THE FEASIBILITY OF USING DREDGED BOTTOM SEDIMENTS AS AN AGRICULTURAL SOIL

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ABSTRACT

The utilization of contaminated bottom sediments as agricultural soil was investigated as a new approach of the dredged sediment disposal.

Bottom sediments collected from Hamilton Harbour, Humber Bay Port Stanley, Detroit River Mouth, and Lake St. Clair were used for the determination of chemical, physical and biological properties considered important for the evaluation of bottom sediments as agricultural soil.

It was proved in leaching experiments and lysimeters that the concentrations of elements, released from the bottom sediments dispersed in water, were lower than those recommended for water for public use with the exception of manganese and nickel. (Cd < 0.001 mg/1, Cr < 0.2 mg/1, Cu 0.08 mg/1, Fe 0.08 mg/1, Pb < 0.001 mg/1, Mn 2.9 mg/1, Hg < 0.05 mg/1, Ni 0.07 mg/1, Zn 1.1 mg/1). The suitability of contaminated bottom sediments from Hamilton Harbour, Humber Bay and Detroit River as agricultural soil was verified in greenhouse experiment by planting tomatoes and corn with a good crop yield. The crop yield of the Humber Bay tomato plants was best, followed by those of Hamilton Harbour and Detroit River.

Tomato plants and corn did not take up various elements in the proportions in which the elements occurred in the sediments,

but exerted a selective action, absorbing greater amounts of some elements than others. Tomato plants took up nutrients and trace elements only to a certain limiting concentration characteristic for individual plant organs. The concentrations were comparable with those found by soil scientists studying the uptake of elements from soils.

Following maximum concentrations were determined for tomato fruit grown in Humber Bay sediment: K 37,000 mg/kg, Mg 2,100 mg/kg, Ca 1,750 mg/kg, Zn 40 mg/kg, Sr 30 mg/kg, Cu 23 mg/kg, Pb 12 mg/kg, Co 7 mg/kg, Cd 2 mg/kg - Arsenic, molybdenum, manganese, chromium, nickel and mercury were below the levels of detection.

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1. INTRODUCTION

The drainage basin of the Great Lakes includes 175,000 square miles of the United States and 120,000 square miles of Canada. The Lakes occupy almost a third of their drainage area(95,000 square miles).

The topographic setting of the Lakes was brought about by pre-glacial erosion of the bedrock creating regional topographic lows in which relatively recent glacial meltwaters accummulated.

Hough (1958) summarized the bedrock geology of the area of the Great Lakes and described the glacial and postglacial history of the lakes. Chapman and Putnam (1966) described the glacial and post-glacial history of the southern Ontario.

A 1,200 per cent increase in the population in the Great Lakes Basin between 1860 and 1960 to over 32,000,000 inhabitants (1973) has created many serious environmental problems including water pollution and eutrophication of the Lower Great Lakes. The population projected for the year 2,000 (57,000,000) will further aggravate the environmental situation by increased use of water, by generating more and new pollutants, and by causing heavy soil erosion.

Factors affecting the population living in Great Lakes Basin including water, have been studied intensively. Water has been used and unfortunately misused to a steadily growing extent. Water quality in Lake Erie, Lake Ontario and Lake Michigan has deteriorated signifcantly. In recent years scientists have focused more attention on the bottom sediments and demonstrated that changes in water composition and increased soil erosion have changed the chemical, physical, and biological properties of the sediments, in particular, in the harbours and river mouths. Brydges, T., (1970), Callender E., (1969), Hartley, R. P., (1961a), Harter, R.D., (1968), Kemp (1971), Kemp et al, (1972), Kindle, E.M., (1925), Lewis, C.F.M., and McNeely R.N., (1967), Lewis, C.F.M., (1966), Rukavina, N.A., (1970), Thomas, R.L., (1969), Thomas, R.L. et al, (1972), Thomas R.L., (1969a), Thomas, R.L., (1971), Wood, L.E., (1964), Williams, J.D.H. et al, (1971).

Navigation on the Great Lakes is one of man's activities. The annual amount of sediments accumulated in Lower Great Lakes harbours and channels in the U.S.A. and Canada is 7,600,000 m^3 and 545,000 m^3 respectively, which must be removed annually by dredging.

With regard to the chemical composition the dredged bottom sediments can be classified as uncontaminated and contaminated. Dredged sediments have been disposed either by dumping in deeper lake water or by transporting and storing on land, so far without utilization. Water pollution caused by dumping contaminated dredged sediments in open lakes initiated a number of R&D projects aimed at a less harmful disposal.

The purpose of this study is to attempt a new approach of the dredged sediments disposal: the utilization of sediments as agricultural soil or as fertilizers. There is an excellent example in the history of mankind. The Nile was to ancient Egypt what fertilizers + water are to modern farmers around the world. It created in the midst of a sterile land an elongated oasis that for thousands of years has nurtured civilization until building of the Aswan dam. Each year the main stream of the Nile, swollen with the torrential rains that fall in Ethiopia, rushes north and spreads its sediment-laden waters over Egypt. The Egyptians never had to fear exhausting soil: every summer the Nile refreshed it, and, moreover, provided irrigation.

2. STATEMENT OF THE PROBLEM

Harbours and channels of the Great Lakes are regularly dredged to remover accumulated bottom sediments: (a) Uncontaminated sediments by man's activities. In general, chemical and physical properties of the sediments correspond to those of the soils of the drainage basin. (b) Sediments contaminated by man's activities which contain more elements or greater amounts of elements than the soils.

