System)

LAND USE[a] / Region / Area(km^2)	ABOVE[b] F-1 27	ABOVE[b] KC-1 29	ABOVE[b] BB-1 11	ABOVE D-2 44	ABOVE[b] D-1 128	ABOVE[b] BI-1 177	ABOVE E-2 46	ABOVE[b] E-1 229	ABOVE P-5 32	ABOVE P-4 48
Mineland	0	0	26.67	0	11.99	0	1.61	2.41	45.77	0
Manufacturing-Industrial	0	0	0	0	.35	.09	0	0	0	0
Urban	0	0	0	0	0	0	4.52	.96	0	0
Rural Residential	0	0	0	0	0	.91	1.29	.34	0	0
Rural Commercial	0	0	0	0	0	0	0	0	0	0
Transportation	0	0	0	0	.12	.36	0	0	0	0
Agriculture	0	0	0	0	0	.18	3.55	3.72	0	0
Forest	85.62	88.46	44.00	70.11	55.11	65.52	77.42	63.02	20.00	76.47
Swamps/Marshes/Bogs	12.42	6.59	0	24.91	18.21	19.42	3.23	19.40	24.23	15.92
Water	1.31	.55	2.67	0	.71	8.08	.65	1.38	1.92	6.57
Open/Vacant	.65	4.40	26.67	4.98	13.51	5.44	7.74	8.26	8.08	1.04

Appendix C.2. (contd.)

LAND USE[a] / Region / Area(km^2)	ABOVE P-3 47	ABOVE P-2 264	ABOVE P-1 335	SECOND CREEK SUBWATERSHED 69	PARTRIDGE WATERSHED 404	ST. LOUIS WATERSHED 350	ABOVE SL-3 157	ABOVE SL-2 243	ABOVE SL-1 754
Mineland	0	8.54	10.50	61.46	18.51	.05	0	0	10.13
Manufacturing-Industrial	0	0	.18	0	.15	.05	0	0	.10
Urban	0	0	.77	.98	.80	0	0	0	.44
Rural Residential	0	.06	.05	0	.04	.05	0	0	.04
Rural Commercial	0	0	0	0	0	0	0	0	0
Transportation	0	0	0	0	0	0	0	0	0
Agriculture	0	0	0	0	0	1.01	0	0	.46
Forest	57.59	51.59	52.82	29.27	49.12	55.72	40.56	47.35	52.11
Swamps/Marshes/Bogs	27.85	24.05	20.59	7.07	18.47	38.15	52.64	46.72	27.40
Water	.95	1.68	3.36	.73	2.95	4.01	6.42	5.49	3.43
Open/Vacant	13.61	14.07	11.73	.49	9.96	.99	.38	.44	5.88

[a]See Appendix B for land use category definitions.
[b]Constitutes entire watershed.

Appendix C.3. 1972 Forest Cover Type in Water Quality Research Area. (In Percent)
(Source: Minnesota Land Management Information System)

FOREST COVER	Region / Area (km^2)	RESEARCH AREA (4738)	KAWISHIWI WATERSHED (1346)	LITTLE ISABELLA SUBWATERSHED (132)	ABOVE[a] I-1 883	ABOVE[a] F-1 (27)	ABOVE[a] KC-1 (29)	ABOVE SR-5 (125)	ABOVE SR-4 (161)	ABOVE SR-3 (466)	ABOVE SR-2 (567)	ABOVE[a] SR-1 (632)
White, Red, or Jack Pine		27.44	40.97	53.86	66.28	37.91	22.53	13.01	5.76	13.57	12.49	15.49
Spruce-Fir		22.83	11.58	24.58	15.64	5.23	21.43	52.32	70.22	55.15	53.48	49.18
Maple-Birch-Basswood		.03	.01	0	0	0	0	.13	0	.10	.08	.08
Aspen-Birch		39.90	40.32	18.55	14.86	56.86	52.75	27.09	14.57	21.12	23.82	26.05
Unproductive		2.61	1.42	.96	.78	0	0	2.79	4.57	2.68	3.34	3.13
Nonforested		7.20	5.70	2.05	2.44	0	3.30	4.65	4.89	7.38	6.77	6.08

Appendix C.3. (contd.)

FOREST COVER / Region Area(km^2)	ABOVE[a] BB-1 (11)	ABOVE D-2 (44)	ABOVE[a] D-1 (128)	ABOVE[a] BI-1 (177)	ABOVE[a] SH-1 (256)	ABOVE K-7 (1474)	ABOVE K-6 (655)	ABOVE K-5 (2536)	ABOVE K-4 (2779)	ABOVE K-3 (3170)	ABOVE[b] K-1 (3489)	ABOVE E-2 (46)	ABOVE[a] E-1 (229)
White, Red, or Jack Pine	9.33	0	3.06	5.72	7.34	60.43	48.19	41.32	38.64	39.58	36.63	6.45	2.00
Spruce-Fir	30.67	30.96	27.14	14.07	9.65	13.53	11.29	24.07	23.02	21.32	20.13	11.61	27.34
Maple-Birch-Basswood	0	0	0	.36	0	0	0	.02	.04	.04	.04	0	0
Aspen-Birch	41.33	49.47	42.30	67.33	76.27	72.07	37.86	27.41	30.43	31.69	35.70	70.97	52.13
Unproductive	0	19.22	11.87	8.08	.18	.78	.51	2.20	2.66	2.39	2.18	.32	8.26
Nonforested	18.67	.36	15.63	4.45	6.55	3.20	2.15	4.98	5.21	4.98	5.32	10.65	10.26

Appendix C.3. (contd.)

FOREST COVER	Region Area(km^2)	ABOVE P-5 (32)	ABOVE P-4 (48)	ABOVE P-3 (47)	ABOVE P-2 (264)	ABOVE P-1 (335)	SECOND CREEK SUBWATERSHED (69)	PARTRIDGE WATERSHED (404)	ST. LOUIS WATERSHED (350)	ABOVE SL-3 (157)	ABOVE SL-2 (243)	ABOVE SL-1 (754)
White, Red, or Jack Pine		.38	0	2.53	4.03	3.50	.49	3.02	.78	0	.06	2.01
Spruce-Fir		31.15	49.83	38.29	36.32	31.32	5.12	27.20	43.91	56.86	51.58	34.78
Maple-Birch-Basswood		0	0	0	0	0	0	0	0	0	0	0
Aspen-Birch		12.31	47.06	58.23	47.38	53.64	29.76	49.89	41.42	21.09	32.09	46.04
Unproductive		8.46	1.04	.63	3.61	2.86	3.41	2.95	1.61	1.25	1.07	2.34
Nonforested		47.69	2.08	.32	8.66	8.68	61.22	16.93	12.27	20.81	15.20	14.82

Appendix C.3. (contd.)

FOREST COVER / Region Area(km^2)	ABOVE WF-1 (24)	ABOVE WF-2 (124)	WHITEFACE WATERSHED (148)	ABOVE[a] W-1 (118)	SOUTH OF LAURENTIAN DIVIDE (1249)
White, Red, or Jack Pine	4.08	0	.65	3.72	2.00
Spruce-Fir	35.37	25.03	26.67	11.31	30.30
Maple-Birch-Basswood	0	0	0	0	0
Aspen-Birch	57.14	66.50	65.01	69.10	51.52
Unproductive	0	7.06	5.94	1.66	3.79
Nonforested	3.40	1.41	1.73	14.21	12.38

[a]Constitutes entire watershed.
[b]Constitutes area north of Laurentian Divide.

1973

Appendix C.4. ^Soil Type in Water Quality Research Area. (In Percent)
(Source: Minnesota Land Management Information System)

SOIL TYPE[a] — Region / Area(km^2)	RESEARCH AREA (4738)	KAWISHIWI WATERSHED (1346)	LITTLE ISABELLA SUBWATERSHED (132)	ABOVE[b] I-1 (883)	ABOVE[b] F-1 (27)	ABOVE[b] KC-1 (29)	ABOVE SR-5 (125)	ABOVE SR-4 (161)	ABOVE SR-3 (466)	ABOVE SR-2 (567)	ABOVE[b] SR-1 (632)
Dusler-Duluth nearly level	0	0	0	.02	0	0	0	0	0	0	0
Ahmeek-Ronneby undulating	1.14	0	2.17	4.52	0	0	0	9.57	3.06	2.49	2.22
Newfound-Newfound(wet)undulating	12.56	.73	8.80	1.88	0	0	37.05	15.00	18.20	16.74	14.91
Unnamed-Toivola undulating	1.44	0	3.01	.49	0	0	5.98	24.57	12.39	10.08	8.98
Toivola-Unnamed-Cloquet undulating to steep	15.43	5.49	71.57	38.22	0	0	7.30	8.91	25.54	30.96	31.07
Mesaba-Barto undulating to hilly	35.26	76.93	0	42.83	88.89	95.05	3.85	0	1.04	.91	7.41
Conic-Insula undulating to hilly	8.19	5.16	0	0	0	0	0	0	0	0	0
Nebish-Mooselake-Shooker hilly	0	0	0	0	0	0	0	0	0	0	0
Cormant-Shawano nearly level	.01	0	0	.02	0	0	0	0	.03	.03	.03
Menahga-Cutfoot undulating	1.81	2.11	0	0	0	0	0	0	0	0	0
Menahga-Barto undulating	.36	.25	0	0	0	0	0	0	0	0	0
Cloquet-Emmert undulating	.64	.23	0	0	0	0	0	0	0	0	0
Unnamed-Hibbing nearly level	.21	0	0	0	0	0	0	0	0	0	0
Hibbing-Unnamed undulating	1.52	0	0	0	0	0	0	0	0	0	0
Greenwood nearly level (peat soils)	1.06	.41	0	0	0	0	0	0	0	0	0
Mooselake nearly level (peat soils)	17.79	7.34	14.10	11.42	11.11	4.95	43.69	41.96	39.00	38.19	34.85
Waskish-Lobo nearly level (peat soils)	.13	0	.36	.05	0	0	0	0	.14	.11	.10
Mine	1.60	.02	0	0	0	0	0	0	0	0	0
Water	.87	1.33	0	.56	0	0	2.12	0	.59	.48	.43

Appendix C.4. (contd.)

SOIL TYPE[a] / Region Area(km^2)	ABOVE[b] BB-1 (11)	ABOVE D-2 (44)	ABOVE[b] D-1 (128)	ABOVE[b] BI-1 (177)	ABOVE[b] SH-1 (256)	ABOVE K-7 (1474)	ABOVE K-6 (655)	ABOVE K-5 (2536)	ABOVE K-4 (2779)	ABOVE K-3 (3170)	ABOVE[c] K-1 (3489)	ABOVE E-2 (46)	ABOVE[b] E-1 (229)
Dusler-Duluth nearly level	0	0	0	0	0	.01	0	.01	.01	.01	0	0	0
Ahmeek-Ronneby undulating	0	0	0	0	0	2.72	0	2.15	1.96	1.70	1.54	0	0
Newfound-Newfound(wet)undulating	0	29.18	12.22	14.07	1.27	1.13	0	5.19	5.66	4.91	4.74	0	0
Unnamed-Toivola undulating	0	0	0	0	0	.30	0	2.45	2.33	1.94	1.76	0	0
Toivola-Unnamed-Cloquet undulating to steep	4.00	9.61	23.15	13.88	1.03	25.70	90.67	25.15	24.06	20.88	19.06	0	8.82
Mesaba-Barto undulating to hilly	70.67	29.89	32.90	20.51	0	58.84	3.82	44.65	43.71	49.58	45.55	20.00	8.82
Conic-Insula undulating to hilly	0	0	0	35.30	89.62	.85	0	.81	3.01	3.30	10.53	0	6.68
Nebish-Mooselake-Shooker hilly	0	0	0	0	.06	0	0	0	0	0		0	0
Cormant-Shawano nearly level	0	0	0	0	0	.01	0	.01	.01	.01	.01	0	0
Menahga-Cutfoot undulating	0	0	0	0	0	0	0	1.13	1.03	.89	.81	45.16	24.86
Mesaba-Barto undulating	0	0	1.88	0	0	0	0	.24	.22	.19	.17	22.90	4.89
Cloquet-Emmert undulating	0	0	0	0	0	0	0	.12	.11	.10	.09	0	11.78
Unnamed-Hibbing nearly level	0	0	0	0	0	0	0	0	0	0	0	0	0
Hibbing-Unnamed undulating	0	0	0	0	0	0	0	0	0	0	0	0	0
Greenwood nearly level (peat soils)	0	0	0	3.63	0	0	0	.20	.43	.37	.34	1.61	12.47
Mooselake nearly level (peat soils)	13.33	31.32	20.69	11.16	4.79	9.79	4.95	17.21	16.15	14.79	13.92	10.32	21.14
Waskish-Lobo nearly level (peat soils)	0	0	0	0	0	.03	0	.04	.04	.04	.03	0	0
Mine	12.00	0	9.17	0	.24	0	0	.57	.52	.45	.43	0	.55
Water	0	0	0	1.45	2.97	.62	.56	.78	.85	.85	1.03	0	0

Appendix C.4. (contd.)

SOIL TYPE[a] Region / Area(km^2)	ABOVE P-5 (32)	ABOVE P-4 (48)	ABOVE P-3 (47)	ABOVE P-2 (264)	ABOVE P-1 (335)	SECOND CREEK SUBWATERSHED (69)	PARTRIDGE WATERSHED (404)	ST. LOUIS WATERSHED (350)	ABOVE SL-3 (157)	ABOVE SL-2 (243)	ABOVE SL-1 (754)
Dusler-Duluth nearly level	0	0	0	0	0	0	0	0	0	0	0
Ahmeek-Ronneby undulating	0	0	0	0	0	0	0	.09	0	0	.04
Newfound-Newfound(wet)undulating	0	74.05	65.19	42.33	43.18	10.49	38.05	42.90	31.83	40.04	40.25
Unnamed-Toivola undulating	0	0	0	0	0	0	0	1.34	2.78	1.83	.61
Toivola-Unnamed-Cloquet undulating to steep	.77	0	6.01	1.32	6.64	2.44	5.98	6.04	5.27	4.22	6.01
Mesaba-Barto undulating to hilly	33.08	0	0	22.49	17.50	5.12	15.56	0	0	0	8.50
Conic-Insula undulating to hilly	0	0	0	0	0	9.02	1.42	0	0	0	.77
Nebish-Mooselake-Shooker hilly	0	0	0	0	0	0	0	0	0	0	0
Cormant-Shawano nearly level	0	0	0	0	0	0	0	0	0	0	0
Menahga-Cutfoot undulating	0	0	0	0	0	0	0	0	0	0	0
Mesaba-Barto undulating	0	0	0	0	0	0	0	0	0	0	0
Cloquet-Emmert undulating	0	0	0	0	0	0	0	0	0	0	0
Unnamed-Hibbing nearly level	0	0	0	0	0	0	0	.65	0	0	.29
Hibbing-Unnamed undulating	0	0	0	0	.64	5.37	1.38	2.54	0	0	1.90
Greenwood nearly level (peat soils)	0	0	0	0	.05	0	.04	1.61	0	0	.75
Mooselake nearly level (peat soils)	32.69	25.26	28.80	28.02	25.05	11.22	22.87	42.39	55.32	50.57	31.73
Waskish-Lobo nearly level (peat soils)	0	0	0	0	0	0	0	1.43	2.97	1.95	.65
Mine	33.46	0	0	5.71	6.50	56.34	14.33	0	0	0	7.83
Water	0	.69	0	.12	.45	0	.38	1.01	1.82	1.39	.67

Appendix C.4. (contd.)

SOIL TYPE[a] — Region / Area(km^2)	ABOVE WF-1 (24)	ABOVE WF-2 (124)	WHITEFACE WATERSHED (148)	ABOVE[b] W-1 (118)	SOUTH OF LAURENTIAN DIVIDE (1249)
Dusler-Duluth nearly level	0	0	0	0	0
Ahmeek-Ronneby undulating	0	0	0	0	.03
Newfound-Newfound(wet)undulating	83.67	61.10	64.69	23.86	34.20
Unnamed-Toivola undulating	0	2.18	1.84	0	.58
Toivola-Unnamed-Cloquet undulating to steep	0	0	0	1.10	5.37
Mesaba-Barto undulating to hilly	0	0	0	0	6.78
Conic-Insula undulating to hilly	0	0	0	0	1.70
Nebish-Mooselake-Shooker hilly	0	0	0	0	0
Cormant-Shawano nearly level	0	0	0	0	0
Menahga-Cutfoot undulating	0	0	0	0	4.58
Mesaba-Barto undulating	0	0	0	0	.90
Cloquet-Emmert undulating	0	0	0	0	2.17
Unnamed-Hibbing nearly level	0	0	0	6.48	.77
Hibbing-Unnamed undulating	0	0	0	49.52	5.71
Greenwood nearly level (peat soils)	0	2.05	1.73	1.10	3.06
Mooselake nearly level (peat soils)	16.33	34.66	31.75	17.79	28.50
Waskish-Lobo nearly level (peat soils)	0	0	0	0	.39
Mine	0	0	0	0	4.85
Water	0	0	0	.14	.42

[a]See Appendix B for soil type definitions.
[b]Constitutes entire watershed.
[c]Constitutes area north of Laurentian Divide.

Appendix C.5. 1974 Land Form in Water Quality Research Area. (In Percent)
(Source: Minnesota Land Management Information System)

LAND FORM / Region Area(km^2)	RESEARCH AREA (4738)	KAWISHIWI WATERSHED (1346)	LITTLE ISABELLA SUBWATERSHED (132)	ABOVE[a] I-1 (883)	ABOVE[a] F-1 (27)	ABOVE[a] KC-1 (29)	ABOVE SR-5 (125)	ABOVE SR-4 (161)	ABOVE SR-3 (466)	ABOVE SR-2 (567)	ABOVE[a] SR-1 (632)	ABOVE[a] BB-1 (11)	ABOVE D-2 (44)	ABOVE[a] D-1 (128)
Glacial Lake Plain	.01	0	0	.02	0	0	0	0	.03	.03	.03	0	0	0
Ground Moraine	.21	0	0	.02	0	0	0	0	0	0	0	0	0	0
Moraine	1.52	0	0	0	0	0	0	0	0	0	0	0	0	0
Moraine and Drumlin Area	13.70	.73	10.96	6.39	0	0	37.05	24.57	21.26	19.24	17.12	0	29.18	12.22
Outwash Plain and Sandy Moraine	1.81	2.11	0	0	0	0	0	0	0	0	0	0	0	0
Outwash Plain	2.08	.23	3.01	.49	0	0	5.98	24.57	12.39	10.08	8.98	0	0	0
Eskers and Outwash Area	15.43	5.49	71.57	38.22	0	0	7.30	8.91	25.54	30.96	31.07	4.00	9.61	23.15
Shallow to Bedrock	43.81	82.38	0	42.83	88.89	95.05	3.85	0	1.04	.91	7.41	70.67	29.89	34.78
Bogs	18.85	7.75	14.10	11.42	1.11	4.95	43.69	41.96	39.00	38.19	34.85	13.33	31.32	20.68
Raised Bogs	.13	0	.36	.05	0	0	0	0	.14	.11	.10	0	0	0
Not Applicable (mineland, water)	2.46	1.32	0	.56	0	0	2.12	0	.59	.48	.43	12.00	0	9.17

Appendix C.5. (contd.)

LAND FORM / Region Area(km^2)	ABOVE[a] BI-1 (177)	ABOVE[a] SH-1 (256)	ABOVE K-7 (1474)	ABOVE K-6 (655)	ABOVE K-5 (2536)	ABOVE K-4 (2779)	ABOVE K-3 (3170)	ABOVE[b] K-1 (3489)	ABOVE E-2 (46)	ABOVE[a] E-1 (229)	ABOVE P-5 (32)	ABOVE P-4 (48)	ABOVE P-3 (47)	ABOVE P-2 (264)	ABOVE P-1 (335)
Glacial Lake Plain	0	0	.01	0	.01	.01	.01	.01	0	0	0	0	0	0	0
Ground Moraine	0	0	.01	0	.01	.01	.01	0	0	0	0	0	0	0	.64
Moraine	0	.06	0	0	0	0	0	0	0	0	0	0	0	0	0
Moraine and Drumlin Area	14.07	1.27	3.85	0	7.34	7.62	6.61	6.28	0	0	0	74.05	65.19	42.33	43.18
Outwash Plain and Sandy Moraine	0	0	0	0	1.12	1.03	.89	.81	45.16	24.86	0	0	0	0	0
Outwash Plain	0	0	.30	0	2.57	2.34	2.03	1.84	0	11.78	0	0	0	0	0
Eskers and Outwash Area	13.88	1.03	25.69	0	25.51	24.07	20.88	19.06	0	8.82	.77	0	6.01	1.32	6.64
Shallow to Bedrock	55.81	89.62	59.70	94.49	45.70	49.96	53.07	56.25	42.90	20.39	33.08	0	0	22.49	17.50
Bogs	14.79	4.79	9.94	4.95	16.77	16.59	15.17	14.25	11.94	33.61	32.69	25.26	28.80	28.02	25.09
Raised Bogs	0	0	.03	0	.04	.04	.04	.03	0	0	0	0	0	0	0
Not Applicable (mineland, water)	1.45	3.22	.62	.56	1.28	1.37	1.30	1.45	0	.55	33.46	.69	0	5.83	6.95

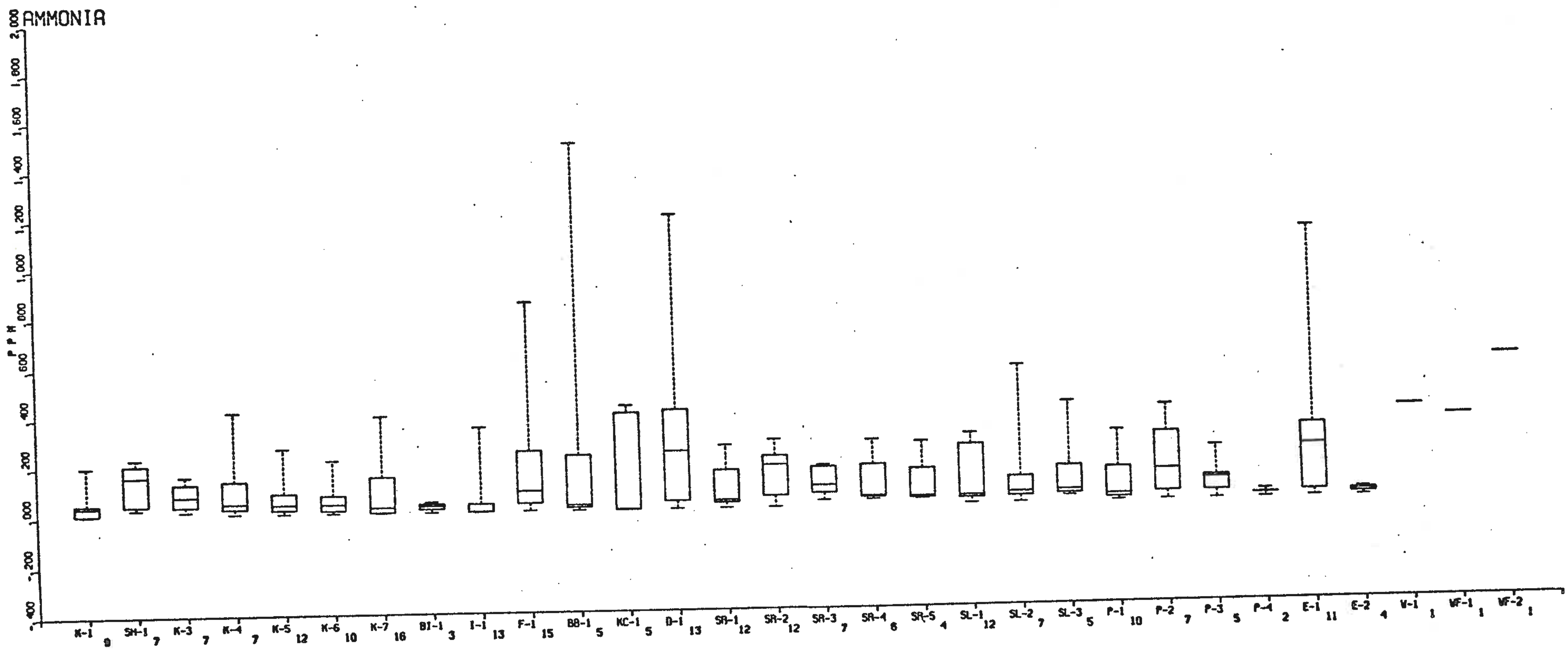
Appendix C.5. (contd.)

LAND FORM / Region Area(km^2)	SECOND CREEK SUBWATERSHED (69)	PARTRIDGE WATERSHED 404	ST. LOUIS WATERSHED (350)	ABOVE SL-3 (157)	ABOVE SL-2 (243)	ABOVE SL-1 (754)	ABOVE WF-1 (24)	ABOVE WF-2 (124)	WHITEFACE WATERSHED (148)	ABOVE[a] W-1 (118)	SOUTH OF LAURENTIAN DIVIDE (1249)
Glacial Lake Plain	0	0	0	0	0	0	0	0	0	0	0
Ground Moraine	0	0	.65	0	0	.29	0	0	0	6.48	.77
Moraine	5.37	1.38	2.54	0	0	1.90	0	0	0	49.52	5.71
Moraine and Drumlin Area	10.49	38.05	42.99	31.83	40.04	40.29	83.67	61.10	64.69	23.86	34.22
Outwash Plain and Sandy Moraine	0	0	0	0	0	0	0	0	0	0	4.58
Outwash Plain	0	0	1.34	2.78	1.83	.61	0	2.18	1.84	0	2.75
Eskers and Outwash Area	2.44	5.98	6.04	5.27	4.22	6.01	0	0	0	1.10	5.37
Shallow to Bedrock	14.15	16.97	0	0	0	9.27	0	0	0	0	9.38
Bogs	11.22	22.91	44.00	55.32	50.57	32.48	16.33	36.71	33.48	18.90	31.56
Raised Bogs	0	0	1.43	2.97	1.95	.65	0	0	0	0	.39
Not Applicable (mineland, water)	56.34	14.71	1.01	1.82	1.39	8.50	0	0	0	.14	5.27

[a]Constitutes entire watershed.
[b]Constitutes area north of Laurentian Divide.

APPENDIX D

BOX PLOTS FOR MISCELLANEOUS PARAMETERS



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800
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400
200
000
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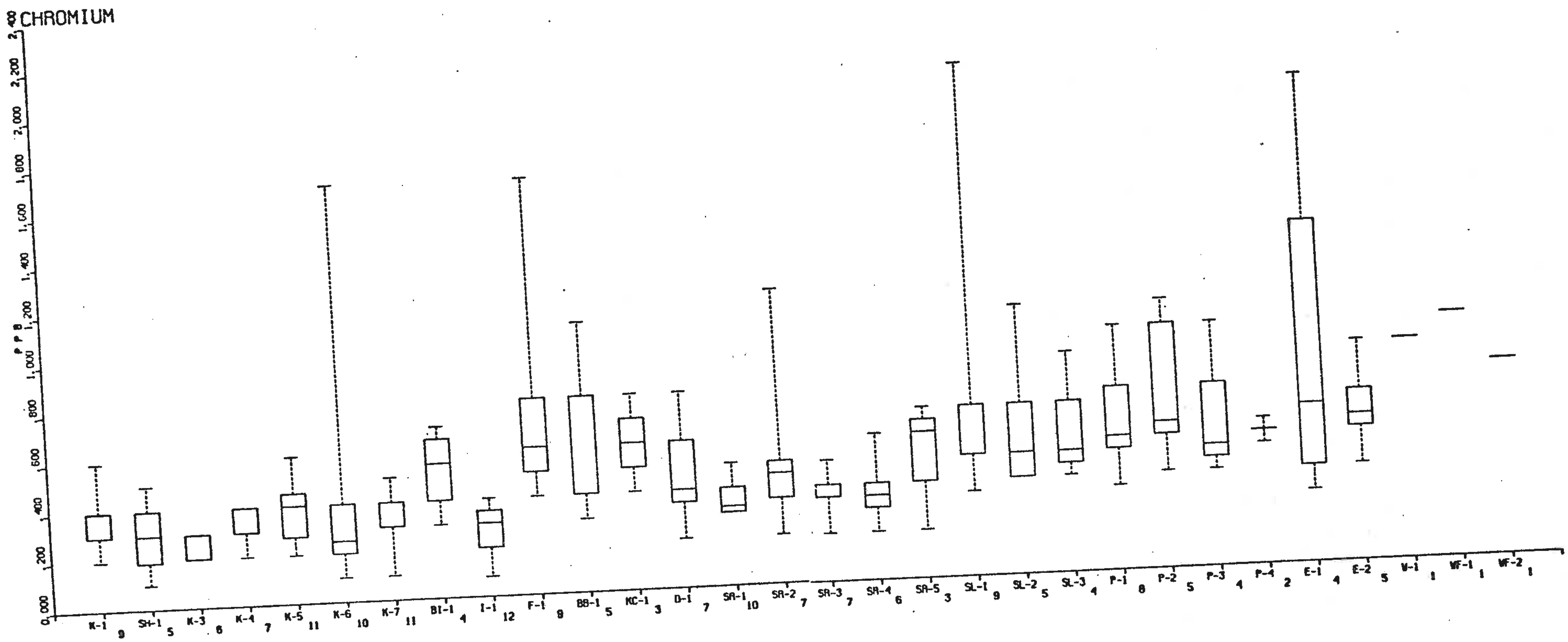
-400
K-1 9
SH-1 7
K-3 7
K-4 7
K-5 12
K-6 10
K-7 16
BI-1 3
I-1 13
F-1 15
BB-1 5
KC-1 5
D-1 13
SR-1 12
SR-2 12
SR-3 7
SR-4 6
SR-5 4
SL-1 12
SL-2 7
SL-3 5
P-1 10
P-2 7
P-3 5
P-4 2
E-1 11
E-2 4
V-1 1
VF-1 1
VF-2 1



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800
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1,600
1,800
2,000
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SH-1 5
K-3 6
K-4 7
K-5 11
K-6 10
K-7 11
BI-1 4
I-1 12
F-1 9
BB-1 5
KC-1 3
D-1 7
SA-1 10
SA-2 7
SA-3 7
SA-4 6
SA-5 3
SL-1 9
SL-2 5
SL-3 4
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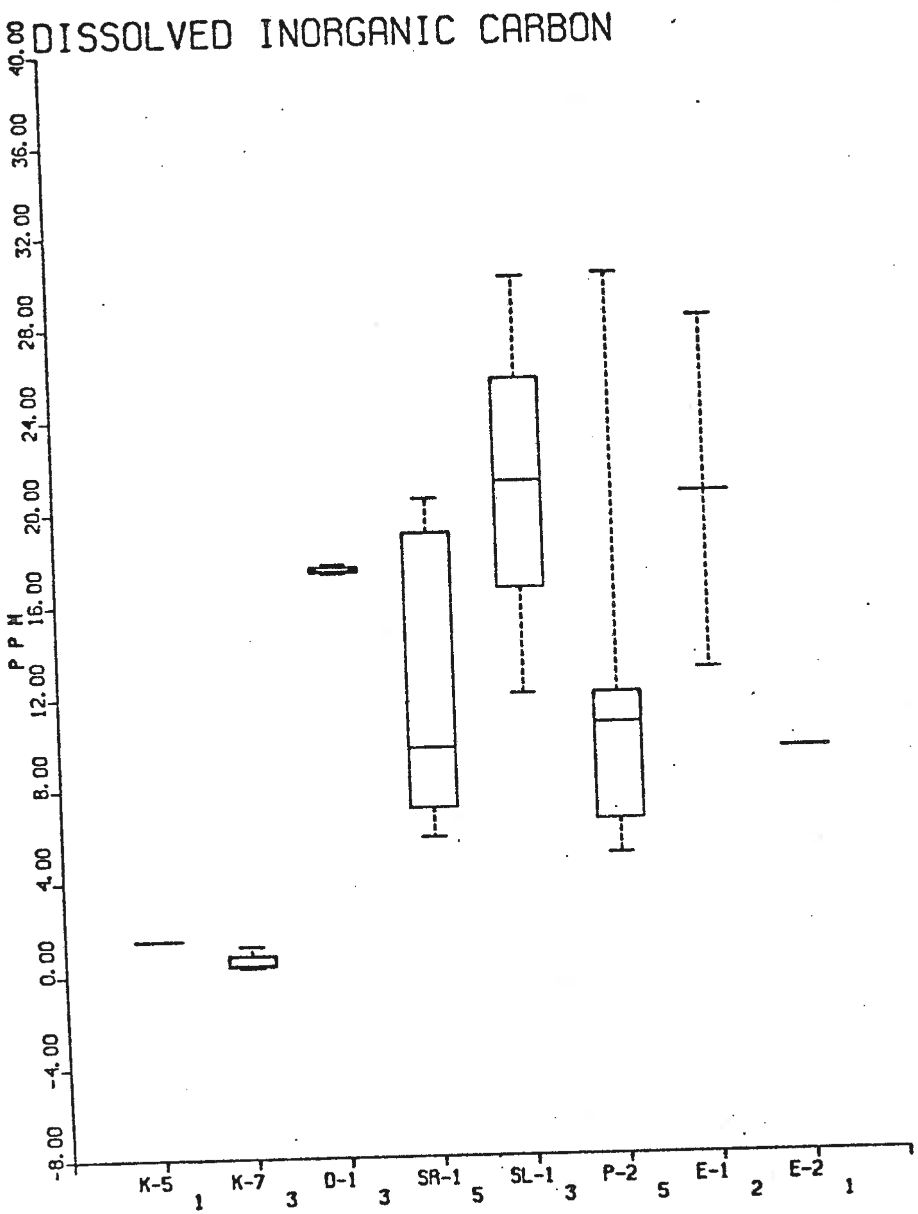
E-1 4
E-2 5
W-1 1
WF-1 1
WF-2 1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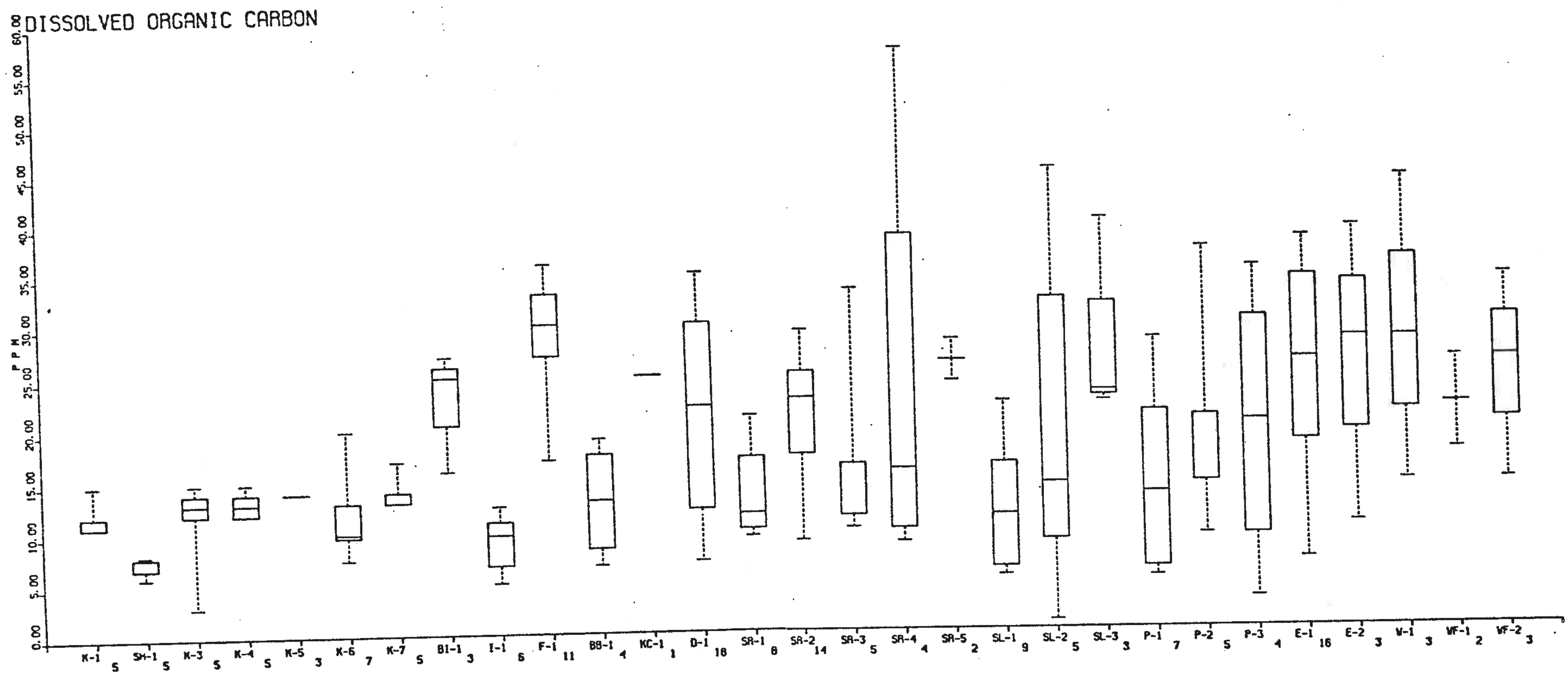
12.00
8.00
4.00
0.00
-4.00
-8.00
P P M
K-5
1
K-7
3
D-1
3
SA-1
5
SL-1
3
P-2
5
E-1
2
E-2
1



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20.00
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30.00
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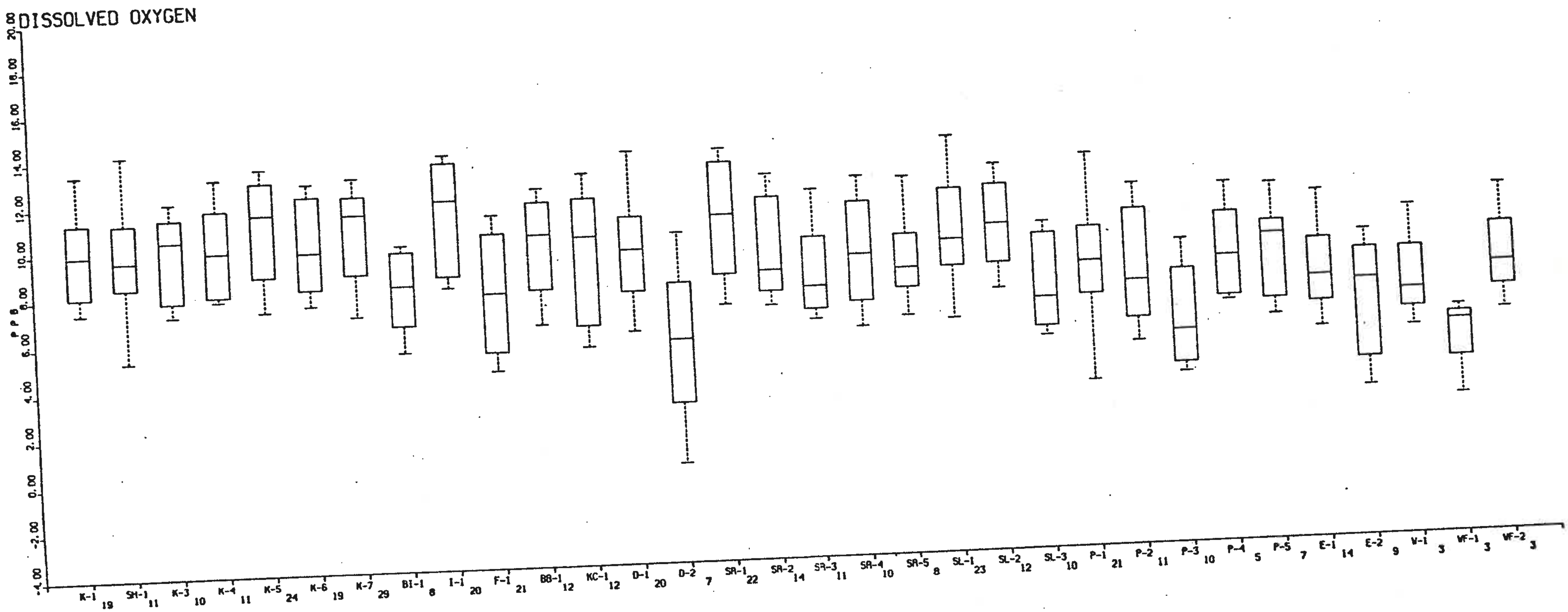
40.00
45.00
50.00
55.00
60.00
K-1 5
SH-1 5
K-3 5
K-4 5
K-5 3
K-6 7
K-7 5
BI-1 3
I-1 6
F-1 11
BB-1 4
KC-1 1
D-1 18
SA-1 8
SA-2 14
SA-3 5
SA-4 4
SA-5 2
SL-1 9
SL-2 5
SL-3 3
P-1 7
P-2 5
P-3 4
E-1 16
E-2 3
V-1 3
VF-1 2
VF-2 3


8 DISSOLVED OXYGEN
P P B
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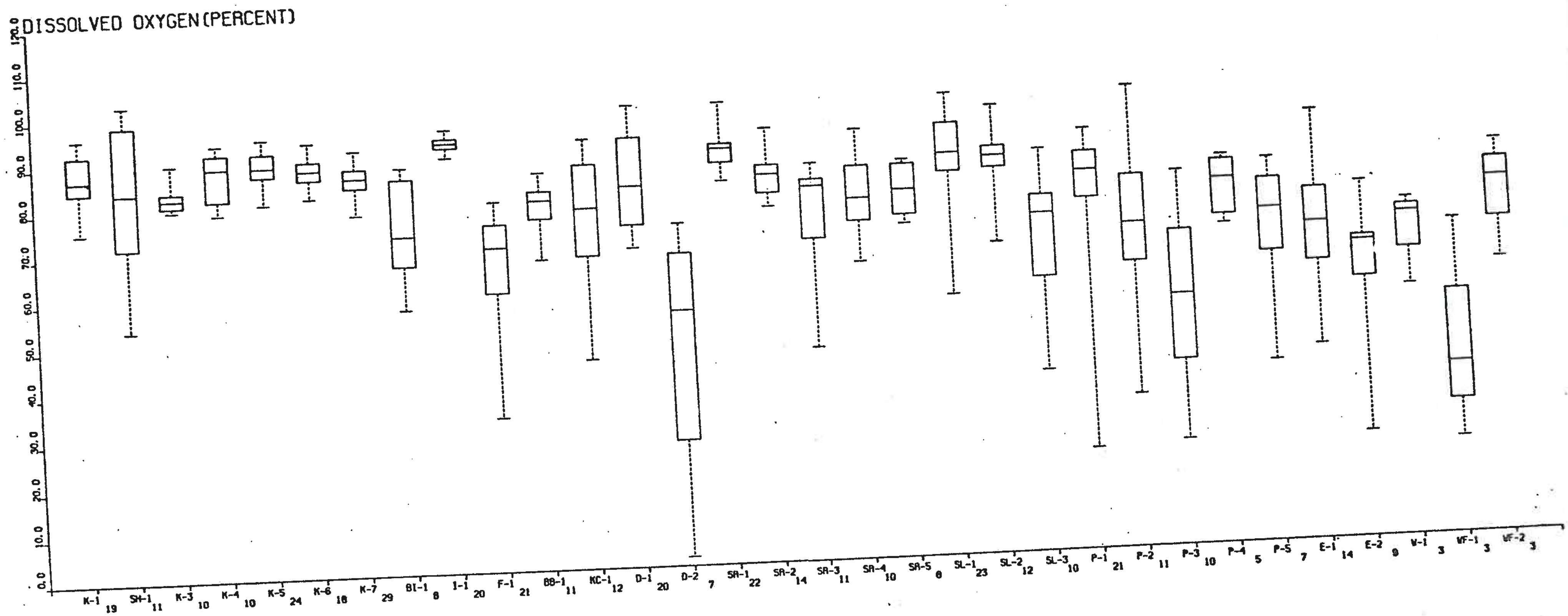
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
K-1 19
SH-1 11
K-3 10
K-4 11
K-5 24
K-6 19
K-7 29
BI-1 8
I-1 20
F-1 21
BB-1 12
KC-1 12
D-1 20
D-2 7
SA-1 22
SA-2 14
SA-3 11
SA-4 10
SA-5 8
SL-1 23
SL-2 12
SL-3 10
P-1 21
P-2 11
P-3 10
P-4 5
P-5 7
E-1 14
E-2 9
V-1 3
VF-1 3
VF-2 3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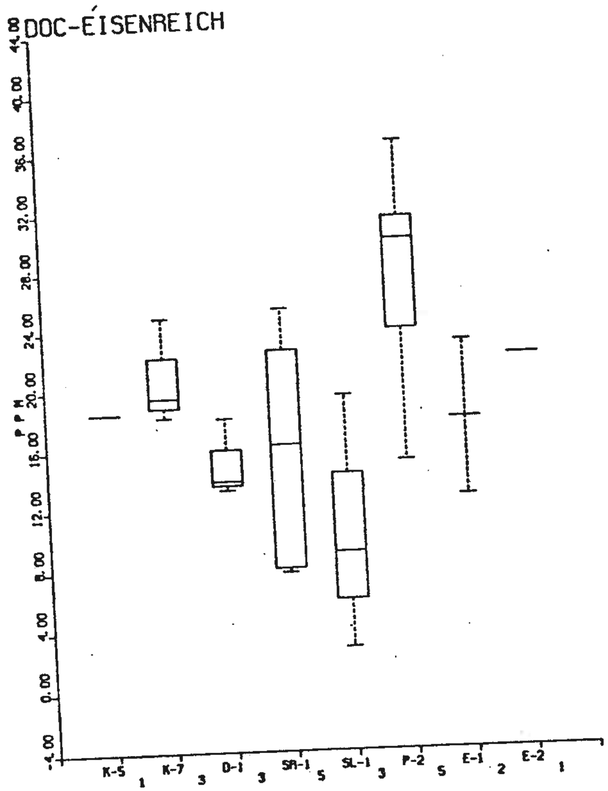
30.0
20.0
10.0
0.0
K-1 19
SH-1 11
K-3 10
K-4 10
K-5 24
K-6 18
K-7 29
BI-1 8
I-1 20
F-1 21
BB-1 11
KC-1 12
D-1 20
D-2 7
SA-1 22
SA-2 14
SA-3 11
SA-4 10
SA-5 8
SL-1 23
SL-2 12
SL-3 10
P-1 21
P-2 11
P-3 10
P-4 5
P-5 7
E-1 14
E-2 9
V-1 3
VF-1 3
VF-2 3



DOC-ÉISENREICH
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36.00
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
-4.00
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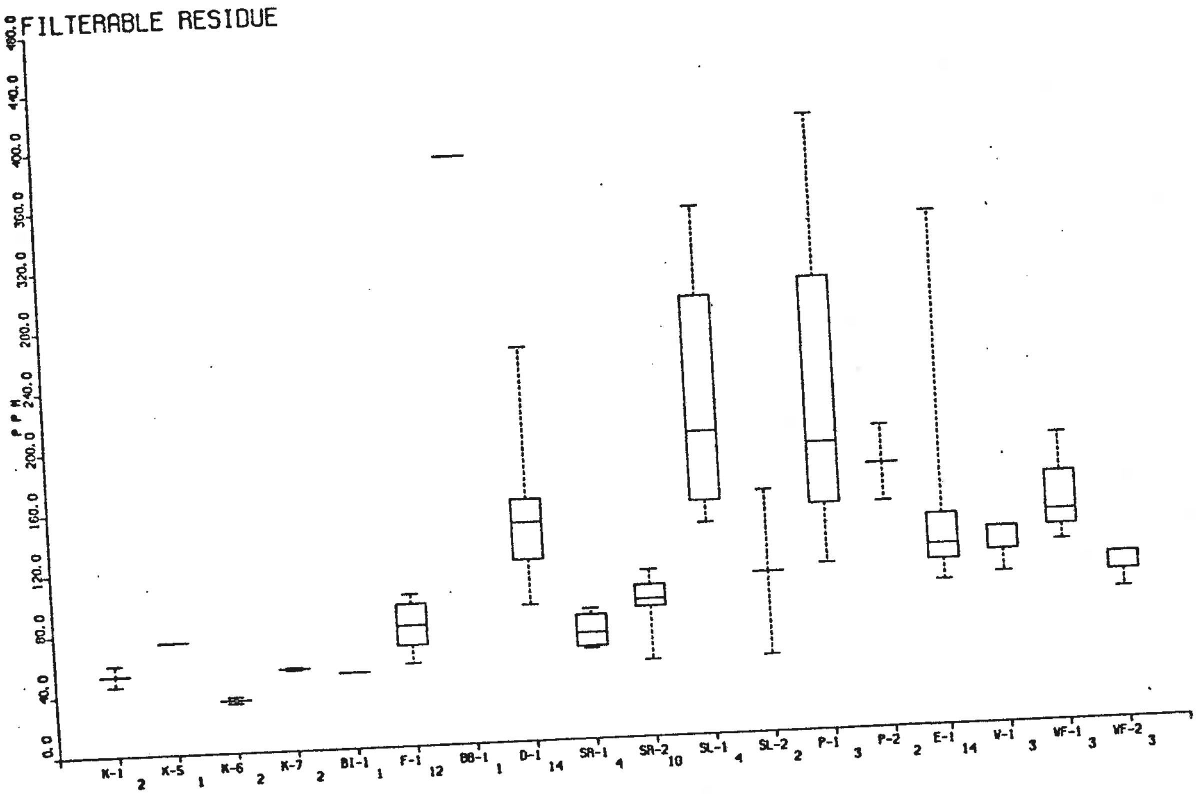
K-7 3
D-1 3
SA-1 5
SL-1 3
P-2 5
E-1 2
E-2 1