The disposal of uncontaminated sediments presents no environmental problems. Conversely, dumping contaminated harbour sediments into the lakes creates an extensive and serious local water pollution. Dredged sediments stored on land have, so far, not been put to practical use. Moreover, if there is no need for landfill the procurement of adequate landfill sites for the dredged materials is a major problem in lake dredging.

3. PURPOSE OF THE PRESENT INVESTIGATION

The utilization of bottom sediments dredged in the Great Lakes as agricultural soil or as fertilizers has not been seriously considered. However, applying dredged contaminated bottom sediments on the fields apparently brings great advantages: (a) No recontamination of the water and sediments of the Great Lakes. (b) No need for adequate landfill sites. (c) Utilization of contaminants, especially trace elements, as valuable nutrients for the plant growth.

The purpose of the present study was to investigate the possibility of using bottom sediments in agriculture. The study has three objectives:-

1. To review dredging in the Lower Great Lakes paying special attention to the extent of dredging, nature, disposal and use of dredged materials.
2. To review and assess the sources which significantly affect chemical, physical and biological properties of bottom sediments of the Great Lakes, i.e. firstly, nature's factors, i.e. climate, soils, and waters of the Great Lakes Basin and, secondly, man's activities, i.e. population growth, contamination caused by municipalities, industries and agriculture.
3. To study the suitability of sediments collected from various locations as agricultural soil, in particular,

   (a) to determine chemical, physical and biological properties considered important for the classification of uncontaminated and contaminated bottom sediments as agricultural soil.

(b) to investigate the effects of various bottom sediments on the growth of selected plants and uptake of elements from the sediments by selected plants in greenhouse experiments,

(c) to prove by appropriate testing that contaminated bottom sediments do not pose any health hazards in soil and in crops to the environment.

4. PREVIOUS WORK - DREDGING

4.1 Purpose of dredging

Most of the dredging carried out in the Great Lakes serves navigation and, to a smaller extent, provides material for landfill and construction material. Responsibility for developing and maintaining 115 Great Lakes harbors and navigational channels in the United States rests with the US Army Corps of Engineers. About 50 harbours and channels are dredged annually and the remainder every two to five years. Littoral drift and river sediments accumulating in harbours and river mouths have been removed by dredgers and nearly always deposited in deeper lake waters. Ritchie and Speakman, (1972), stated that these sediments amount to approximately 7,600,000 m^3 and vary in character from uncontaminated to heavily contaminated. The amount of dredged sediments on the Canadian side is approximately 545,000 m^3. Dredging projects for 1973-74 administered by Department of Public Works of Canada, Ontario Region are shown in Table 1. A relationship between purpose of dredging, quality of sediments and disposal of sediments is illustrated schematically in Figure 1.

Dredging presents two main environmental problems during dredging, at the site of dredging and the disposal site in the lake:

(a) Dispersal of contaminants, creating a localized source of high oxygen demand,

(b) Disposal of contaminated sediments.

4.2 Nature of dredged sediments

The sediment deposition in the St. Lawrence Great Lakes reflect the bedrock morphology of each lake. Each lake is divided into a number of individual basins filled with accumulated fine grain sediments. The sediment texture reflects the energetics of the individual lake system. Fine grain sediment accummulates in the individual troughs in each lake and coarser grained sediment is found in the nearshore zone and on the ridges between the individual troughs. The fine grain sediments are generally soft, medium gray compressible clays or silty clays at the centre of each subbasin becoming more silty towards the rim of the basin. Gravel, sand and silt occur on the ridges and in the nearshore zones. The overall chemical and physical properties of bottom sediments are closely related to glacial deposits and soils of the Great Lakes Basin and vary widely. The surficial sediments contain variable amounts of quartz, (20-95%), feldspar, (5-25%), clay minerals, (3-70%), organic carbon (0.1-6%) and calcite, (0-5%). Quartz and feldspar are most abundant in the coarser nearshore sediments while clay minerals and organic carbon are dominant in the finer offshore sediments. The clay minerals are usually chlorite, illite, and kaolinite with some montmorillonite.

Quantities of contaminants and toxic elements and compounds have steadily increased in the bottom sediments of Lake Erie and Lake Ontario. (Kemp, A.L.W. - 1973), Table 2. Due to the high adsorption capacity of most of the lake and river bottom sediments some compounds from industrial and municipal waste waters become resident in the sediments. Adsorption capacity varies considerably among sediments, depending on the particle size distribution, type of clay and the chemical composition of the sediments, (Williams et al - 1970),(Harter - 1968),(Shukla et al - 1971).

Most of the bottom sediments dredged in major harbours are heavily contaminated (Gannon, Beeton - 1969). The major contaminants, in particular, nitrogen, phosphorus, metals, and oil, arise from municipal and industrial wastes from the adjacent areas. Although efforts are being made to reduce these discharges, major improvements are not likely to take place for a number of years, especially for the large U.S. urban areas. In the long term, however, the waste loads in the Great Lakes should gradually be reduced as waste treatment facilities are installed and old plants are phased out.

In areas outside the harbors, mainly in channels, contaminant levels are usually lower. Some problems are specific to particular areas, such as mercury in Lake St. Clair.

4.3 Dredging techniques

Existing dredges and dredging practices have been designed apparently with only one aspect in mind: to remove as much material as possible for minimum cost. The industry is almost exclusively interested in excavated quantities. If there are any requirements on dredging, for example, to reduce the loads of fines, the efficiency of operations is decreased and the cost increased. Consequently, at present the fines most heavily contaminated are allowed to drift away or are not desired in the output. Contract unit prices for lake dredging vary from $0.45 to $1.50 per cubic meter of removed material. The major factor influencing cost are the project size, type of material to be excavated, distance to disposal sites, and the availability of properly equipped dredging contractors.

Dredging can be accomplished by mechanical or hydraulic underwater dredges which operate from the water surface. Mechanical dredges include: the dipper, clamshell and bucket ladder. Hydraulic dredges include the dustpan, trailer hopper, and cutterhead dredges. Equipment suitable for accurate operation and minimal disturbance and loss of fines includes dustpan dredge, airpump, plain suction and mud-cat. Acres (1972) reviewed, in detail, techniques and equipment.

4.4 Disposal and uses of dredged sediments

Environmentally, disposal of dredgings is now considered a critical operation. Much consideration has been given recently to the disposal of the contaminated sediments on land.

Acres Consulting Services Ltd (1972) proposed that harbours be used as contaminant traps minimizing scouring action and maximizing the quantity of sediments to be dredged in one area. This may be considered a promising approach aimed at improving overall lake quality at the expense of accumulating contaminants only in the harbours.

Dumping of Sediments in open lakes

Disposal in the open lake is the cheapest approach with the material transported in a pipe to the new site located as close as possible to the harbourbut in a sufficient depth or dumped from a scow or hopper dredge. However, there have been serious objections against dumping contaminated sediments, in particular, dredged in harbours. They disperse in water and resettle over a larger area and thus increase the overall water pollution. Gannon and Beeton (1969), demonstrated that the disposal of the dredged contaminated bottom sediments in the open lakes is harmful to many living species.

Landfill

Landfill with dredged material is widespread world-wide. However, if there is no need for landfill the procurement of adequate landfill sites for the dredged material is a major problem in lake dredging. If in Ontario the sediment is heavily contaminated, and, consequently, is considered a potential hazard to the environment, only landfill disposal must be considered.

Storage on the shore without immediate use

The Congress of the United States, through Public Law 91-116 authorized the U.S. Army Corps of Engineers: (1) to design and construct a system of confined disposal facilities at various harbours whose sediments are deemed polluted by the U.S. Environmental Protection Agency. (2) to transport polluted dredgings from harbour bottoms aboard dredges to these disposal facilities where solids will be allowed to settle out and the supernatant water discharged into the Lakes through a weir system.

Ritchie and Speakman, (1972) investigated the proposed procedure and assessed its affectiveness during dredging at Ashtabula

(288,000 m^3 annual dredging) and Fairport Harbors (524,000 m^3 annual dredging). Samples were taken from hoppers of a hopper dredge operating in both harbours. In the settling experiments the concentrations of particulate contaminants in the supernatant water were reduced by 85 to 97 per cent at settling time of one to four hours. It was concluded that contaminant loading to Lake Erie from dredging would be reduced by more that 95 per cent using confined disposal facilities. It is assumed that settling will be carried out for ten years. After that time efficient waste treatment plants are supposed to eliminate the contamination of harbours.

Disposal - agricultural soil

Little information was found in the literature on use of dredged bottom sediments as agricultural soil. The author of this study successfully planted tomatoes in various sediments (Hamilton Harbour, Lake Ontario, Lake Erie) in pots, in 1970-1971 at CCIW, Burlington.

Malmer (1971) studied the use of the sediments collected from Lake Trummen, Sweden, in agriculture. Dried sediments were mixed with arable soil. For all soil-sediment ratios, including 100 per cent sediment the crop was better than for soil only. For example, a crop of avena showed a maximum increase in crop weight of 70 per cent for a mixture of 30 per cent soil and 70 per cent sediment.

Woodhouse, Seneca and Broom (1972) described the experiments with the establishment of new cordgrass on some dredged spoil areas in North Carolina. Direct seeding appeared to offer a rapid and relatively economical route to stabilize dredged spoil. It was proved that complete cover was achieved in two growing seasons.

5. SOURCES AFFECTING THE FORMATION, CHEMICAL AND PHYSICAL PROPERTIES OF BOTTOM SEDIMENTS

Classification of nutrient sources

Vollenweider (1970) proposed a division of nutrient sources into diffuse and point sources. Point sources include sewage and industrial waste water systems. Diffuse sources are natural sources of nutrients (untouched mountain and woodland streams, soil erosion, aeolian loading and biological sources such as aquatic birds, falling leaves and pollen), and artificial and semiartificial sources (nutrient supply resulting from human activities, for example, artificial and natural fertilizers leached from farmland). It is obvious that both nutrient sources affect the quality of water as well as the chemical and physical characteristics of sediments. Vollenweider's classification was used here with slight modifications to water and bottom sediments:

Point nutrient sources:

1. Contamination caused by municipalities
2. Contamination caused by industries

Both factors are affected by population growth.

Diffuse sources

1. Natural sources: watersheds and soils of Great Lakes Basin (affected by climate)
2. Contamination caused by agriculture.

5.1 Point Sources

Contamination caused by municipalities

The Great Lakes are the source of domestic raw water supplies for about 240 municipalities as well as for numerous industrial plants situated near or on the shores of the Lakes. Some of the plants are supplied by the municipal system, but some have their own intakes. McNish and Lawhead (1968) estimated that in 1966 28,000,000 persons were supplied by water pumped from the Great Lakes, (approximately 15×10^9 gallons per day). The aggregate capacity for industrial pumpage from the lakes was approximately three times the capacity of the municipal pumping stations.

The available data indicate that for a 75 per cent increase in population, from 1956 to 1966, the combined municipal and industrial pumpage rate increased about sixfold.