FILTERABLE RESIDUE
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280.0
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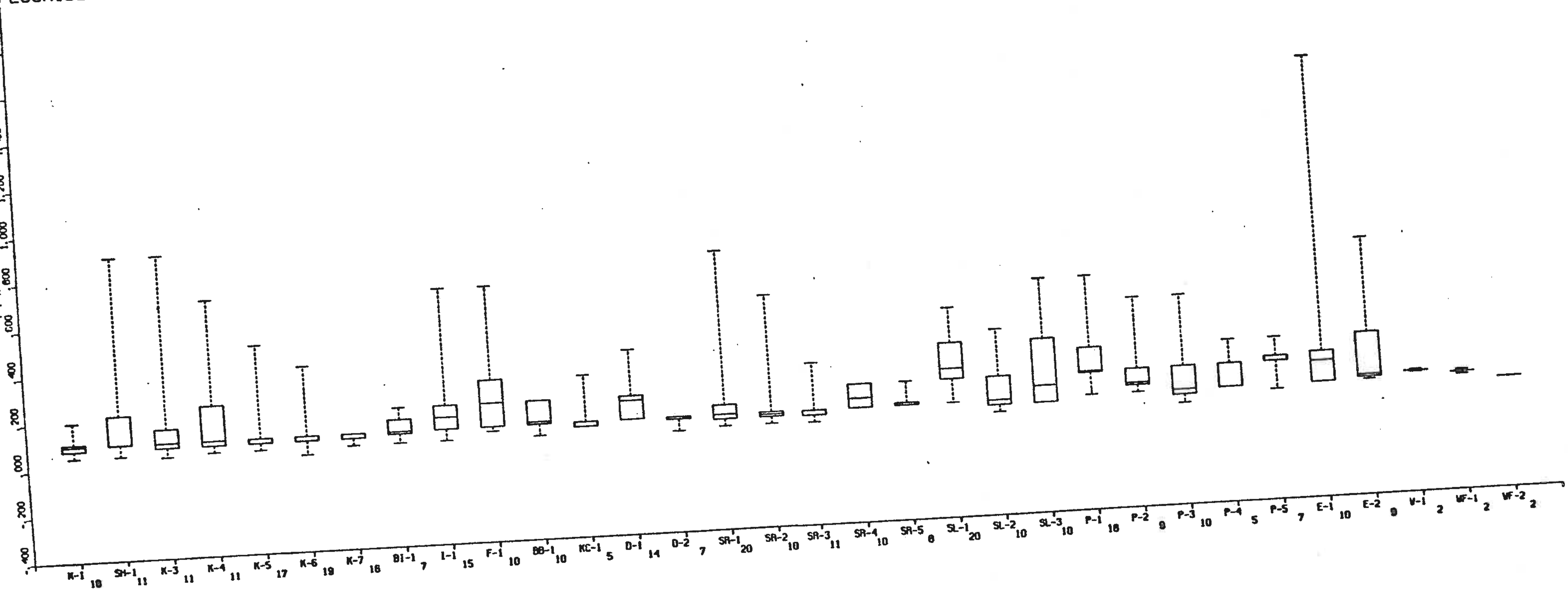
200.0
160.0
120.0
80.0
40.0
0.0
K-1 2
K-5 1
K-6 2
K-7 2
BI-1 1
F-1 12
BB-1 1
D-1 14
SA-1 4
SA-2 10
SL-1 4
SL-2 2
P-1 3
P-2 2
E-1 14
V-1 3
VF-1 3
VF-2 3

FLUORIDE



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800
600
400
200
000
200
400
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SH-1 11
K-3 11
K-4 11
K-5 17
K-6 19
K-7 16
BI-1 7
I-1 15
F-1 10
BB-1 10
KC-1 5
D-1 14
D-2 7
SR-1 20
SR-2 10
SR-3 11
SR-4 10
SR-5 8
SL-1 20
SL-2 10
SL-3 10
P-1 18
P-2 9
P-3 10
P-4 5
P-5 7
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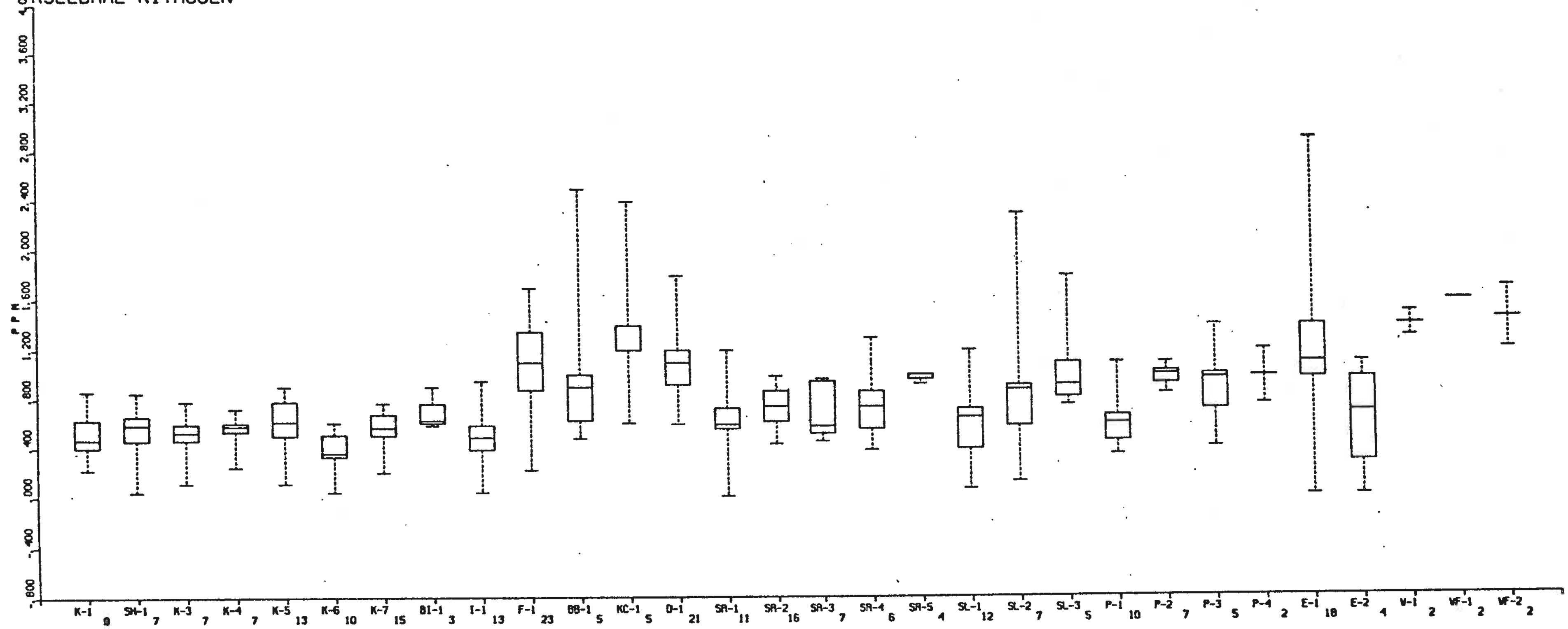
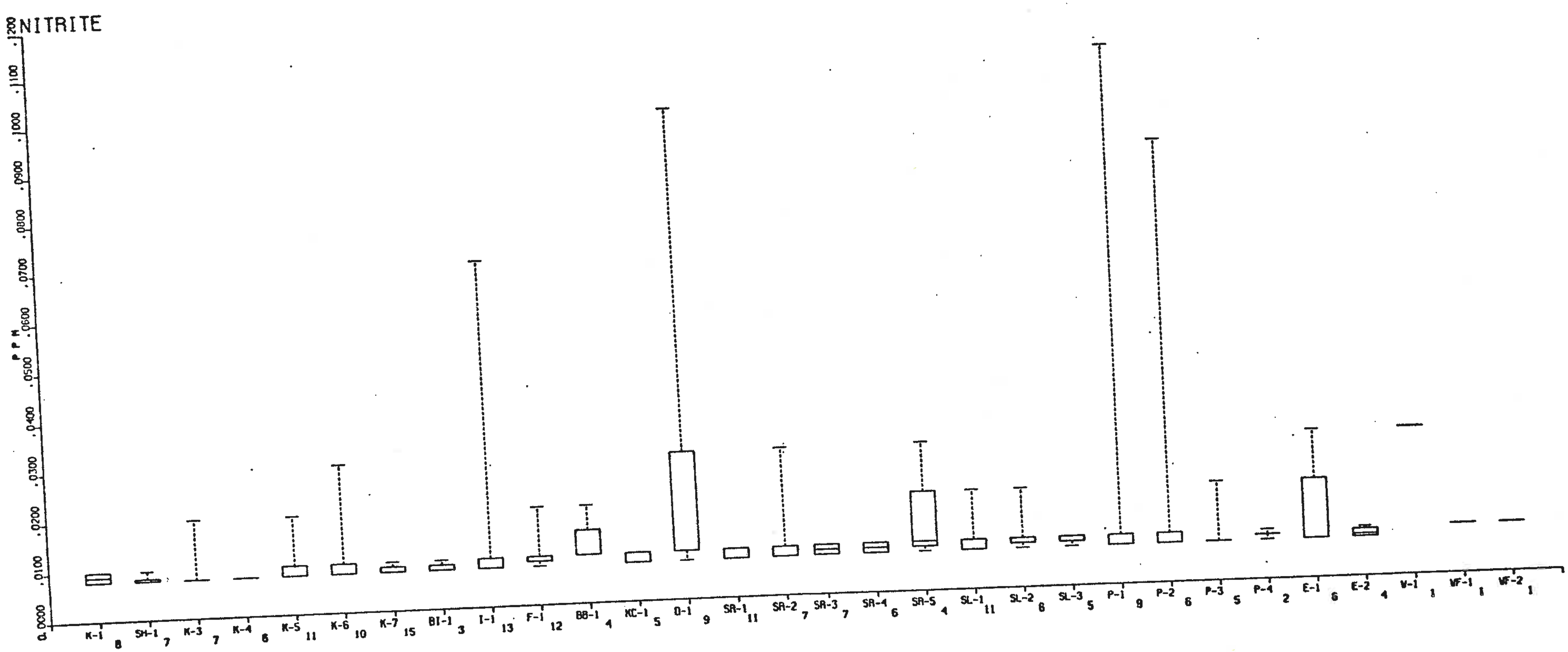
E-2 9
V-1 2
WF-1 2
WF-2 2

KJELDAHL NITROGEN

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.0300
.0400
.0500
.0600
.0700
.0800
.0900
.1000
.1100
.1200
K-1 8
SH-1 7
K-3 7
K-4 8
K-5 11
K-6 10
K-7 15
BI-1 3
I-1 13
F-1 12
BB-1 4
KC-1 5
D-1 9
SR-1 11
SR-2 7
SR-3 7
SR-4 6
SR-5 4
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SL-2 8
SL-3 5
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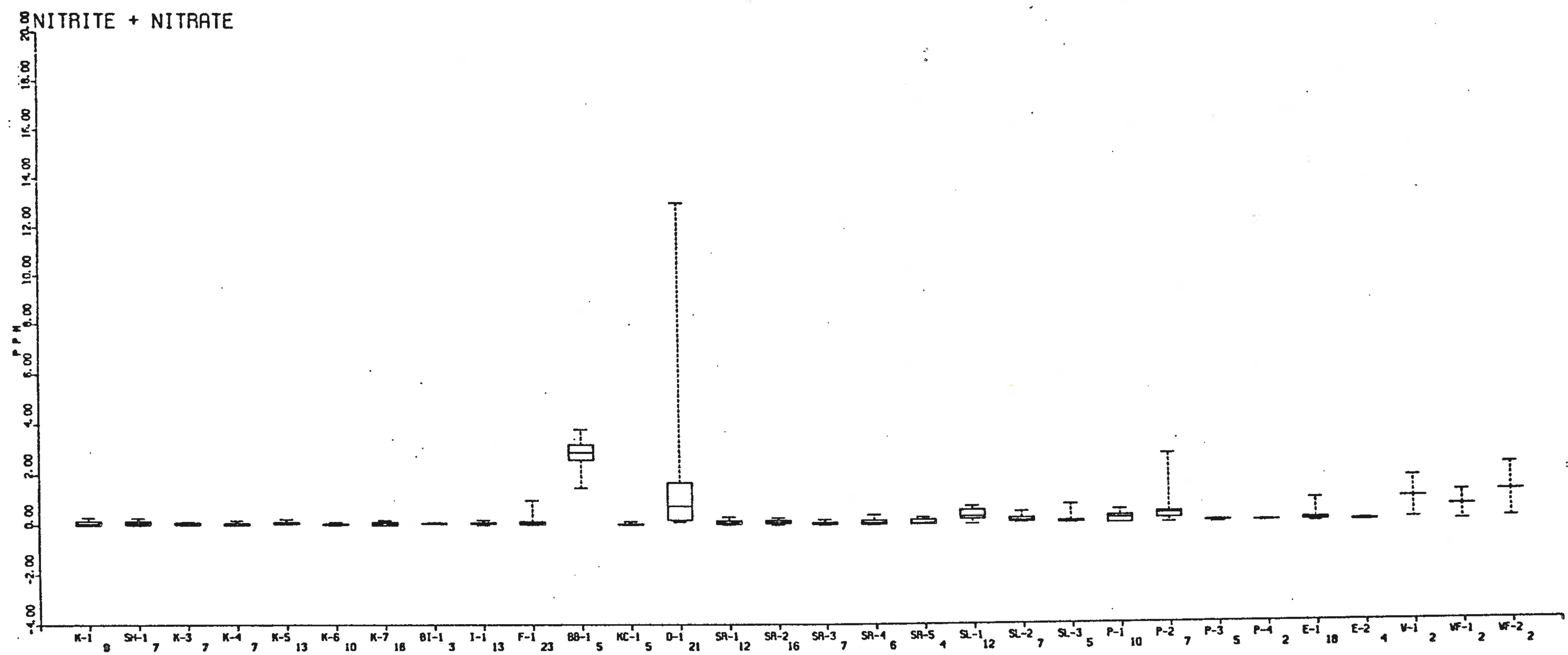
P-2 6
P-3 5
P-4 2
E-1 6
E-2 4
W-1 1
WF-1 1
WF-2 1



NITRITE + NITRATE
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12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
K-1 9
SH-1 7
K-3 7
K-4 7
K-5 13
K-6 10
K-7 18
BI-1 3
I-1 13
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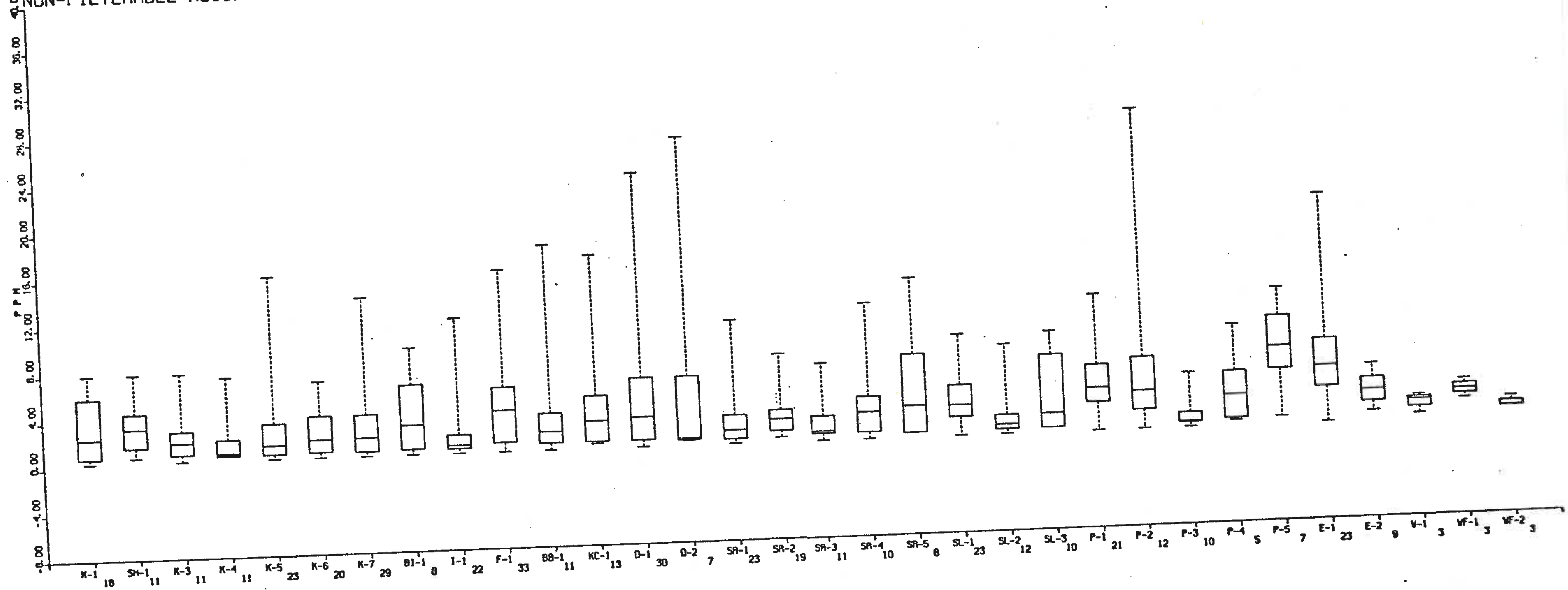
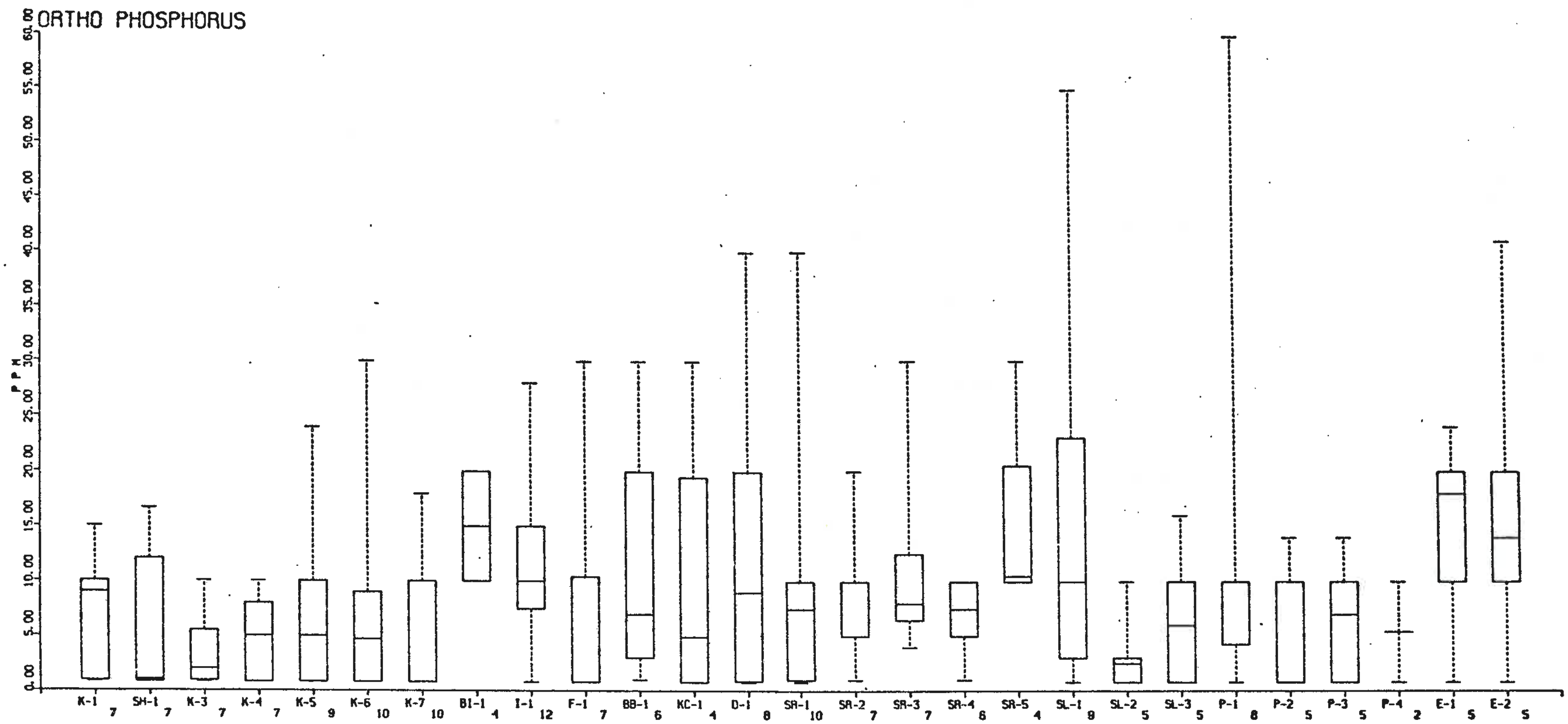
KC-1 5
D-1 21
SR-1 12
SR-2 16
SR-3 7
SR-4 6
SR-5 4
SL-1 12
SL-2 7
SL-3 5
P-1 10
P-2 7
P-3 5
P-4 2
E-1 18
E-2 4
V-1 2
VF-1 2
VF-2 2

NON-FILTERABLE RESIDUE

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P P M
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10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
K-1 7
SH-1 7
K-3 7
K-4 7
K-5 9
K-6 10
K-7 10
BI-1 4
I-1 12
F-1 7
BB-1 6
KC-1 4
D-1 8
SR-1 10
SR-2 7
SR-3 7
SR-4 6
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P-3 5
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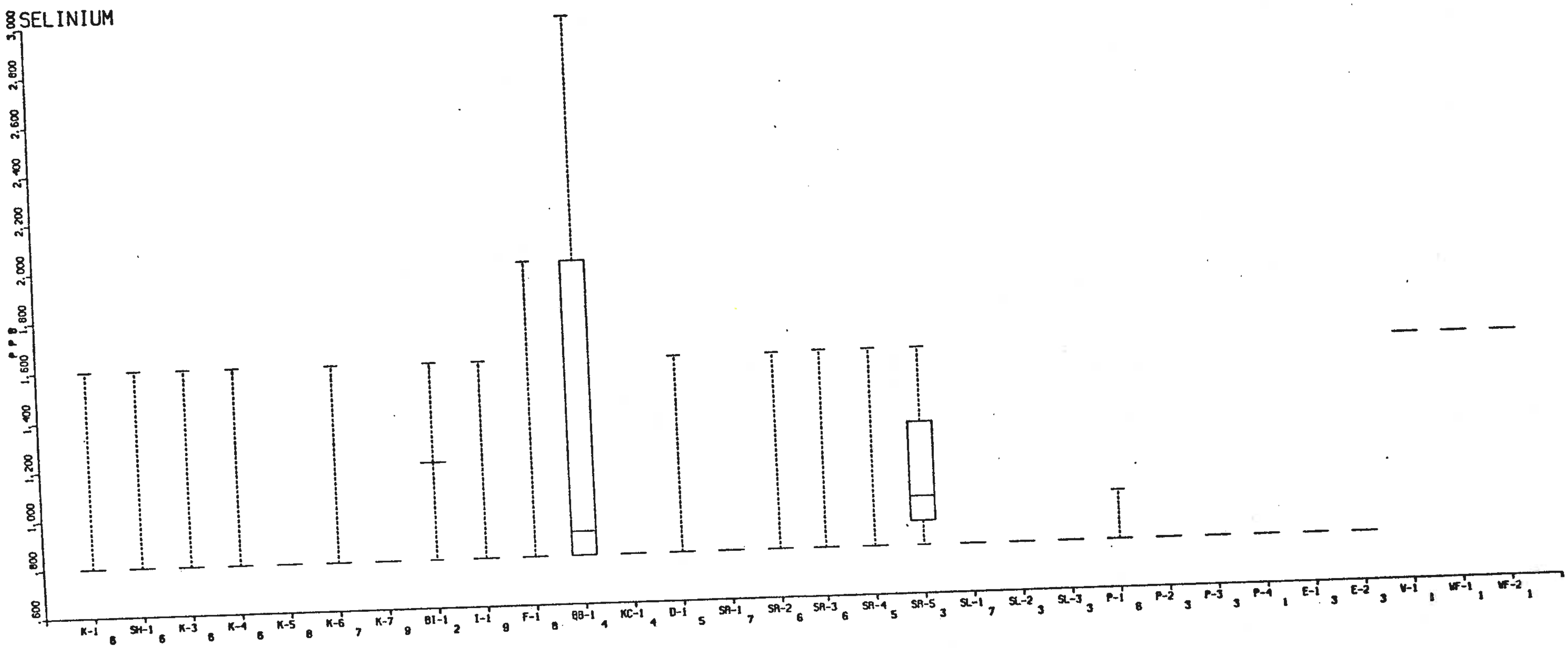
E-2 5



SELINIUM
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800
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1,200
1,400
1,600
1,800
2,000
2,200
2,400
2,600
2,800
3,000
K-1 8
SH-1 6
K-3 8
K-4 6
K-5 8
K-6 7
K-7 9
BI-1 2
I-1 9
F-1 8
BB-1 4
KC-1 4
D-1 5
SR-1 7
SR-2 6
SR-3 6
SR-4 5
SR-5 3
SL-1 7
SL-2 3
SL-3 3
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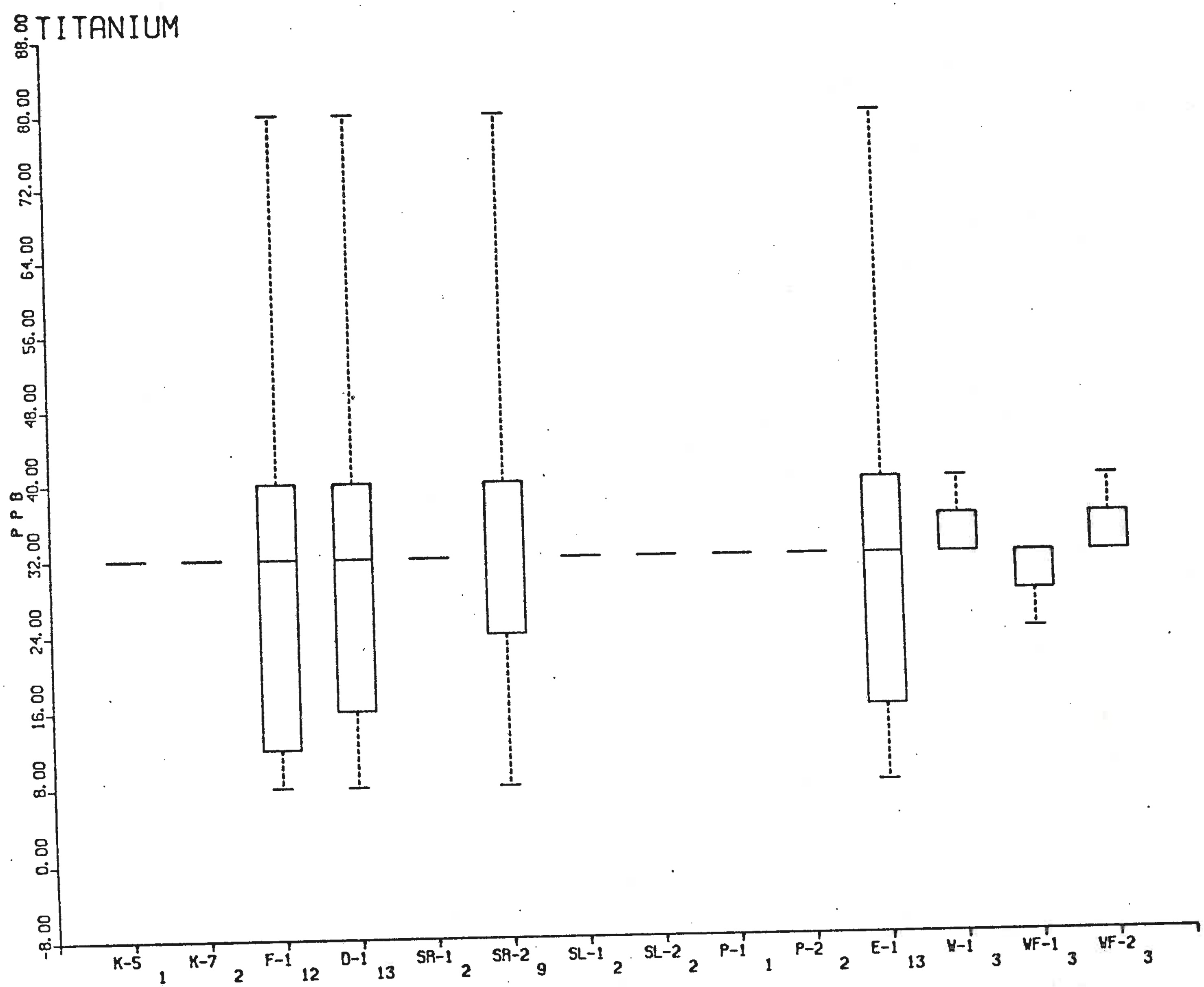
E-2 3
V-1 1
WF-1 1
WF-2 1



TITANIUM
P P B
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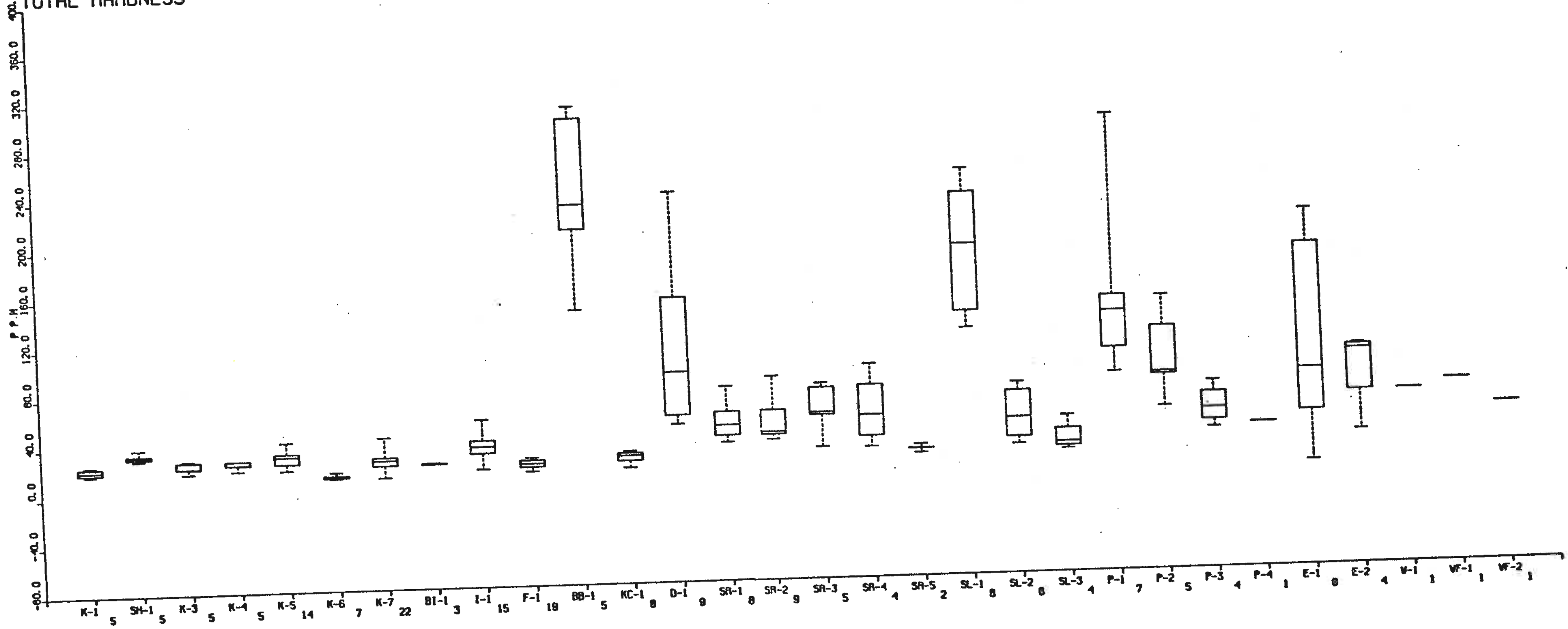
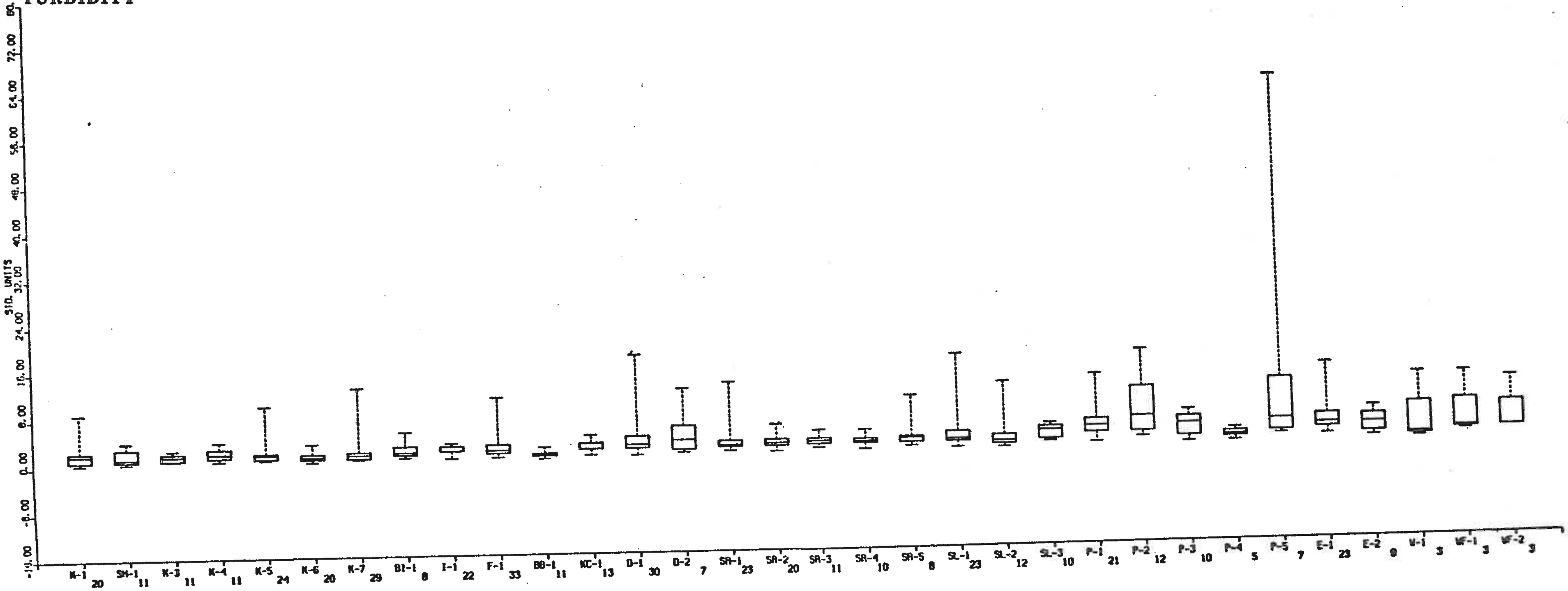
80.00
72.00
64.00
56.00
48.00
40.00
32.00
24.00
16.00
8.00
0.00
-8.00
K-5 1
K-7 2
F-1 12
D-1 13
SR-1 2
SR-2 9
SL-1 2
SL-2 2
P-1 1
P-2 2
E-1 13
W-1 3
WF-1 3
WF-2 3

TOTAL HARDNESS



TURBIDITY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SH-1 11
K-3 11
K-4 11
K-5 24
K-6 20
K-7 29
BI-1 8
I-1 22
F-1 33
BB-1 11
KC-1 13
D-1 30
D-2 7
SA-1 23
SA-2 20
SA-3 11
SA-4 10
SA-5 8
SL-1 23
SL-2 12
SL-3 10
P-1 21
P-2 12
P-3 10
P-4 5
P-5 7
E-1 23
E-2 9
V-1 3
VF-1 3
VF-2 3

APPENDIX E

HISTORICAL WATER QUALITY DATA

Table 1

PARAMETER LIST

GENERAL

RESIDUE: FILTERABLE AND NONFILTERABLE
TURBIDITY
COLOR
TOC
DOC
SPECIFIC CONDUCTANCE
DO
TEMPERATURE
SECCHI DISK
pH
ALKALINITY

METALS, NUTRIENTS, CATIONS, ANIONS

COPPER
NICKEL
ZINC
CADMIUM
LEAD
IRON
COBALT
ALUMINUM
MERCURY

ARSENIC
SELENIUM
TITANIUM
PHOSPHORUS: TOTAL & ORTHO
NITROGEN: TOTAL, NO_2, NO_3, KJD, NH_4

CALCIUM
MAGNESIUM

MANGANESE
POTASSIUM
SODIUM
CHLORIDE
SULFATE
FLUORIDE
BICARBONATE

OTHERS

OIL AND GREASE
MBAS
PHENOLS
BOD

FECAL COLIFORMS
GRASS ALPHA, BETA
CHLOROPHYLL A
BARIUM

Table 2a. Drainage areas of Water Quality Research Area watersheds.

WATERSHED NAME	DRAINAGE AREA (km^2)	PERCENTAGE OF RESEARCH AREA
Kawishiwi River	1346	28.4
Isabella River	883	18.6
Filson Creek	27	.6
Keeley Creek	29	.6
Stony River	632	13.3
Unnamed Creek	11	.2
Dunka River	128	2.7
Bear Island River	177	3.7
Shagawa River	256	5.4
Total North of Laurentian Divide	3489	73.6
Embarrass River	229	4.8
Partridge River	404	8.5
St. Louis River	350	7.4
Whiteface River	148	3.1
Water Hen Creek	118	2.5
Total South of Laurentian Divide	1249	26.4
Total All Watersheds	4738	100.0

Table 2b. Drainage areas of subwatersheds in Water Quality Research Area.

NORTH OF LAURENTIAN DIVIDE (Rainy River Drainage)

WATERSHED NAME	SUBWATERSHED NAME	SUBWATERSHED AREA (km^2)	FEEDER SUBWATERSHEDS	TOTAL DRAINAGE THROUGH SUBWATERSHED (km^2)
Isabella River	Little Isabella	132	none	132
	i1	751	Little Isabella	883[a]
Filson Creek	f1	27	none	27[a]
Keeley Creek	kc1	29	none	29[a]
Stony River	sr5	125	none	125
	sr4	161	none	161
	sr3	180	sr5+sr4	466
	sr2	101	sr5+sr4+sr3	567
	sr1	65	sr5+sr4+sr3+sr2	632[a]
Unnamed Creek	bb1	11	none	11[a]
Dunka River	d2	44	none	44
	d1	84	d2	128[a]
Bear Island R.	bi1	177	none	177[a]
Shagawa River	sh1	256	none	256[a]
Kawishiwi River	k6	655	none	655
	k7	236[b]	Little Isabella+i1+½k6	1474[b]
	k5	262[b]	Little Isabella+i1+f1+kc1+sr5+sr4+sr3+sr2+sr1+bb1+d2+d1+½k6+k7	2536[b]
	k4	66[b]	Little Isabella+i1+f1+kc1+sr5+sr4+sr3+sr2+sr1+bb1+d2+d1+bi1+½k6+k7+k5	2779[b]
	k3	64	Little Isabella+i1+f1+kc1+sr5+sr4+sr3+sr2+sr1+bb1+d2+d1+bi1+k6+k7+k5+k4	3170
	k1	63	Little Isabella+i1+f1+kc1+sr5+sr4+sr3+sr2+sr1+bb1+d2+d1+bi1+sh1+k6+k7+k5+k4+k3	3489

Table 2b (contd.)

SOUTH OF LAURENTIAN DIVIDE (Lake Superior Drainage)

WATERSHED NAME	SUBWATERSHED NAME	SUBWATERSHED AREA (km^2)	FEEDER SUBWATERSHEDS	TOTAL DRAINAGE THROUGH SUBWATERSHED (km^2)
Embarrass River	e2	46	none	46
	e1	183	e2	229[a]
Partridge River	p5	32	none	32
	p4	48	none	48
	p3	47	none	47
	p2	137[c]	p5+p4+p3	264[c]
	p1	71	p5+p4+p3+p2	335[c]
St. Louis River	Second Creek	69	none	69
	s13	157	none	157
	s12	86	s13	243
	s11	107	p5+p4+p3+p2+p1+Second Creek+s13+s12	754[c]
Whiteface River	wf1	24	none	24
	wf2	124	none	124
Water Hen Creek	w1	118	none	118[a]

SOURCE: U.S. Geological Survey, St. Paul, MN.

[a]Drainage area of entire watershed.
[b]Drainage areas estimated because of North/South Kawishiwi River split.
[c]Includes 13km^2 in subwatershed p2 defined by USGS as noncontributing.

Table 3. Stations not sampled due to drought conditions 1976-1977.

STATION	DATE SAMPLING NO LONGER POSSIBLE	CONDITION
P-4	Aug. 25	Dry
SR-5	Nov. 8	Frozen to bottom
D-1	Dec. 15	Dry
BI-1	Dec. 27	Frozen to bottom
E-2	Jan. 1	Frozen to bottom
F-1	Jan. 3	Frozen to bottom
KC-1	Jan. 25	Frozen to bottom

Table 4. Characteristics of monitored lakes in Kawishiwi River Watershed.

LAKE	HEADWATER LAKE	SURFACE AREA A_o (km^2)	DRAINAGE AREA A_d (Km^2)	MEAN DEPTH $\bar{Z}$ (m)	MAXIMUM DEPTH Z max (m)	VOLUME $VX10^6$ (m)	MEAN ANNUAL DISCHARGE $QX10^6$ (m^3yr^{-1})		AREAL WATER LOAD $q_a=Q/A_o$		FLUSHING RATE e (yr^{-1})		STRATIFICATION[a]
							b	c	b	c	b	c	
Birch	no	25.62	2536	4.15	7.62	106.18	596.36	490	23.28	19.1	5.62	4.61	Does not stratify
Gabbro	no	3.63	1034	3.66	15.24	13.27	254.22	193	70.03	53.1	19.16	14.54	Does not stratify
White Iron	no	13.85	2779	6.00	14.33	83.13	650.55	539	46.97	38.9	7.83	6.48	Weakly dimictic
August	yes	.90	9.6	2.46	5.79	2.20	2.98	1.48	3.31	1.65	1.35	.67	Does not stratify
Clearwater	yes	2.61	9.2	7.44	14.00	19.39	2.86	1.42	1.10	.54	.15	.07	Does not stratify
Lake One	no	3.55	638	3.14	17.37	33.30	160.66	117	45.26	32.9	4.82	3.51	Strongly dimictic
Turtle	yes	1.36	6.4	1.13	3.05	1.55	1.95	.97	1.43	.72	1.22	.63	Does not stratify
Fall	no	8.93	3489	3.99	9.75	35.70	807.59	683	90.44	76.5	22.62	19.13	Weakly dimictic

[a]See Appendix B5 for definitions.
[b]Ten-year average.
[c]March 1, 1976 through February 28, 1977 average.

Table 5. Water users and dischargers in Kawishiwi River Watershed.

		USE (10^6 gallons)[a]						DISCHARGE		
USER/ DISCHARGER	SURFACE OR GROUND	1971	1972	1973	1974	1975	1976	DESCRIPTION[b]	RECEIVING BODY[a,b]	AMOUNT (10^6 gal/ yr)[b]
Winton WTP	Surface	7.5	9.7	7.1	7.5	7.4	8.8	filter backwash treated	Fall Lake	3.3[c]
MP&L Hydro-electric Power Plant, Winton Dam	Surface	174,042.3	180,974.3	196,454.4	138,220.1	149,082.0	104,163.2		Colby Lake& Partridge River	
Winton WWTP								Tertiary treatment	Swamp to Shagawa River to Fall Lake	9.5

[a]Source: USGS unpublished data 1978
[b]Source: MPCA NPDES permit files 1977
[c]Discharge every 10 days

Table 6. Characteristics of monitored lakes in Stony River Watershed.

LAKE	HEADWATER LAKE	SURFACE AREA A_o (km^2)	DRAINAGE AREA A_d (Km^2)	MEAN DEPTH $\bar{Z}$ (m)	MAXIMUM DEPTH Z max (m)	VOLUME VX10^6 (m)	MEAN ANNUAL DISCHARGE QX10^6 (m^3yr^{-1})		AREAL WATER LOAD q_s=Q/A_o		FLUSHING RATE e (yr^{-1})		STRATIFICATION[a]
							b	c	b	c	b	c	
Greenwood	yes	5.06	105.7	1.27	2.13	6.43	29.10	18.0	5.75	3.56	4.53	2.80	Does not stratify
Sand	yes	2.05	41	1.45	11.58	2.98	11.82	6.72	5.77	3.28	3.97	2.56	Does not stratify
S. McDougal	yes	1.12	37.4	.51	1.52	.57	10.84	6.11	9.68	5.45	19.02	10.72	Does not stratify
Slate	no	.96	466	1.51	3.05	1.45	119.19	84.12	124.16	87.7	82.20	58.07	Does not stratify

[a] See Appendix B for definitions.
[b] Ten-year average.
[c] March 1, 1976 through February 28, 1977 average.

Table 7. Water users and dischargers in Unnamed Creek Watershed.

USER/DISCHARGER	USE (10^6 gallons)[a]				DISCHARGE		
	SURFACE OR GROUND	1974	1975	1976	DESCRIPTION[b]	RECEIVING BODY[a,b]	AMOUNT (10^6gal/yr)[b]
Erie Mining Co. Area 8[c]	Ground	855.7	766.5	825.9		Unnamed Creek	
Erie Mining Co. Dunka Pit							
011					Mine pit water	Unnamed Creek	839.5
012					Mine pit water	Unnamed Creek	164.3

[a]Source: USGS unpublished data 1978.
[b]Source: MPCA NPDES permit files 1977.
[c]Also in Dunka River Watershed; figures are totals.

Table 8. Water users and dischargers in Dunka River Watershed.

		USE (10^6 gallons)[a]						DISCHARGE		
USER/ DISCHARGER	SURFACE OR GROUND	1971	1972	1973	1974	1975	1976	DESCRIPTION[b]	RECEIVING BODY[a,b]	AMOUNT (10^6gal/ yr)[b]
Erie Mining Co. Area 8[c]	Ground				855.7	766.5	825.9		Unnamed Creek (Unnamed Cr. Watershed)	
Reserve Mining Co.										
001	Ground	1700.9	942.8	1053.9	987.9	1363.7	718.3	Mine dewatering,/ shop water	Unnamed trib. to Dunka R.	1058.5
002	Ground	389.0	1003.1	862.5	1541.8	872.2	722.0	Mine dewatering	Langley Creek	766.5
004								shop water, sewage treatment plant, water treatment plant	Unnamed trib. to Langley Cr.	6.9 1.8[d]
005								truck wash shop, paint shops	Unnamed trib. to Langley Cr.	94.9

[a]Source: USGS unpublished data 1978.
[b]Source: MPCA NPDES permit files 1977.
[c]Also in Unnamed Creek Watershed; figures are totals.
[d]Discharge once/week.

Table 9. Characteristics of monitored lakes in Bear Island River Watershed.

LAKE	HEADWATER LAKE	SURFACE AREA A_o (km^2)	DRAINAGE AREA A_d (Km^2)	MEAN DEPTH $\bar{Z}$ (m)	MAXIMUM DEPTH Z max (m)	VOLUME $VX10^6$ (m)	MEAN ANNUAL DISCHARGE $QX10^6$ (m^3yr^{-1})		AREAL WATER LOAD $q_s=Q/A_o$		FLUSHING RATE e (yr^{-1})		STRATIFICATION[a]
							b	c	b	c	b	c	
Bear Island	yes	8.64	85	8.74	21.95	75.46	23.66	14.3	2.74	1.66	.31	.19	Strongly dimictic
Perch	yes	.44	3.2	2.30	9.14	1.01	1.05	.47	2.39	1.08	1.04	.47	Weakly dimictic

[a] See Appendix B for definitions.
[b] Ten-year average.
[c] March 1, 1976 through February 28, 1977 average.

Table 10. Water users and dischargers in Shagawa River Watershed.

	USE (10^6 gallons)[a]							DISCHARGE		
USER/ DISCHARGER	SURFACE OR GROUND	1971	1972	1973	1974	1975	1976	DESCRIPTION[b]	RECEIVING BODY[a,b]	AMOUNT (10^6gal/yr)[b]
Ely WTP	Surface	402.7	387.8	398.0	402.5	409.4	409.4	Filter backwash untreated	Shagawa Lake	6.6[c]
Ely WWTP								Tertiary treatment	Shagawa Lake	580.4

[a]Source: USGS unpublished data 1978.
[b]Source: MPCA NPDES permit files 1977.
[c]Discharge once/week summer, once/month winter.

Table 11. Water users and dischargers in Embarrass River Watershed.

USER/ DISCHARGER	SURFACE OR GROUND	USE (10^6 gallons)[a] 1971	1972	1973	1974	1975	1976	DISCHARGE DESCRIPTION[b]	RECEIVING BODY[a,b]	AMOUNT (10^6gal/yr)[b]
Babbitt WTP	Ground	110.0	101.9	98.6	108.1	107.2	128.1		Treatment plant Embarrass River	
Babbitt WWTP								Primary & secondary treatment	Hay Lake to Embarrass River	73.0
Village of Babbitt, self-supplied domestic	Ground	13.0	13.0	13.0	13.0	13.0	13.0		Sewage systems	
Irrigation Mackie	Surface		3.1	3.4	5.0	2.3	9.9		Evaporation	
Zumbrurnen	Surface	83.2	55.1	9.8	39.6				Evaporation	

[a]Source: USGS unpublished data 1978.
[b]Source: MPCA NPDES permit files.

Table 12. Characteristics of monitored lakes in Partridge River Watershed.

LAKE	HEADWATER LAKE	SURFACE AREA A_o (km^2)	DRAINAGE AREA A_d (Km^2)	MEAN DEPTH $\bar{Z}$ (m)	MAXIMUM DEPTH Z max (m)	VOLUME $VX10^6$ (m)	MEAN ANNUAL DISCHARGE $QX10^6$ (m^3yr^{-1})		AREAL WATER LOAD $q_s=Q/A_o$		FLUSHING RATE e (yr^{-1})		STRATIFICATION[a]
							b	c	b	c	b	c	
Colby	no	2.24	332	3.13	10.36	7.00	86.31	59.2	38.53	26.4	12.33	8.46	Weakly dimictic
Big	no	3.21	9.2	?	4.57	4.92	2.87	1.42	.89	.44	.58	.29	Weakly dimictic

[a] See Appendix B for definitions.
[b] Ten-year average.
[c] March 1, 1976 through February 28, 1977 average.

Table 13 Water users and dischargers in Partridge River Watershed.

USER/ DISCHARGER	SURFACE OR GROUND	USE (10^6 gallons)[a] 1971	1972	1973	1974	1975	1976	DISCHARGE DESCRIPTION[b]	RECEIVING BODY[a,b]	AMOUNT (10^6 gal/yr)[b]
Hoyt Lakes WTP	Surface	117.4	126.3	123.5	123.2	120.1	147.5	Filter backwash untreated	Colby Lake	91.3
Hoyt Lakes WWTP								Primary & secondary treatment	Whitewater lake	97.1
Aurora WTP	Ground	102.0	122.8	178.6	205.5	132.5	140.9	Primary & secondary treatment	St. James abandoned open pit	2.9
Aurora WWTP								Primary & secondary treatment	Unnamed tributary to St.Louis River	175.2
Village of Hoyt Lakes self-supplied domestic	Ground	.3	.3	.3	.3	.3	.3			
MP&L thermo-electric Power Plant	Surface	44,174.7	43,798.2	42,800.1	44,200.2	49,289.9	50,237.0		Colby Lake & Partridge River	
004								Track hopper, drainage& coal pit runoff	Colby Lake & Partridge River	18.3

Table 13 (contd.)