Except for the Chicago diversion of about 3,200 cubic feet per sec. into the drainage basin of the Mississipi River the water used by the municipalities and industries is returned to the Lakes. Unfortunately, it is very often heavily contaminated. This leads to pollutional effects particularly apparent in lake areas adjacent to large centres of population and industry.

The municipal statistics published every year in "Water and Pollution Control's Directory" demonstrate that in 1968-69 of 324 cities in the Province of Ontario, 11% had primary waste treatment and 20% had primary with secondary or secondary equivalent waste treatment. In 1972-73 of 340 cities, 19% had primary and 17% primary with secondary or equivalent secondary waste treatment.

Domestic wastes refer to the human excreta, waste arising from food preparation and other discarded products both mineral and organic. The ratio of the contribution of the urban population and agriculture toward phosphorus pollution is about 10:1, toward nitrogen pollution 2:1. EPA (1971), Henkens (1972), DeJoung (1972), Smith (1967) published some data on the nitrogen contribution per square mile per year from urban and rural watersheds.

The addition of nitrogen from the Great Lakes watershed in Ontario was 94,595 tons of nitrogen per year, and the addition from Lake Erie watershed is 51,978 tons per year.

Contamination caused by industrial processing

Much of North American industry is located along the Great Lakes because of the great water requirements. Industrial water consumption in the Great Lakes area is greater than the average in the U.S.A. and Canada.

In addition to the required products industrial processes generate great amounts of solid and liquid wastes and obnoxious gases of several kinds:

1. Toxic substances e.g. sulfuric acid, cyanides, metal salts, phenol, mine wastes, etc.
2. Matter not harmful to human population, plant, fish or animal life but causing undesirable odor, taste or colour.

3. Decomposable organic matter added to the streams in quantities so great that they consume their free oxygen content.
4. Substances too indigestable for ordinary treatment (e.g. cellulose and ligneous matter from paper and pulp industry, oils from petroleum processing). They are slowly digested, if at all, by biochemical processes and are harmful to every environment.
5. Solid wastes practically insoluble in water, e.g. slugs, sludge, fines etc.
6. Heat. The effluent from thermal processes such as condensed coolant may have harmful effects on streams.
7. Radioactivity, i.e. effluents from nuclear power plants.

Anderson (1969) reports that chemical industry used approximately 700 billion gallons of water in the Great Lakes region in 1959, and it may require 2,000 billion gallons a year by 1980. The pulp and paper industry in the Great Lakes region used 300 billion gallons in 1959 and may need 500 billion gallons per year by 1980.

Tate (1971) analyzed the water use in three integrated iron and steel plants in the Canadian section of the Great Lakes (Stelco, Dofasco, Algoma) and estimated the amount of total water intake for 1968 as approximately 163,292 million gallons. He forecasts that the water consumption will reach about 300,000 million gallons in 1980.

Wixom and Zeisler(1966) summarized the variety of wastes and discharge substances that can emanate from various industrial processes.

Although it is mandatory that the harmful and toxic compounds in water be treated in municipal and industrial treatment plants the present practice leaves very much to be desired. Solid wastes are dumped directly into the Great Lakes and untreated waste waters are allowed to flow directly into the river of the Great Lakes.

5.2 Diffuse sources

Watersheds of the Great Lakes Basin

Disregarding lake outflows such as Detroit River, Niagara River etc. the drainage basin of the Great Lakes is characterized by an absence of major tributaries. Few large river but many small riversand streams flow into the Great Lakes. The largest tributary is the Nipigon River contributing an annual average flow up to 13000 cubic feet per sec. The outlet flow of the Lakes is almost uniform throughout the year because of their extremely large storage capacity. The Great Lakes contain about 25,000 km^3 of water. The composition of water in rivers and creeks of the Great Lakes is affected by natural reactions with solids, liquids and gases.

Soils of the Great Lakes Drainage Basin

The knowledge of the soil characteristics of any drainage basin is helpful in evaluating correctly the chemical and physical properties of bottom sediments deposited in harbours and river mouths by rivers and creeks. Generallv, the sediments corresnond to the soils available in the drainage basin.

Figure 2 shows the soil groups in the basin (modified after Webber and Hoffman 1970 and Papadakis 1969). Figure 3 shows the division by textural class: clays, clay loams, loams, sands and sand loams, and by the topographic groups (after Webber and Hoffman 1970).

Soil erosion is an important factor detaching soil textures from land and moving them into streams and lakes where they deposit as bottom sediments.

Climate of the Great Lakes Drainage Basin

Climate, especially precipitation and temperature, is a dominant factor of soil formation affecting leaching intensity, vegetation, organic matter decay, and weathering. Phillips and Mc Culloch (1972) provided detailed information on the climate of the Great Lakes Basin. Petland (1968) presented a table of seasonal runoff distribution, (Figure 4).

The soil eroded by runoff settles in the Great Lakes and forms the bulk of surficial sediments. However, these factors were not studied systematically.

Contamination from agricultural land

The sources of contamination from agricultural land are:

1. Animal wastes. (Donahue et al 1970) estimated that the domestic animals in the United States produce over one billion tons per year of fecal wastes. Manure, primary organic matter, produces offensive odours, may be a source of infection agents and during heavy rains produces a runoff high in biochemical oxygen demand.