USER/ DISCHARGER	SURFACE OR GROUND	USE (10^6 gallons)[a] 1971	1972	1973	1974	1975	1976	DISCHARGE DESCRIPTION[b]	RECEIVING BODY[a,b]	AMOUNT (10^6gal/ yr)[b]
U.S. Steel, Stephens Mine (69-0088)	Ground	762.4	371.2	464.2	529.6	431.3	184.8	Mine pit water	Second Creek	1058.5
(69-0152)	Ground						831.9	Mine pit water	Second Creek	142.35
Pittsburgh Pacific Co. Lincoln D Mine	Ground	231.7	274.4	251.5	241.5		298.1		Second Creek	
Knox Mine	Ground					1374.5	791.6	Mine pit water treated by settling pond	Second Creek	4197.5
Erie Mining Co. Area 1	Ground				2309.1	1212.7	730.9		First Creek	
Area 2	Ground					436.1	214.8			
Area 3	Ground				333.0	259.1	168.1		Wyman Creek	
Area 6	Ground				846.2	177.0	792.5		First Creek	
Area 9	Ground				294.8	132.5	219.6		First Creek	
Area 9 So.	Ground				322.3	352.4	269.4		First Creek	
Wentworth	Ground	433.3	587.8	720.4	605.3	574.3	197.0		First Creek	

Table 13 (contd.)

USER/ DISCHARGER	USE (10^6 gallons)[a]							DISCHARGE		
	SURFACE OR GROUND	1971	1972	1973	1974	1975	1976	DESCRIPTION[b]	RECEIVING BODY[a,b]	AMOUNT (10^6gal/yr)[b]
Erie Mining[c] Co. 009								Mine pit water	Wyman Creek	365.0
010								Mine pit water	Wyman Creek	547.5
001								Mine pit & surface runoff water	Knox Creek	985.5
005								" " "	" "	912.5
007								" " "	" "	365.0
008								" " "	" "	438.0
002								Mine pit water	First Creek	2080.5
003								" " "	" "	211.7
004								" " "	" "	157.0
006								" " "	" "	803.0
Reserve Mining Co.	Ground	4119.2	2323.8	3143.8	2949.6	2318.0	1615.8	Mine pit water	Partridge R.	3248.5
Erie Mining Co. WWTP								Primary and secondary treatment	Drainage ditch to swamp to Knox Creek	38.3

[a]Source: USGS unpublished data 1978.
[b]Source: MPCA NPDES permit files.
[c]Some Erie Mining discharges may be result of pumping at areas listed above.

Table 14. Inactive and exhausted mines in Partridge River Watershed.

A. Inactive Mines-those which have been closed and are not expected to be operated during the current year.

MINE	OWNER
1. Donora Mine	U.S. Steel Corp.
2. Embarrass Mine(?) (off watershed map)	State of Minn., C.M. Hill Lumber Co. et al.
3. Fowler Mine	E.M. Fowler Estate (Eveleth Fee Office)
4. Graham Mine	Burlington Northern, Inc.
5. Miller-Mohawk Mine	Village of Aurora
6. Perkins Annex Mine	Harris, Stephens & Tupaney et al.
7. Stephens Mine	U.S. Steel Corp.
8. Wentworth No. 1 Mine	6.N. Iron Ore Prop.
9. Wentworth No. 2 Mine	6.N. Iron Ore Prop.

B. Exhausted Mines-those which no shipments have been made from during the past five years and which, according to the Minnesota Department of Revenue, do not contain any merchantable ore.

1. Adriatic Mine	State of Minn.
2. Hudson Mine	Harris, Stephens & Tupaney et al.
3. Knox Mine	Burlington Northern, Inc.
4. Mayas Mine	State of Minn. et al.
5. Meadow Mine	Meadow Land Co.
6. Meadow Extension Mine	U.S. Steel Corp.
7. Pacific Mine	Burlington Northern, Inc.
8. Perkins Mine	Harris, Stephens & Tupaney et al.
9. St. James Mine	White Township

Table 14 (contd.)

MINE	OWNER
10. Siphon Mine	Harris, Stephens, Tupaney et al.
11. Vivian Mine	Burlington Northern, Inc.
12. Weed Mine	Congdon Trust et al.
13. Arne Mine	U.S. Steel Corp.

Table 15. Characteristics of monitored lakes in St. Louis River Watershed.

LAKE	HEADWATER LAKE	SURFACE AREA A_o (km^2)	DRAINAGE AREA A_d (Km^2)	MEAN DEPTH $\bar{Z}$ (m)	MAXIMUM DEPTH Z max (m)	VOLUME $VX10^6$ (m)	MEAN ANNUAL DISCHARGE $QX10^6$ (m^3yr^{-1})		AREAL WATER LOAD $q_s=Q/A_o$		FLUSHING RATE e (yr^{-1})		STRATIFICATION[a]
							b	c	b	c	b	c	
Seven Beaver	yes	5.63	157	1.46	1.68	8.24	42.38	27.1	7.53	4.82	5.14	3.29	Does not stratify
Pine	yes	1.77	14.8	2.34	4.27	4.14	4.50	2.33	2.54	1.32	1.09	.56	Does not stratify
Long	yes	1.79	21.6	.50	1.83	.90	6.43	3.45	3.59	1.93	7.14	3.83	Does not stratify

[a] See Appendix B for definitions.
[b] Ten-year average.
[c] March 1, 1976 through February 28, 1977 average.

Table 16. Characteristics of monitored lakes outside of designated watersheds.

LAKE	HEADWATER LAKE	SURFACE AREA A_o (km^2)	DRAINAGE AREA A_d (Km^2)	MEAN DEPTH $\bar{Z}$ (m)	MAXIMUM DEPTH Z max (m)	VOLUME $VX10^6$ (m)	MEAN ANNUAL DISCHARGE $QX10^6$ (m^3yr^{-1})		AREAL WATER LOAD $q_s=Q/A_o$		FLUSHING RATE e (yr^{-1})		STRATIFICATION[a]
							b	c	b	c	b	c	
Whiteface Res.	yes	17.22	337	3.15	9.14	54.19	87.59	60.1	5.09	3.49	1.62	1.11	Weakly dimictic
Tofte	yes	.47	1.7	10.73	22.25	5.09	.56	.25	1.19	.52	.11	.05	Monomictic[d]
Triangle	yes	1.32	5.5	3.99	12.19	5.29	1.75	.83	1.33	.63	.33	.16	Strongly dimictic
Bass	no	.68	13	5.51	10.67	3.77	3.97	2.03	5.84	2.99	1.04	.54	Strongly dimictic
Bearhead	yes	2.74	13.1	4.49	13.72	12.31	4:01	2.05	1.46	.75	.33	.17	Weakly dimictic
Wynne	no	1.15	374.9	11.1	15.85	12.80	96.93	67.1	84.29	58.4	7.57	5.24	Strongly dimictic
Cloquet	yes	.74	5.8	.85	2.13	.63	1.86	.88	2.51	1.19	2.95	1.40	Does not stratify

[a]See Appendix B for definitions.
[b]Ten-year average.
[c]March 1, 1976 through February 28, 1977 average.
[d]Overturns in late fall.

Table 17. Median Secchi disk and summer chlorophyll α.

Lake	Median Secchi Disk (m)	Summer Chlorophyll α (μg/l)
August	1.9	
LA-1	1.9	ND
LA-Z	3.4	ND
Bass	3.3	3.3
Bear Island		
LBI-1	2.5	ND
LBI-2	2.6	5.3
Big	3.0	5.3
Birch		
LBH-1	1.6	6.0
LBH-2	1.5	6.4
LBH-3	1.6	7.6
LBH-4	1.8	8.0
Clearwater	4.2	2.7
Colby		
LCY-1	1.8	4.4
LCY-2	1.6	ND
Cloquet	0.9	8.7
Fall	1.8	8.7
Gabbro		
LGO-1	1.2	8.7
LGO-2	1.6	ND
Greenwood	0.8	4.0
One	2.3	6.7
Long	1.0	5.3
Perch	1.8	4.7
Pine	1.9	8.0
Sand	1.3	7.4

Table 17. (Contd.)

Lake	Median Secchi Disk (m)	Summer Chlorophyll α (μg/l)
Seven Beaver		
LSB-1	0.8	12.0
LSB-2	0.7	8.4
Slate	1.6	10.7
S. McDougal	0.7	8.0
Tofte	4.8	3.3
Triangle	3.4	5.3
Turtle	1.8	6.0
White Face	1.0	ND
White Iron		
LWI-1	1.6	4.4
LWI-2	1.4	6.7
Wynne	1.8	4.7

ND = No data

Table 18. Correlations: general parameters. ($p \leq 0.05$)

STREAMS

Sp. Cond.:	Ni
	Ca
	Mg
	Suspended solids
	Total dissolved solids(t)
	pH
Color:	KJD-N
	TOC
	DOC
	Fe(t)
Ca:	pH
	Mg(t)
	Suspended solids
	Specific conductivity
	Total dissolved solids(t)
Mg:	Suspended solids
	Ca(t)
	Specific conductivity(t)
	Total dissolved solids(t)
TOC:	Color
	Tot-N
	KJD-N
	DIC(t)
	TDS(t)
	TON(t)

LAKES

Sp. Cond.:	Cu
	Ni
	Suspended solids
	Mg
	Alkalinity(t)
	Total dissolved solids(t)
Color:	Fe
	Tot-N
	KJD-N
	S.D.(t)
	TOC
	DOC
	D.O.
Ca:	Alkalinity
	Specific conductivity(t)
	pH
	Suspended solids
	Cu(t)
	Ni(t)
	Total dissolved solids(t)
	$\bar{Z}$ (t)
Mg:	Cu(t)
	Suspended solids(t)
	Specific conductivity
	Alkalinity(t)
	Color(t)
	Dissolved solids(t)
TOC:	Secchi disk
	Iron
	Color
	Suspended solids
	DO(%)
	KJD-N
	Ortho-P
	Zinc (t)
	Lead (t)
	Tot-N (t)
	D.O.(%)(t)
	$\bar{Z}$; $\bar{Z}_{max}$(t)
	KJD-N (t)
	TSI-SD (t)

(t)=log transformed data

Table 19. Results of analysis of variance, general parameters.

PARAMETER	LEVELS OF SIGNIFICANCE BETWEEN GROUPS			
Ca	A>>B	($p<0.005$)	B>>C	($p<0.005$)
Mg	A>>B	($p<0.005$)	B>>C	($p<0.005$)
Na	A=B		A,B>>C	($p<0.005$)
K	A>>B	($p<0.005$)	B>>C	($p<0.005$)
Cl	A>>B	($p<0.005$)	B>>C	($p<0.005$)
Silica	A>>B	($p<0.005$)	B>>C	($p<0.005$)
Color	A>>B	($p<0.005$)	B > C	($p=0.01$)
TOC	A>>B	($p<0.005$)	B > C	($p=0.01$)

Table 20. Representative examples showing general trends in data variability.

	LEVELS OF SIGNIFICANCE	
PARAMETER	MEANS	VARIANCES
Color	F-1>>K-7 ($p<0.005$)	F-1>>K-7 ($p<0.005$)
Color	SL-1=SL-2	SL-2>>SL-1
Calcium	SL-1>>SL-2 ($p<0.005$)	SL-1>>SL-2 ($p<0.005$)

DRAINAGE AREAS (km^2)

F-1	27	
K-7	1974	1974
SL-1	754	7-54
SL-2	243	243

Table 21. Flow dependency analysis, general parameters.

WATERSHED	PARAMETER Ca	Mg	K	Na	Cl
Filson	3[a]	3	3[a]	3	3
Dunka	3[b]	3[b]	3	3[a,b]	3[b]
Partridge	2	3[b]	3	2[a]	3[b]
Isabella	3[a,b]	3	3[a,c]	3[a]	3[a]
Stony (at SR-2)	3[b]	3	3	3[b]	3[a]
Bear Island	3	3	3[a]	3	3[a]
St. Louis	2	3[b]	3[b]	3[b]	3[b]
Shagawa	3	3	3	3	3
Kawishiwi (at K-5)	3	3[b]	3[a]	3[a,c]	3[a]
Kawishiwi (at K-6)	3[a]	3[a,b]	3[a,b]	3[b]	3[a]
Kawishiwi (at K-7)	3[a]	3[b]	3	3	3[a]

[a] first flush phenomenon
[b] limited dilution
[c] limited accelerated washoff

Table 22. Correlations: buffering parameters. ($p \geq 0.05$)

STREAMS

Alkalinity:	HCO_3
	DIC
	pH
	SO_4
	Ni
pH:	Alkalinity
	HCO_3
	Ca
	Cu
	Suspended solids
	Specific conductivity(t)
	Total dissolved solids(t)
SO_4:	Alkalinity
	HCO_3
	DIC

LAKES

Alkalinity:	HCO_3
	DIC
	pH
	Ca
	Ni
	$\bar{Z}$
	Co(t)
	Mg(t)
	Specific conductivity(t)
pH:	Alkalinity
	HCO_3
	Ca
	Pb
	D.O.%
	Co
	Fe(t)
SO_4:	CSI(t)

(t)=log transformed data

Table 23. Results of analysis of variance, buffering parameters.

PARAMETER	LEVELS OF SIGNIFICANCE BETWEEN GROUPS	
pH	A>B (p=0.01)	B>>C (p<0.005)
Alkalinity	A>B (p=0.01)	B>>C (p<0.005)
Bicarbonate	A=B	A,B>>C (p<0.005)
Sulfate	A>>B (p<0.005)	B>>C (p<0.005)
DIC	A=B	A,B>C (p=0.03)

Table 24. Flow dependency analysis, buffering parameters.

WATERSHED	PARAMETER ALKALINITY	PARAMETER SULFATE
Filson	2	2
Dunka	2	2
Partridge	2	2
Isabella	2	3
Stony (at SR-2)	2	3
Bear Island	3	2
St. Louis	2	2
Shagawa	3	3
Kawishiwi (at K-5)	2	3
Kawishiwi (at K-6)	3	3
Kawishiwi (at K-7)	3	3

Calcite saturation index (CSI), Regional Copper-Nickel Study lakes.

LAKE	CSI	LOCATION[a]
Tofte	0.3	H,N
Wynne	1.1	S
Triangle	1.4	H,N
Colby	1.4	S
Bass	1.5	N
Slate	1.5	N
Bearhead	1.6	H,N
Sand	1.8	H,N
Cloquet	2.0	H,S
Birch	2.0	N
Big	2.0	
Pine	2.1	H,S
Gabbro	2.3	N
White Face	2.3	H,S
Bear Island	2.3	H,N
Fall	2.6	N
White Iron	2.6	N
Seven Beaver	2.8	H,S
South McDougal	2.9	H,N
Clearwater	3.0	H,N
August	3.1	H,N
Turtle	3.1	H,N
One	3.2	N
Greenwood	3.3	H,N
Perch	3.4	H,N
Long	4.1	H,S

[a]H=headwater lake
N=North of Divide
S=South of Divide

Table 26. CSI-selected BWCA lakes.

WELL BUFFERED		POORLY BUFFERED	
LAKE	CSI	LAKE	CSI
Cypress	1.5	Silver Island	3.1
North	1.5	Vernon	3.1
South	2.2	Sawbill	3.3
Magnetic	2.2	Alice	3.3
Dunkan	2.3	Karl	3.4
Splash	2.5	Kawishiwi	3.5
Seagull	2.6	Gaskin	3.5
Kekekabic	2.6	Agnes	3.6
Crooked	2.6	Stuart	3.6
Alpine	2.7	Malberg	3.7
Saganaga	2.7	Sunday	3.7
Basswood	2.8	Grace	3.7
Gabigichigami	2.9	Cherokee	4.0
LaCroix	2.9	Carp	4.0
S. Fowl	3.0	Pauness	4.1

Table 27. Correlations: nutrient parameters. ($p \geq 0.05$)

STREAMS		LAKES	
Tot-P:	Tot-N	Tot-P:	Secchi disk(t)
	$NO_2 + NO_3$		D.O.(%) (t)
	KJD,N		
	D.O.	Tot-N:	Color
Tot-N:	Tot-P		Suspended solids
	TOC		Secchi disk(t)
			TOC(t)
			TSI-SD(t)
			TDS(t)

(t)=log transformed data

Table 28. Results of analysis of variance, nutrient parameters.

PARAMETER	LEVELS OF SIGNIFICANCE BETWEEN GROUPS	
Total phosphorus	A=B	A,B<C (p=.02)
Total Nitrogen	A>B (p=.05)	B>>C (p<0.005)

where A = P-1, SL-1, BB-1
B = D-1, E-1, P-2
C = all others

Table 29. Flow dependency analysis, nutrient parameters.

WATERSHED	PARAMETER	
	NITROGEN	PHOSPHORUS
Filson	3	3
Dunka	3*	3
Partridge	3	3
Isabella	3	3
Stony (at SR-2)	3	3
Bear Island	3	3
St. Louis	3	3
Shagawa	3	3
Kawishiwi (at K-5)	3	3
Kawishiwi (at K-6)	3	3
Kawishiwi (at K-7)	3	3

*Two distinct distributions of equal slope.

Median trophic state indices, Regional Copper-Nickel Study lakes.

LAKE	TSI(SD)	TSI(TP)	LOCATION[a]
Tofte	37	37	H,N
Bearhead	43	40	H,N
Triangle	42	46	H,N
Bass	42	47	N
Clearwater	39	50	H,N
Bear Island	46	47	H,N
August	51	42	H,N
Wynne	51	45	S
Pine	51	45	H,S
Colby	52	44	S
One	48	51	N
Big	44	55	H,S
Turtle	52	48	H,N
White Iron	53	48	N
Birch	53	49	N
Gabbro	54	48	N
Fall	52	51	N
Perch	52	51	H,N
Slate	53	54	N
Sand	56	55	H,N
White Face	58	53	H,S
Long	60	55	H,S
Cloquet	62	55	H,S
Seven Beaver	63	54	H,S
Greenwood	61	59	H,N
South McDougal	66	59	H,N

[a]H=Headwater Lake
N=North of Divide
S=South of Divide

Table 32. Results of analysis of variance, metals.

PARAMETER	LEVELS OF SIGNIFICANCE BETWEEN GROUPS	
Al	A=B	A,B=C
Fe	A<C (p=0.01)	C<<B (p<0.005)
Mn	A>B (p=0.06)	B>>C (p<0.005)
Cu	A=B	A,B>>C* (p<0.005)
Ni	A>>B (p=0.004)	B>C (p=0.06)
Cd	A>B (p=0.05)	B>>C (p=0.003)
Zn	A=B	A,B>>C (p<0.005)
Pb	A=B	A,B>>C (p<0.005)
Co	A>B (p=0.01)	B>>C (p=0.001)

*See text for exceptions.

Table 33. Flow dependency analysis, metals.

WATERSHED	PARAMETER Cu	Ni	Cd	Zn	Pb	Fe
Filson	3	3	3	3	3[a]	3[a]
Dunka	3	3	3	3	3	3[a,b]
Partridge	3	3[a]	3	3	3[a]	3[a]
Isabella	3	3	3	3	4	3
Stony (at SR-2)	3[a]	3	3	3[a,c]	3[a]	3
Bear Island	3	3	3[a,c]	3[a]	3[c]	3[b]
St. Louis	3	3[a]	3[a]	3	3[a]	3[a]
Shagawa	3	3	3[a,c]	3[a]	3	3[a,c]
Kawishiwi (at K-5)	3	3	3[a]	4[a]	3[a,c]	3
Kawishiwi (at K-6)	3	3[a]	3[a]	4[a]	4[a]	3
Kawishiwi (at K-7)	3	3	3	3[c]	3[c]	3[b]

[a]first flush phenomenon.
[b]limited dilution.
[c]limited accelerated washoff.

LOCATION OF
WATER QUALITY RESEARCH AREA IN MINNESOTA

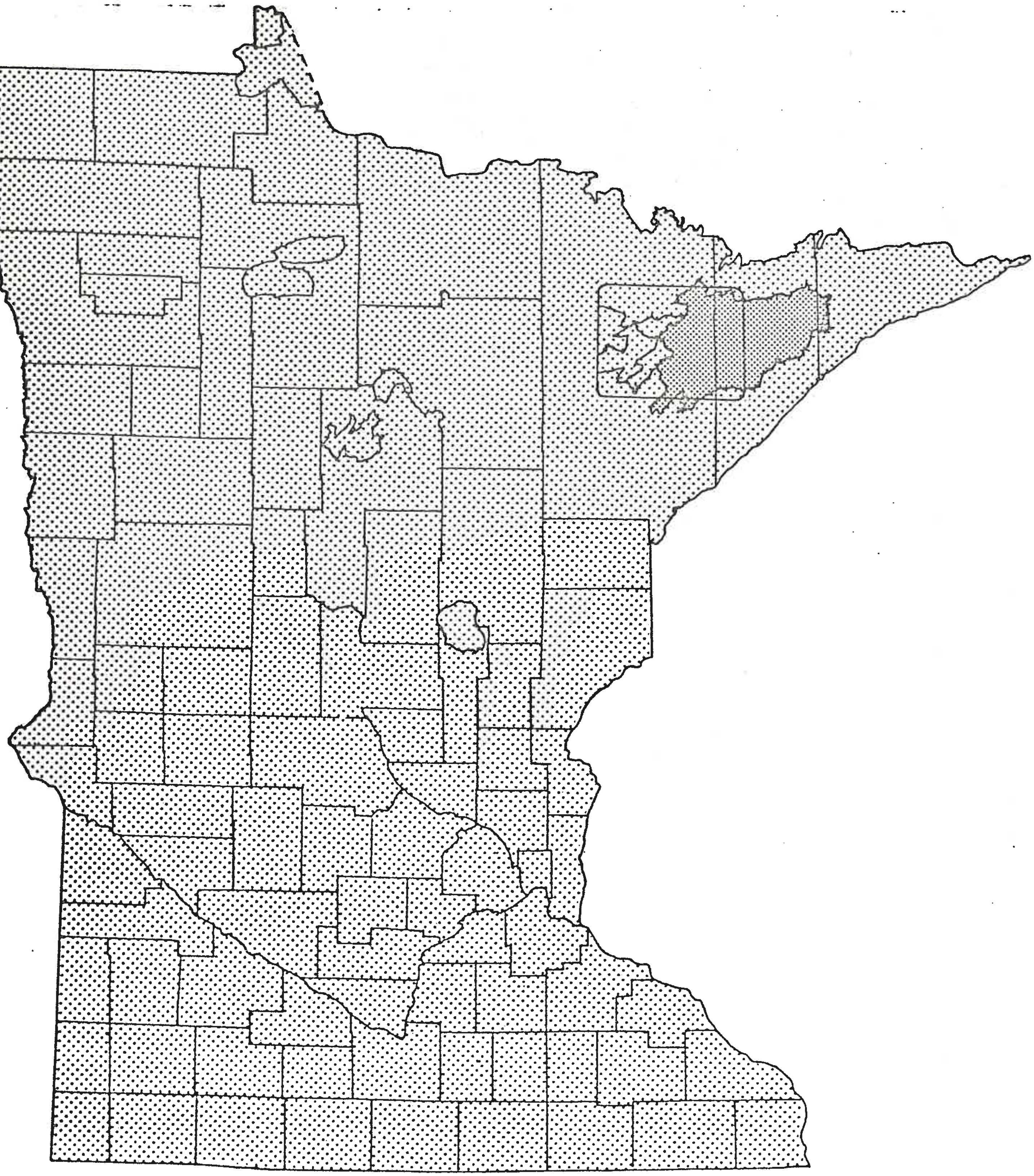
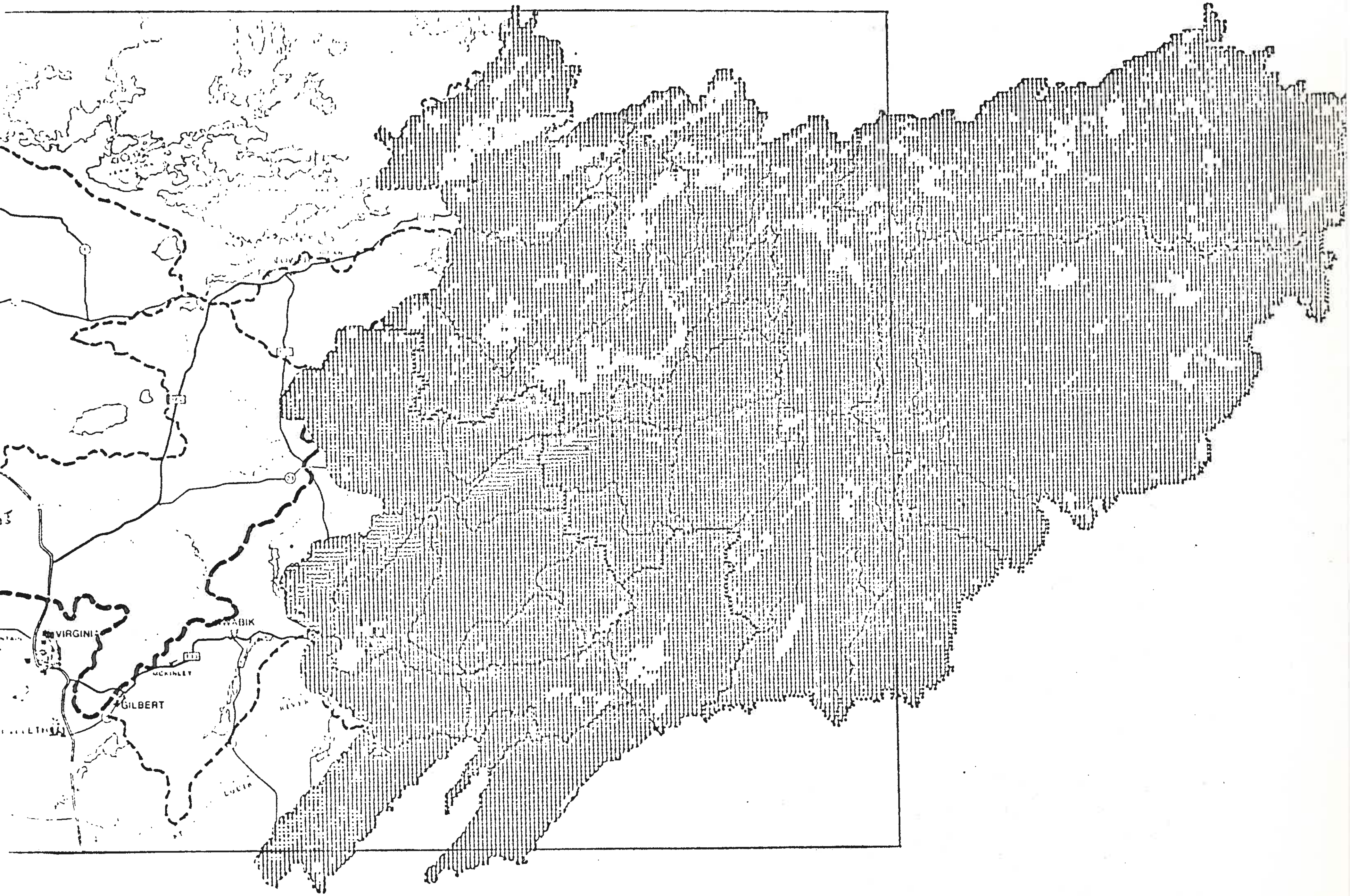
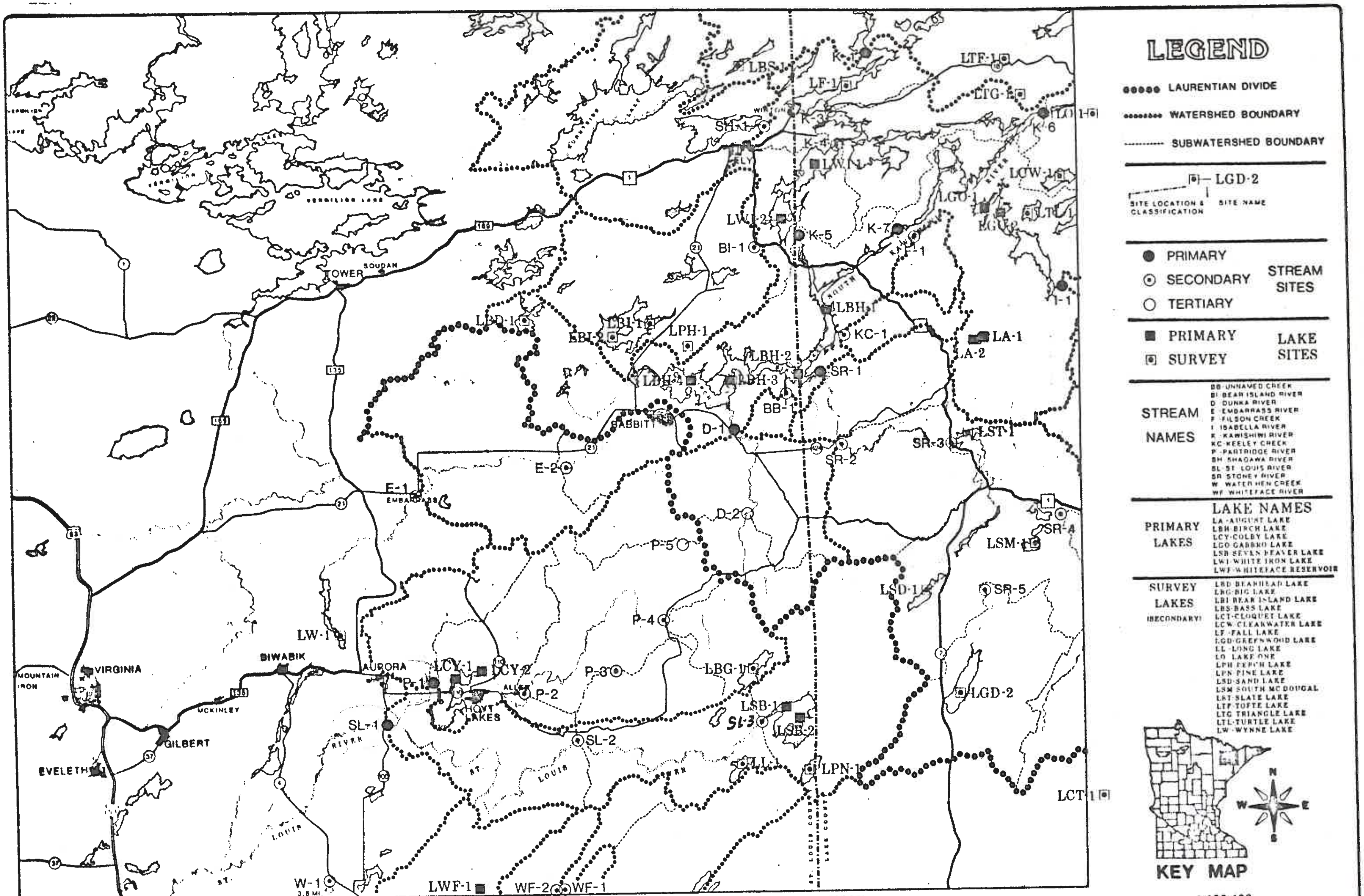


FIGURE 1


GILBERT

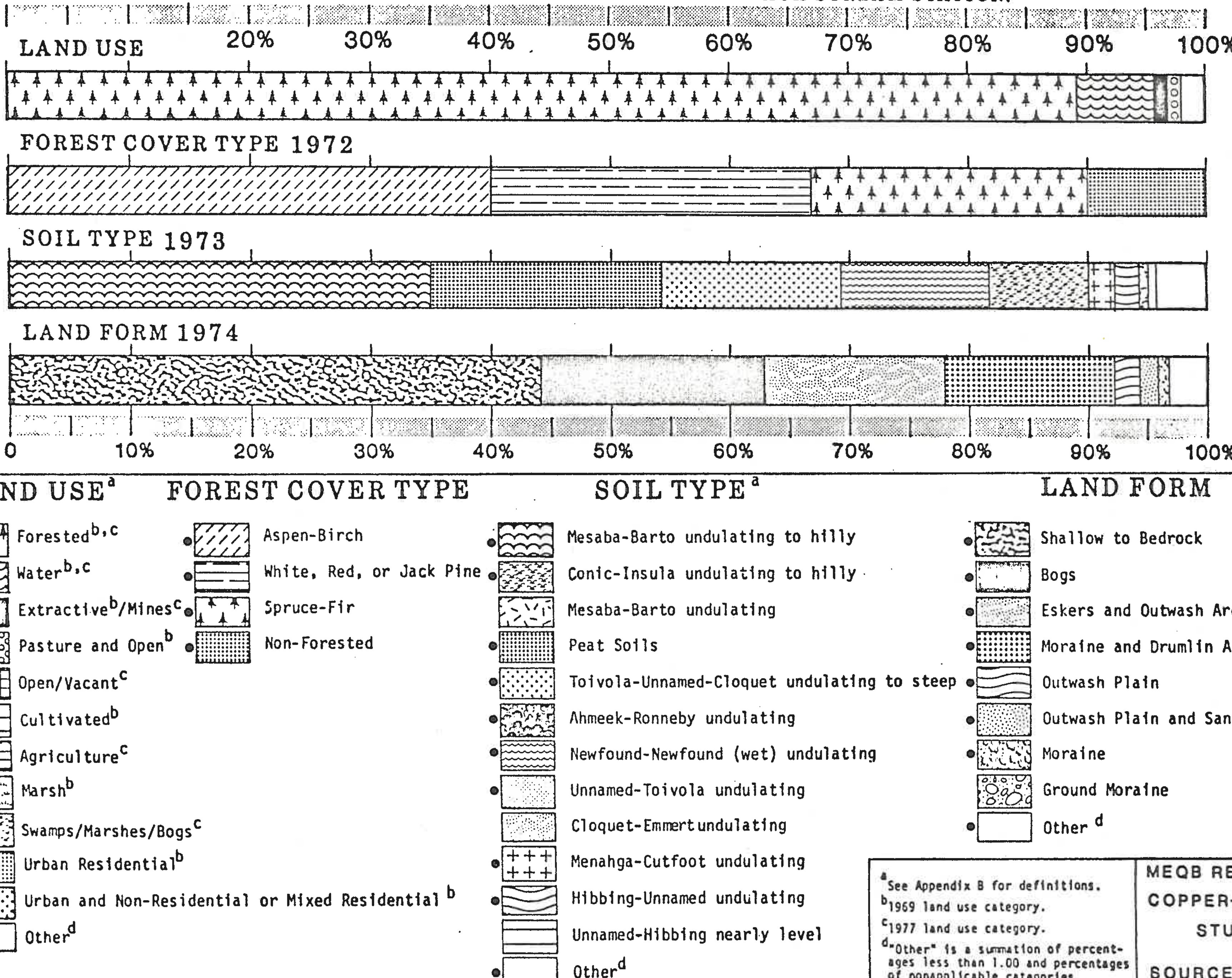


MEQB REGIONAL COPPER-NICKEL STUDY

FIGURE 2. SURFACE WATER QUALITY MONITORING SITES

FIGURE 3. CHARACTERISTICS OF WATER QUALITY RESEARCH AREA

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)

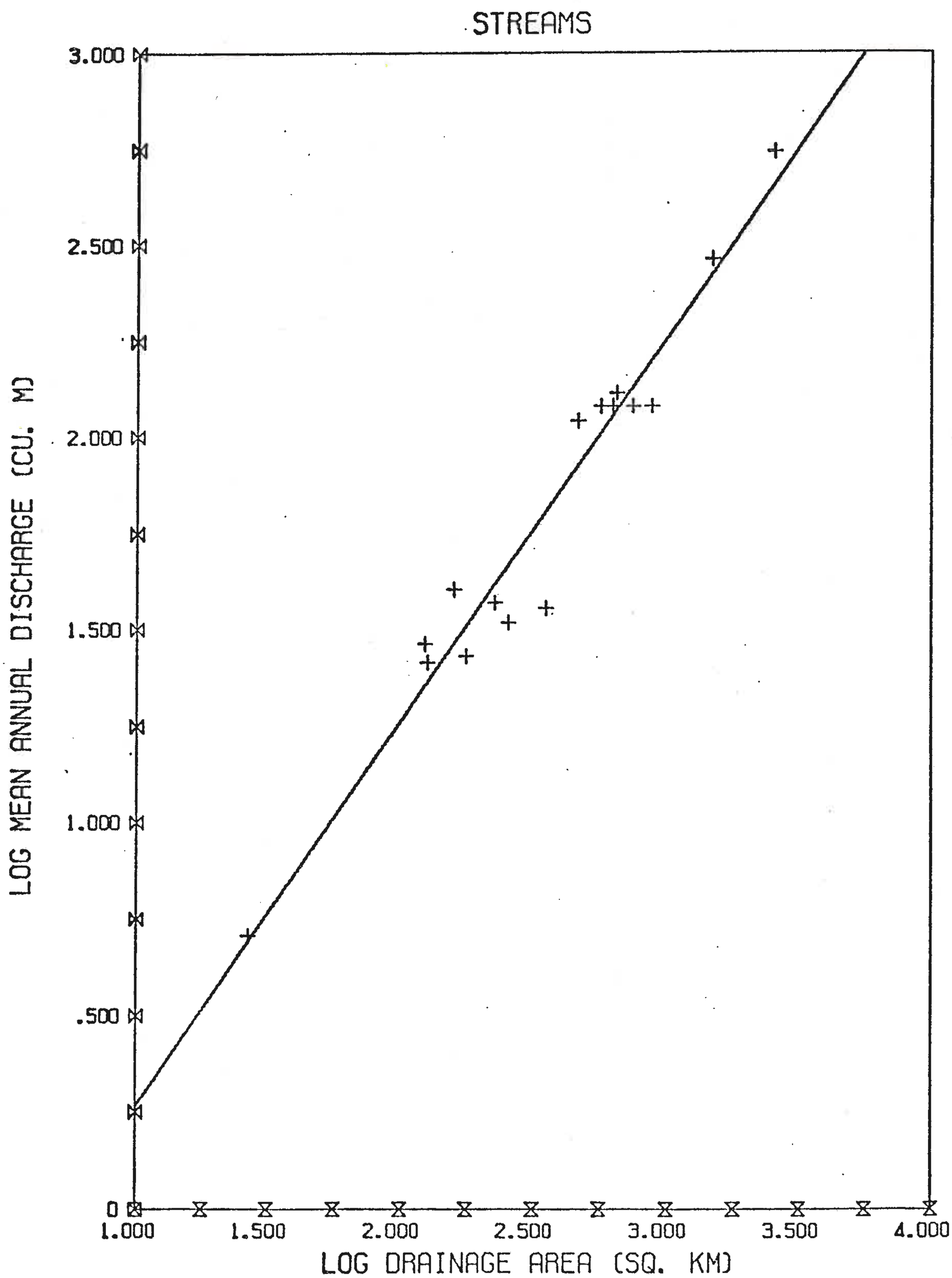


[a]See Appendix B for definitions.
[b]1969 land use category.
[c]1977 land use category.
[d]"Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

Figure 4. Relationships between stream drainage area and mean annual discharge.



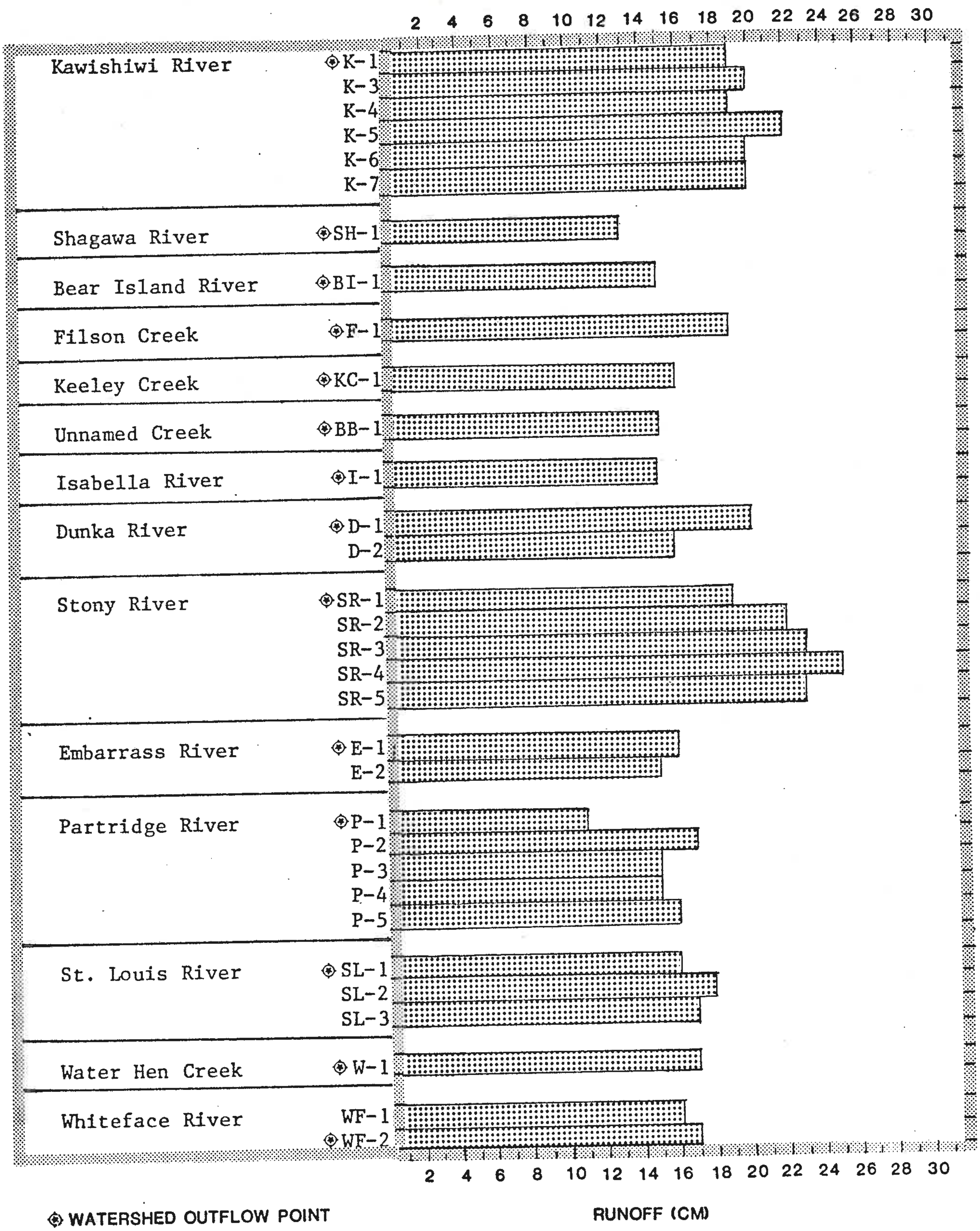


Figure 5

Runoff, March 1, 1976 - February 28, 1977.

Figure 6. Two hydrographs illustrating differences in watershed response.

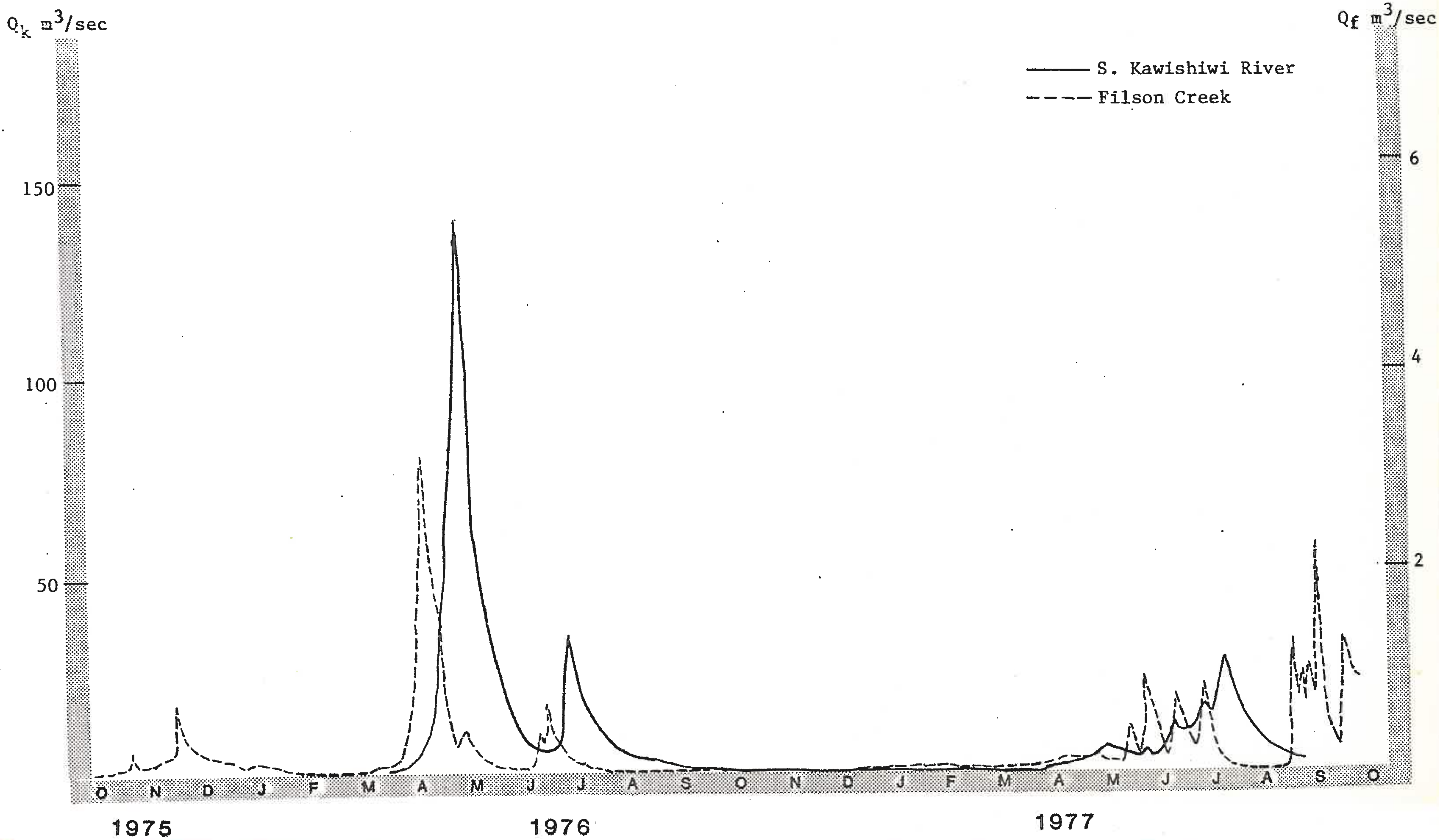


FIGURE 7. CHARACTERISTICS OF KAWISHIWI RIVER WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)

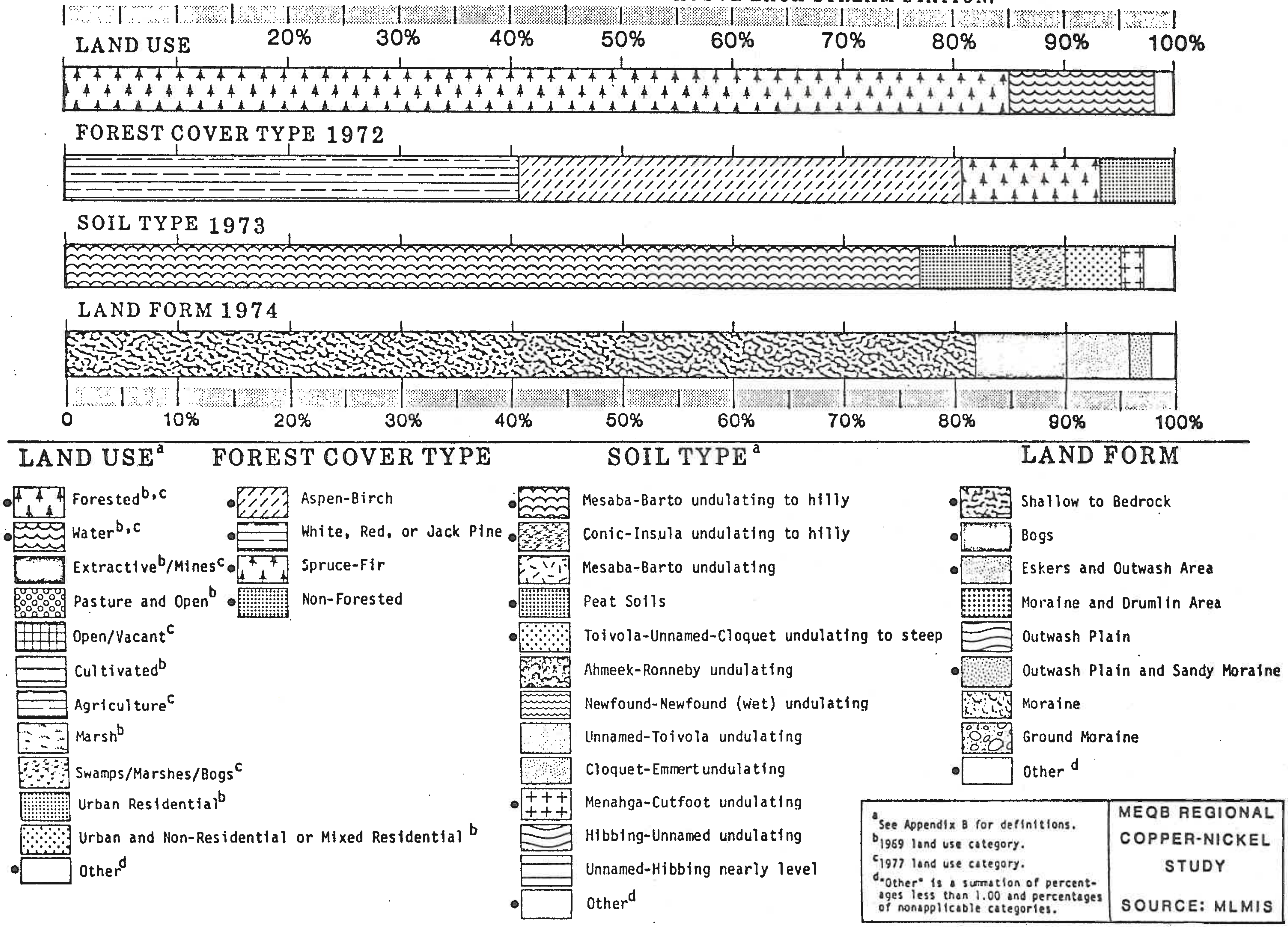
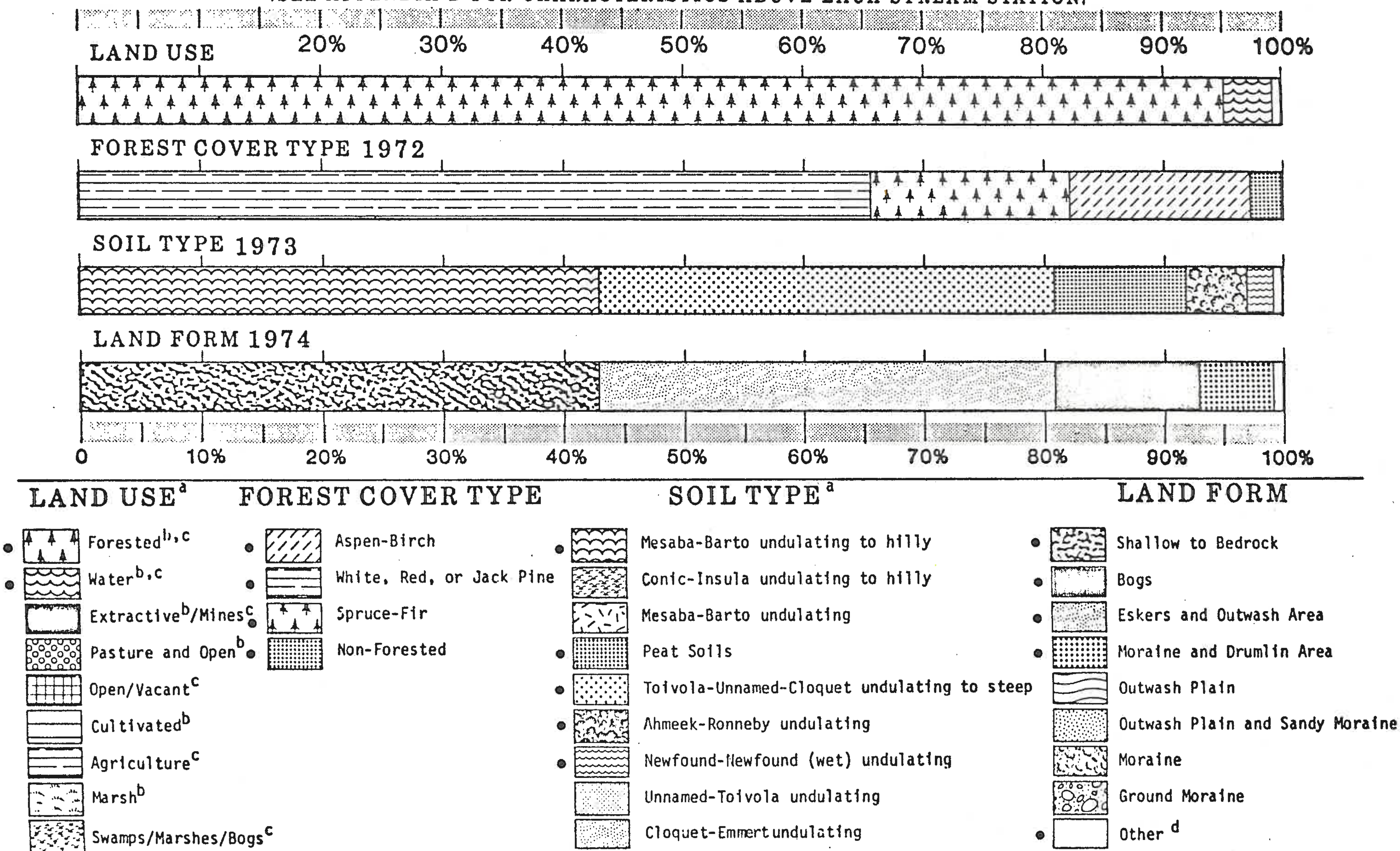