2. Processing wastes including wastes from canneries, meat processing, poultry industry, vegetable processing, the cotton textile industry etc.
3. Plant residues generated by farm and forest operations.
4. Plant nutrients, i.e. fertilizers. Commercial fertilizers used in proper amounts do not contribute significantly to pollution. When used at excessively high levels, any of the fertilizer elements may pollute waters and cause eutrophication. The amount of nitrogen and phosphorus and potassium in fertilizers sold in Ontario and Canada in 1971 and 1972 are recorded in Table 3. In 1972 use of fertilizers was highest in the Lake Erie basin (516,145 tons), followed by Lake Huron (216,174 tons), Lake Ontario (409,046 tons) and Lake Superior basins (1,907 tons).

About 75 per cent of all pesticides used in Ontario are for agricultural purposes. EPA monitoring conducted in Ontario in 1969 and 1970 has proved that the levels of pesticides found in Ontario soil and surface water in the Great Lakes Basin were relatively low and would not contribute significantly to direct contamination in the Great Lakes Basin.

Hutjens (1972), Kohlenbrander (1972), Henkens (1972) reviewed two very important elements in agriculture: nitrogen and phosphorus.

6. EXPERIMENTAL

6.1 Introduction

Since very little has been done on the utilization of the bottom sediments in the agriculture it was necessary to start according to the objectives outlined previously.

Firstly, select, adopt and modify suitable chemical, physical and biological methods for testing sediments.

Secondly, to verify the suitability of dredged bottom sediments as agricultural soil in greenhouse experiments by planting selected plants under aerobic conditions.

Required properties of dredged sediments selected for agricultural purposes

Dredged sediments which are to be considered for use as agricultural soil must obviously meet two basic conditions:

1. Safety aspects
   - (a) Toxic elements in crops planted in bottom sediments or soils mixed with bottom sediments should not exceed permissible levels.
   - (b) Concentrations of harmful or toxic elements and compounds released from the sediments by water, rain, snow, sleet, should be lower than those recommended for water for public use.
2. Fertility and crop yield should be equivalent to those of good, productive soils.

Required chemical composition for bottom sediments used as agricultural soil

To be classified as highly productive soils as well as bottom sediments must contain certain elements in a suitable form. Sixteen elements have been demonstrated to be essential for the growth and reproduction of crop plants. Nitrogen was first proven to be essential for plants in the eighteenth century, the other 15 elements were subsequently proven essential later. Plants contain sodium, iodine, selenium and cobalt which have not yet been proven essential for them but which are a necessity for man and animals who eat plants. Silicon and aluminium also occur in all plants but apparently they serve no useful purpose. Nineteen elements are known to be essential for animals that require 15 of the 16 elements needed by plants (boron is not required by animals) but, in addition, animals need sodium, cobalt, selenium and iodine (Lamb, 1958).

After systematic investigations essential elements were divided basically into the following groups:

1. Essential macronutrients: carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, magnesium, calcium, potassium; for the most part the macronutrients form the plant structure.
2. (a) Essential micronutrients: iron, boron, manganese, molybdenum, copper, zinc.
   (b) supplementary micronutrients: vanadium, chromium, nickel cobalt, tungsten and titanium.

The accurate function of micronutrients (iron, manganese, zinc, copper, boron, molybdenum) is not known. These elements may limit plant growth either because they may be deficient in the soil, or, as it is more often the case, because some condition in the soil reduces their availability.

The group 2(b) forms a somewhat arbitrary grouping based on the consideration that each of these elements can assume various valency levels and hence participate in oxydation-reduction processes within the plant cell (Giese, 1973).

There are many papers, reviews, and monographs covering the uptake of nutrients and trace elements from soils by various plants and the metabolic and physiological functions of trace elements in the fields of plant, animals, and microrganisms (Giese, 1973), (Lamb et al, 1958). The review of the whole subject is beyond the scope of this study. Only little attention has been focused on the uptake of elements from lake bottom sediments.

6.2 Sampling

Sampling locations

Main criteria for the selection of locations for sampling bottom sediments were as follows:

1. To sample sediments from the areas selected for dredging in 1973-74.
2. To collect sediments characteristically contaminated by industrial and municipal waste waters and by runoff from farmland.

Five locations were chosen, each representing certain types of environmental influences on the sediment.

1. Hamilton Harbour - Sediments affected mainly by industrial (steel industry) and municipal waste waters containing soluble and insoluble contaminants. (Figure 6)
2. Port Stanley - Sediments contaminated by runoff from farmland and industrial waste waters. Dredging projects are scheduled for Port Stanley in 1973-74. (Figure 7)
3. Detroit River Mouth - Lake Erie - Sediments contaminated by industrial and municipal waste water input. (Figure 8)
4. Lake St. Clair - Sediments steadily contaminated mostly by industrial (chemical) waste waters brought by St. Clair River. A large dredging project is being carried out on Lake St. Clair. (Figure 9)
5. Humber Bay - Sediments contaminated by industrial (various industries) and municipal waste waters brought by Mimico Creek and Humber River. (Figure 10)

The longitudes and latitudes of sampling locations and water depth are presented in Table 4.

Factors affecting the properties and composition of bottom sediments in the selected locations are summarized in Table 5.

6.2.2 Sampling methods

Following the methods outlined by Sly (1969) sediment samples were collected with Shipek bucket sampler and Benthos gravity core using 200 cm long plastic tube of 6.7 cm internal diameter. The Shipek sampler was used to collect surficial sediments with the maximum cutting depth up to 10 cm. The Benthos corer was used for sediment sampling down to a depth of 100 cm. These samples allowed a determination of selected parameters at different sediment depths.

To obtain a representative sample from each area (approximately 400 m^2) a number of Shipek buckets were collected at different locations in each area. Some properties, in particular, texture, colour, odour, were assessed and visually compared. The final sample was collected for the location representing typical sediment properties for the whole area.