FIGURE 8. CHARACTERISTICS OF ISABELLA RIVER WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



[a] See Appendix B for definitions.
[b] 1969 land use category.
[c] 1977 land use category.
[d] "Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

FIGURE 9. CHARACTERISTICS OF FILSON CREEK WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)

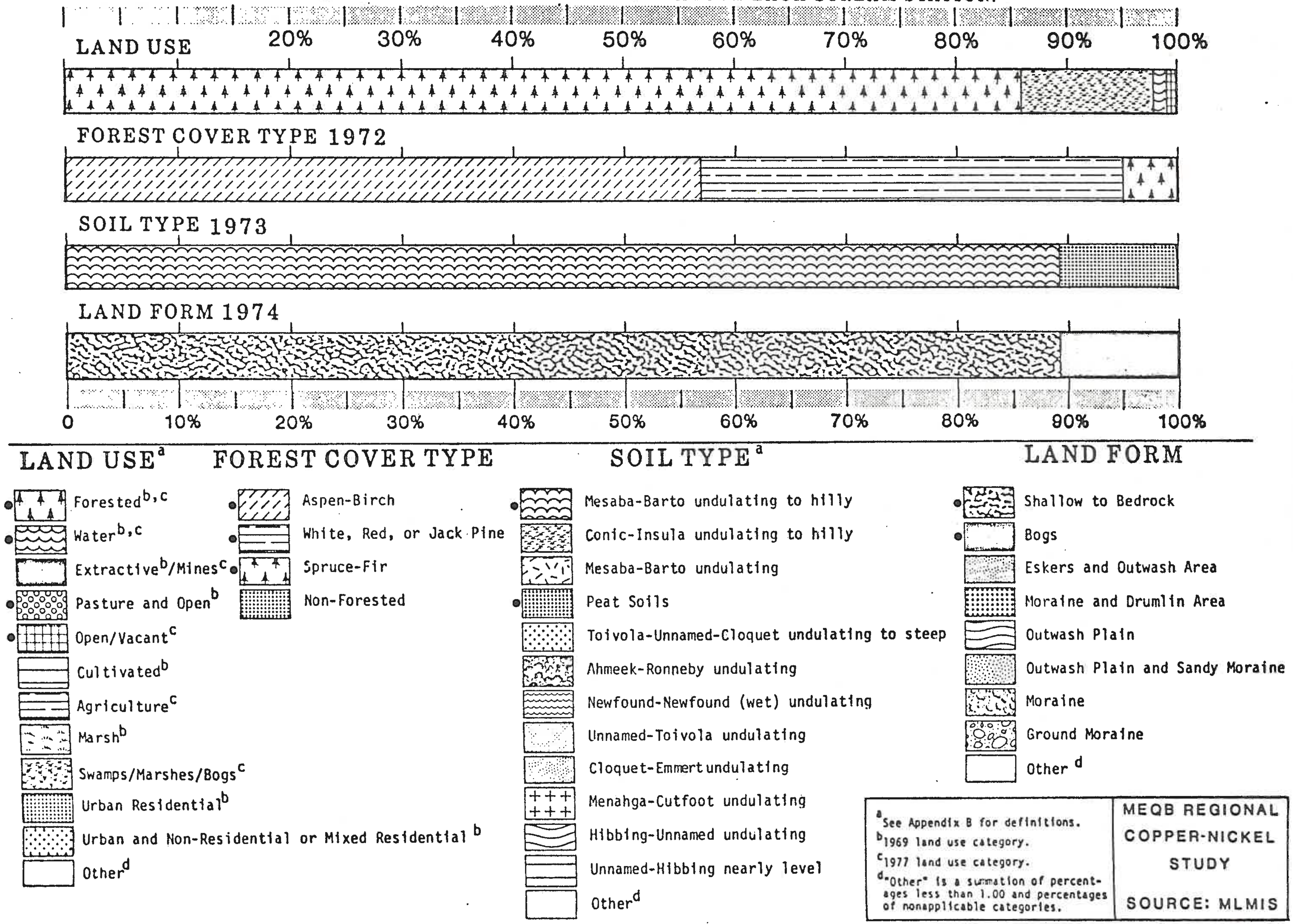
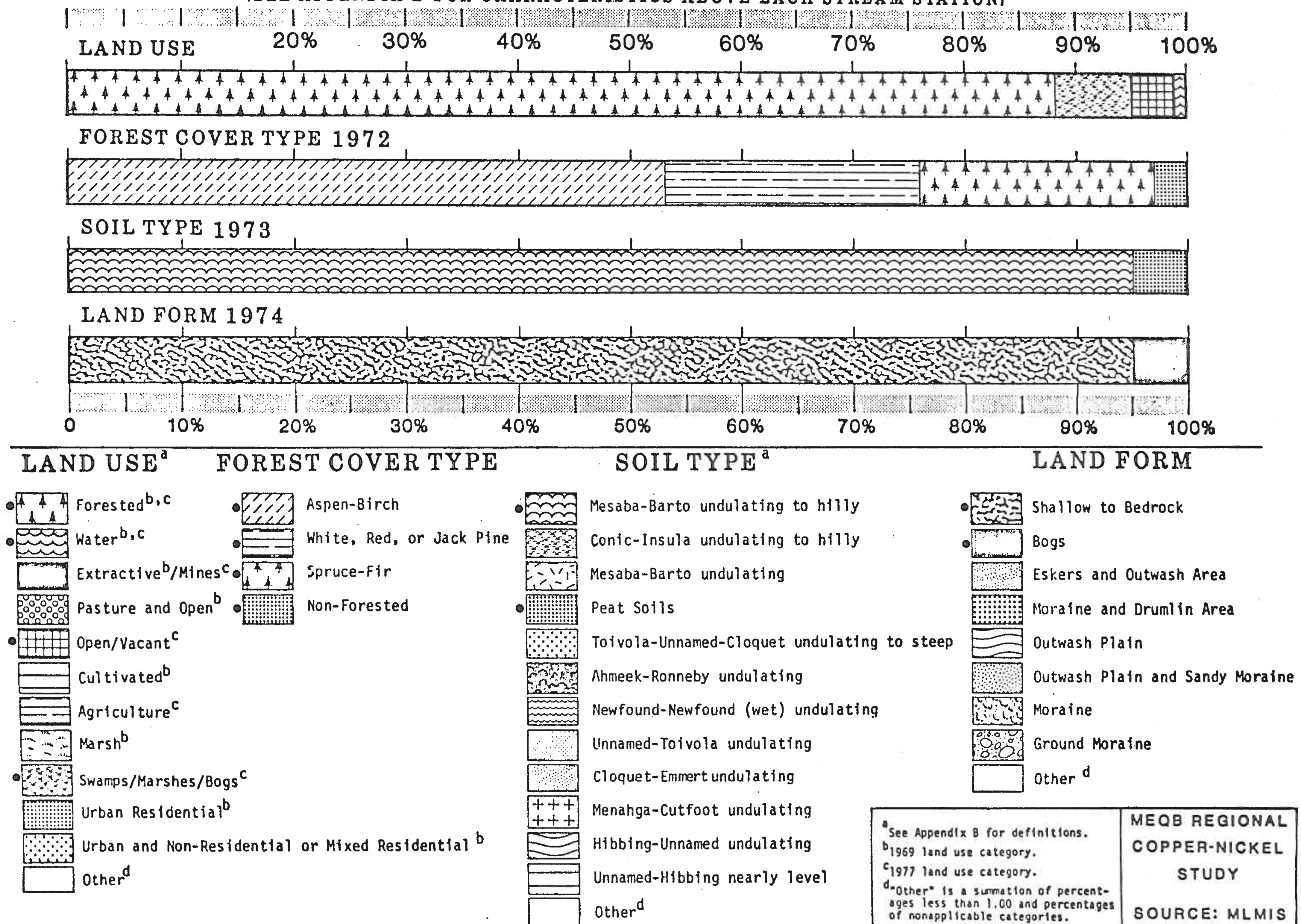


FIGURE 10. CHARACTERISTICS OF KEELEY CREEK WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



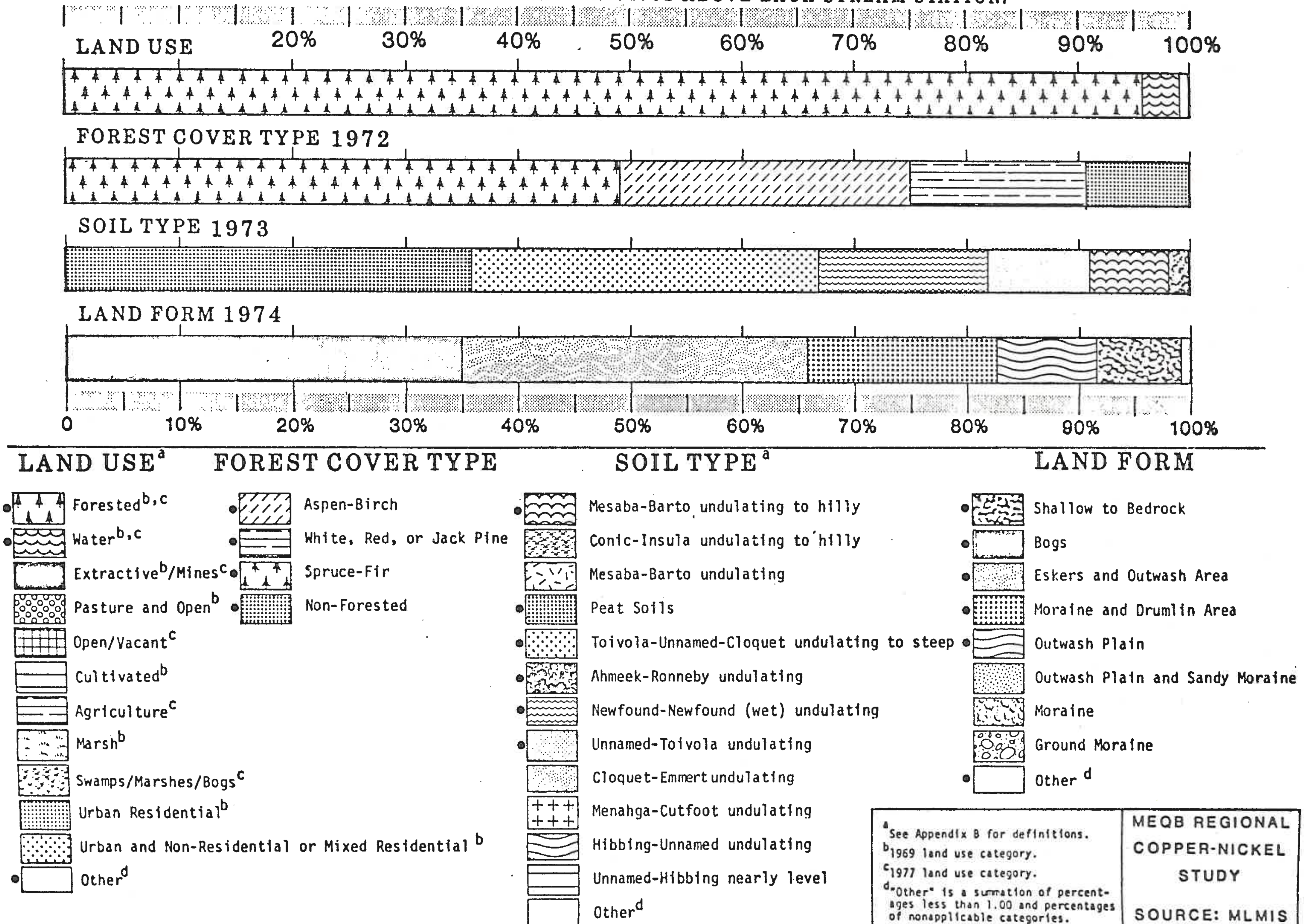
[a]See Appendix B for definitions.
[b]1969 land use category.
[c]1977 land use category.
[d]"Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

FIGURE 11. CHARACTERISTICS OF STONEY RIVER WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



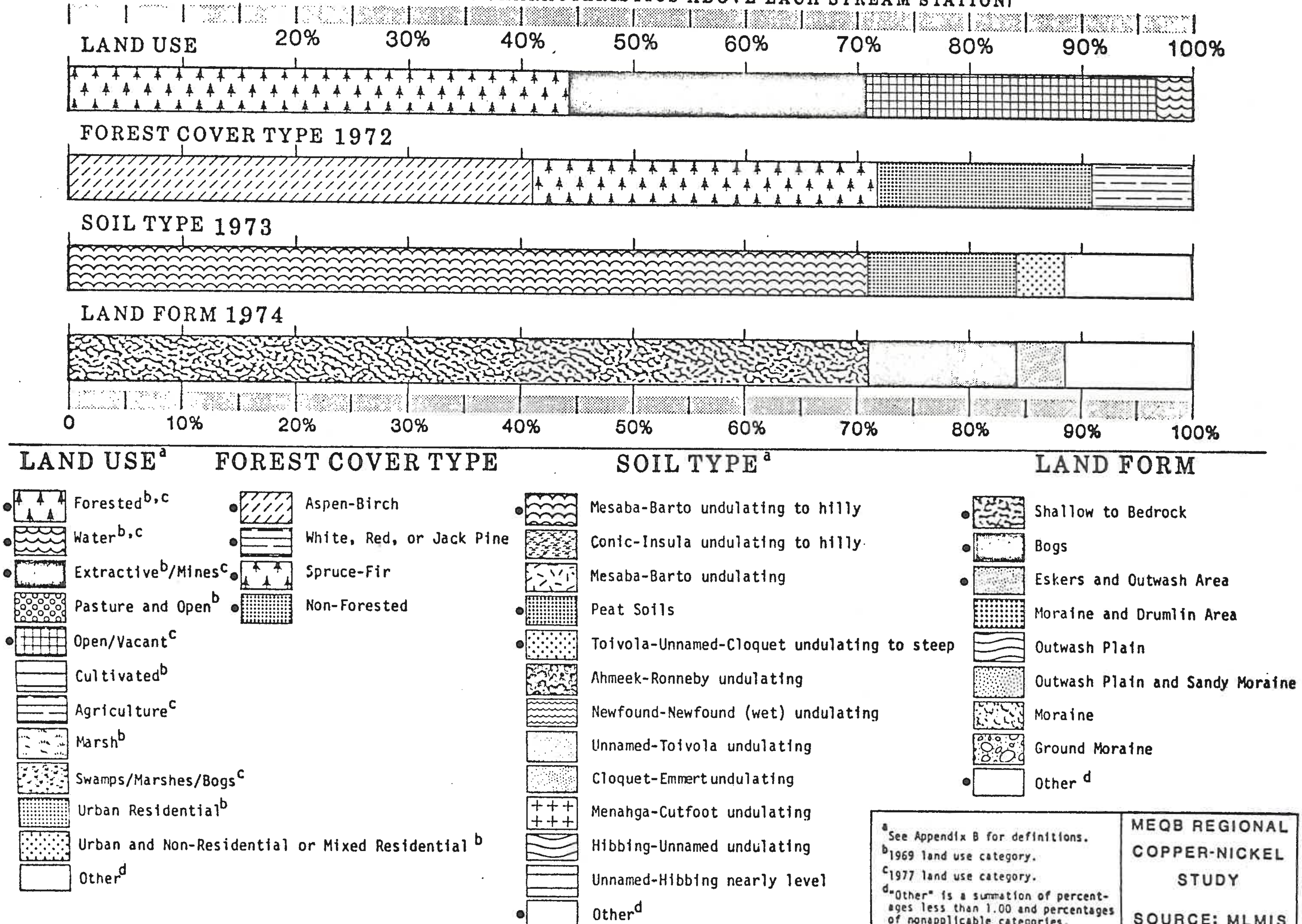
[a]See Appendix B for definitions.
[b]1969 land use category.
[c]1977 land use category.
[d]"Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

FIGURE 12: CHARACTERISTICS OF UNNAMED CREEK WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



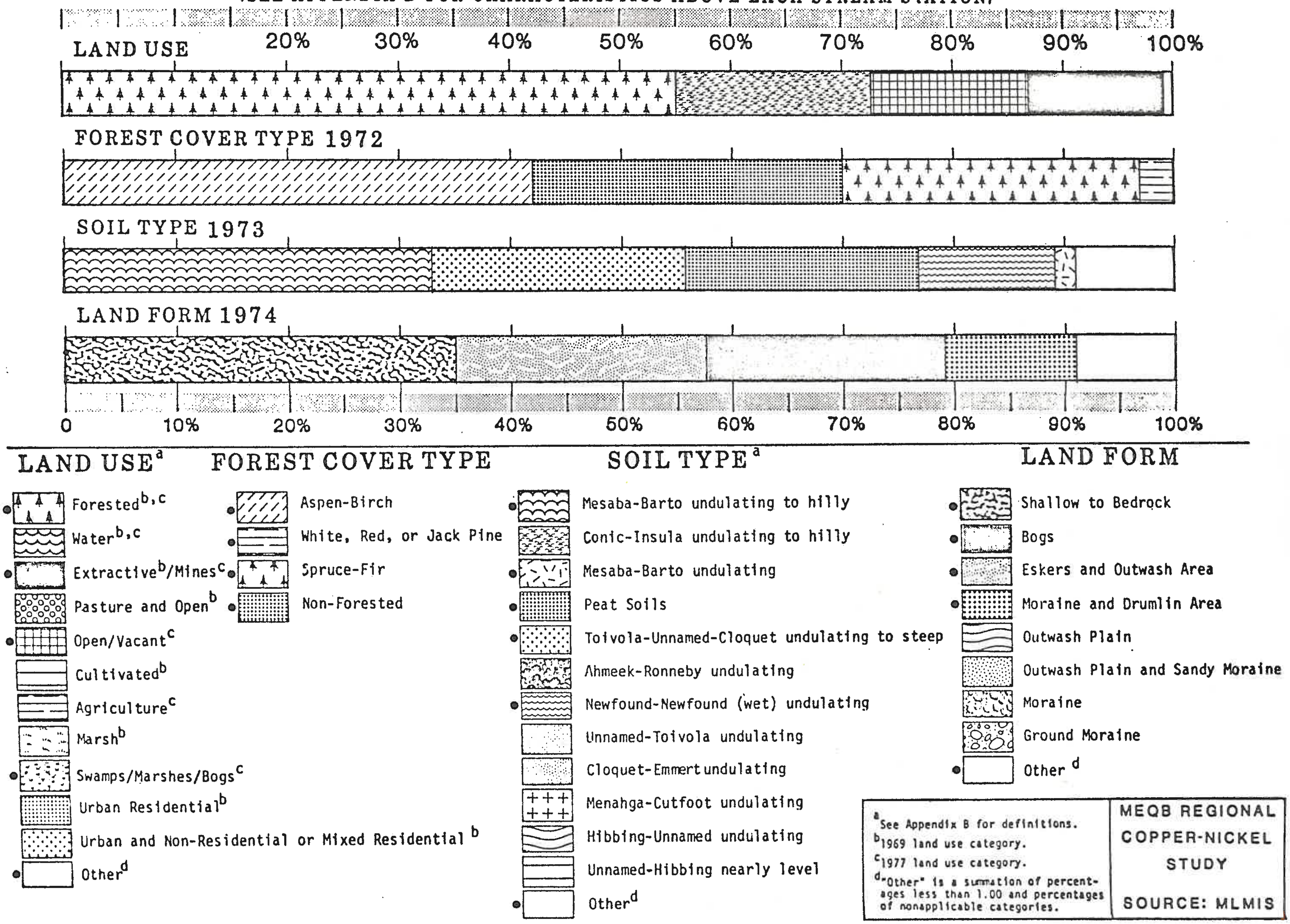
[a] See Appendix B for definitions.
[b] 1969 land use category.
[c] 1977 land use category.
[d] "Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

FIGURE 13. CHARACTERISTICS OF DUNKA RIVER WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



[a] See Appendix B for definitions.
[b] 1969 land use category.
[c] 1977 land use category.
[d] "Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

FIGURE 14. CHARACTERISTICS OF BEAR ISLAND RIVER WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)

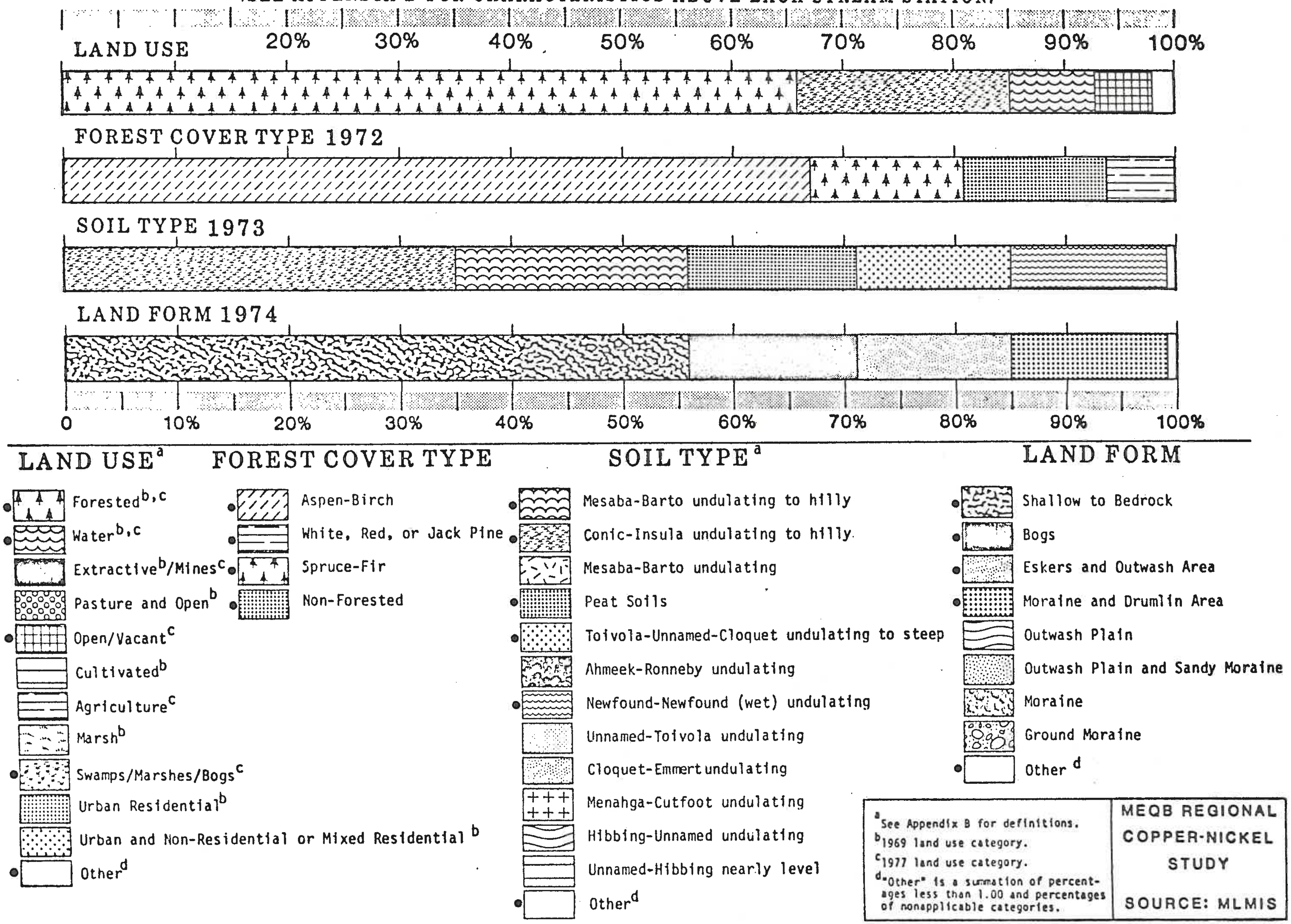
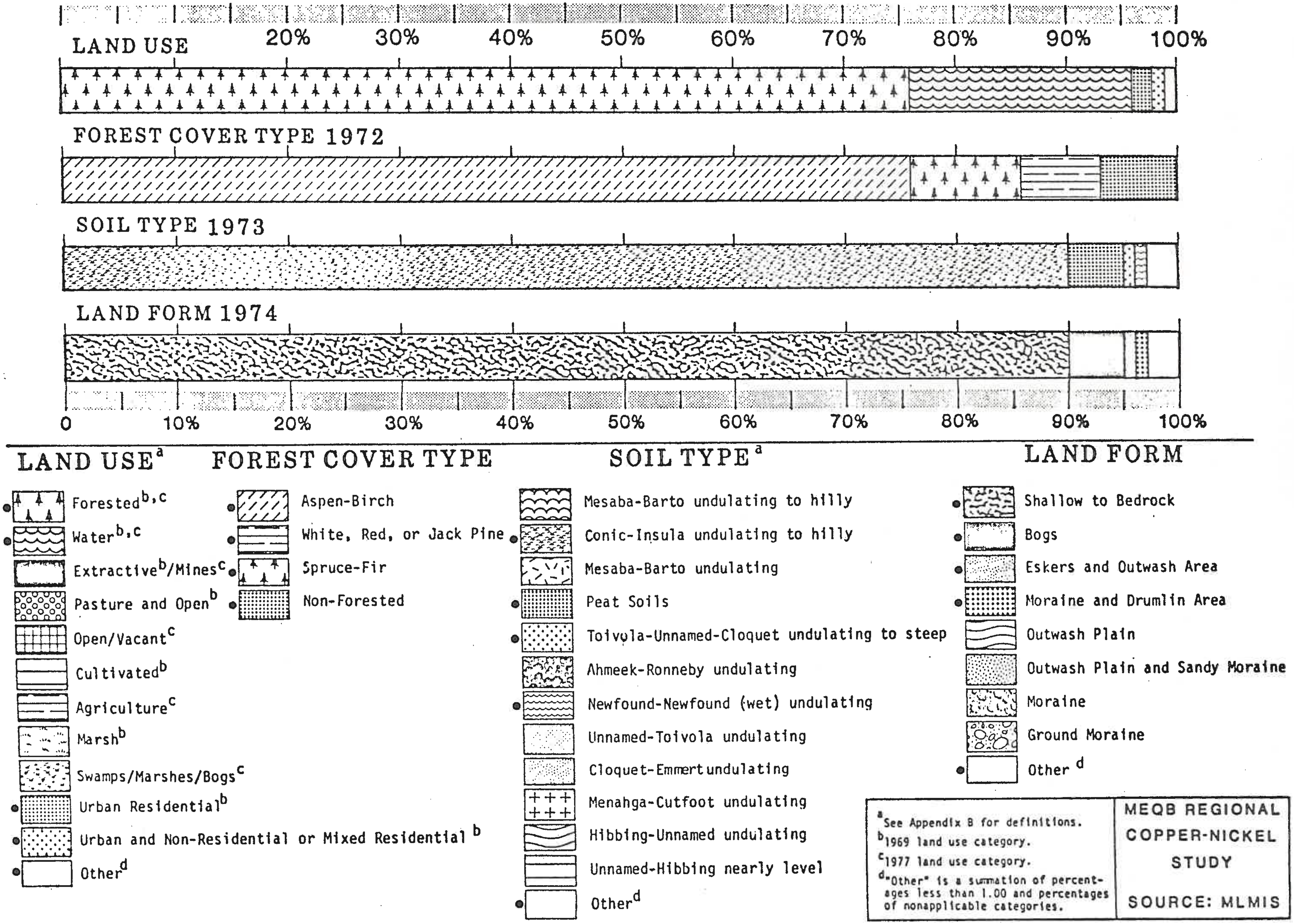


FIGURE 15. CHARACTERISTICS OF SHAGAWA RIVER WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



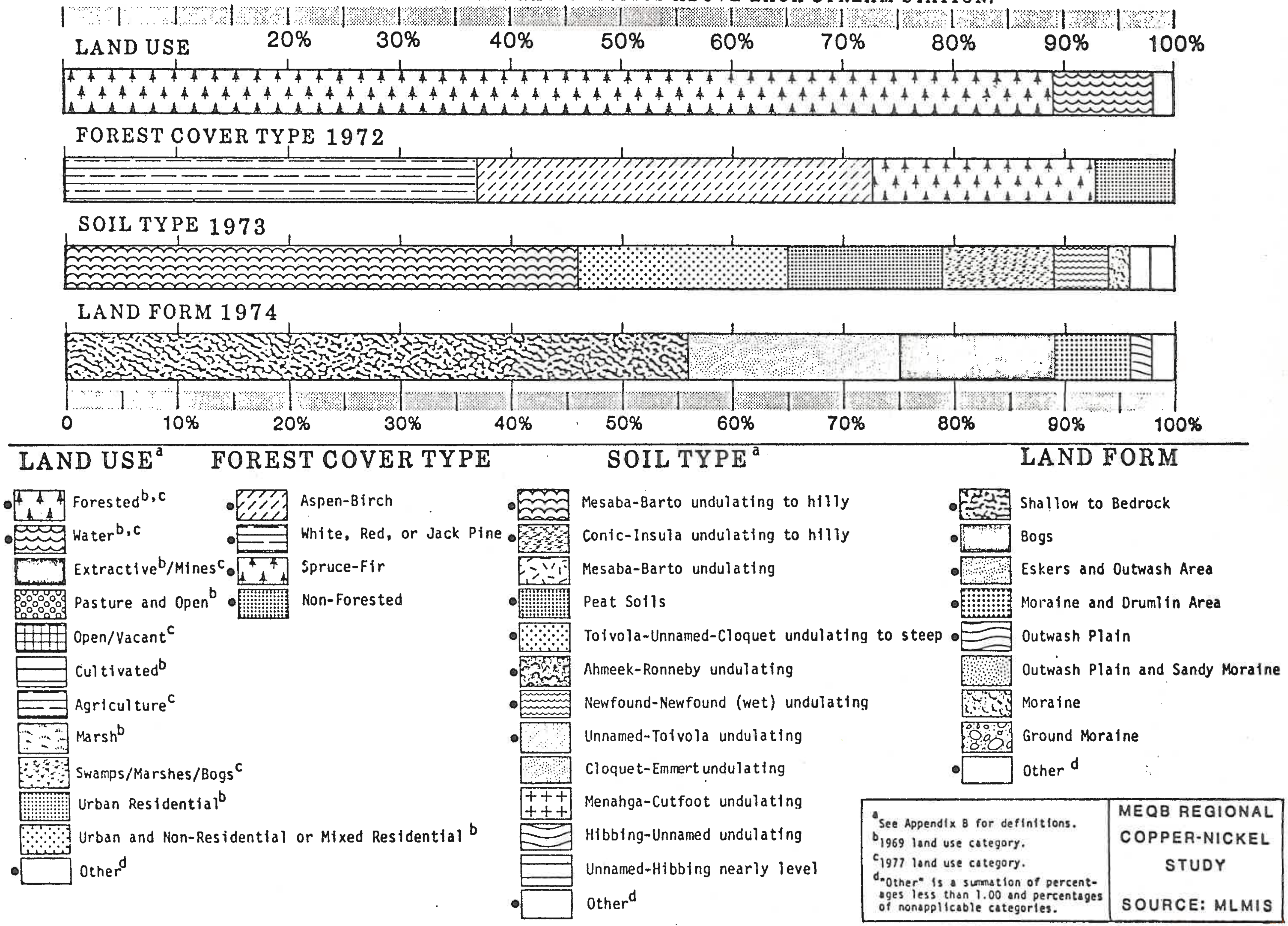
[a]See Appendix B for definitions.
[b]1969 land use category.
[c]1977 land use category.
[d]"Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

FIGURE 16. CHARACTERISTICS OF RAINY RIVER DRAINAGE BASIN

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



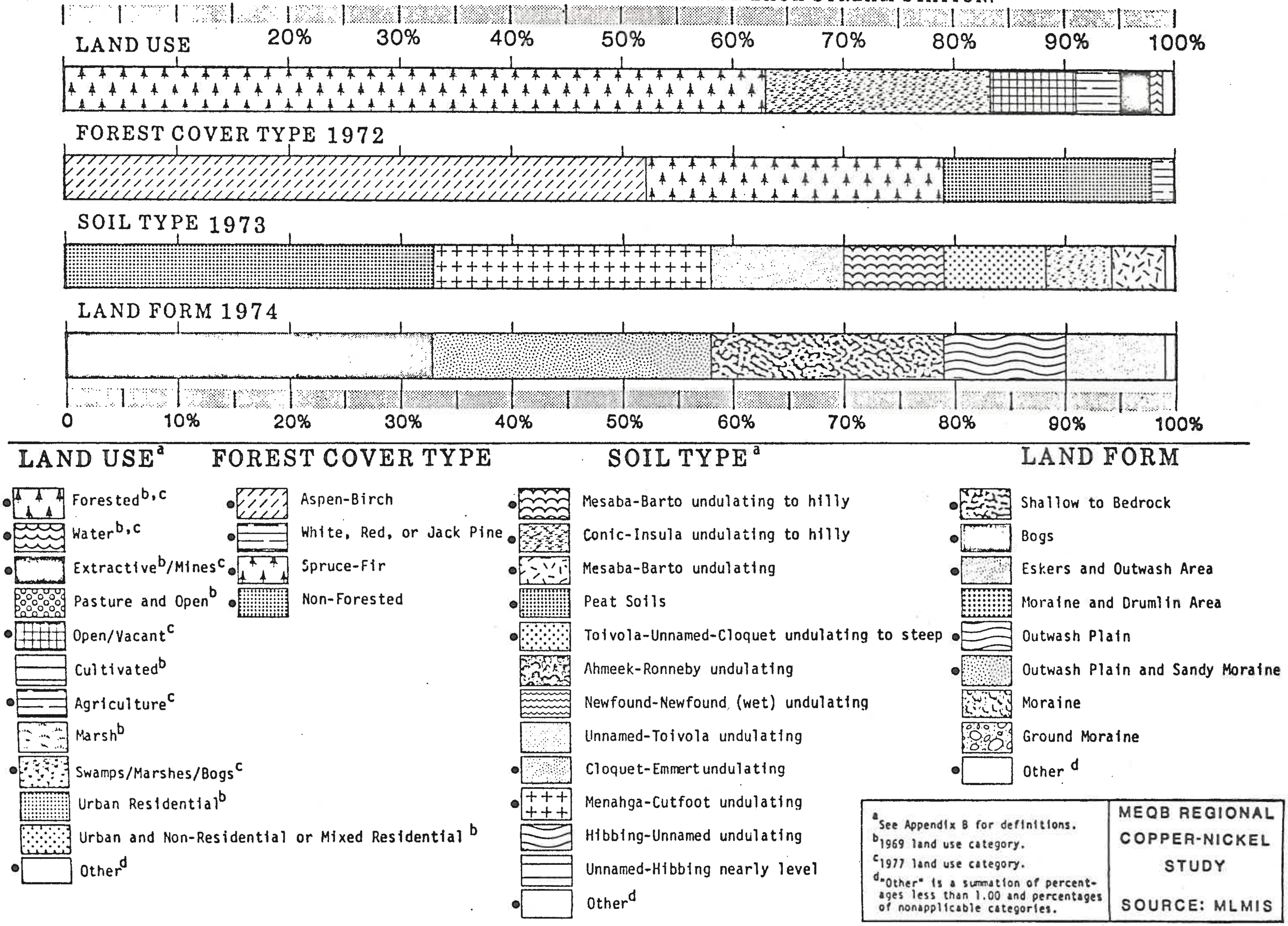
[a] See Appendix B for definitions.
[b] 1969 land use category.
[c] 1977 land use category.
[d] "Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

FIGURE 17. CHARACTERISTICS OF EMBARRASS RIVER WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



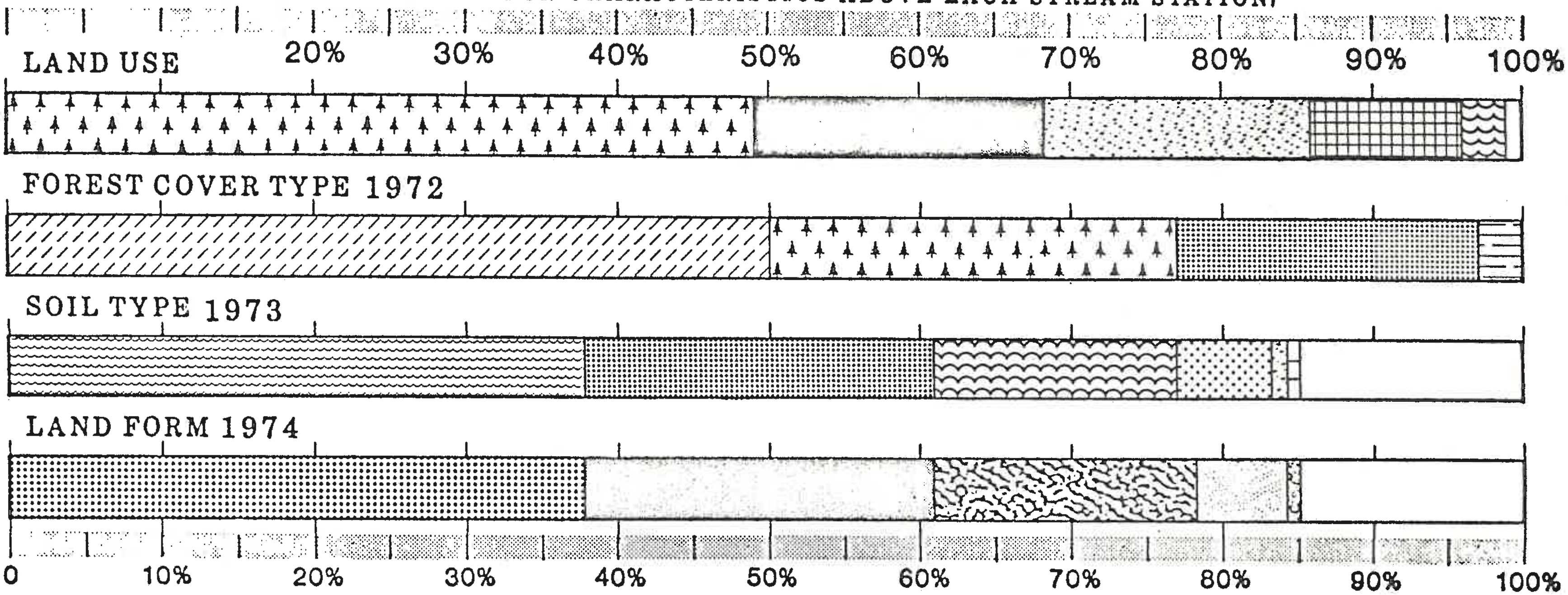
[a]See Appendix B for definitions.
[b]1969 land use category.
[c]1977 land use category.
[d]"Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

FIGURE 18. CHARACTERISTICS OF PARTRIDGE RIVER WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



LAND USE[a]

- Forested[b,c]
- Water[b,c]
- Extractive[b]/Mines[c]
- Pasture and Open[b]
- Open/Vacant[c]
- Cultivated[b]
- Agriculture[c]
- Marsh[b]
- Swamps/Marshes/Bogs[c]
- Urban Residential[b]
- Urban and Non-Residential or Mixed Residential[b]
- Other[d]

FOREST COVER TYPE

- Aspen-Birch
- White, Red, or Jack Pine
- Spruce-Fir
- Non-Forested

SOIL TYPE[a]

- Mesaba-Barto undulating to hilly
- Conic-Insula undulating to hilly
- Mesaba-Barto undulating
- Peat Soils
- Toivola-Unnamed-Cloquet undulating to steep
- Ahmeek-Ronneby undulating
- Newfound-Newfound (wet) undulating
- Unnamed-Toivola undulating
- Cloquet-Emmert undulating
- Menahga-Cutfoot undulating
- Hibbing-Unnamed undulating
- Unnamed-Hibbing nearly level
- Other[d]

LAND FORM

- Shallow to Bedrock
- Bogs
- Eskers and Outwash Area
- Moraine and Drumlin Area
- Outwash Plain
- Outwash Plain and Sandy Moraine
- Moraine
- Ground Moraine
- Other[d]

[a]See Appendix B for definitions.
[b]1969 land use category.
[c]1977 land use category.
[d]"Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

FIGURE 19. CHARACTERISTICS OF ST. LOUIS RIVER WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)

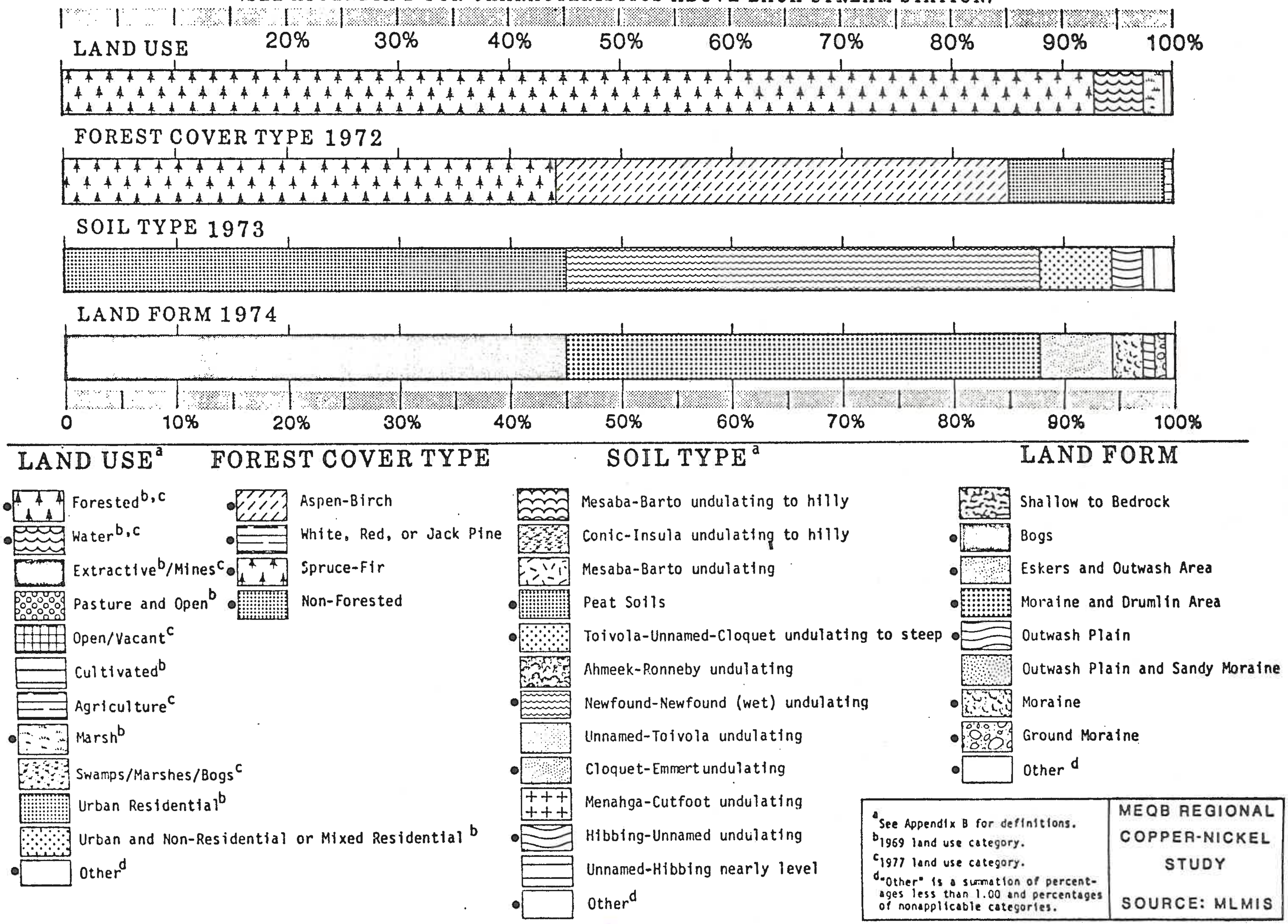


FIGURE 20. CHARACTERISTICS OF WHITEFACE RIVER WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)

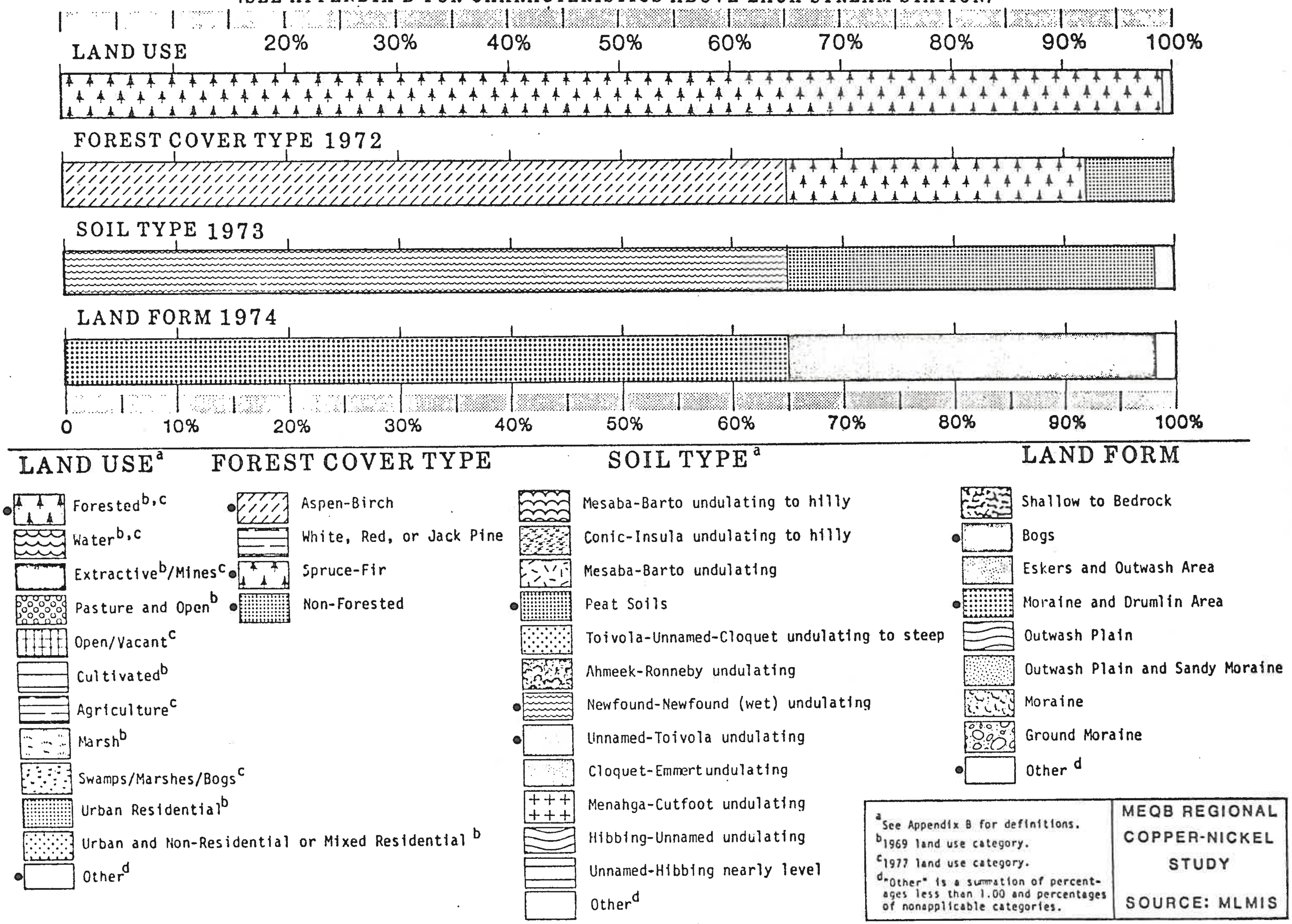
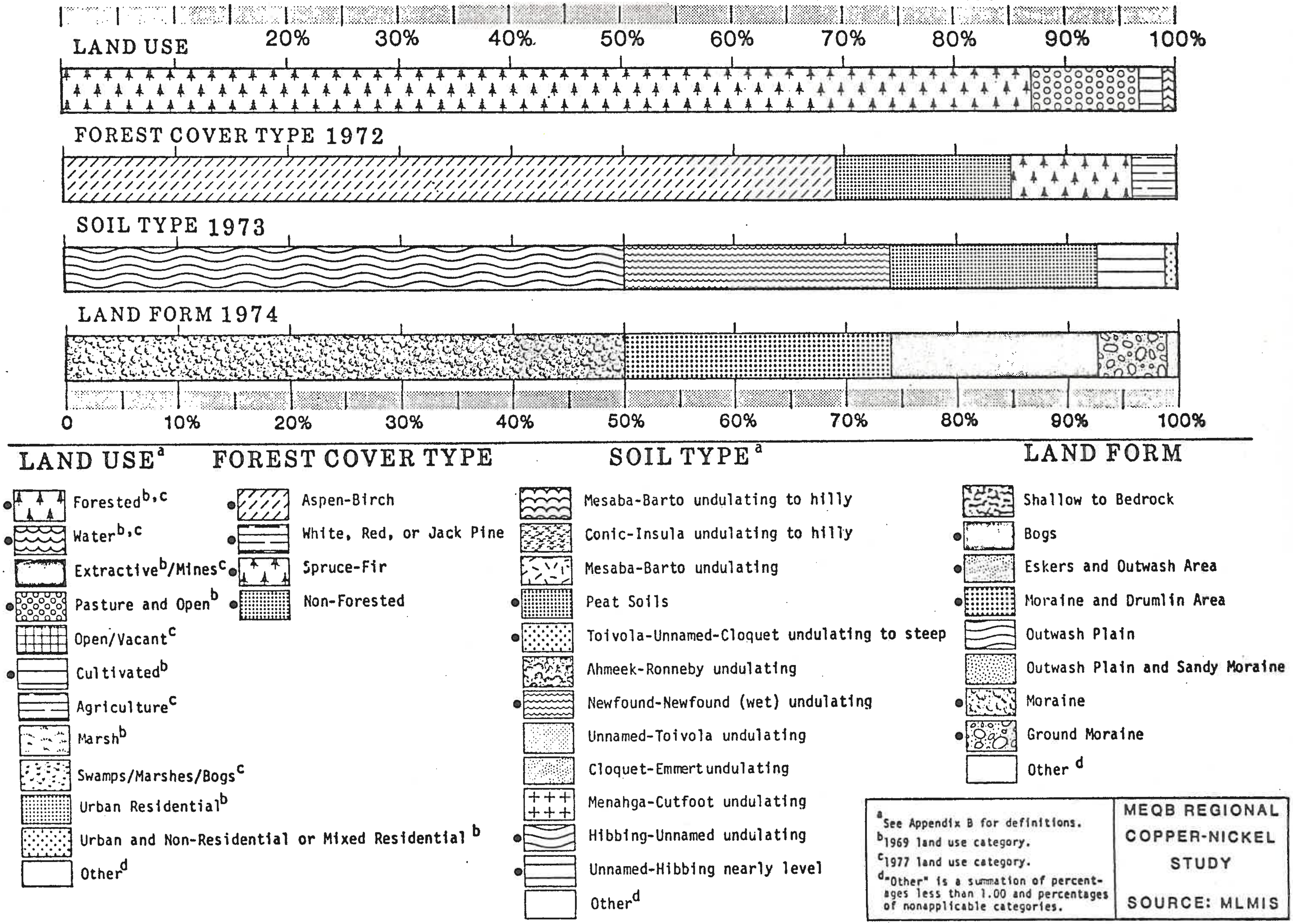


FIGURE 21. CHARACTERISTICS OF WATER HEN CREEK WATERSHED

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



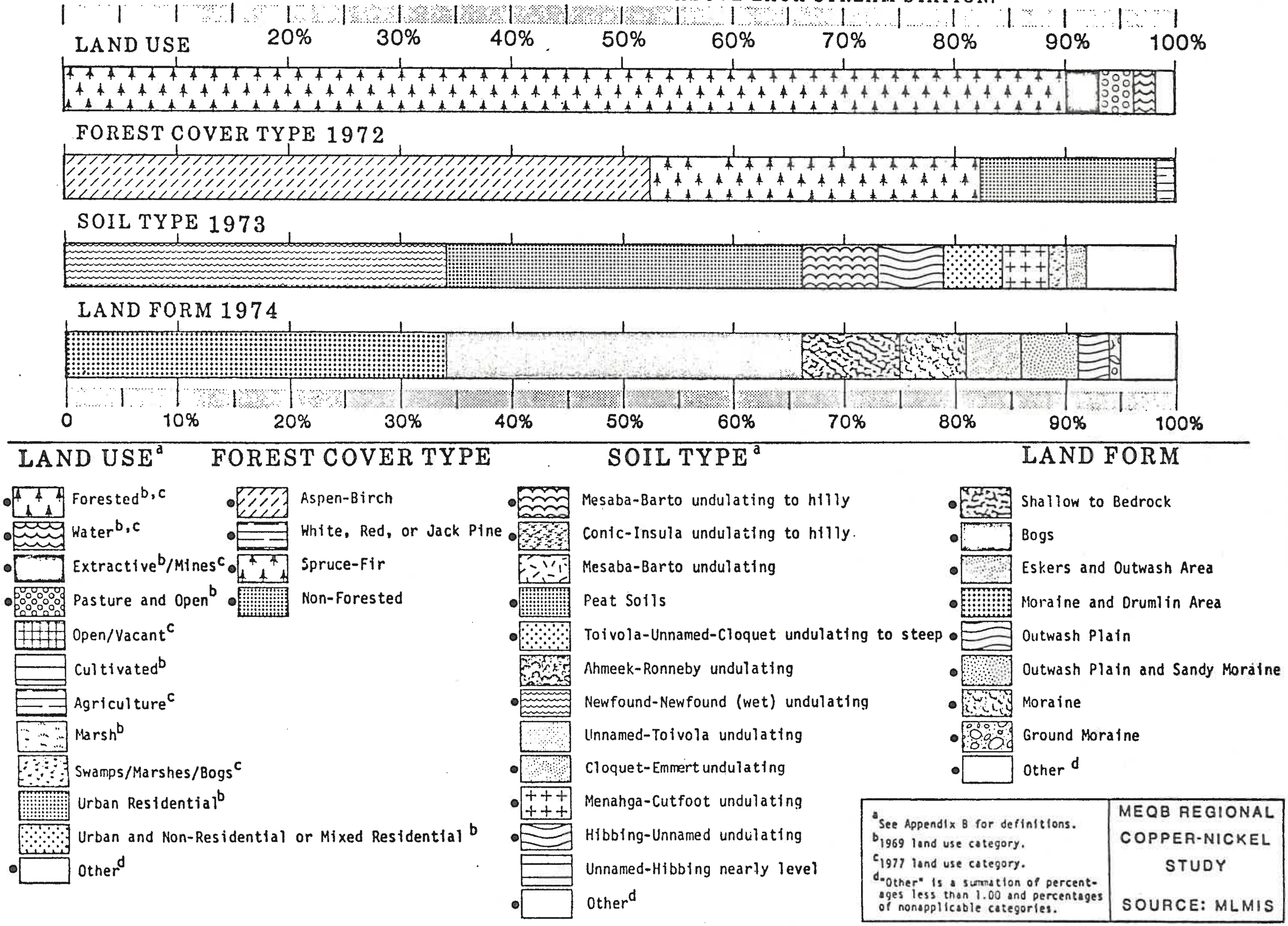
[a]See Appendix B for definitions.
[b]1969 land use category.
[c]1977 land use category.
[d]"Other" is a summation of percentages less than 1.00 and percentages of nonapplicable categories.

MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

FIGURE 22. CHARACTERISTICS OF LAKE SUPERIOR DRAINAGE

(SEE APPENDIX B FOR CHARACTERISTICS ABOVE EACH STREAM STATION)



MEQB REGIONAL COPPER-NICKEL STUDY

SOURCE: MLMIS

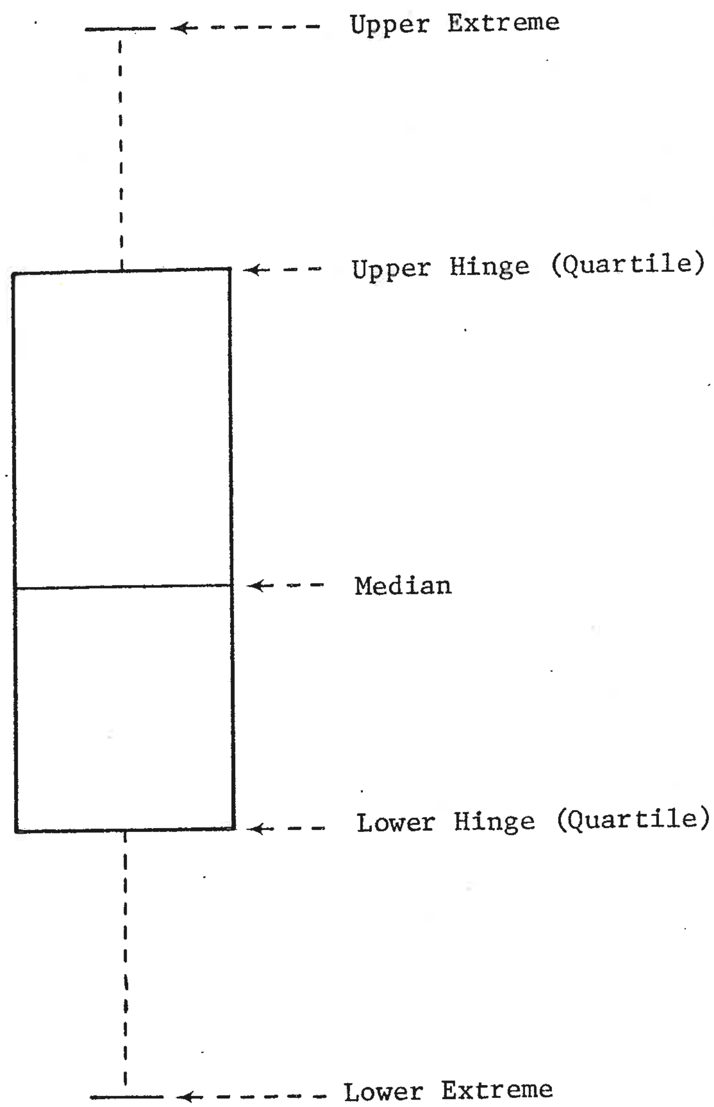


Figure 23. Example, box plot.

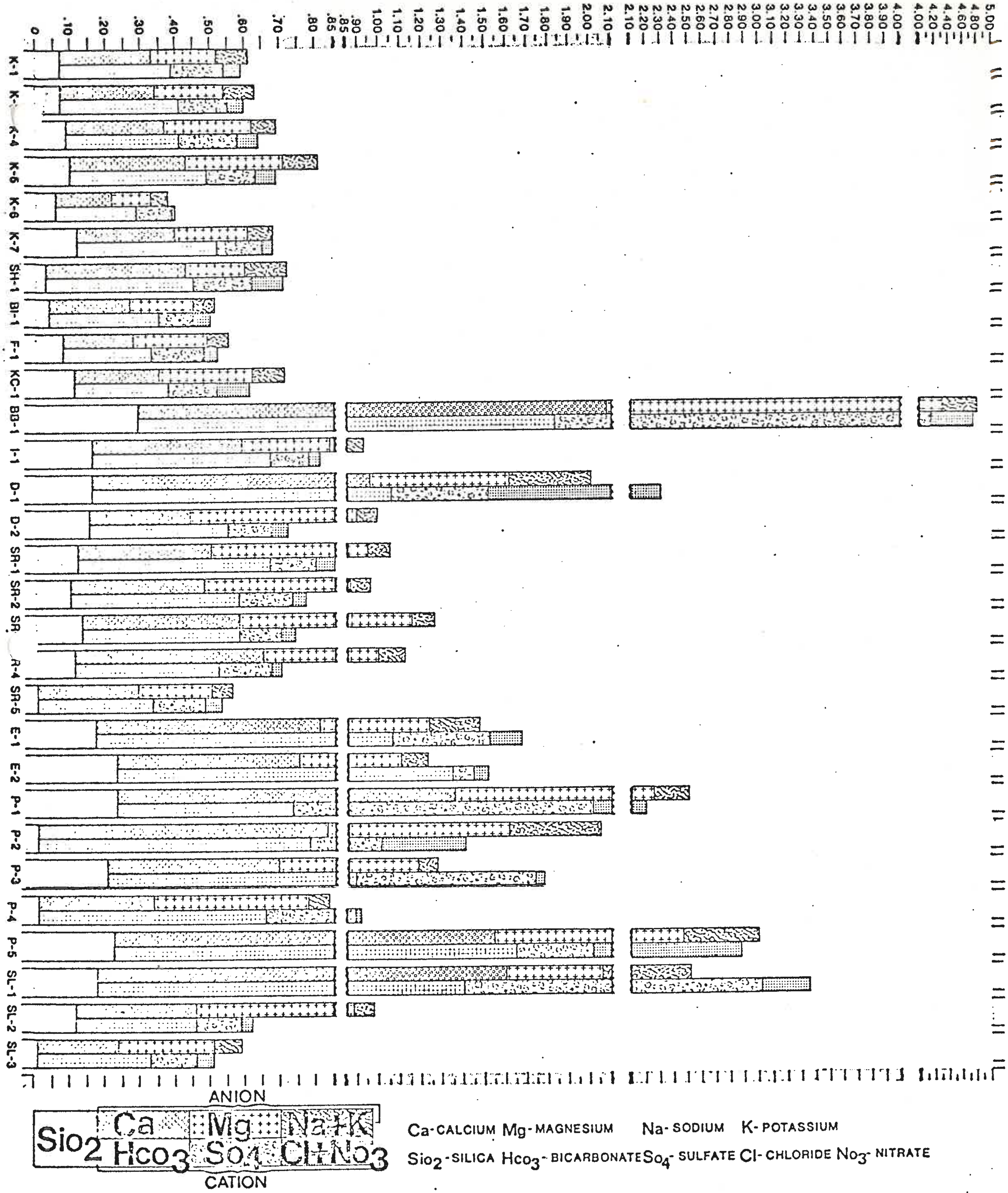


Figure 21

Median silica (millimoles/ℓ), cations, and anions (meq/ℓ) at stream stations.

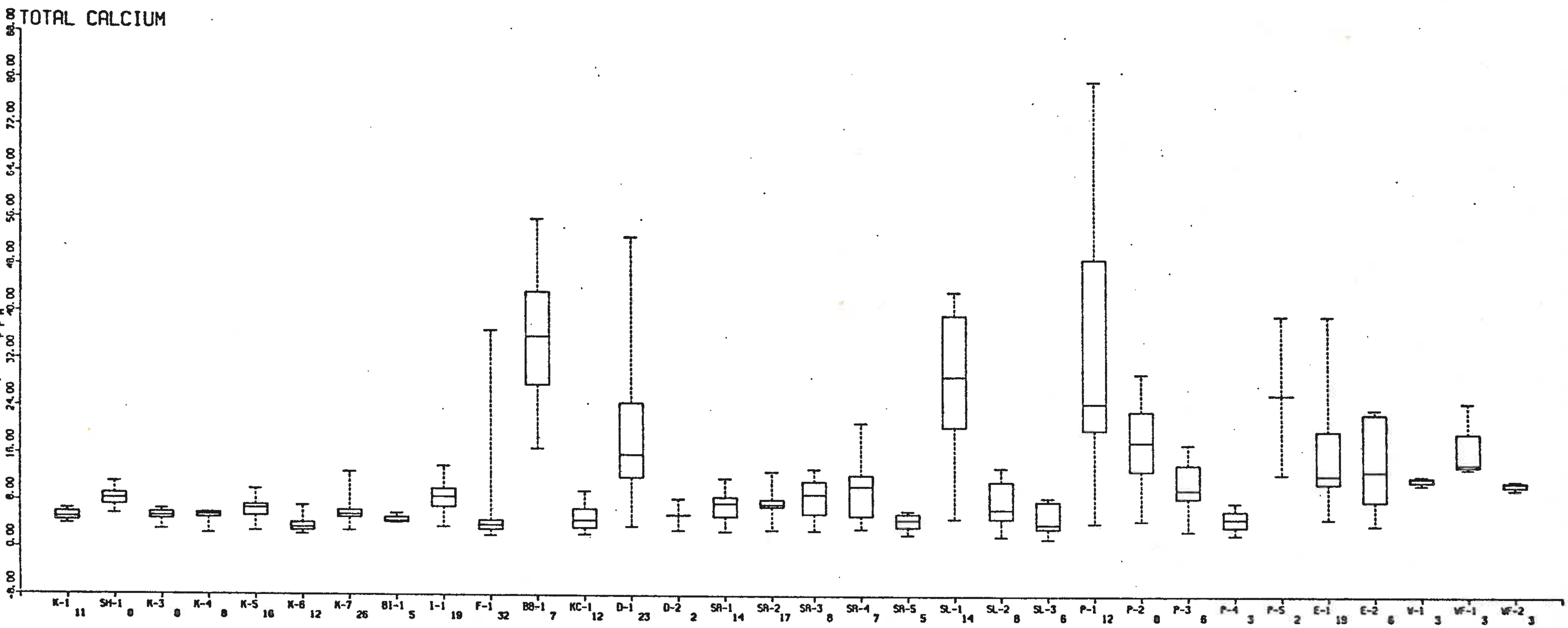


Figure 25. Box plots of summary statisitcs, general parameters.

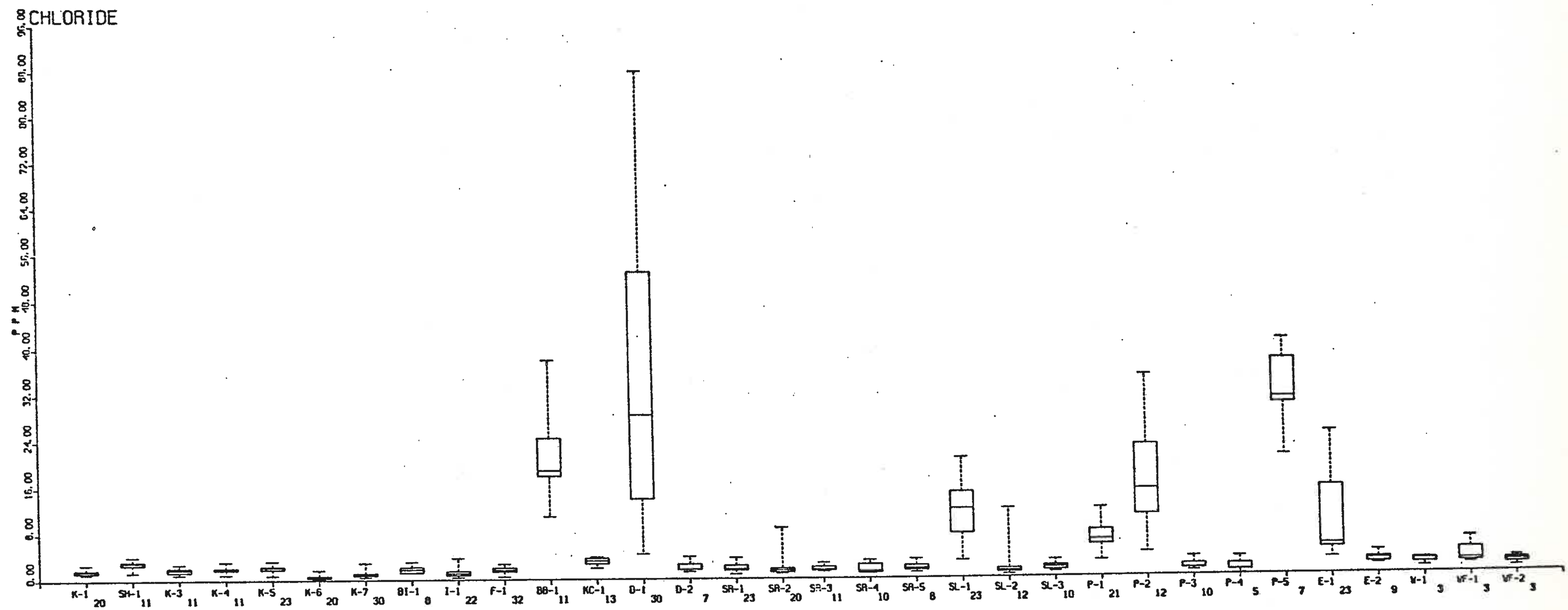


Figure 25. (Contd.)

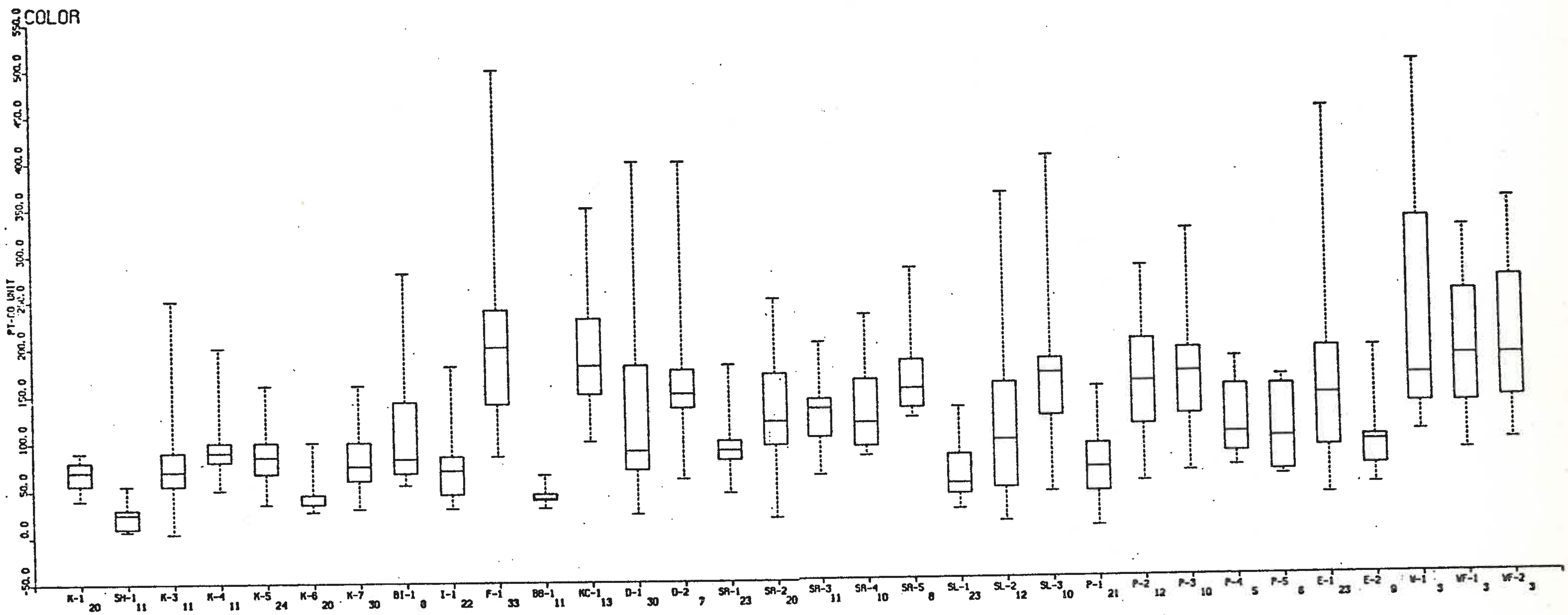


Figure 25. (Contd.)

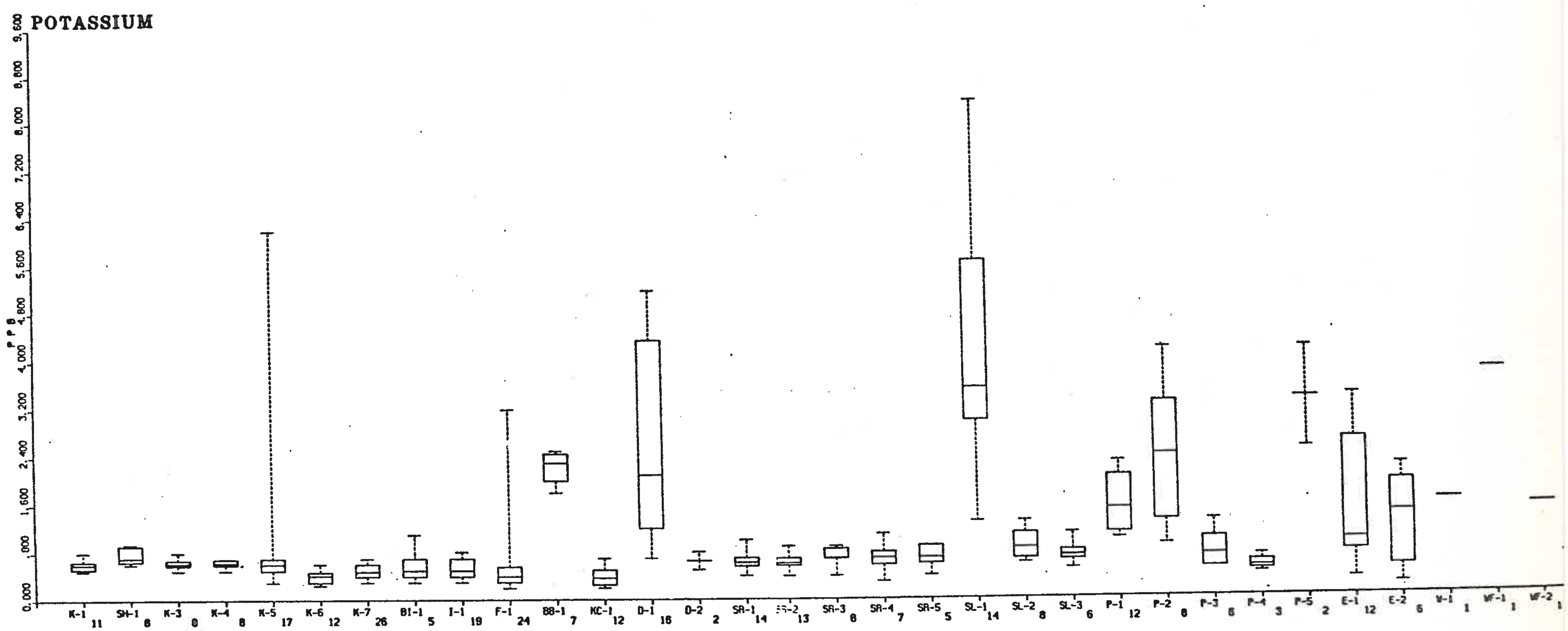


Figure 25. (Contd.)

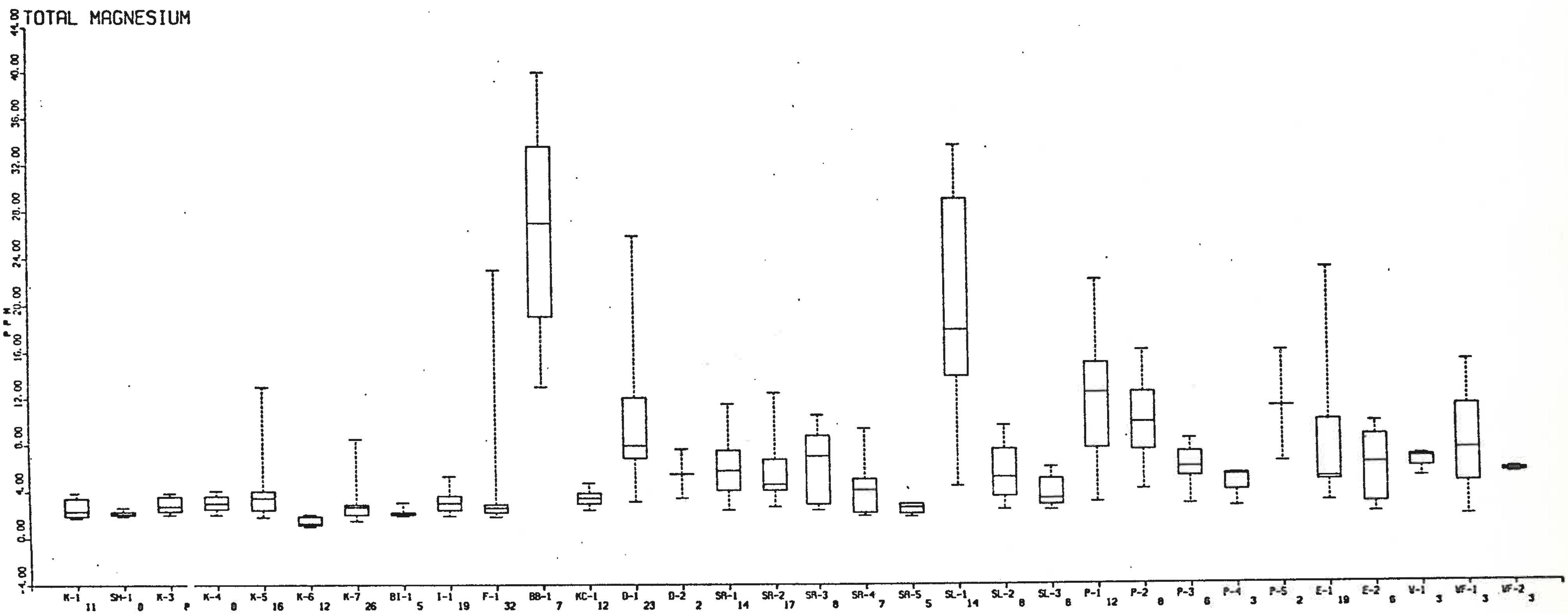


Figure 25. (Contd.)

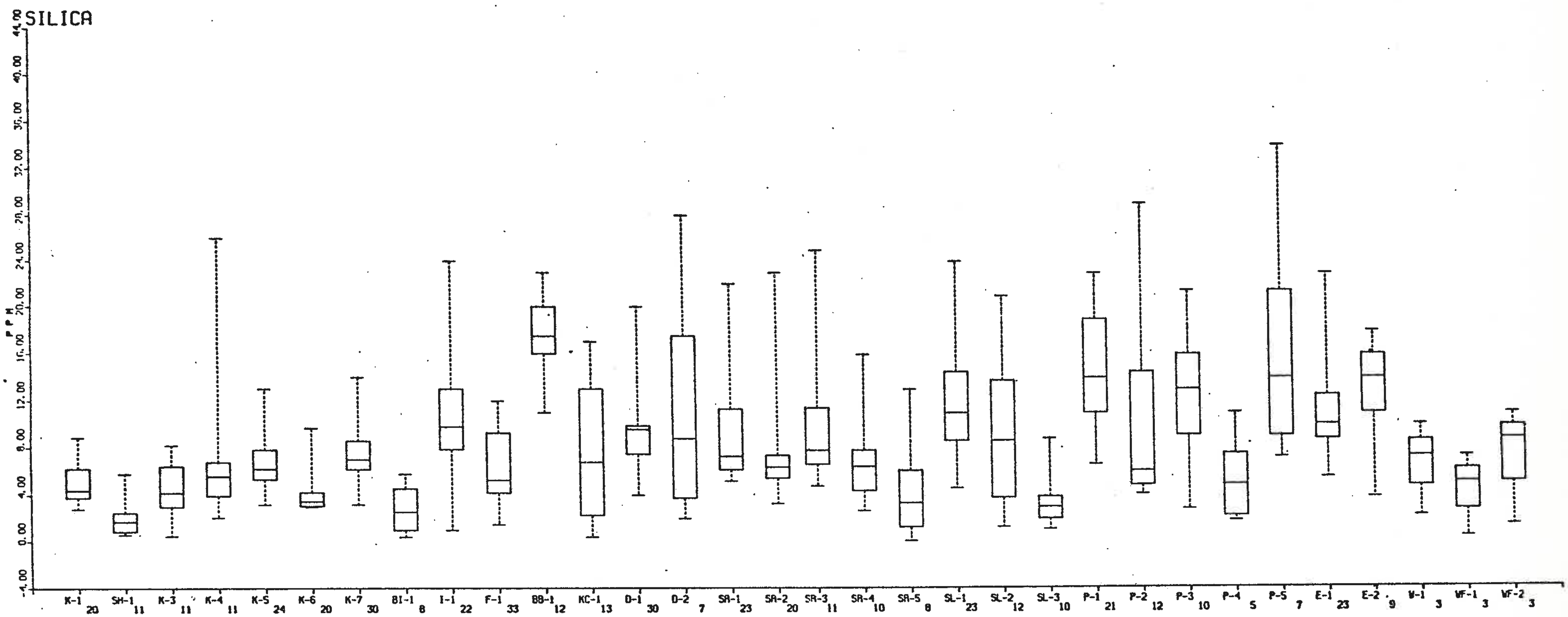


Figure 25. (Contd.)

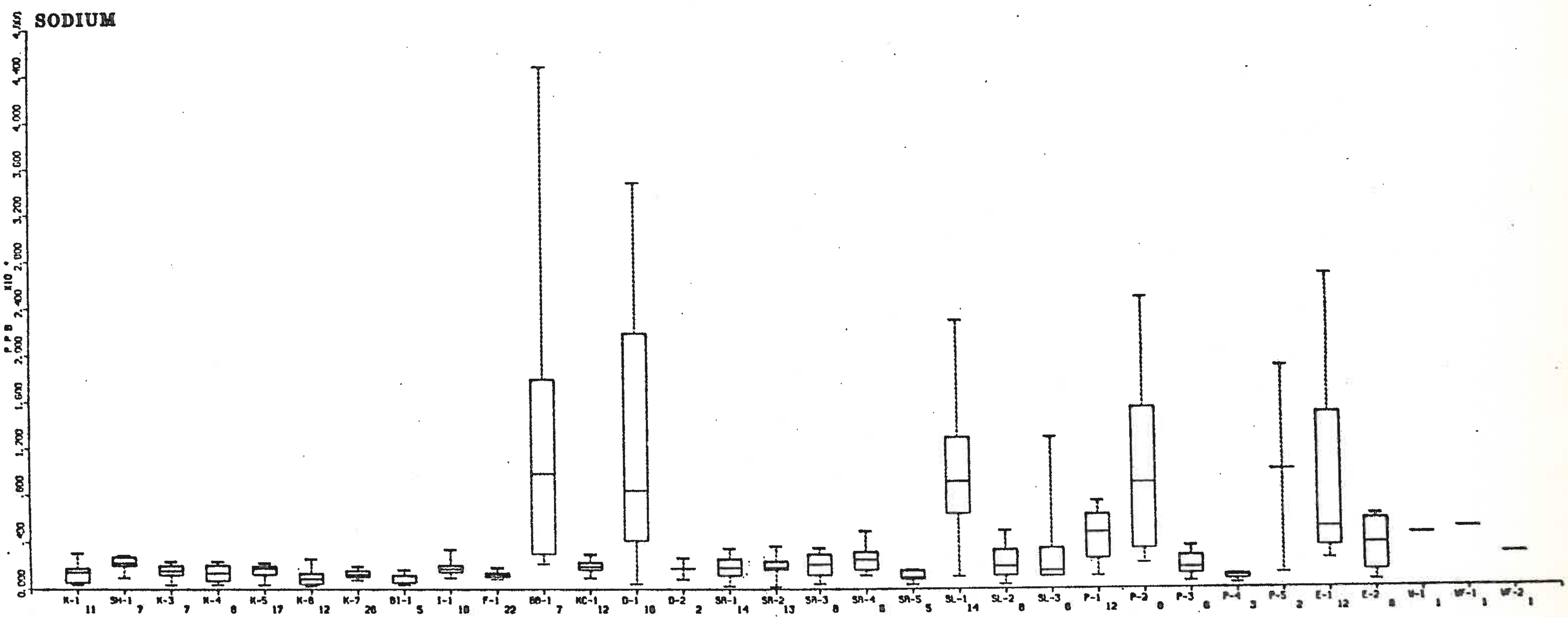


Figure 25. (Contd.)

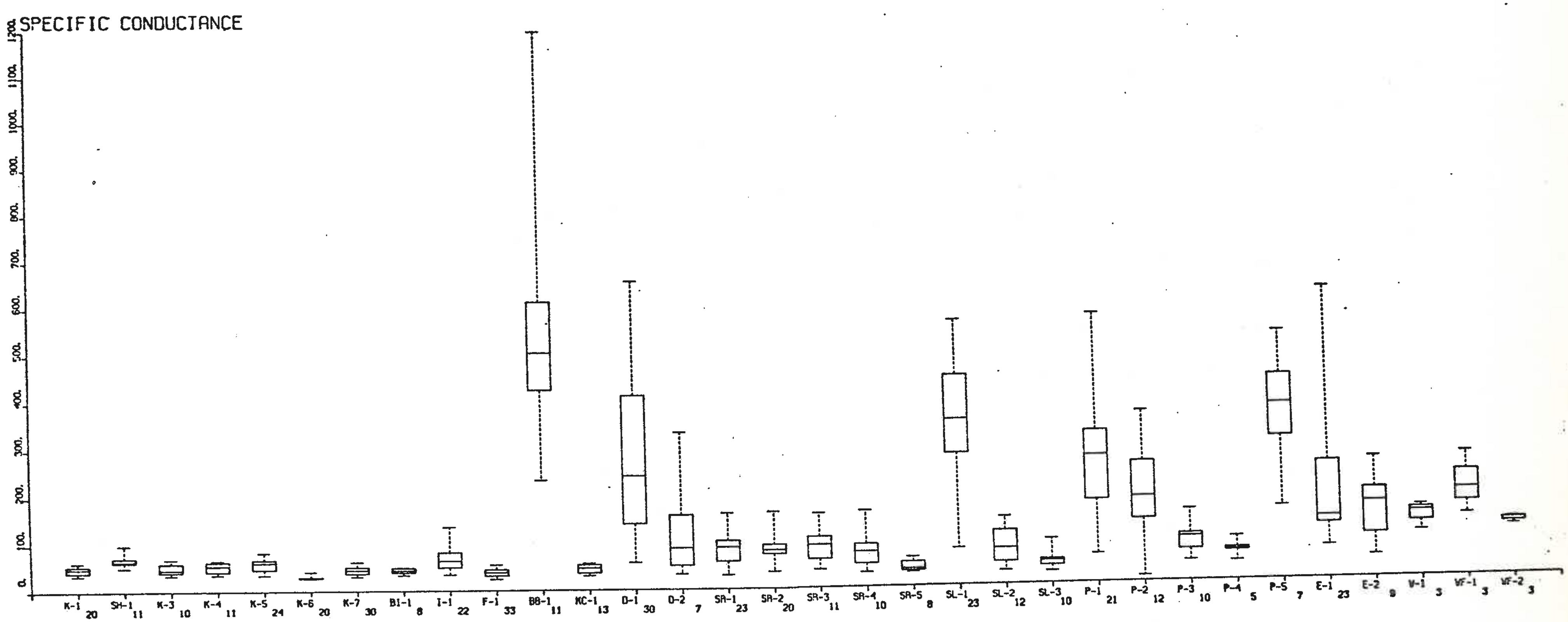


Figure 25. (Contd.)

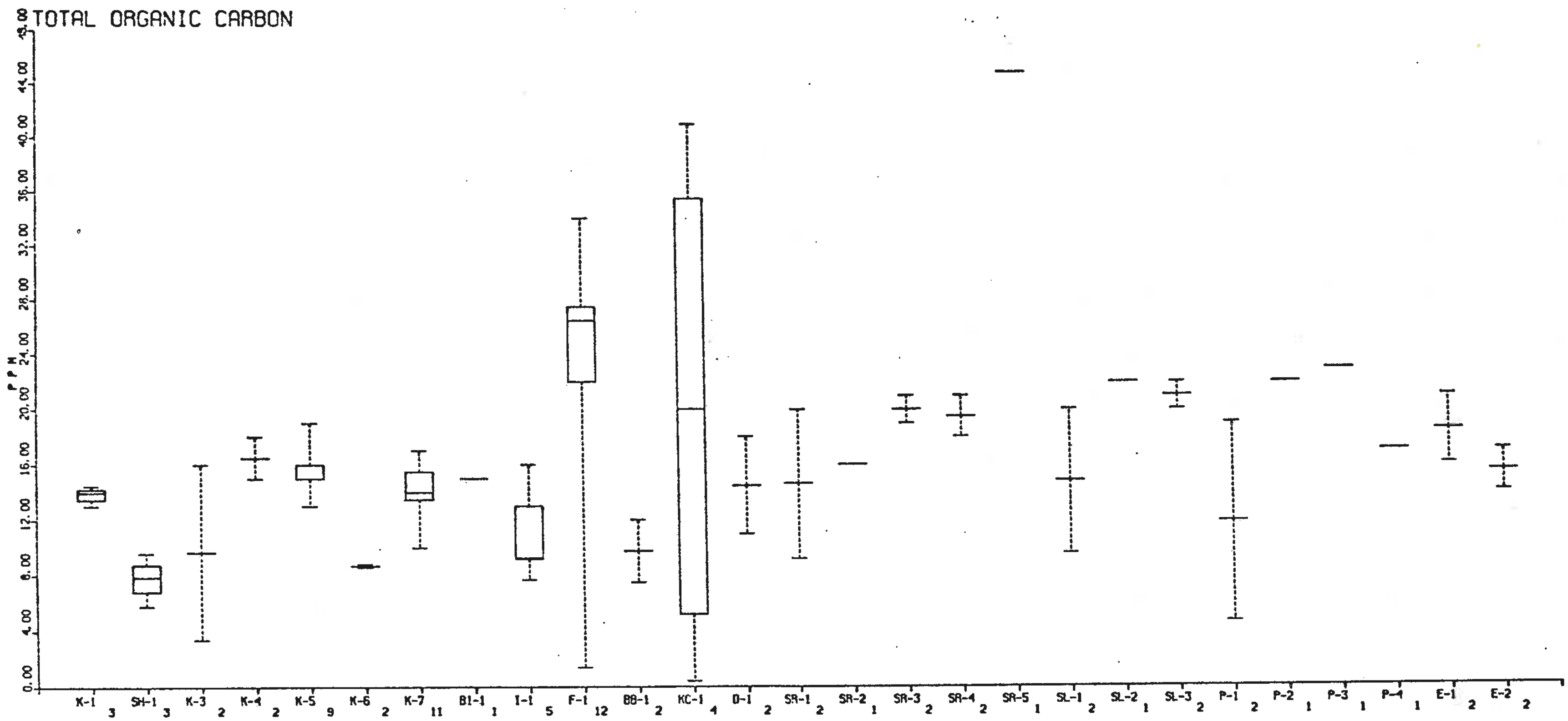


Figure 25. (Contd.)

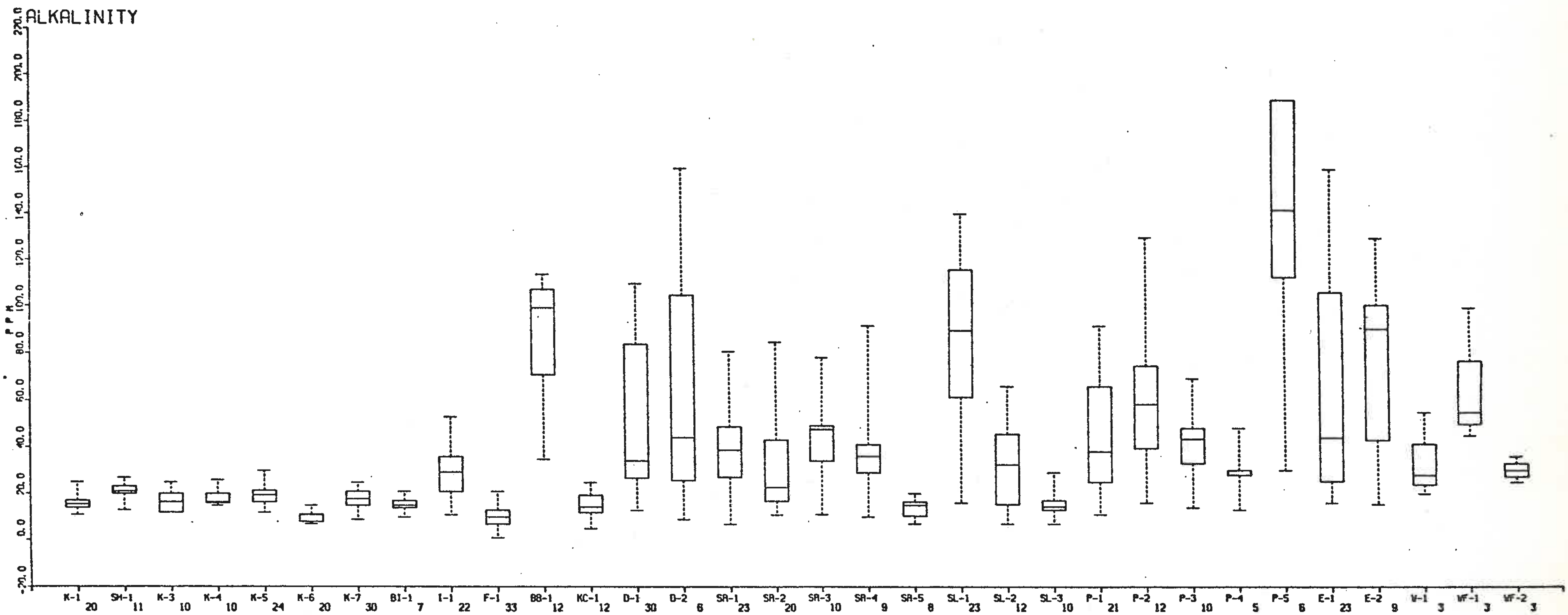


Figure 26. Box plots of summary statistics, buffering parameters.

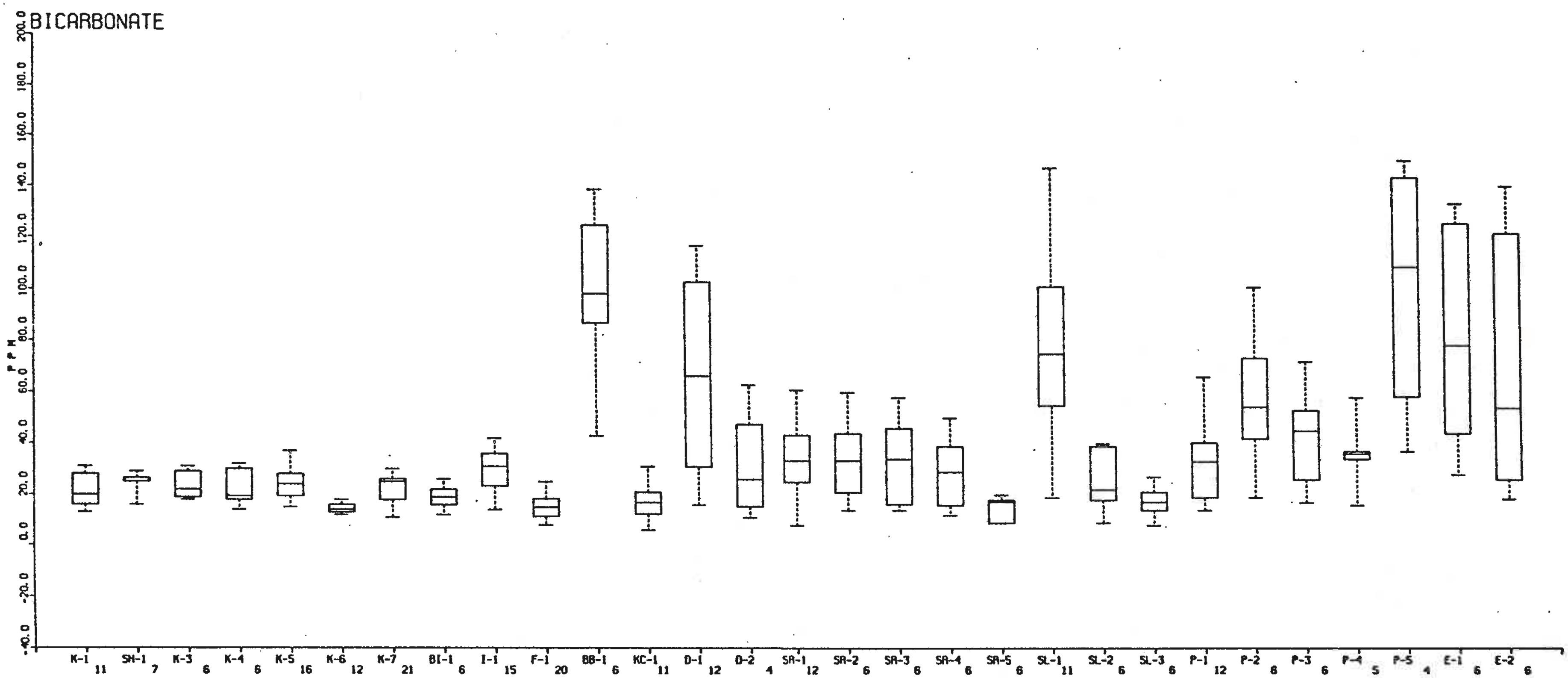


Figure 26. (Contd.)

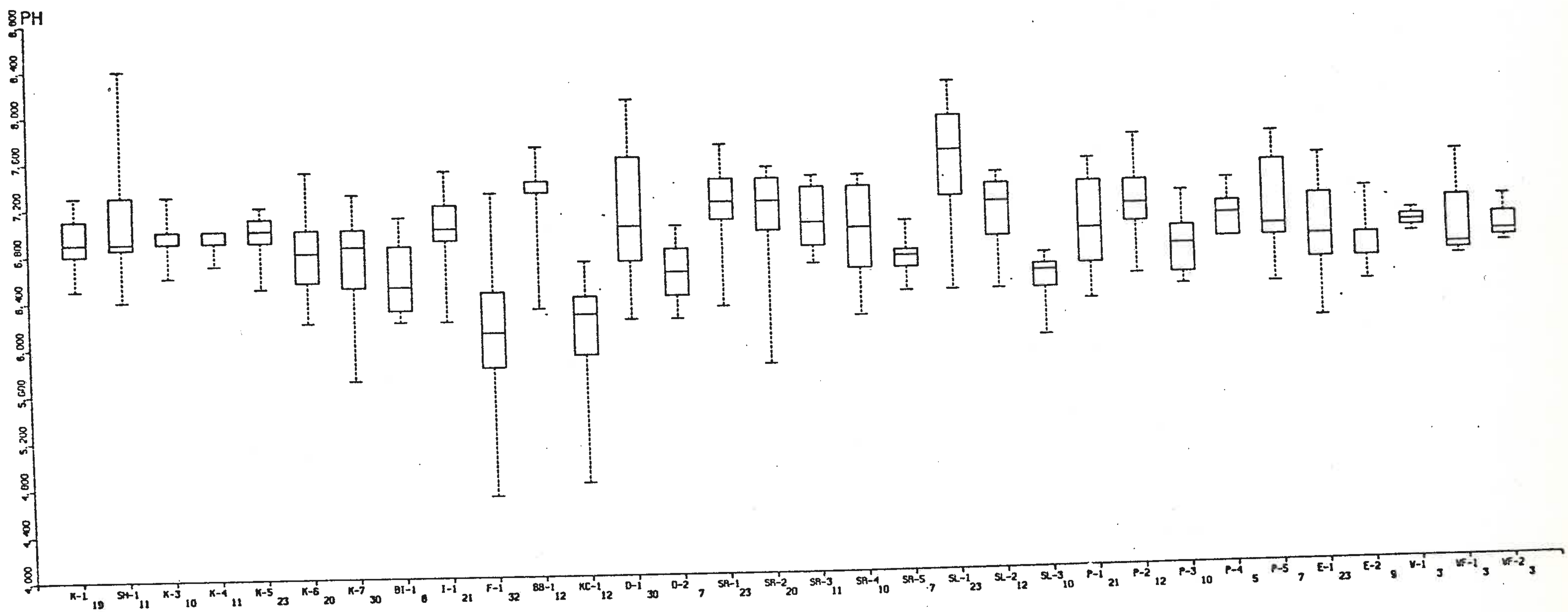


Figure 26. (Contd.)