6.2.3 Storage, preparation and description of sediments

Collected Shipek samples were placed in 20 l-plastic buckets and covered with Argon gas. The buckets were sealed and stored in the coldroom at a temperature of 4°C. The Benthos cores were stored at 4°C and within three days extruded and subsampled.

ph and Eh were measured in Shipek buckets immediately after retrieval and on the Benthos core at the time of subsampling. The sediment external properties (colour, texture, odour) were described while subsampling the Benthos cores. Methods for extruding and subsampling the cores and measuring the Eh and pH were those of Kemp et al (1971). The colour of the sediment was described using the Munsell colour scale. *

To obtain a representative sample a few cores were taken from storage buckets by hand with a 40 cm long plastic Benthos tube.

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*Munsell Color Company Inc., Baltimore, Maryland, 21218, U.S.A.

Samples collected by this method were mixed in a large beaker and divided into two parts. One part was air dired, stored in sealed plastic bags and used later for all experiments which required dry sediments. The second part was used for water content determination (by freeze drying) and for all analyses which were carried out on wet sediments. The freeze dried sample after water content determination was sieved throught a 35 mesh screen to remove any shells or large pieces of detritus. It was ground to pass 200 mesh, stored in plastic vials in a desiccatorand finally used for the determination of chemical parameters.

6.3 Methods

The methods applied in thisstudy are summarized on Page 27-28. If necessary, more details on the methods are on Page 31-40. The previous application of these methods is summarized on Page 29-30.

The selected methods permitted to assess the impact of the bottom sediments on soil and crop safety as well as soil fertility and yield. An interrelatinnship among chemical and physical properties, safety aspects and fertility of the sediments is shown in Figure 20.

termination	Purpose:	Method:	Reference
emical alysis of diments:	To determine the amounts of essential elements in collected sediments	Metals: Acid extraction followed by A.A. Spectro photometric determination	St. Johns (1973) Klein (1972)
		Total Phosphorus : colorimerical as orthophosphate after sodium carbonate fusion.	Parsons and Strickland (1968) Jackson (1958)
		Total Nitrogen: Kjeldahl digestion followed by steam distillation into boric acid solution	Bremner (1965)
		Total Sulphur: by sodium carbonate and sodium nitrate fusion	Jackson (1958a)
		Hot water soluble boron: colorimetrical by curcumin method	J.I. Wear (1965)
		Inorganic and organic carbon: High temperature combustion in Leco analyzer.	Tabatabai and Bremner (1970) Kemp and Lewis (1968)
aching exp- iment	To determine the quantities of elements released from sediments by simulating conditions during dredging or when sediments are spread on fields during torrential rains.	A new method specially developed for this determination.	This study Page 31

ermination	Purpose	Method	Reference
imeters	To determine the quantities of elements released from sediment column by percolating water and assess the extent of leaching elements from sediments spread on the fields.	Method based on literature references, with specially designed glass lysimeters (Fig. 11)	This study Page 32
rmeability	To determine the volume of water percolating through a sediment column and assess the possible runoff and irrigation capacity of bottom sediments.	Water maintained at a constant level in lysimeters percolating through a sediment column	R.C. Reeve (1965)
lk density rticle nsity, Por- ity, Partic- size stribution	To determine physical properties of sediments considered important for good crop yields.	Standard Methods for soil testing F.A.S.T. particle size analysis based on pipette analysis and Emery settling tube analysis.	Blake, (1965) Vomocil (1965) Rukavina and Duncan (1970)
ay mineral- gy	To determine the minerals present in sediments which affect the cation exchange capacity and retention of elements in the sediment.	X-ray diffraction	Dell (1973)
ation ex- ange apacity	To determine potential soil fertility	Ammoniun acetate (pH - 7)	Chapman (1965)

termination	Purpose	Method	Reference
oassay	To evaluate potential soil fertility	Modified microbiological assay using mixed algal culture.	Tchan (1959)
eenhouse	To study the suitability of various bottom sediments as agricultural soil by growing selected plants and evaluate crop yield	Growing selected plants under constant conditions (temperature, humidity, sediment amount, drainage, watering)	
emical ιalysis of ops	To determine the presence and amounts of elements contained in roots, leaves and crop of grown plants.	Metals: dry ashing followed by acid extraction and A.A. spectrophotometric determination	Ward and Johnson (1962) Water & Waste water treatment Research Subdivision, CCIW Burlington, (1973)

ıterrelationship between chemical and physical properties of sediments and safety aspects ıd fertility is illustrated in Fig. 20.

termination	Previous Work	Purpose
simeters	Lehman and Wilson (1971) used lysimeters filled with calcareous soil for percolating the domestic sewage effluent	To study the chemical changes in effluent
	Vinnik and Bolyshev (1972) used lysimeters planted with trees and grass	To study the amount and chemical composition of water percolating through the lysimenter.
lk density	Donahue et al (1971), Harmon and Fraulini (1940), Grim and Bray (1936) used this phenomenon.	To study relationship between soil texture, fertility and CEC, to study difference in CEC on clays, to determine the variations in CEC of clay minerals with particle size.
	Toth and Ott (1970) - determined CEC on bottom sediments from Hudson and Delaware Rivers	To study the effects of organic matter content on CEC and changes in CEC on wet and dry sediments.
ioassay	Gannon and Beeton (1969) studied the effect of dredged materials from selected Great Lakes harbours on plankton and benthos.	To consider the disposal of dredged spoils in the open lake.