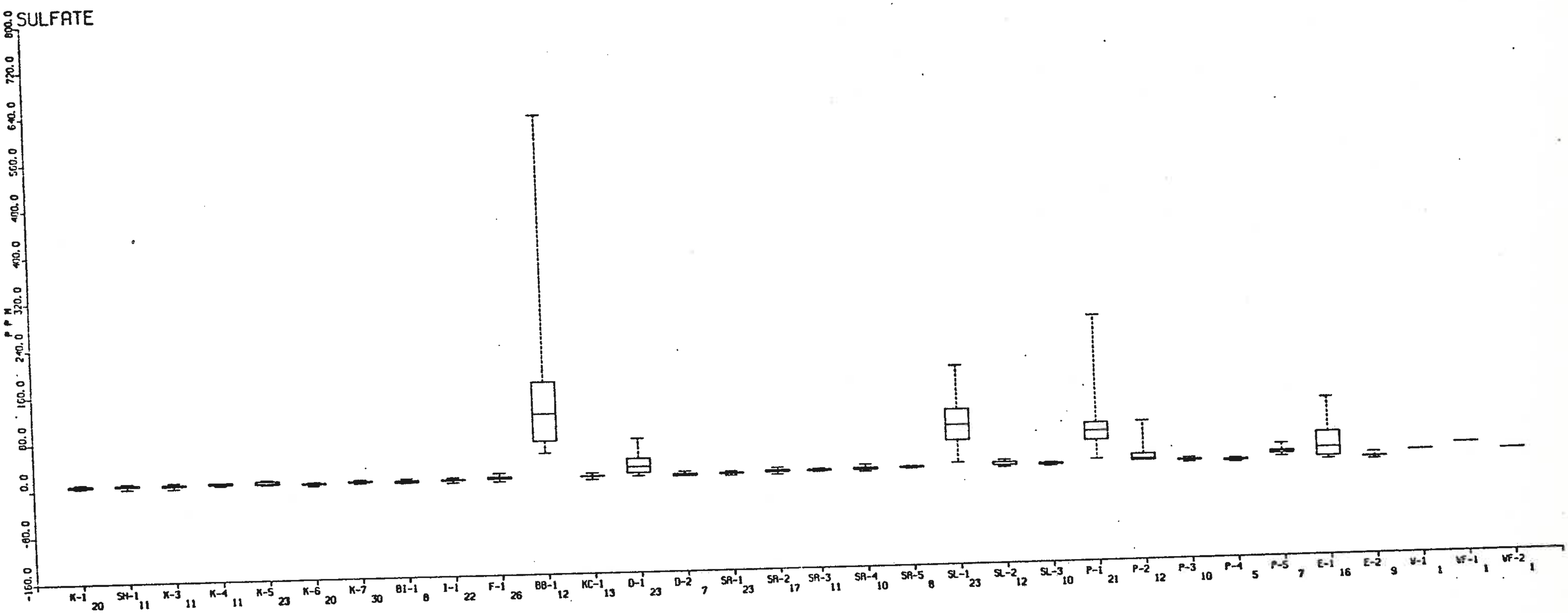


Figure 26. (Contd.)

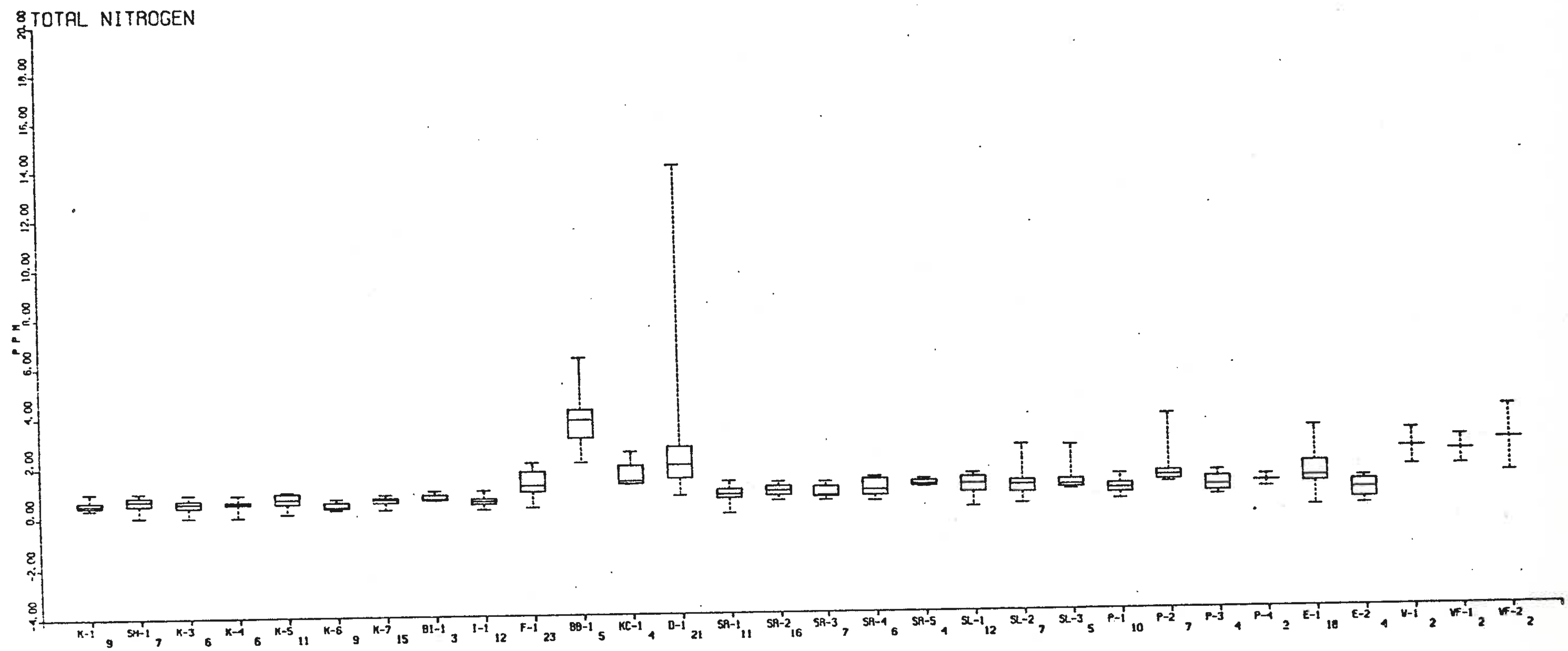


Figure 27. Box plots of summary statistics, nutrient parameters.

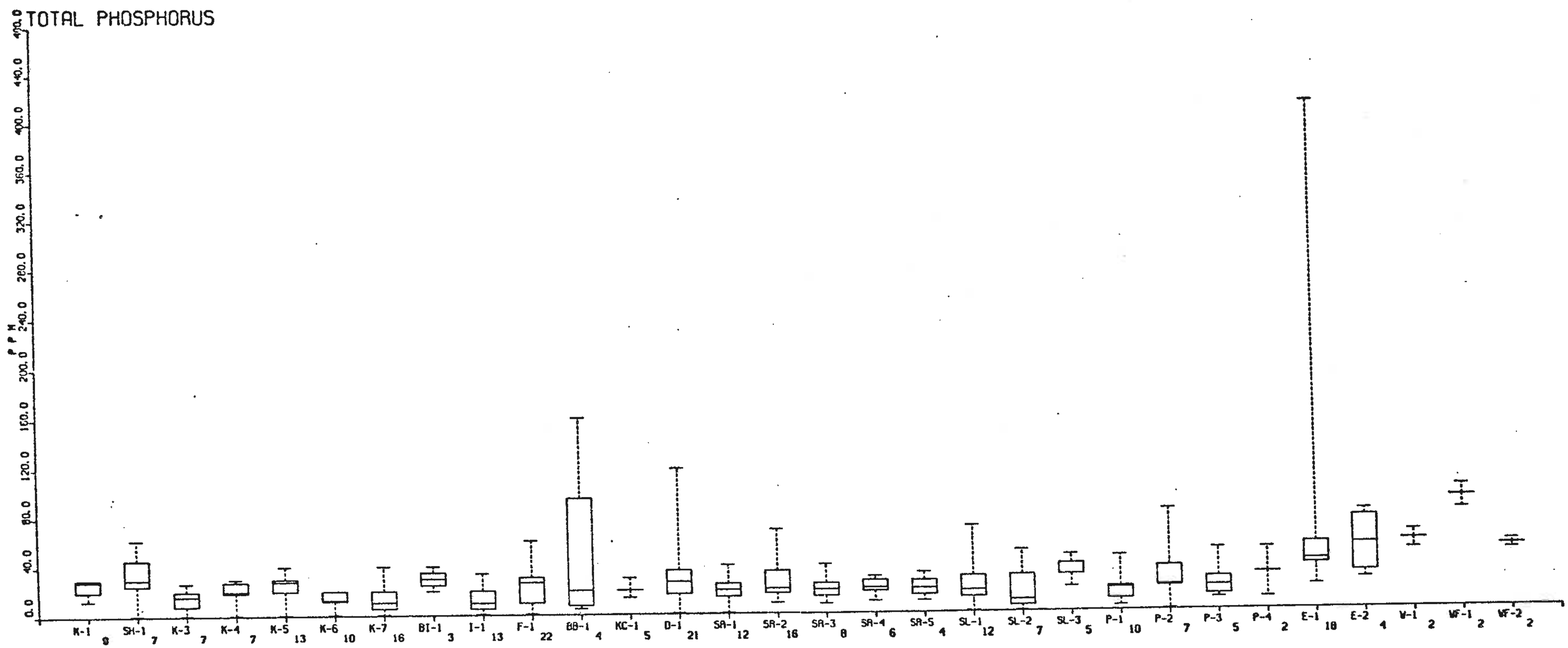


Figure 27. (Contd.)

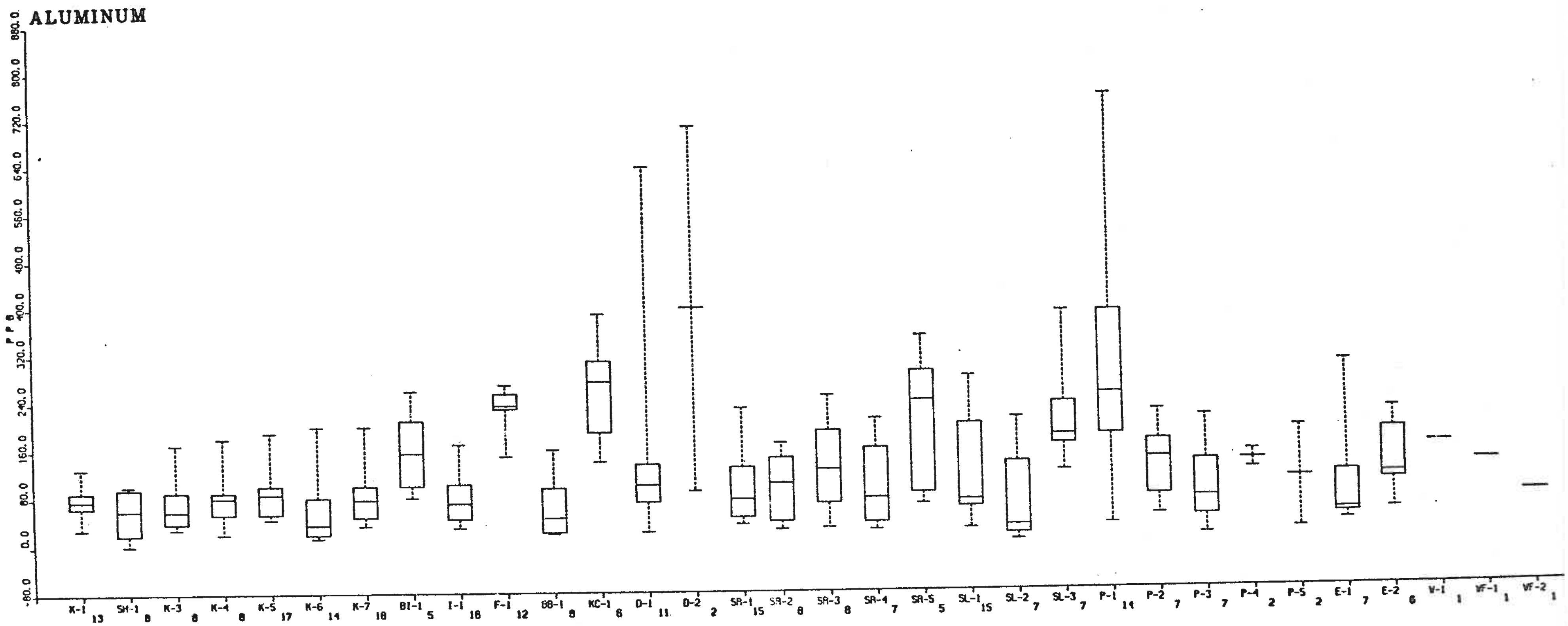


Figure 28. Box plots of summary statistics, metal parameters.

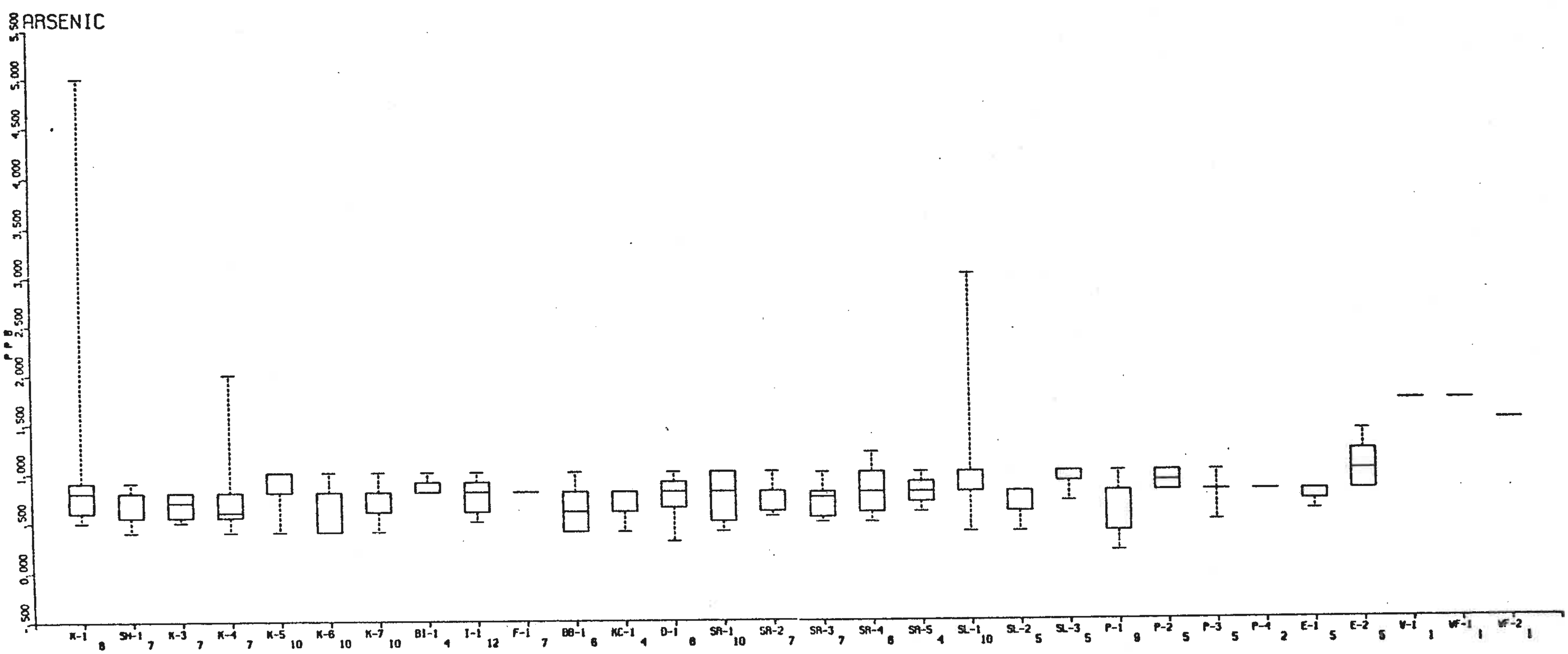


Figure 28. (Contd.)

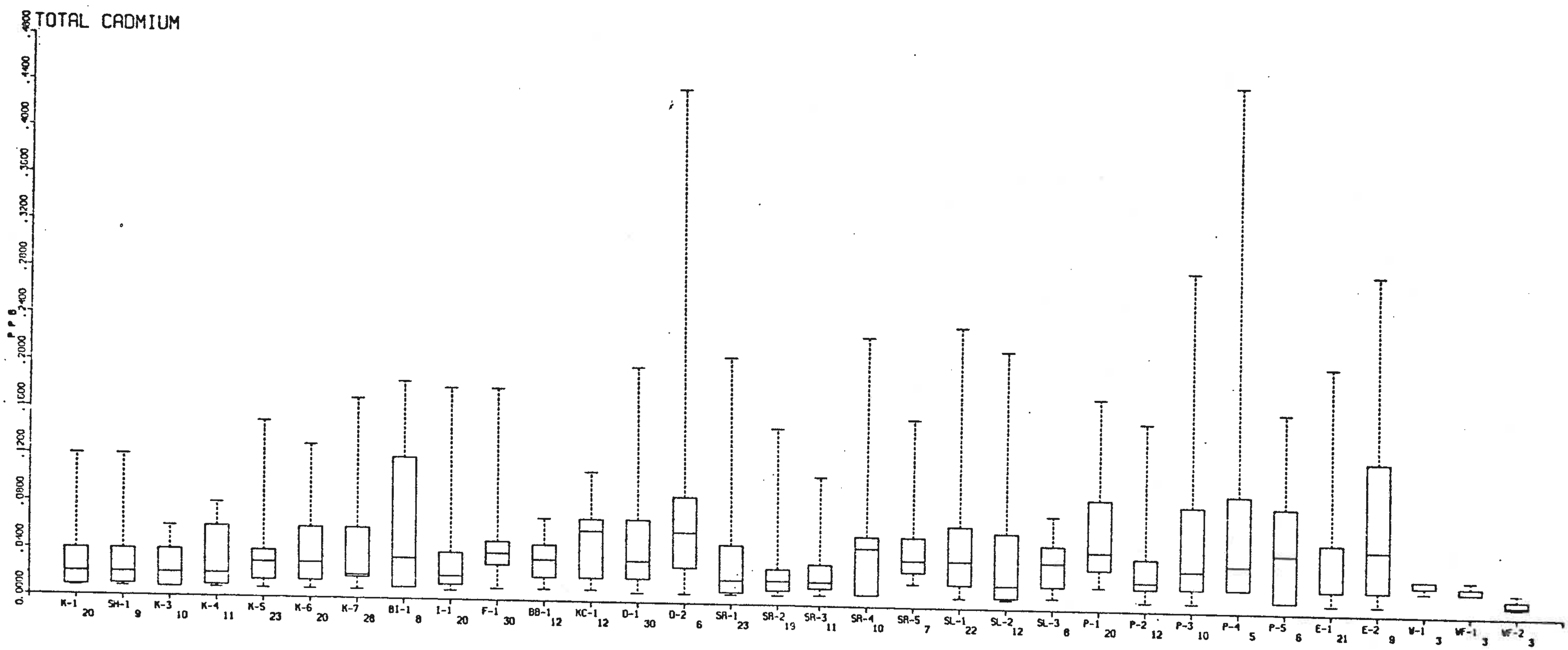


Figure 28. (Contd.)

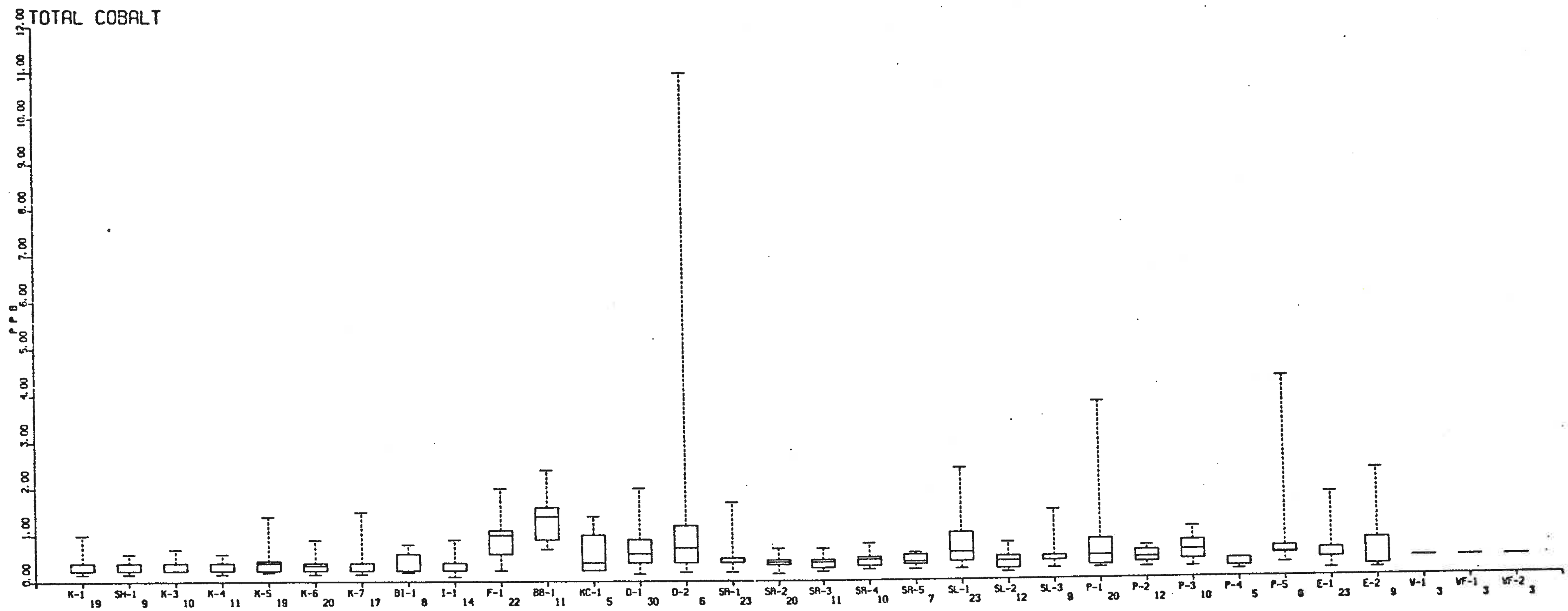


Figure 28. (Contd.)

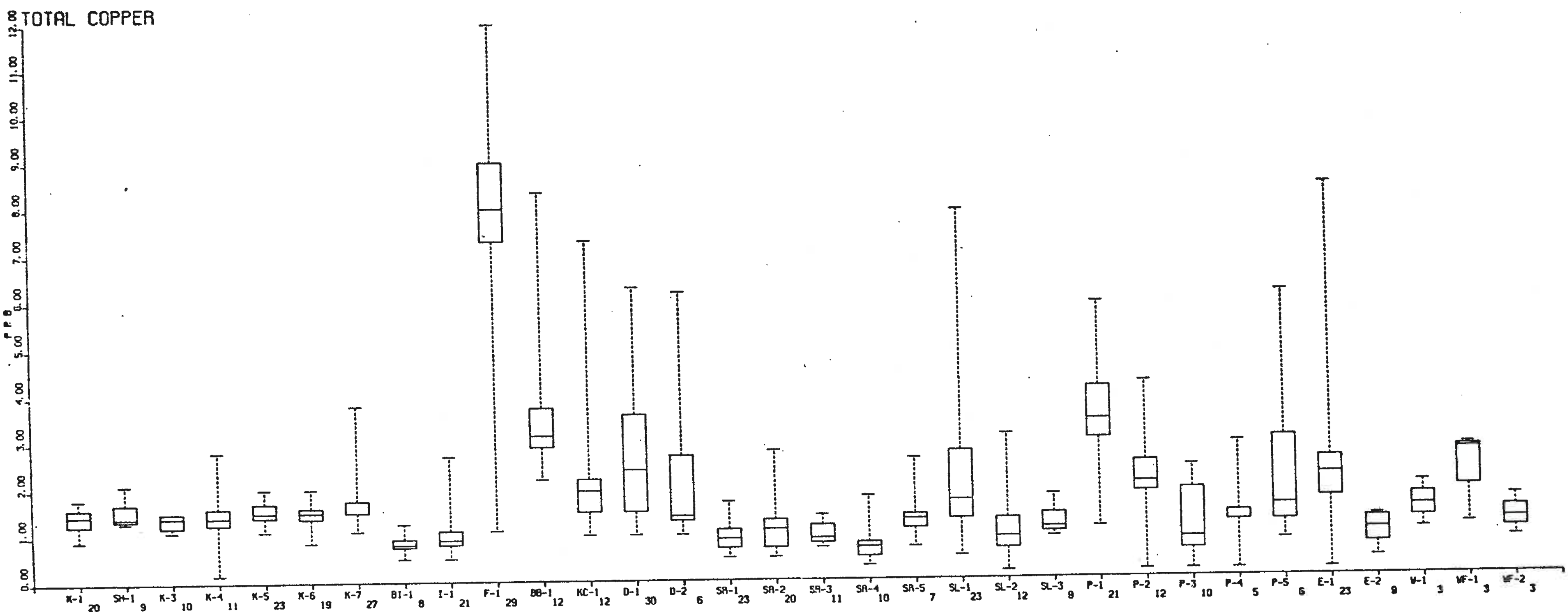


Figure 28. (Contd.)

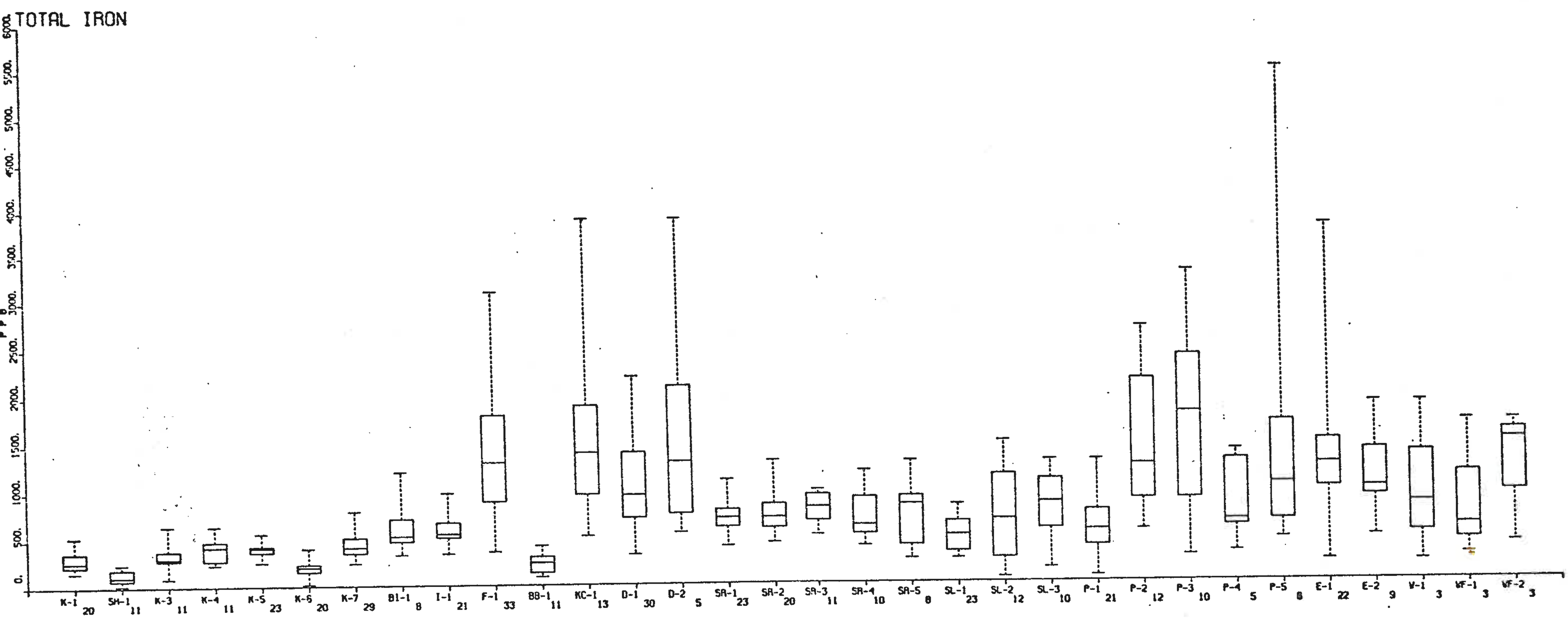


Figure 28. (Contd.)

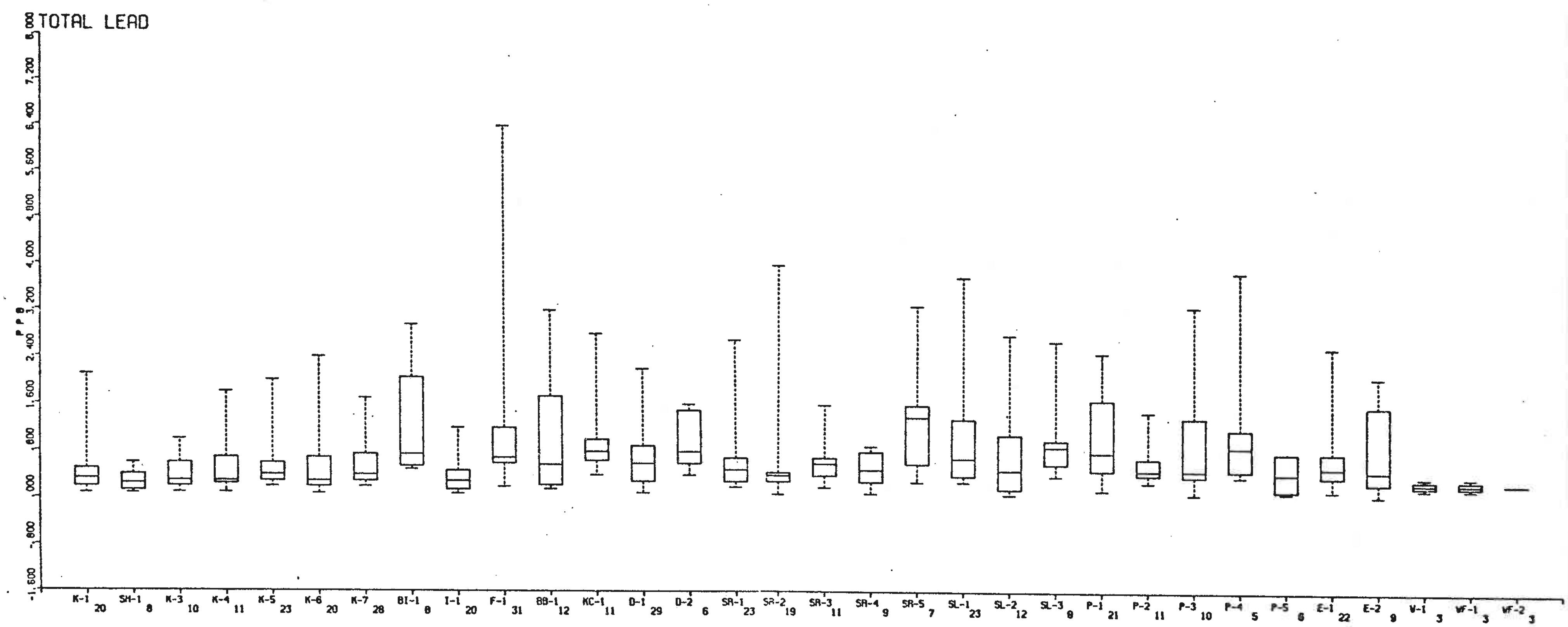


Figure 28. (Contd.)

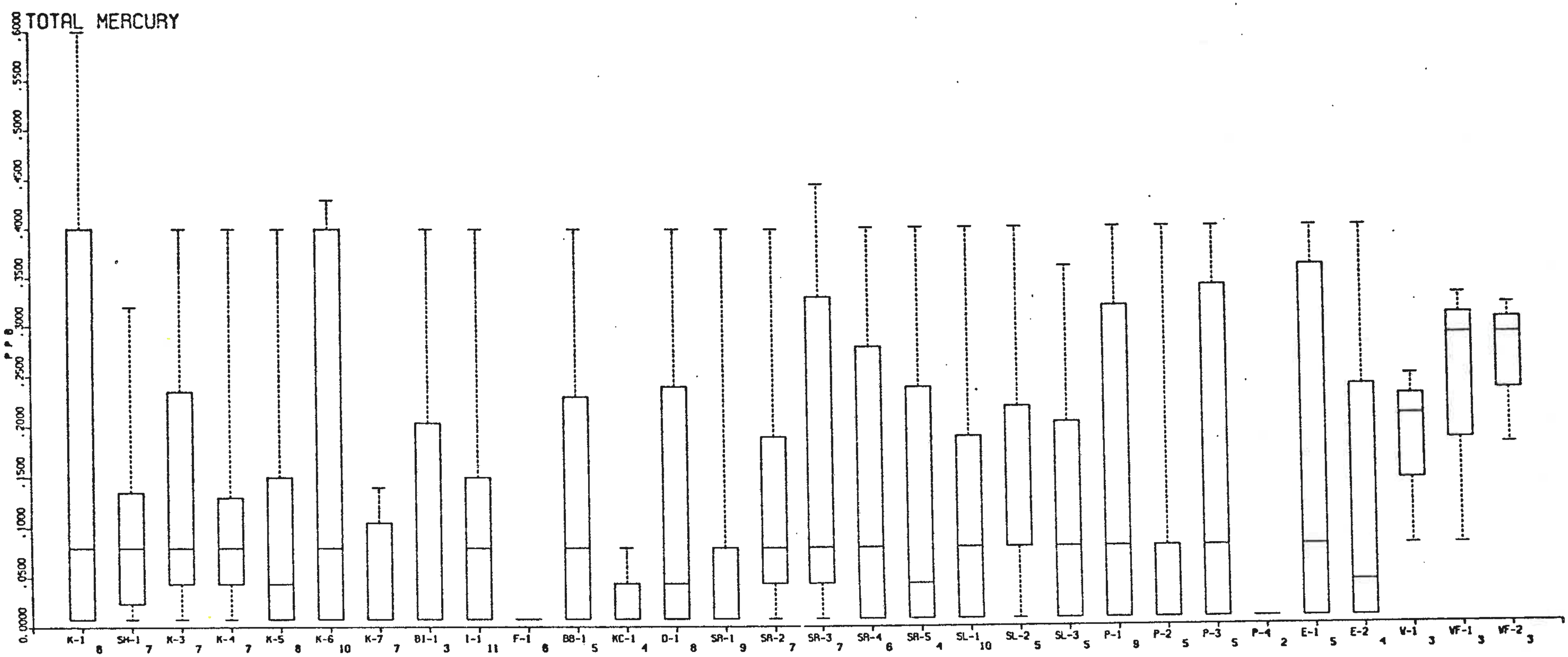


Figure 28. (Contd.)

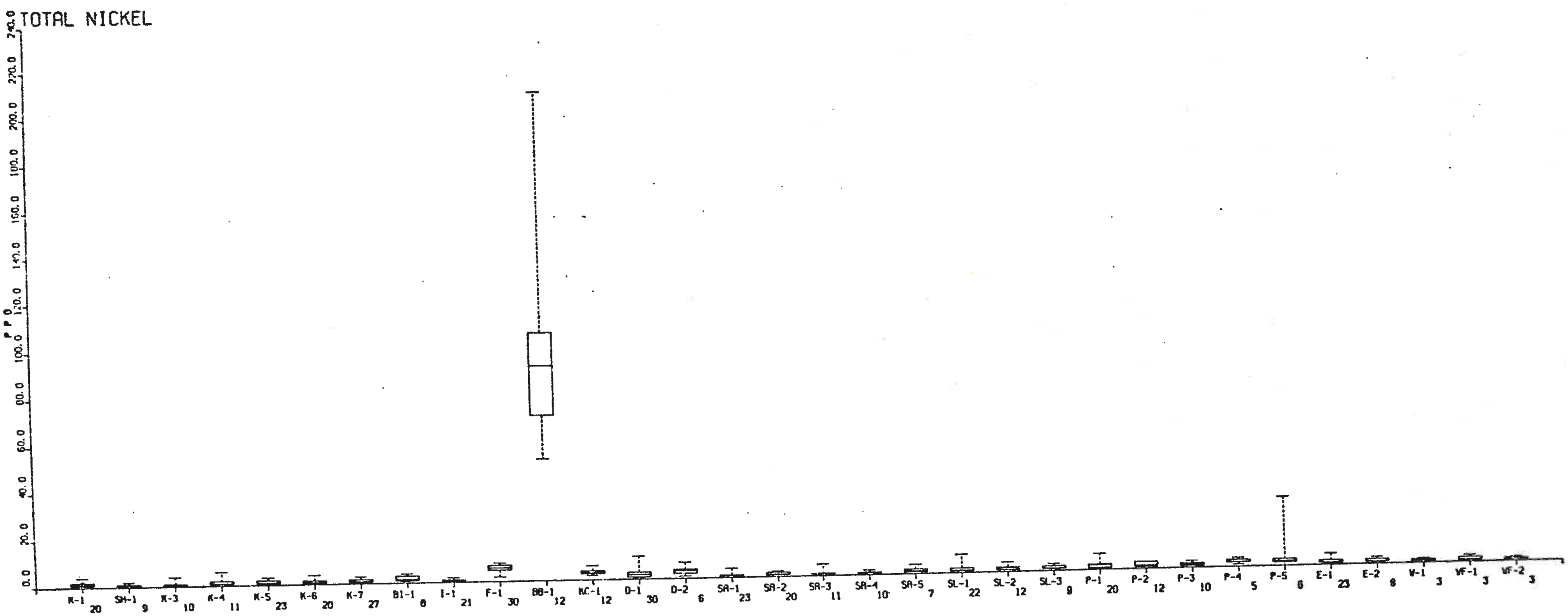


Figure 28. (Contd.)

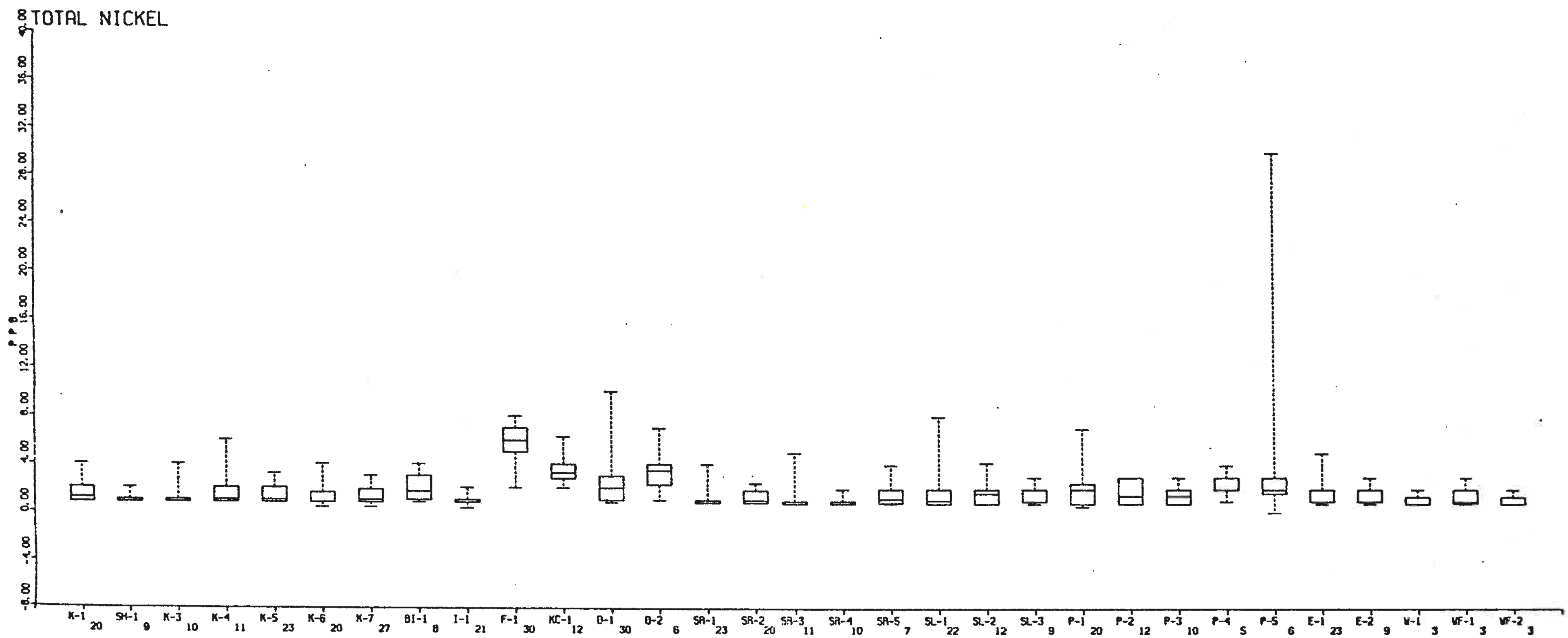


Figure 28. (Contd.)

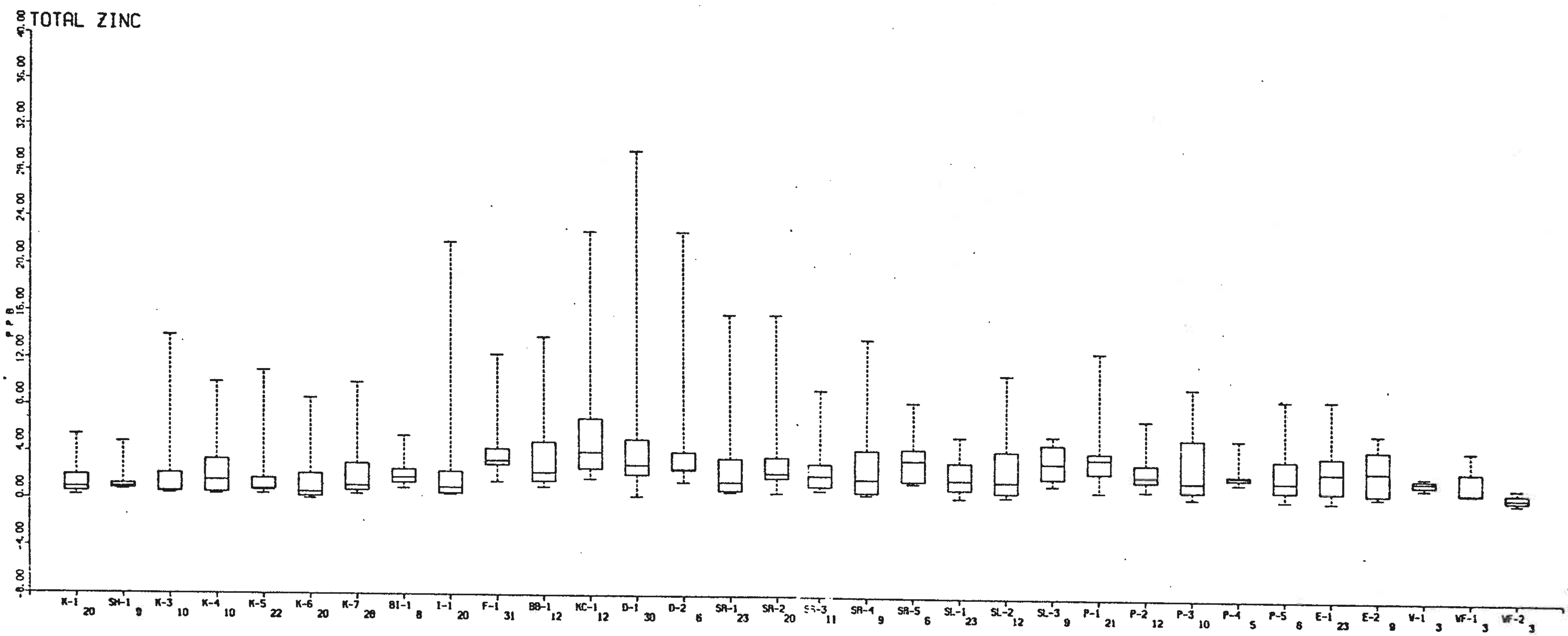
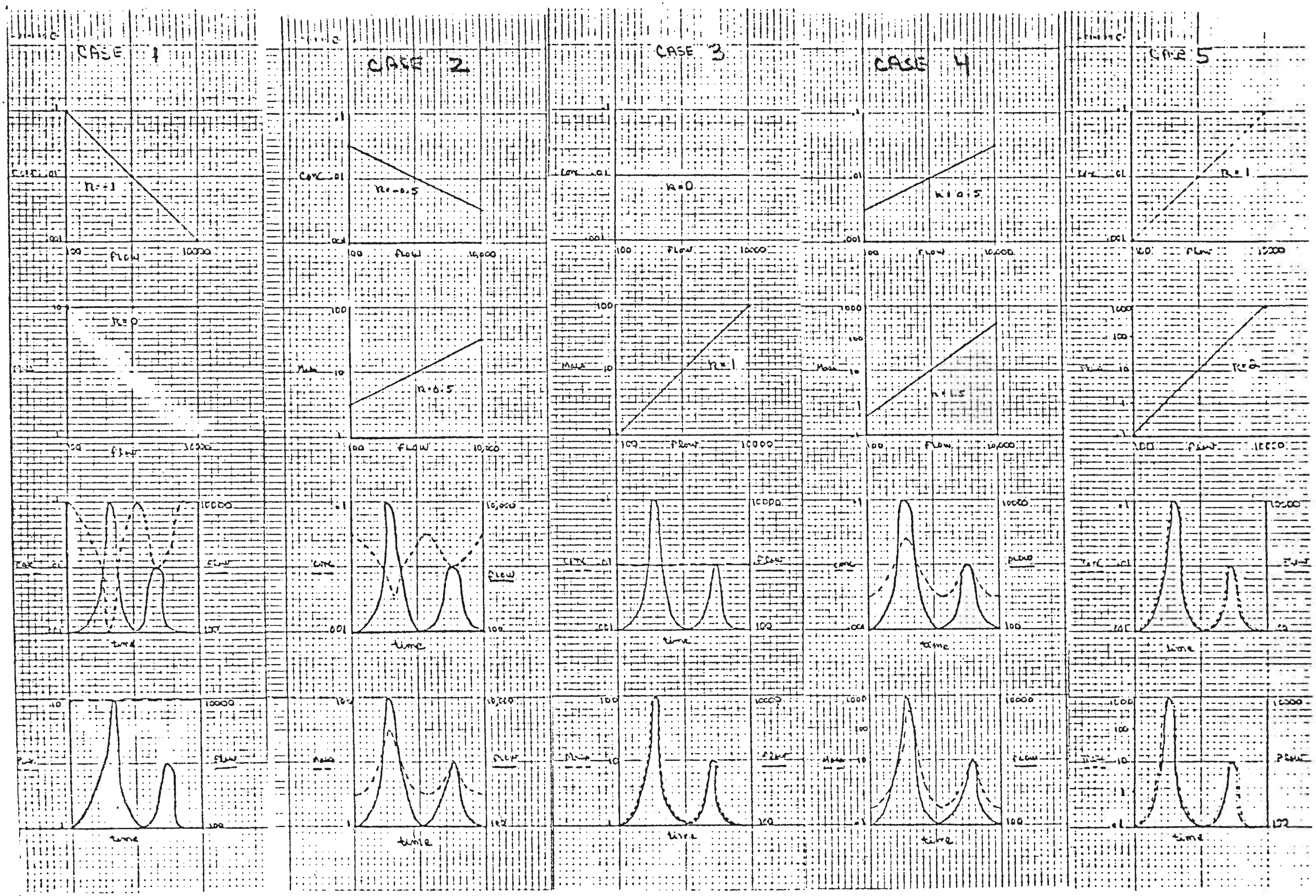
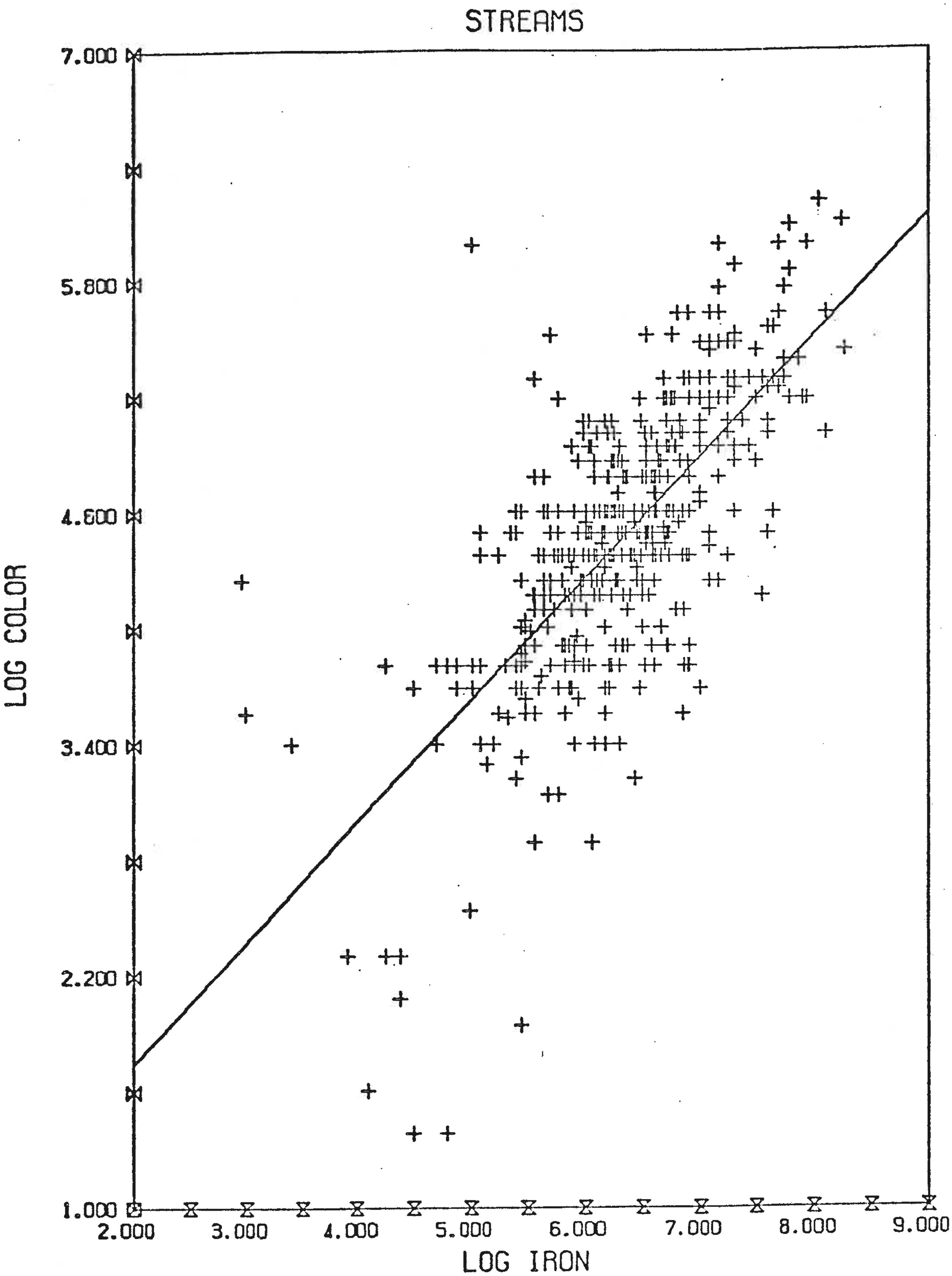


Figure 28. (Contd.)

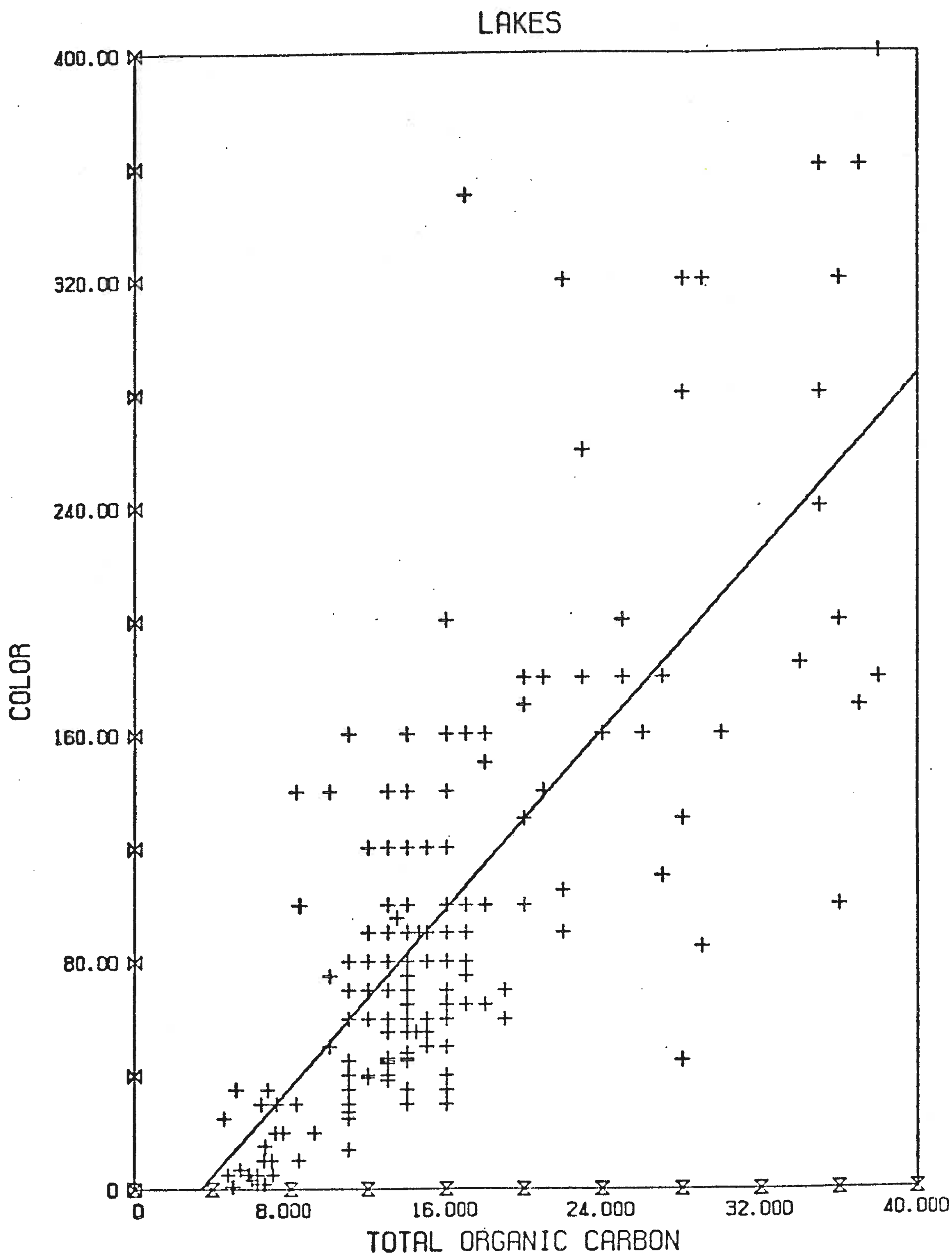
Figure 1. Types of parameter flow – frequency relationships.





STREAMS
7.000
5.800
4.600
3.400
2.200
1.000
LOG COLOR
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
LOG IRON

Fig 32



LAKES
400.00
320.00
240.00
160.00
80.00
0
COLOR
0
8.000
16.000
24.000
32.000
40.000
TOTAL ORGANIC CARBON

Fig 31

Figure 32. Log specific conductvity vs. log filtrable residue in streams.

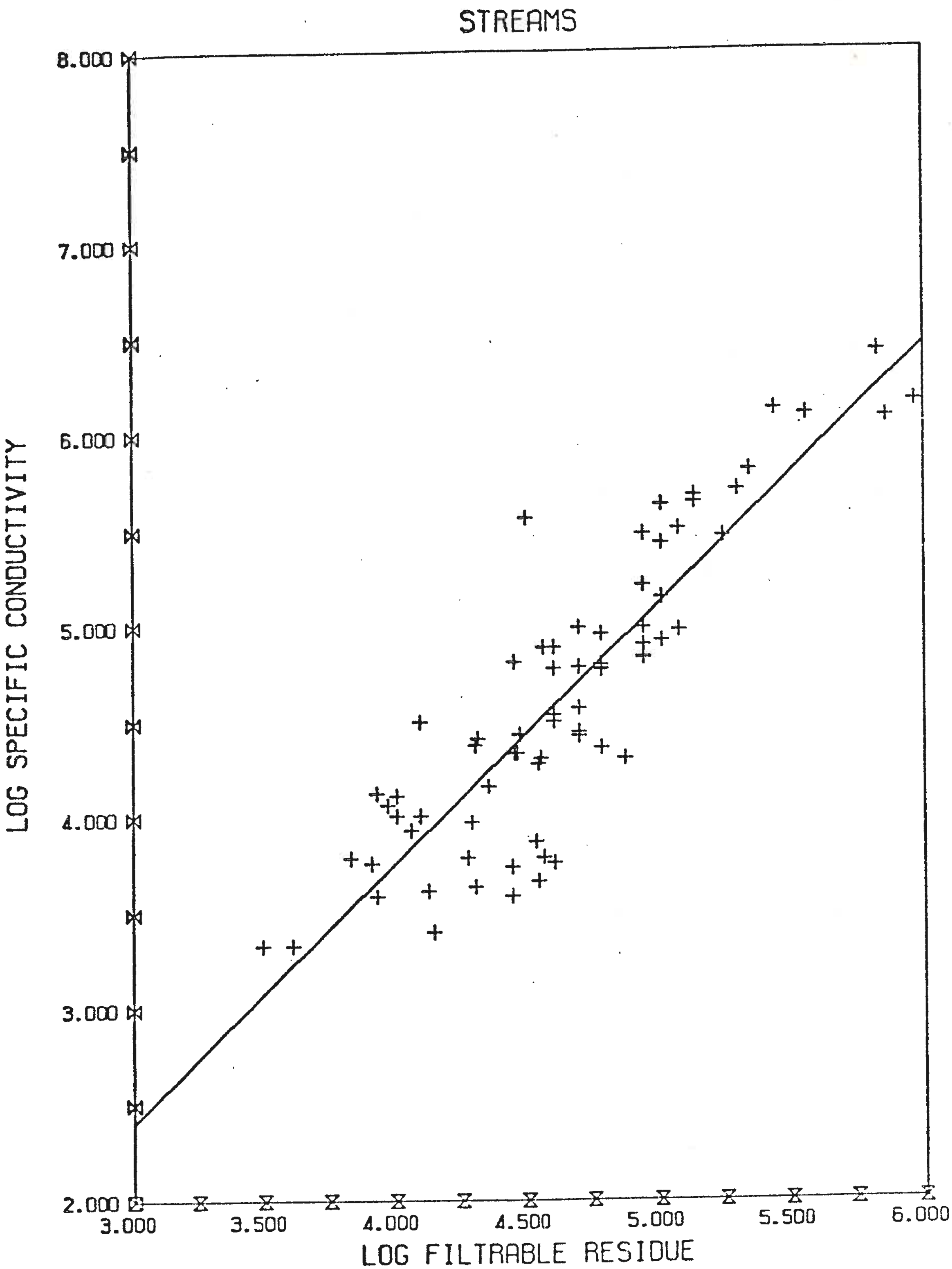
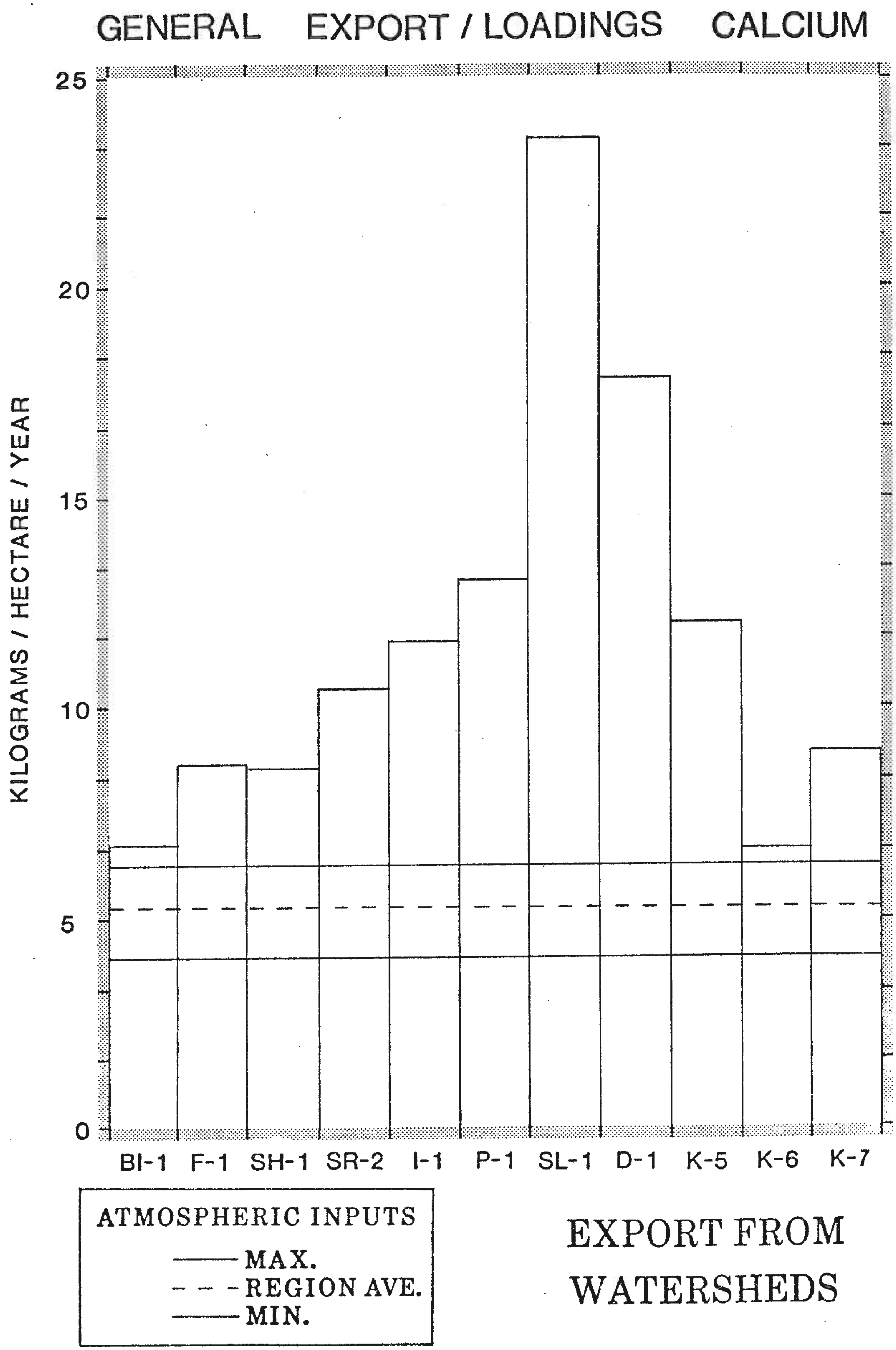


Figure 33



GENERAL EXPORT / LOADINGS CALCIUM
KILOGRAMS / HECTARE / YEAR
25
20
15
10
5
0
BI-1
F-1
SH-1
SR-2
I-1
P-1
SL-1
D-1
K-5
K-6
K-7
ATMOSPHERIC INPUTS
MAX.
REGION AVE.
MIN.
EXPORT FROM WATERSHEDS

Figure 33. (Contd.)

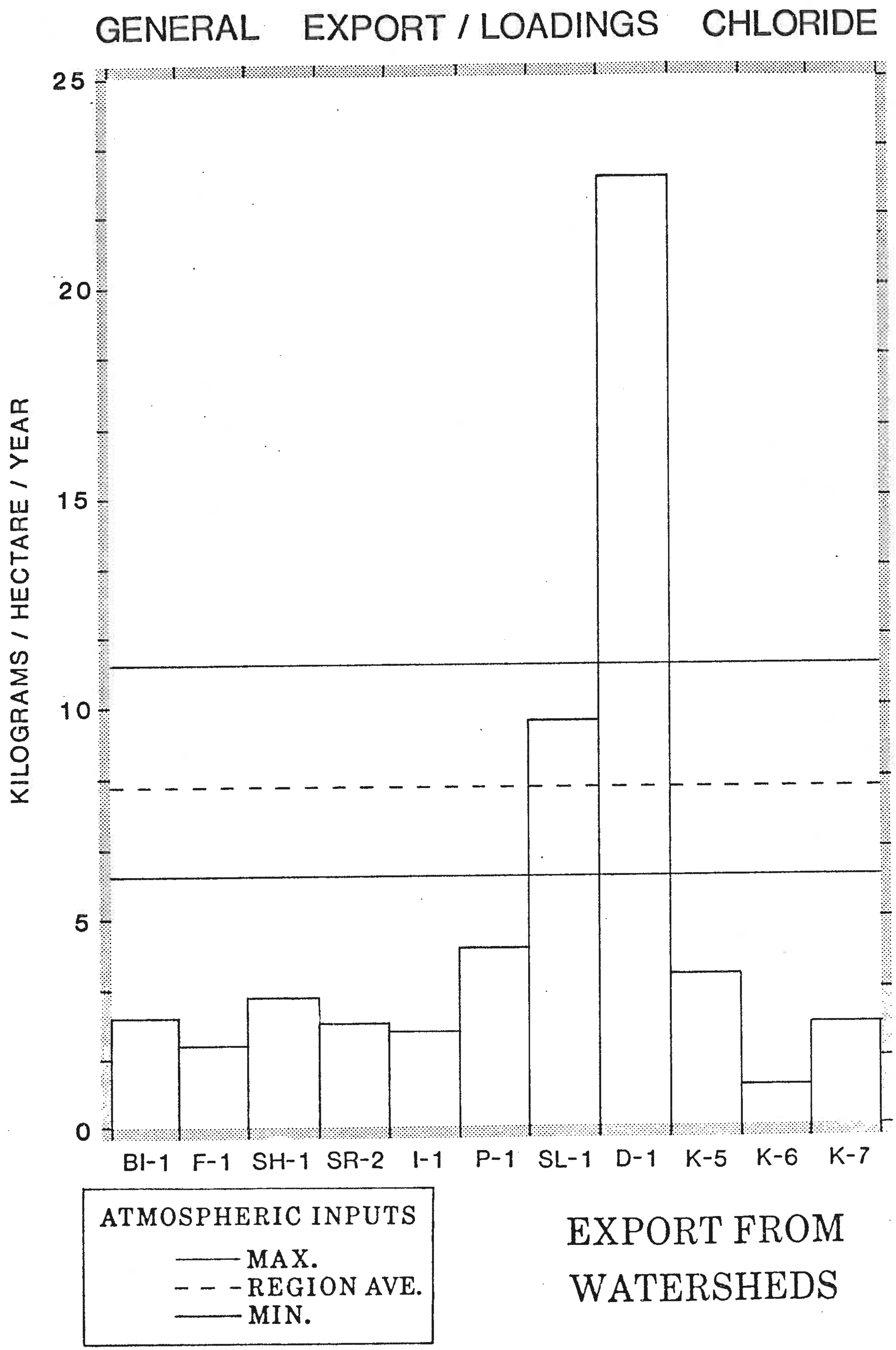


Figure 33. (Contd.)

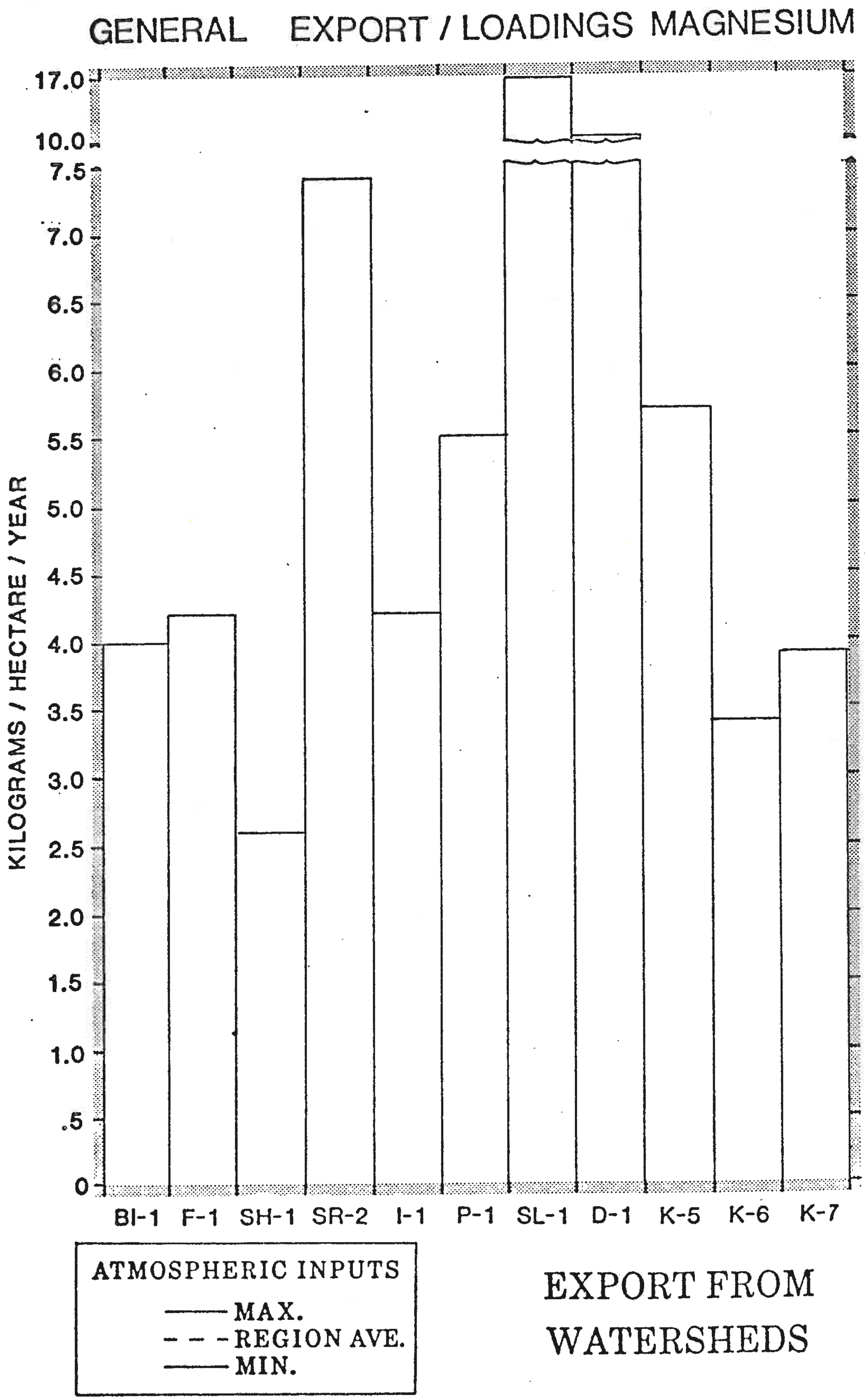
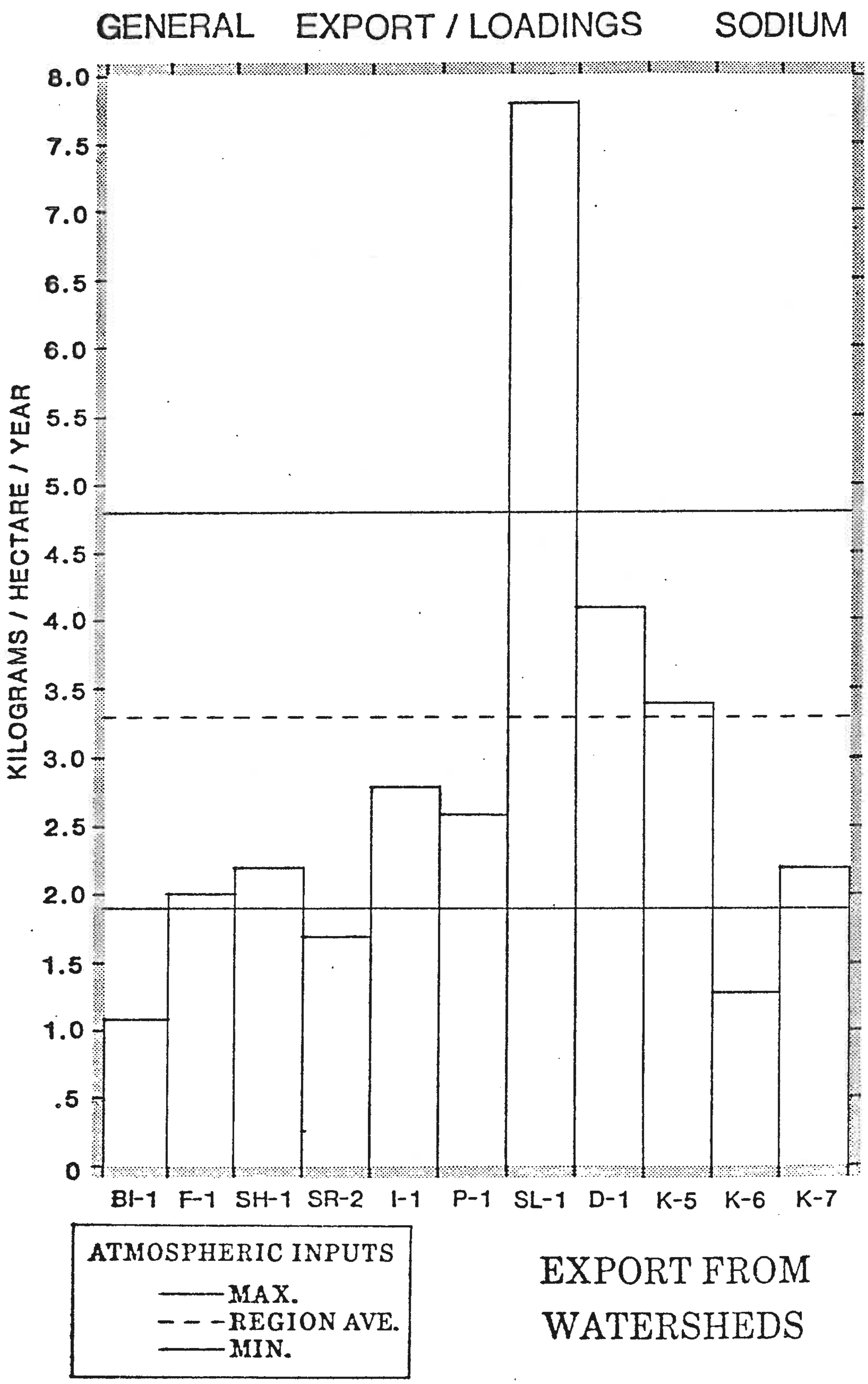


Figure 33. (Contd.)



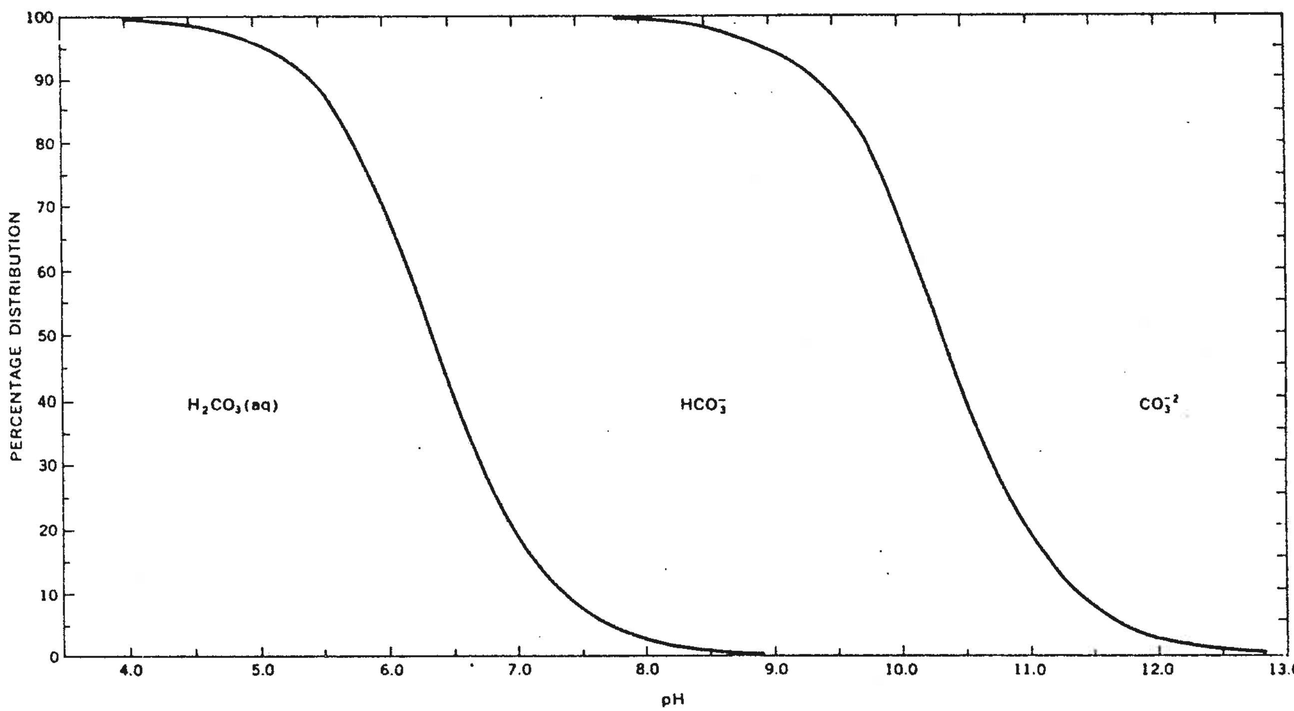


Figure 34. Percentages of total dissolved carbon dioxide species in solution as a function of pH, 25°C; pressure 1 atmoshpere.

Source: Hem 1970.

Figure 35

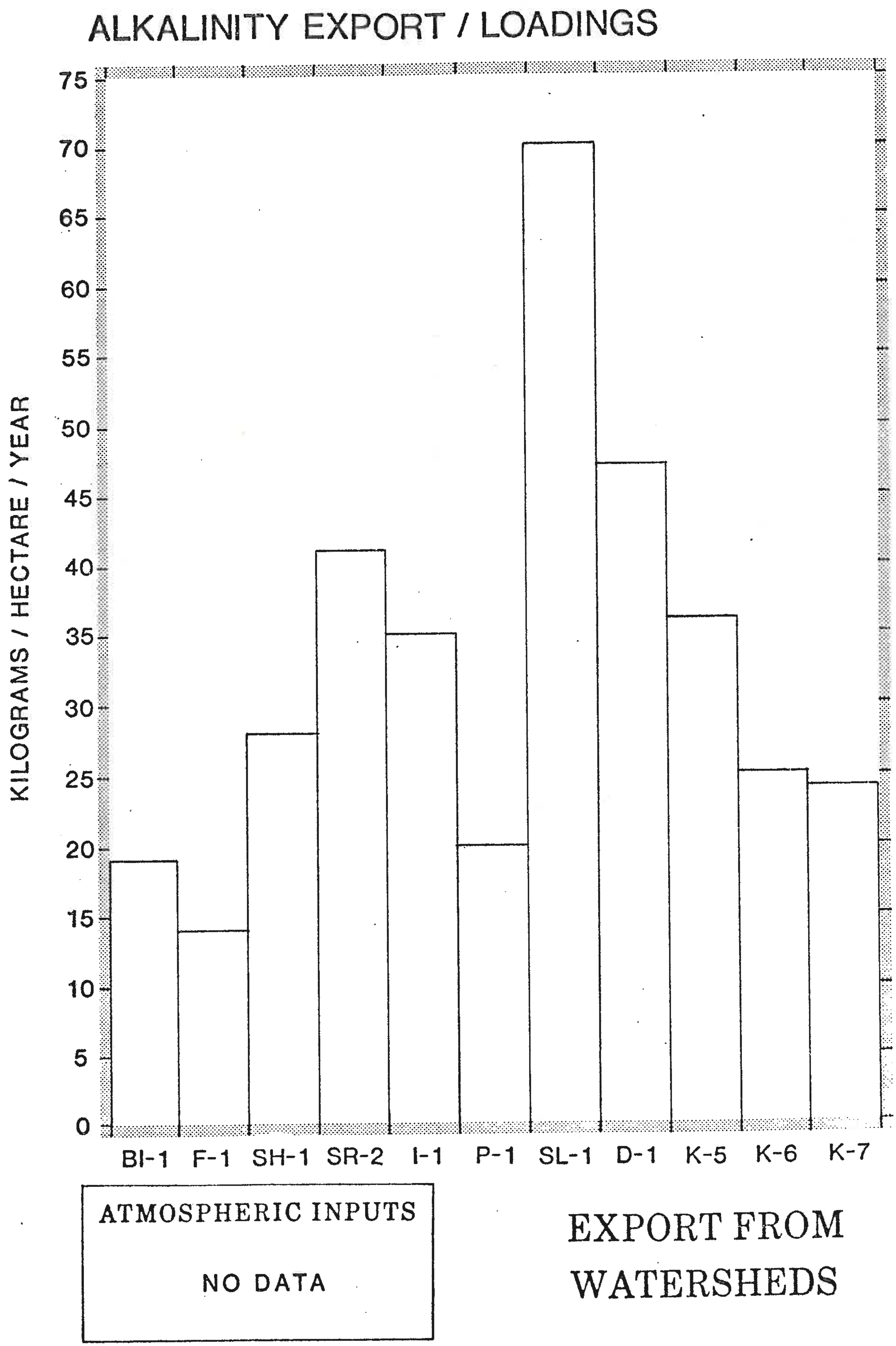

ALKALINITY EXPORT / LOADINGS
KILOGRAMS / HECTARE / YEAR
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
BI-1
F-1
SH-1
SR-2
I-1
P-1
SL-1
D-1
K-5
K-6
K-7
ATMOSPHERIC INPUTS
NO DATA
EXPORT FROM WATERSHEDS

Figure 35 (cont)

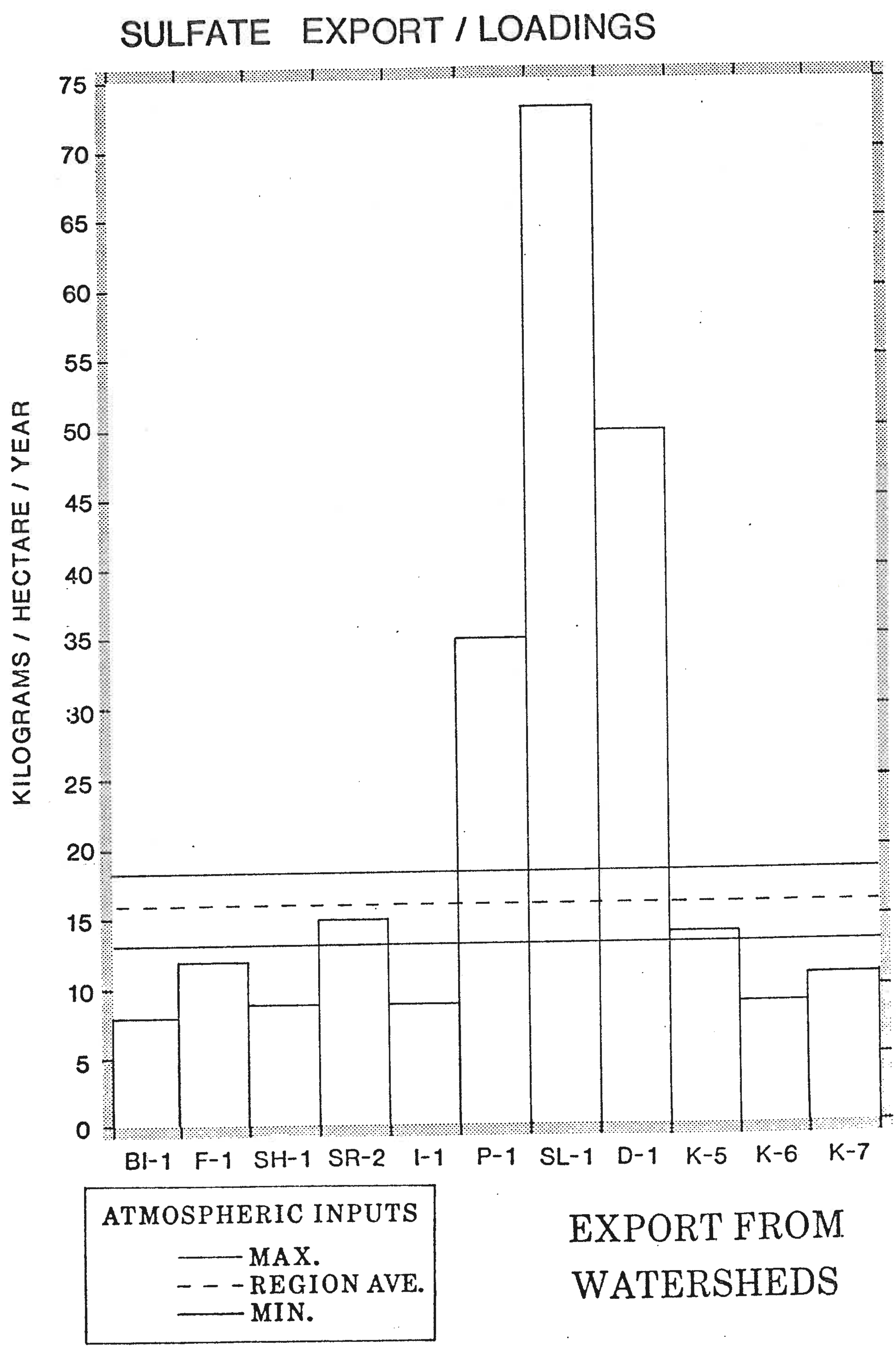


Figure 36. Total phosphorous vs. chlorophyll a in lakes.

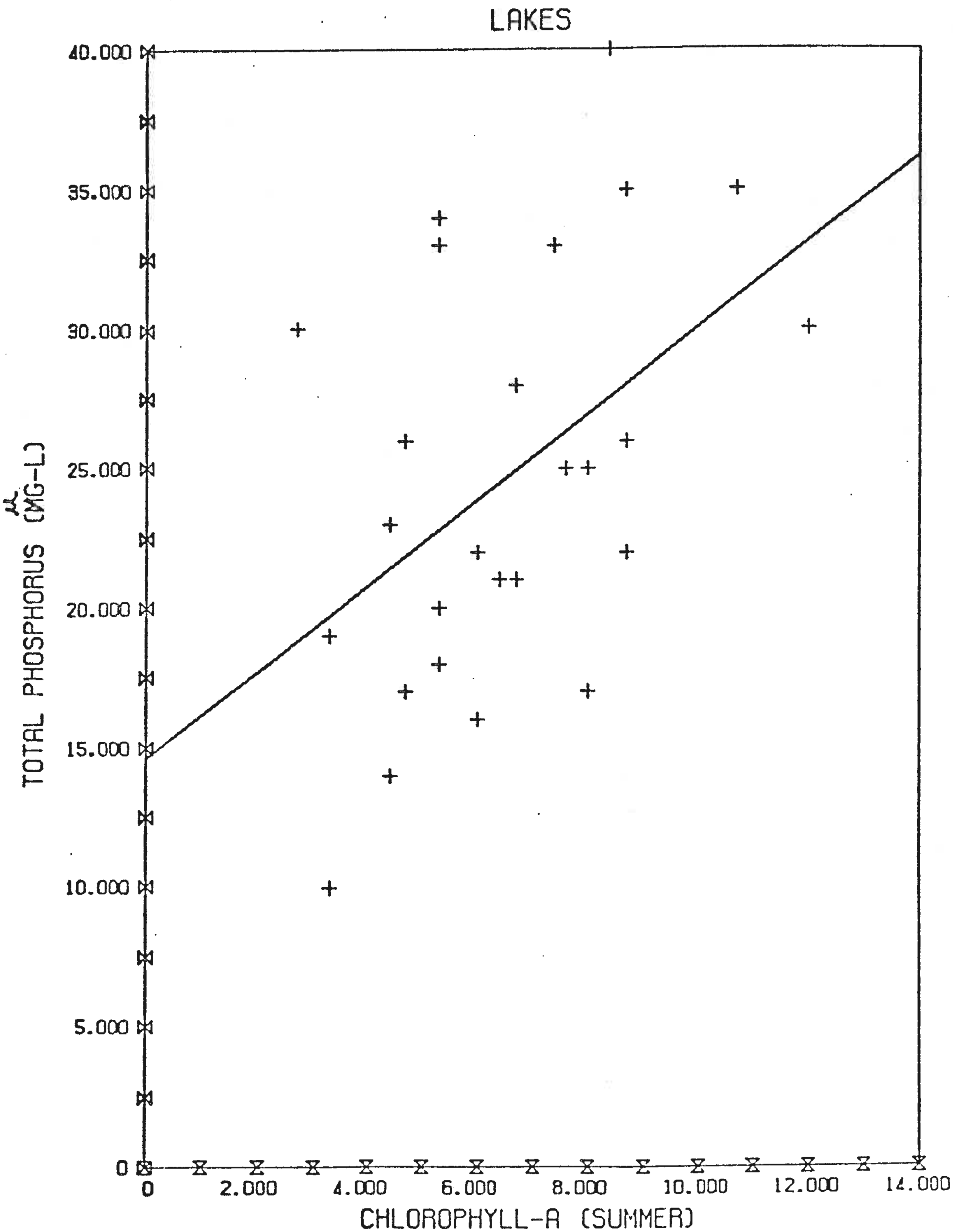


Figure 37. Secchi disk vs. chlorophyll a in lakes.

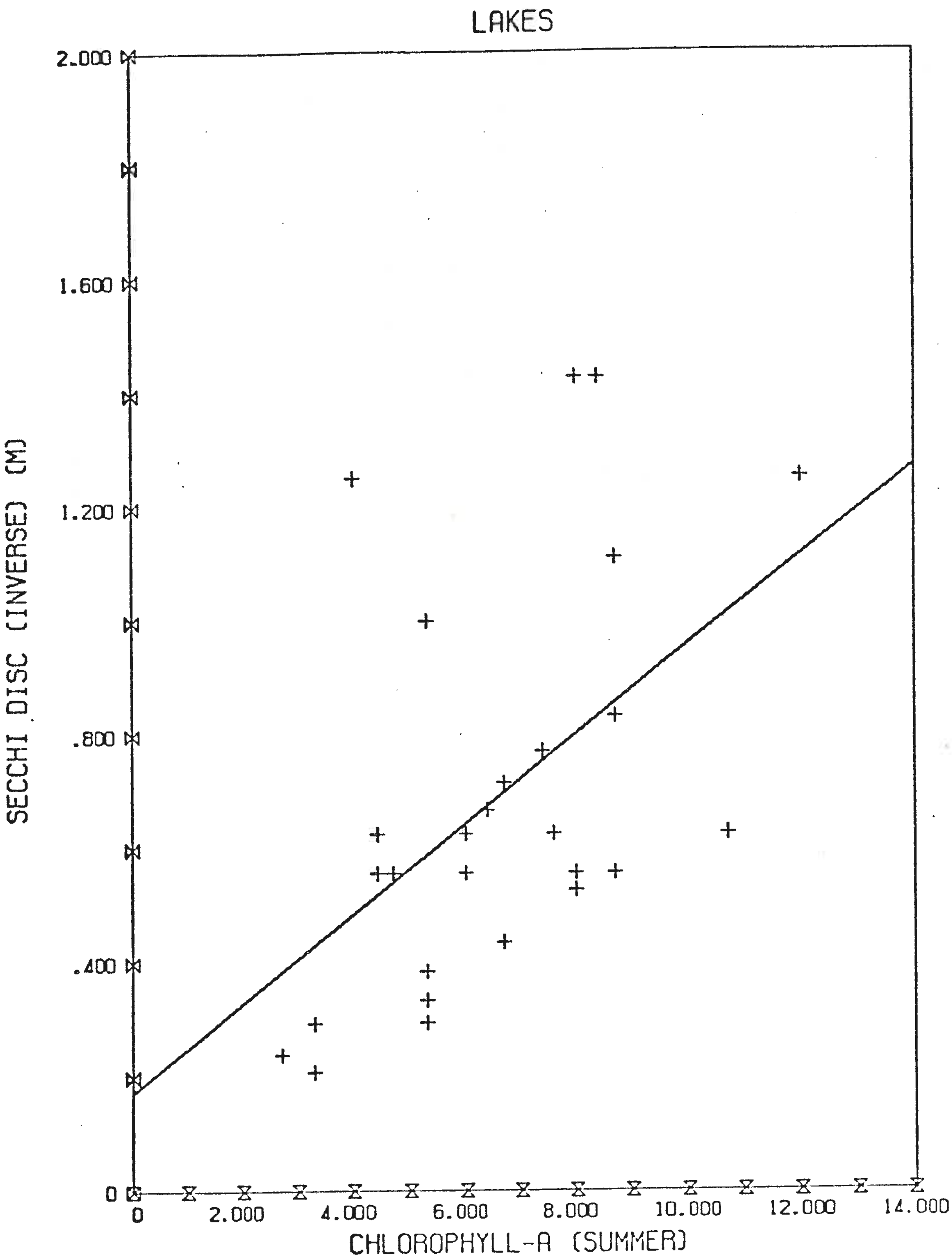


Figure 38. Total phosphorus vs. Secchi disk in lakes.

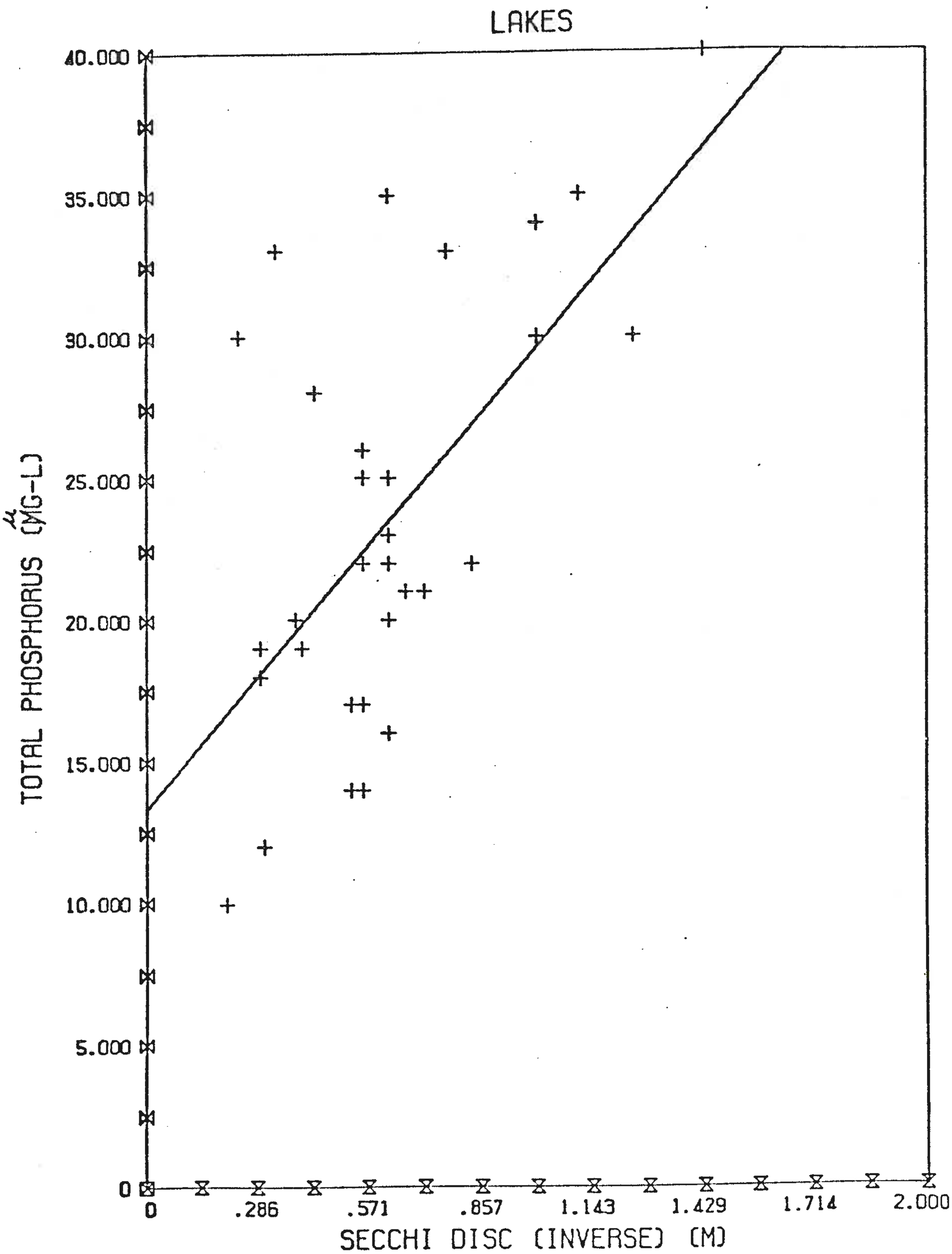
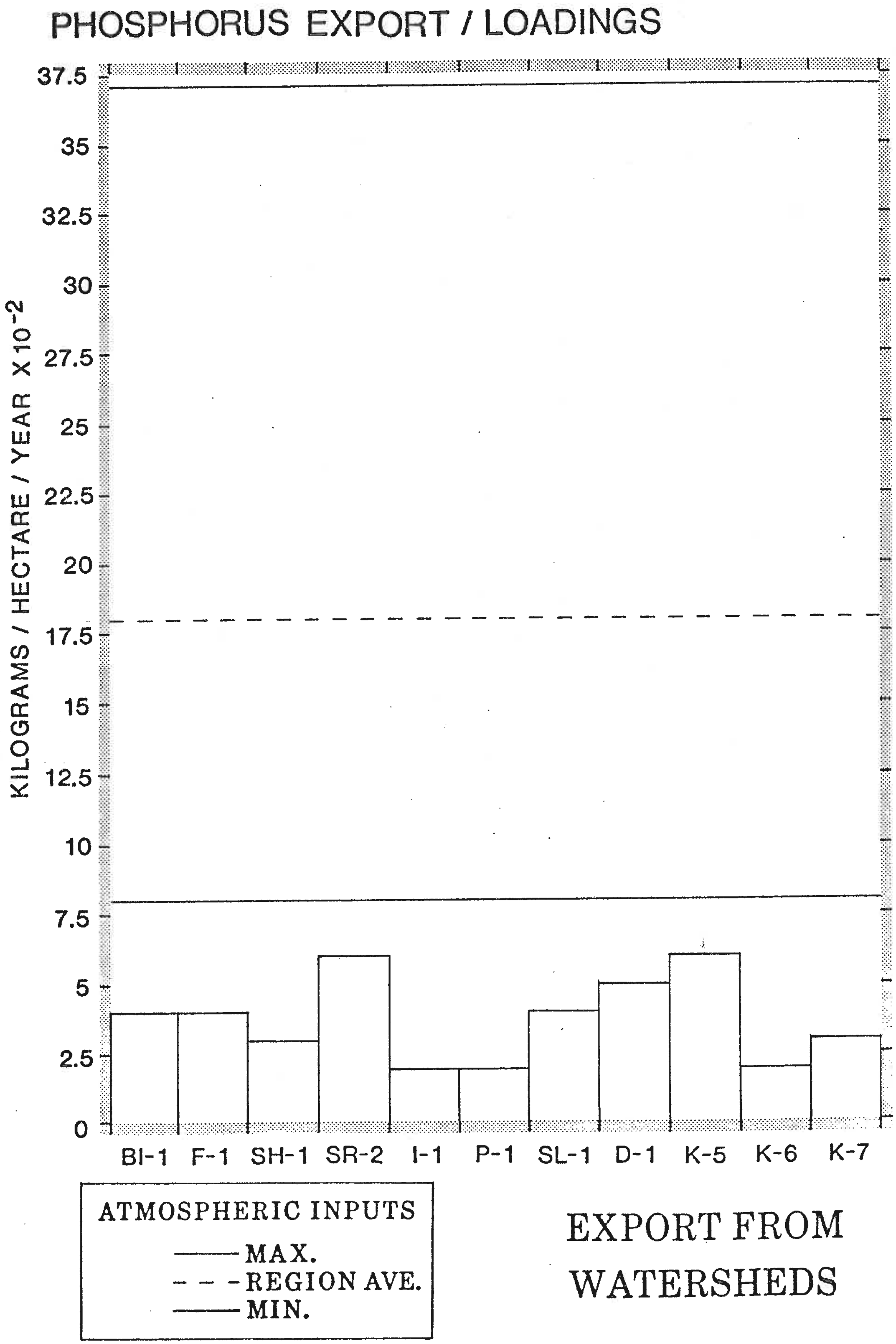
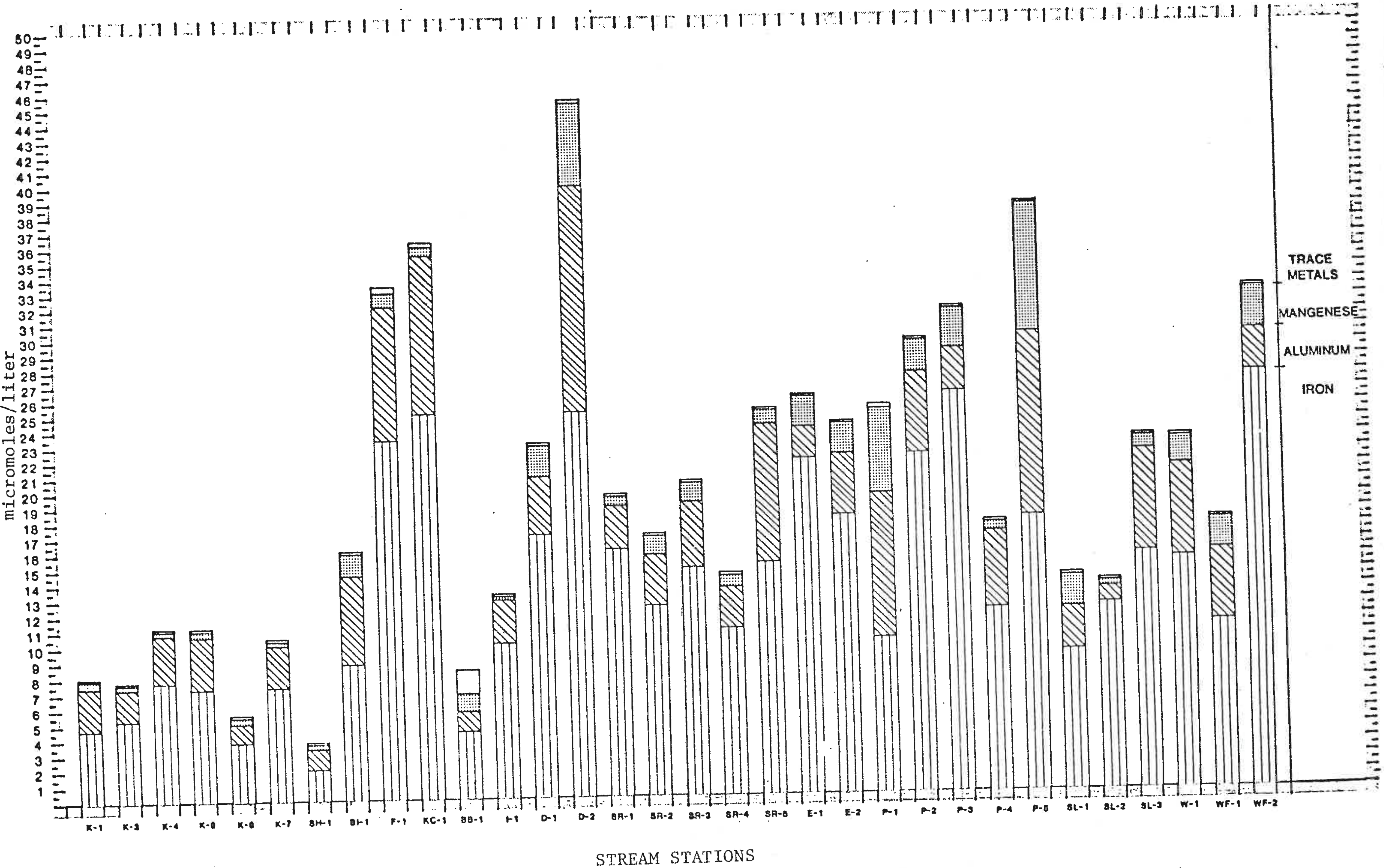


Figure 39.