6.3.1 Leaching Experiments

Leaching experiment is a simple test introduced with the objective to simulate conditions during dredging or when sediments are spread on fields during torrential rains. In both cases the sediment is mixed with a large volume of water and stirred vigorously; therefore, in a laboratory investigation a specific amount of the sediments must be stirred in a many times greater mass volume of water and the quantities of elements released by whatever mechnisms from the sediment into the water determined analytically. The quantities released from suspended sediments can be considered the miximum under the prevailing conditions.

Hamilton Harbour air dried and wet sediment, considered extremely contaminated, and Lake St. Clair air dried and wet sediment, considered less contaminated, were used for leaching experiments.

Sixty g of the wet sediment and approximately 120 ml distilled water were stirred with a Teflon stirring bar in a 500 ml Erlenmeyer flask for 24 and 48 hours at a constant room temperature (20°C). The Erlenmeyer flask was covered with polyethylene film to prevent evaporation. Distilled water was added to the air dried sediments to bring the total volume to 180 ml. After 24 hours of mixing without letting the suspension settle 50 ml of it was quickly poured into a 100 ml graduated cylinder. Most of the sediment was removed by centrifuging and the rest by filtration through 0.45 Millipore filter. After 48 hours of mixing the rest of the suspension was handled the same way.

The filtrate was analyzed for selected elements by analytical procedures described by Traversy (1971). The element concentrations were expressed in ppm.

6.3.2 Lysimeters

Lysimeters were employed to determine extractability, release, and mobilization of elements in bottom sediments. The elements analyzed in the effluent were calcium, magnesium, sodium, potassium, cobalt, cadmium, copper, iron, lead, manganese, mercury, nickel, zinc, nitrogen, phosphorus and organic carbon.

Apparatus

Ten, 90 cm long, 7 cm diameter lysimeters were designed and constructed for this project. They consisted of two parts, top open cylinder and bottom part, both made of glass. (Figure 11)

The top cylinder had four holes for inserting pH and Eh electrodes. The electrodes were mounted in Nalgene stoppers and connected to a pH and Eh meter. pH electrodes were calibrated against buffer solutions of pH values 7 and 4. The Eh electrode was calibrated against a mixed solution of M/300 $K_3Fe(CN)_6$, M/300$K_4Fe(CN)_6$ and M/10 KCl. The top cylinder was separated from the bottom part by a disc of nylon 18 screen mesh, supplied by B. and S.H. Thompson & Co. Ltd, Montreal. After placing the disc on top of the bottom part both parts were joined by metal springs mounted on the glass hooks. A Teflon outflow tubing was attached to the outlet of the bottom part. The lysimeters were filled with wet and dry sediments to a level slightly above the first electrode outlet. The weight of the sediment was approximately 700 g. It took about 24 hours before the sediment settled down in the lysimeters. Three elution liquids distilled water, dilute citric acid, pH=4, and sulfuric acid, pH=4, were poured carefully on the sediment so that the sediment surface was not disturbed. A constant height of the liquid column of 10 cm was maintained by adding elution liquids with a separating funnel. A 500 ml Erlenmayer flask was used as a receiver for the percolate. This liquid was analyzed for the above mentioned elements. The volume of liquids applied and percolated in the lysimeters during the 14 day experiment was only about 400 ml mainly due to the very low permeability of the sediment. Wet Humber Bay sediment was practically impermeable; therefore, this lysimeter experiment was cancelled.

The chemical analyses of effluents were carried out by methods described by Traversy (1971).

6.3.3 Permeability

Permeability of soil to water is a parameter used commonly in soil science and is an absolute measure of the soil physical condition. No information was found on permeability of bottom sediments to water. However, the knowledge of permeability was considered important to assess irrigation capability of bottom sediments.

R.C. Reeve (1965) described permeability along with methods for permeability determination. Lysimeters used for the study of element release were employed for the determination of permeability of bottom sediments to water.

The lysimeters were filled with the individual sediments so that the column height was 30 cm. The frozen sediments were allowed to thawed and then used. The distilled water column above the sediment column was maintained constantly 10 cm high. The temperature of water was 18-20°C. The volume of percolate was measured and recorded daily.

Permeability of the sediment to water was calculated by the equation

$$K_w = \frac{\eta}{\rho_w g} \frac{VL}{A \Delta h \Delta t}$$

in which K_w = permeability with water, cm^2

V = Volume of percolate in time Δt, cm^3

L = length of the soil colum, cm

Δh = differnece in hydraulic head between the inflow and outflow ends of the soil column, cm

A = cross sectional area of the soil column, cm^2

Δt = time interval for volume of percolate V to pass through the soil, sec.

η = viscosity of water at given temperature, poises

ρ_w = density of water, g per cm^3

g = acceleration of gravity, $cm.sec^{-2}$

O'Neal proposed permeability classes based on hydraulic conductivity and permeability, Table (6)

TABLE 6

Permeability Classes for Saturated Subsoils, and the Corresponding Ranges of Hydraulic Conductivity and Permeability (O'Neal, 1952)

Class	Hydraulic conductivity		Permeability
	inches/hour	cm./hour	$cm.^2$
Very slow	0.05	0.125	3×10^{-10}
Slow	0.05-0.2	0.125-0.5	$3 \times 10^{-10} - 15 \times 10^{-10}$
Moderately slow	0.2-0.8	0.5 -2.0	$15 \times 10^{-10} - 60 \times 10^{-10}$
Moderate	0.8-2.5	2.0 -6.25	$60 \times 10^{-10} - 170 \times 10^{-10}$
Moderately rapid	2.5-5.0	6.25 -12.5	$170 \times 10^{-10} - 350 \times 10^{-10}$
Rapid	5.0-10.0	12-5 -25.0	$350 \times 10^{-10} - 700 \times 10^{-10}$
Very rapid	10.0	25.0	700×10^{-10}

6.3.4 Bulk density, particle density, total porosity

Determination of bulk density, particle density, and total porosity of wet and air dried sediments was carried out by methods described in "Methods of Soil Analyses".