PHOSPHORUS EXPORT / LOADINGS
KILOGRAMS / HECTARE / YEAR X 10^{-2}
37.5
35
32.5
30
27.5
25
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
BI-1
F-1
SH-1
SR-2
I-1
P-1
SL-1
D-1
K-5
K-6
K-7
ATMOSPHERIC INPUTS
MAX.
REGION AVE.
MIN.
EXPORT FROM WATERSHEDS



Major and trace metal proportions at stream stations.

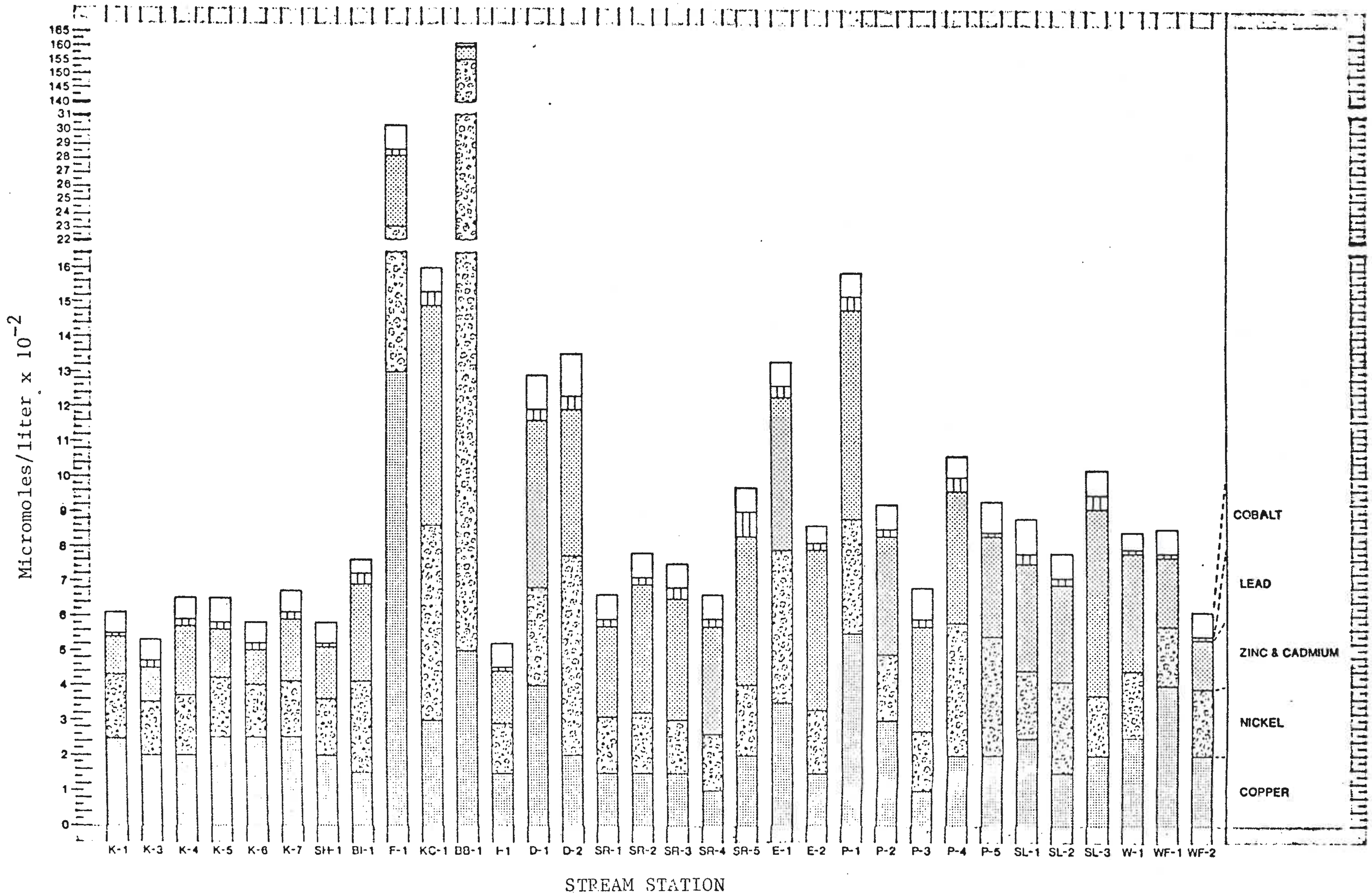


Figure 46b

Trace metal proportions at stream stations.

Figure 41

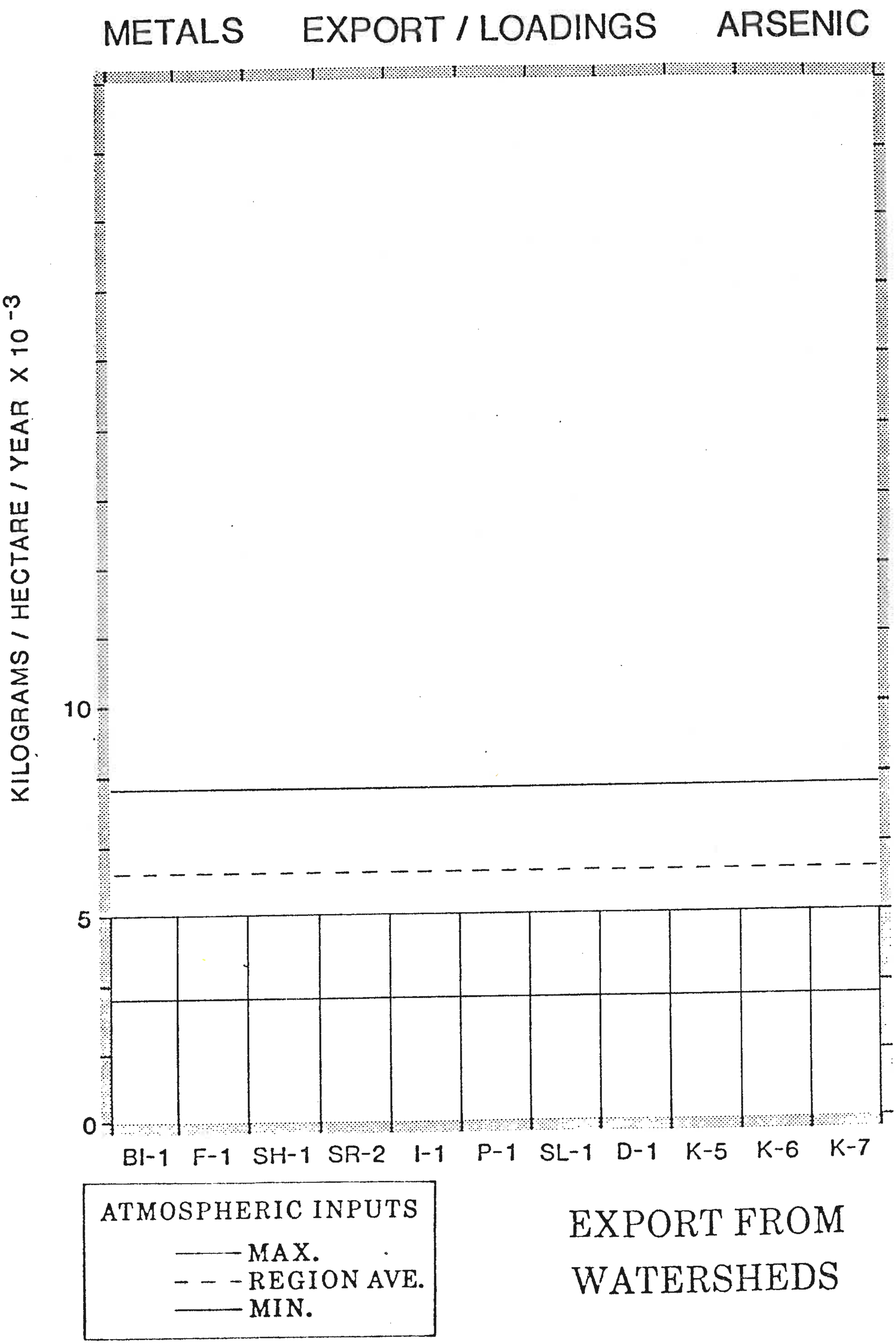

METALS EXPORT / LOADINGS ARSENIC
KILOGRAMS / HECTARE / YEAR X 10 -3
10
5
0
BI-1
F-1
SH-1
SR-2
I-1
P-1
SL-1
D-1
K-5
K-6
K-7
ATMOSPHERIC INPUTS
MAX.
REGION AVE.
MIN.
EXPORT FROM WATERSHEDS

Figure 41. (Contd)

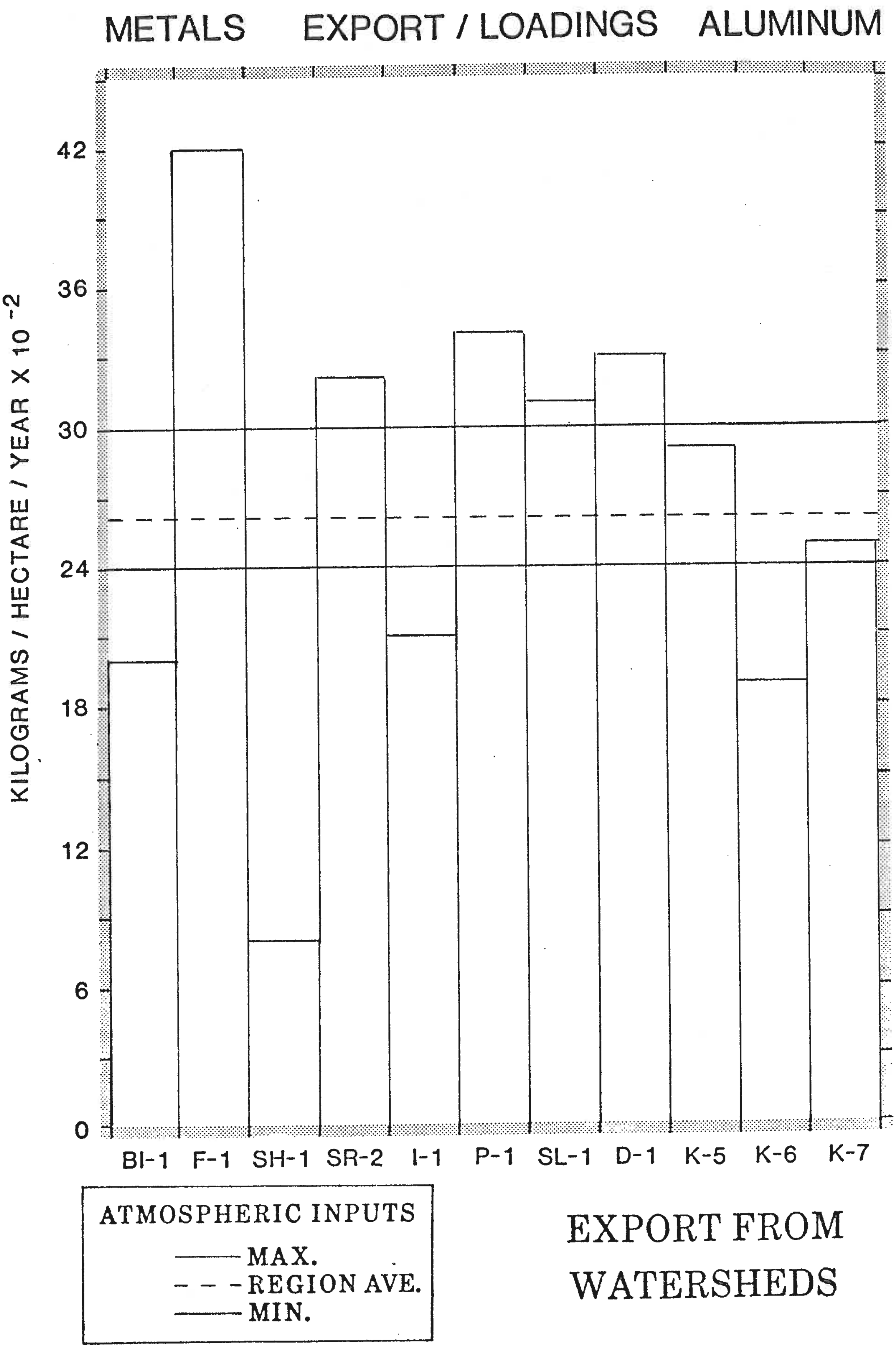


Figure 41. (Contd.)

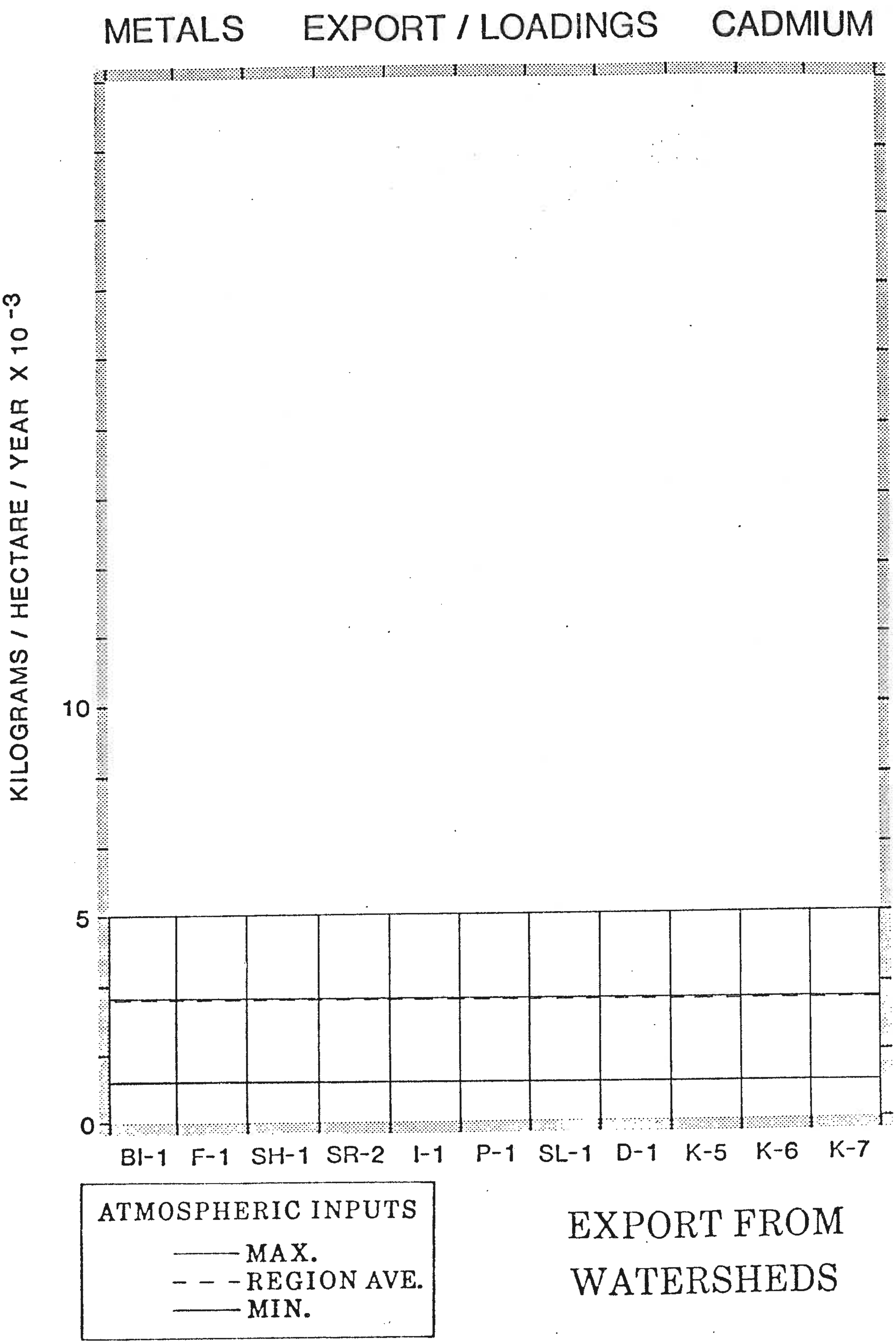


Figure 41. (Contd.)

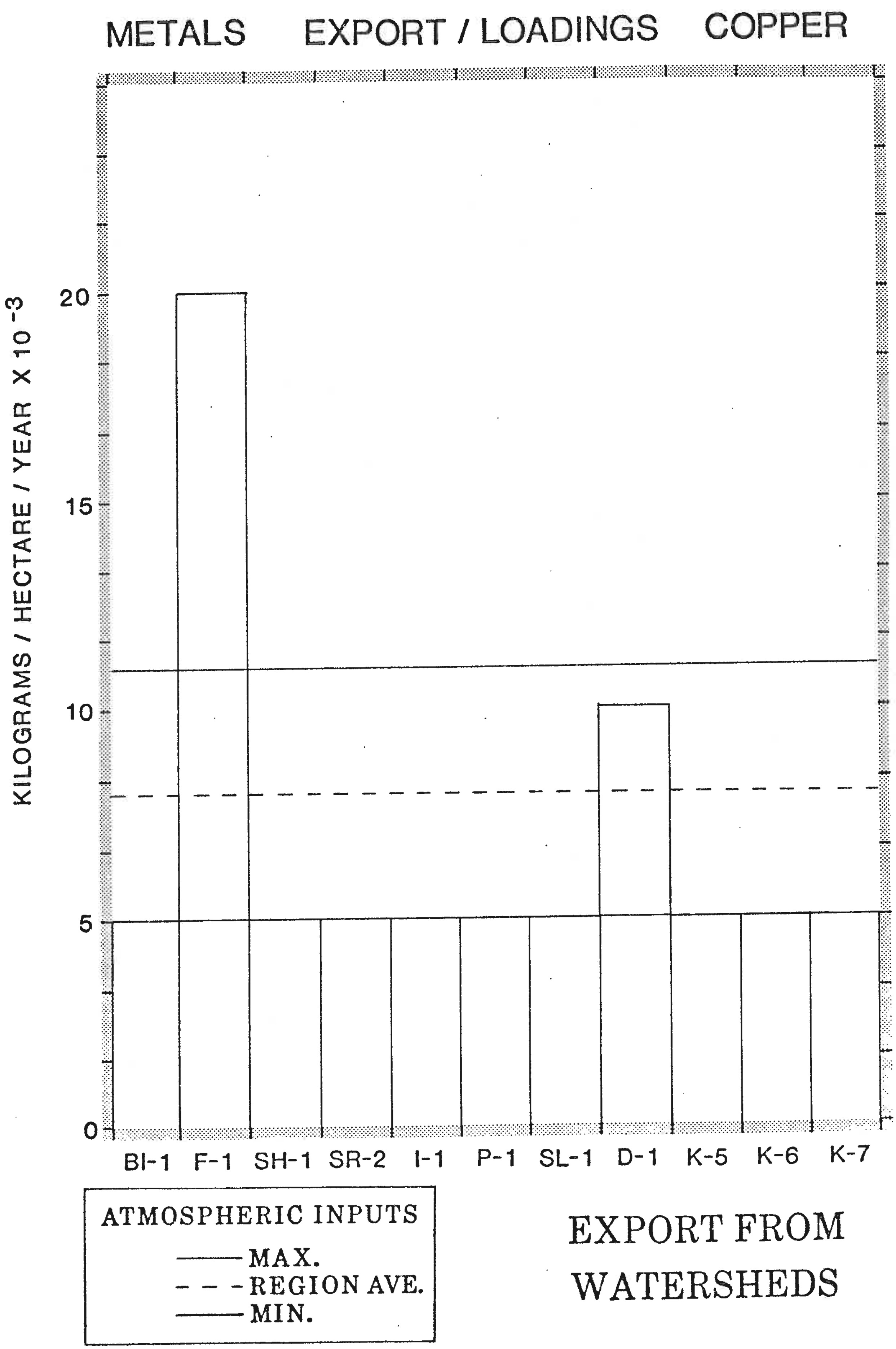


Figure 41. (Contd.)

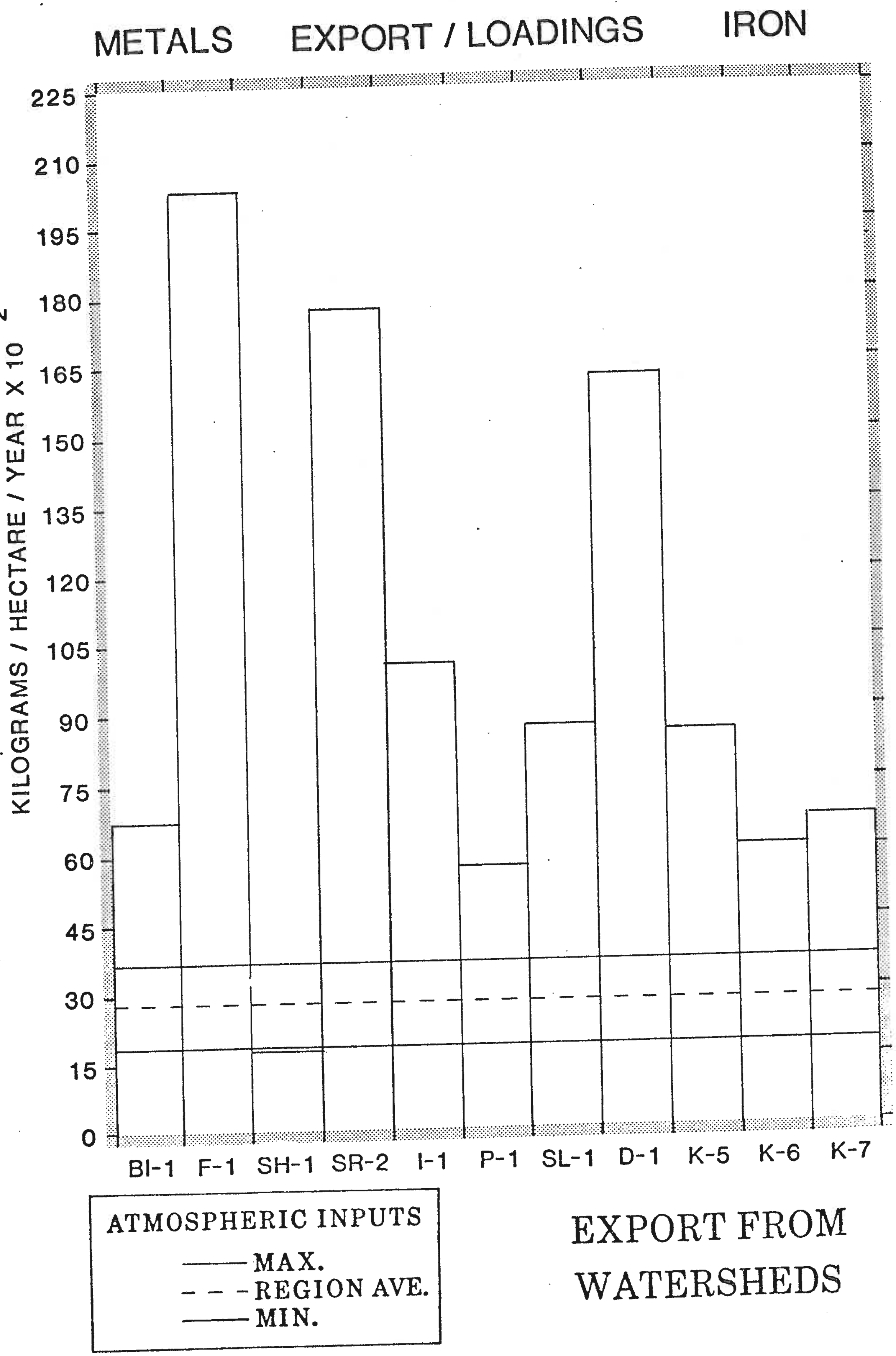


Figure 41. (Contd.)

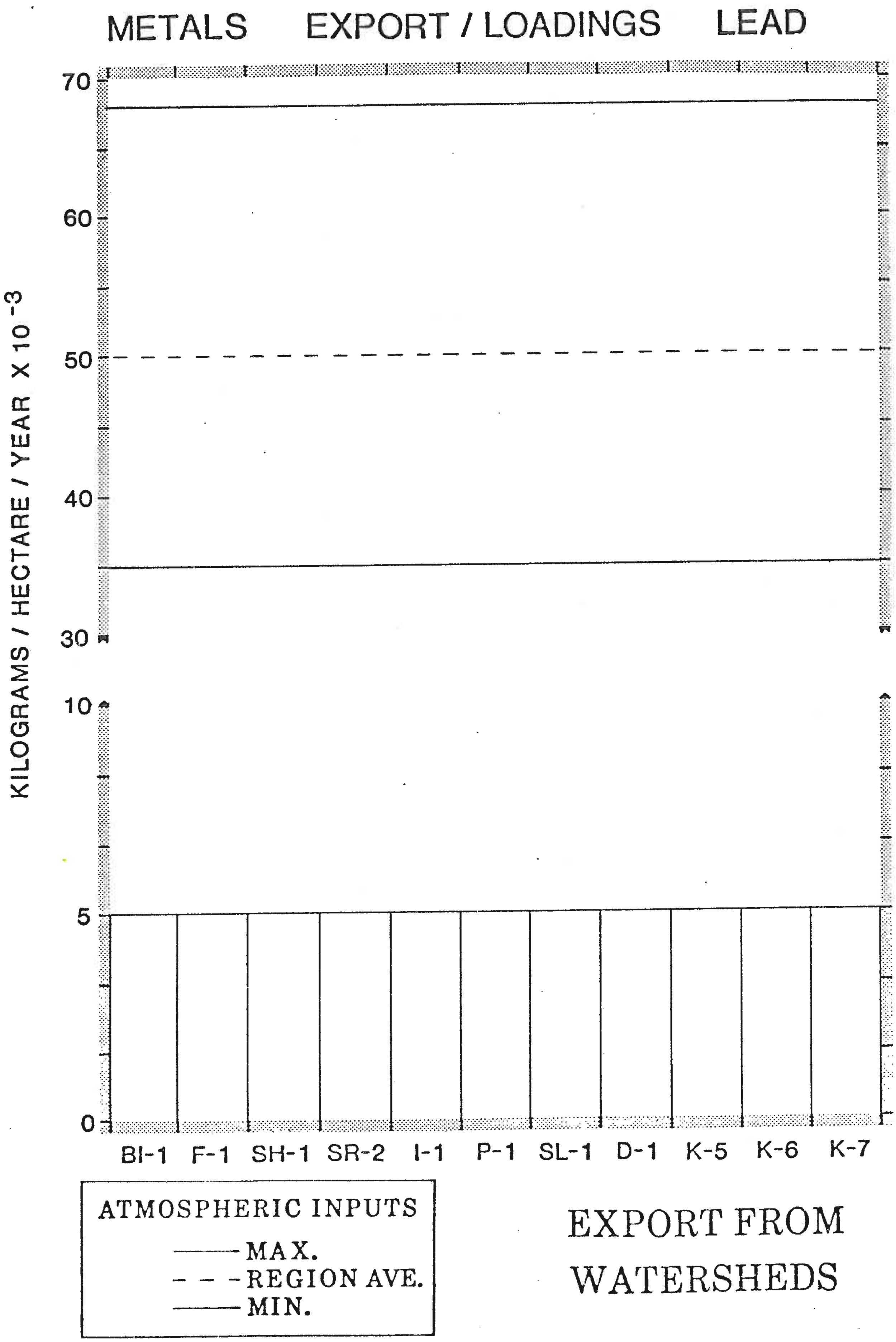


Figure 41. (Cont.)

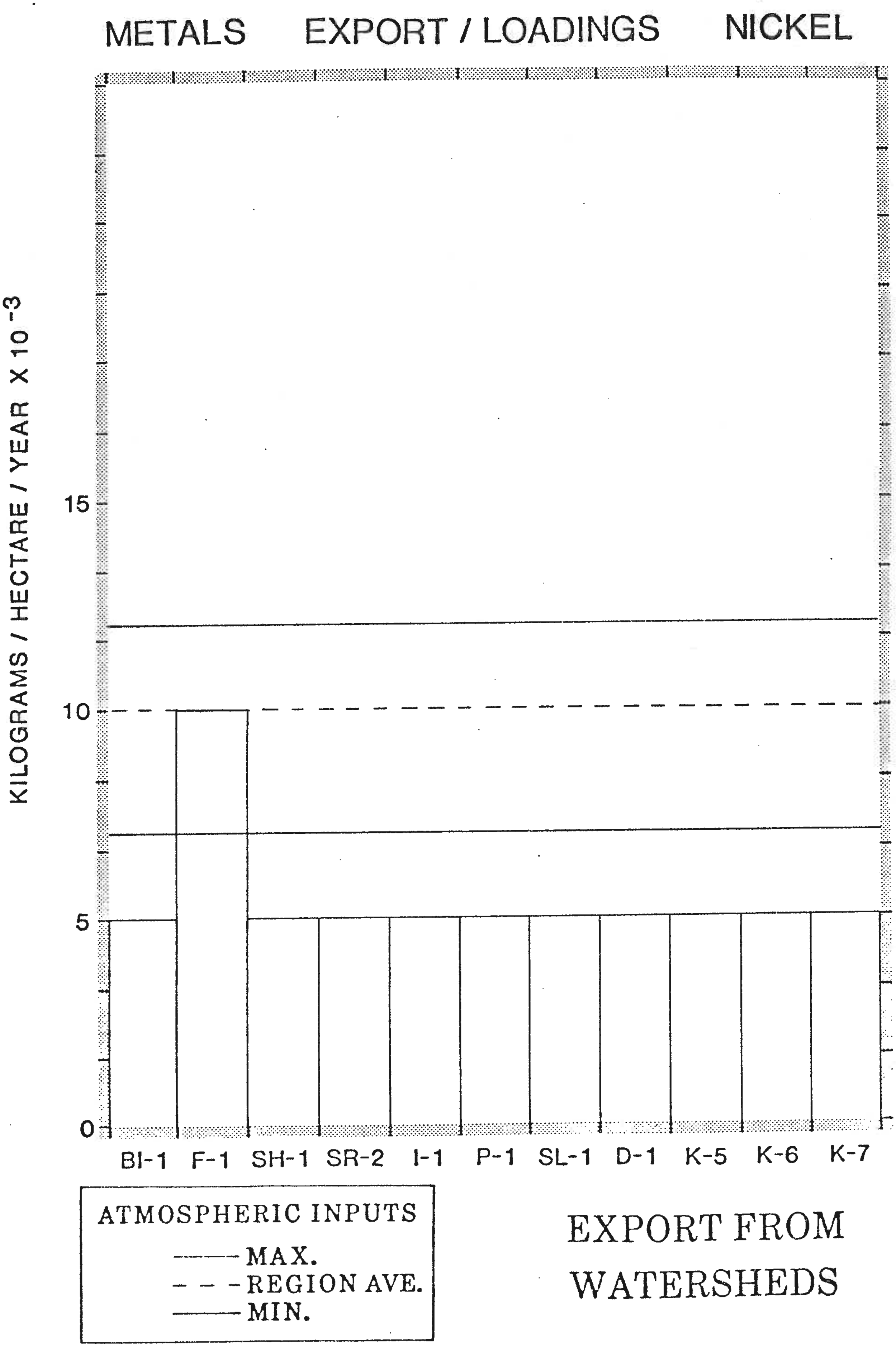


Figure 41. (Contd.)

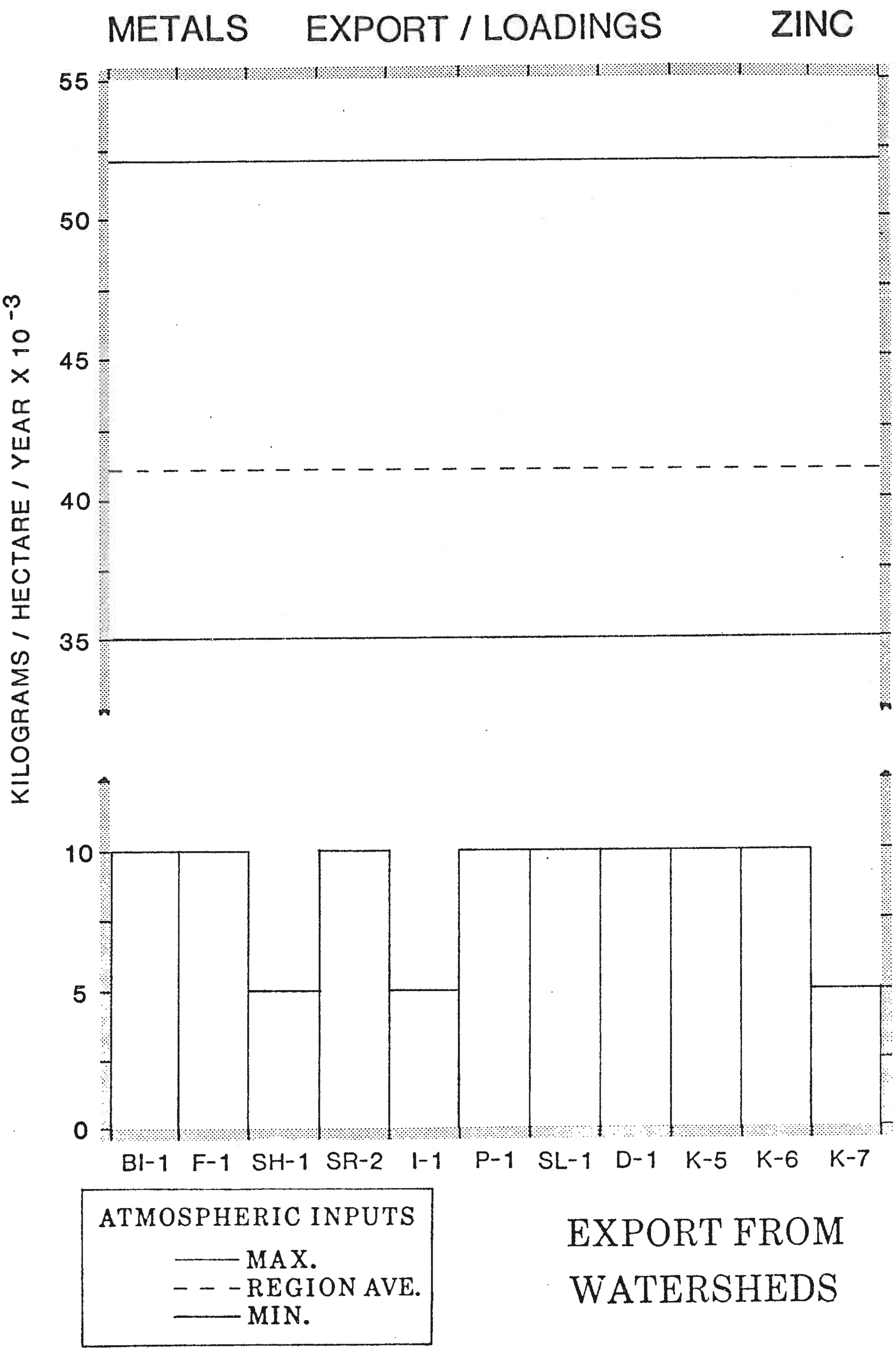


Figure 42. Total organic carbon vs. complexing capacity in lakes.

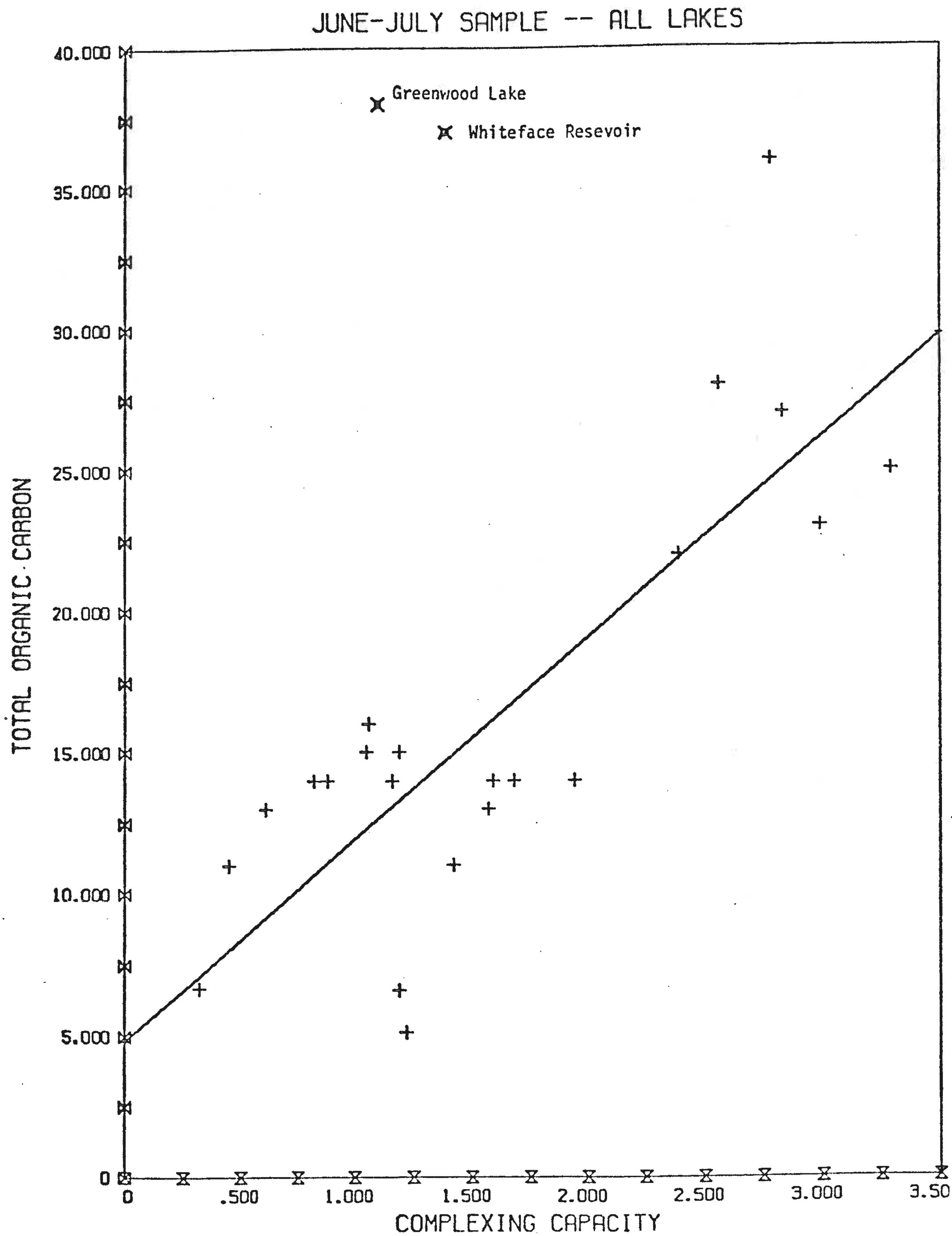


Figure 43. Color vs. complexing capacity in lakes.

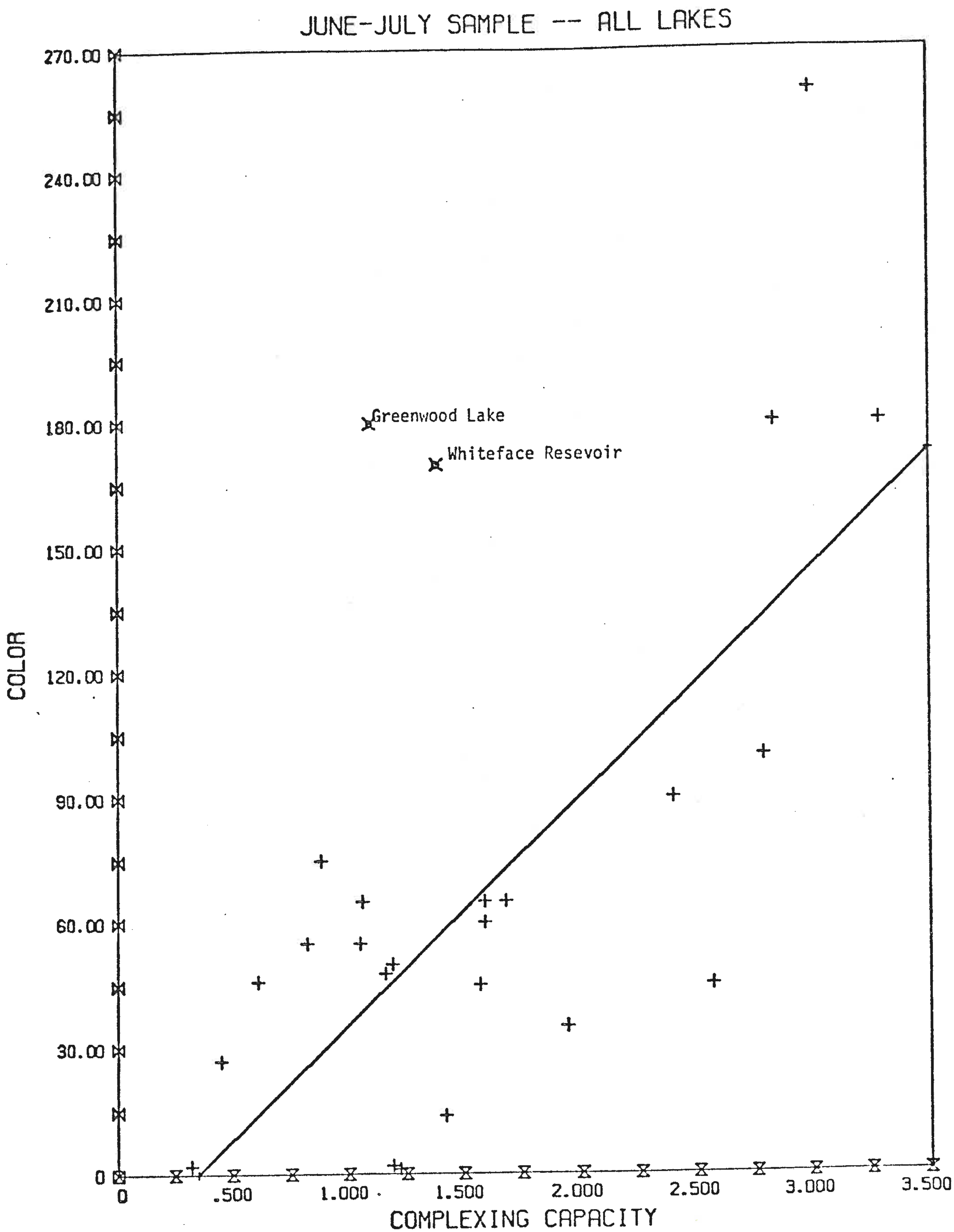
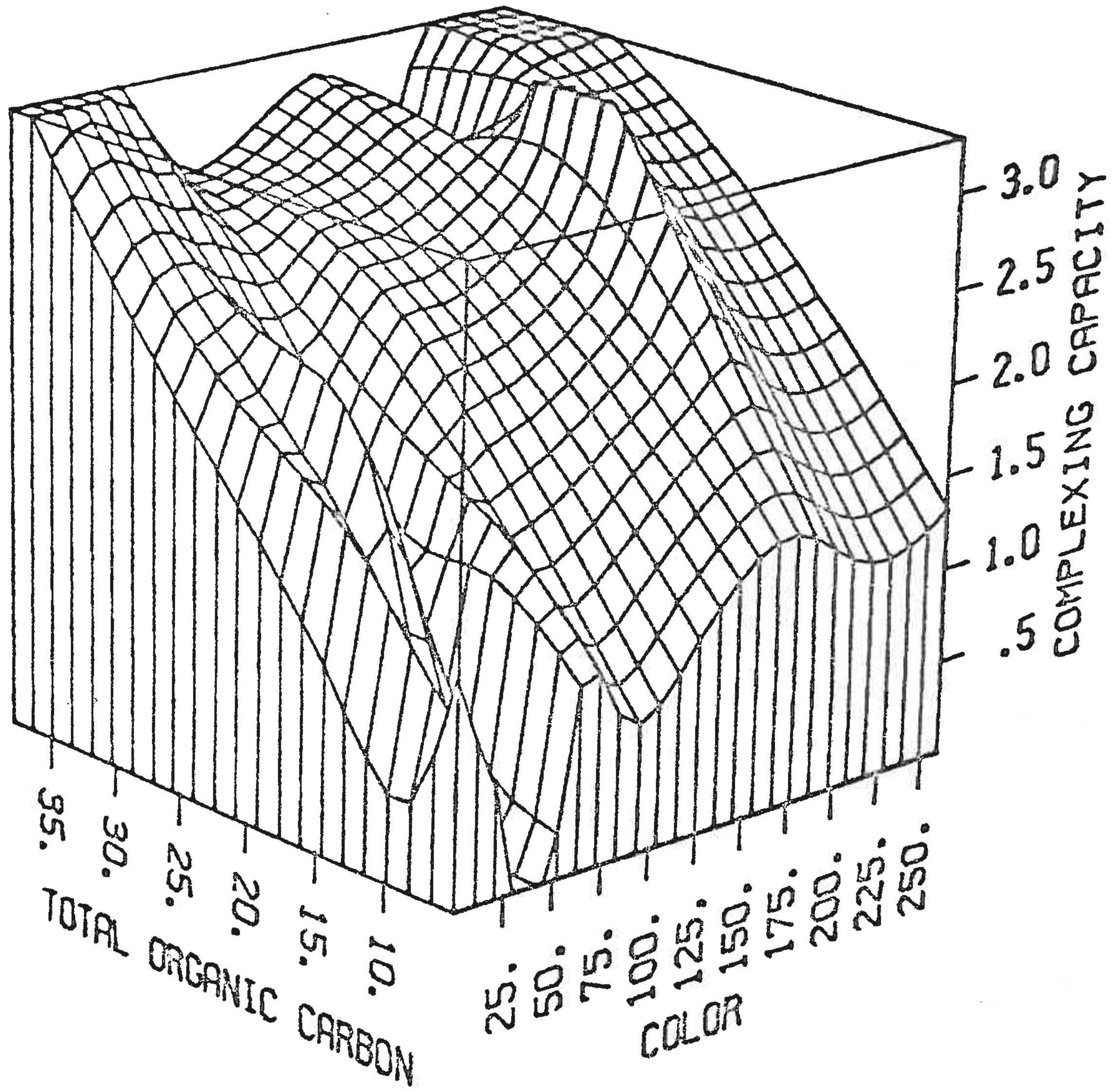


Figure 44. TOC vs. color vs. complexing capacity in lakes.



June-July Sample - All Lakes

Figure 45. Change in complexing capacity in lakes.