6.3.5 Particle size distribution

The particle size distribution of a soil or a bottom sediment expresses the proportions of the various sizes of particles which it contains.

The sand, silt, clay percentage composition of each sediment was determined by a F.A.S.T. particle size analysis. The method based on two established procedures, pipette analysis and Emery settling tube analysis, was described in detail by Rukavina and Duncan, (1972).

6.3.6 Clay mineralogy

X-ray diffraction method is the most useful method for the identification of mineral species and quantitative estimation of their propertions in such polycomponent systems. A method described by Dell (1973) was used to study the bottom sediments.

The $< 2\mu$ fraction was obtained by sedimentation and then magnesium saturated by washing three times with 1N $MgCl_2$. Excess salts were removed from sample by washing with distilled water and methanol until the decantate yielded a negative chloride test. The clay was concentrated by centrifugation and then placed on porous ceramic plates using an eye-dropper and allowed to dry at room temperature. One plate was glycerol saturated by dropping glycerol onto the dried sample and allowing to dry twelve hours before X-raying. Another plate was run first as an air-dried sample and X-rayed again after heat treatment. The samples were examined with a Philips X-ray diffractometer using Cu $K\alpha$- radiation.

Four differently prepared samples were used for X-ray determination: 1) air-dried sample, 2) glycerol-treated sample, 3) sample heated to 400°C for two hours, cooled in the furnace to 200°C and placed in a desiccator until X-rayed, 4) sample heated to 520°C for two hours, cooled in the furnace to 200°C and placed in a dessicator until X-rayed.

6.3.7 Cation exchange capacity

Cation exchange capacity and the content of exchangeable cations are among the factor frequently used to characterise agricultural soils, therefore, they were used for the evaluation of bottom sediments as agricultural soil.

Most investigators at present employ methods based on saturating the exchange complex with a given cation, and then determining the total of the adsorbed cations. Three reagents commonly used for this purpose are 1N ammonium acetate (pH 7), 1N sodium acetate (pH 8.2) and 0.5N barium chloride plus 0.2N triethanoamine solution (pH 8.2). The first two methods can be used on both calcareous and noncalcareous soils: the third is used on acid soils where it is desired to determine both exchange capacity and the amounts of exchangeable hydrogen. The ammonium acetate method was used in this work and is described by Chapman (1965).

The determination of exchangeable cations was carried out by a method described by Jackson (1958) using the ammonium acetate extract. In the solution the metals were determined by atomic absorbtion spectroscopy.

6.3.8 Bioassay

It was assumed that the application of microbiological tests for the evaluation of sediment fertility would bring fast orientation results.

Bioassay experiments were carried out with air dried, wet and frozen sediments by a method developed by Tchan (1959).

Five g (dry weight) of sample was mixed with 50 ml distilled water in 250 ml Erlenmeyer flask, which was pluged loosely with a cotton plug. The sediment was allowed to settle and the solution to clear. A mixed algal culture was used as inoculum. After the inoculation the sample was incubated at room termperature under a battery of fluorescent lamps for 14 days at a recommeded light intensity of about 400 - 500 foot candle. The light conditions were kept constant for each 24 hours: 18 hours light, 6 hours dark. The position of the flask was changed every day to eliminate unequal illumination. After 14 days the samples and controls were filtered through glass filter paper on Buchner funnel. The residue with the filter paper was returned to the flask and extracted overnight by methanol in darkness at $4^{o}C$. The residues were washed out with small quantities of methanol, filtered, diluted to 50 ml; absorbance was measured at

6650 Å. The control values were subtracted from the values of the inoculated samples.

Mixed algae culture and preparation of the inoculum: A mixed algae culture was obtained from Ward's Natural Science Establishment, Inc. and contained following species: Pediastrum sp, Eudorina sp., Anabeana sp., Spirogyra sp., Oedogonium sp., Corteria sp, The algae cultures were chosen because of their fast growth rate, size and ease of handling. The recommended medium for chosen species is Soil-water medium (Pringsheim, 1946). Variations of this medium are for nonsterile culture, specially for isolation purposes and for growing algae in order to secure normal growth forms. The algal culture was filtered through loosed packed glass wool to obtain a homogeneous suspension. The algal cells were then separated and washed in distilled water, centrifuged and finally resuspended in distilled water. Two drops of this washed suspension were used for each flask.

6.3.9 Greenhouse experiments

The greenhouse experiments were carried out in the greenhouse of McMaster University, Hamilton, Ontario, under constant conditions (temperature 20-22°C, constant humidity, regular watering). Wet sediments collected in Hamilton Harbour, Humber Bay and Detroit River and transported in closed plastic buckets were placed separately in three plastic trays about six weeks before planting. The sediments became relatively dry. No fertilizers, manure or mulch were applied during the whole experiment.

Three 10 cm tomato seedling of indeterminate type and three corn seedlings were planted in each tray containing approximately 150 kg sediment. The progress of tomato and corn growing was observed regularly once a week. Photographs (slides) were taken every two or three weeks for a future evaluation.

Two tomato plants from each sediment type were used for plant analysis. They were removed carefully from the soil and immediately subdivided into four organs.

1. roots which were washed free of soil with water.
2. stems
3. leaves
4. fruits.

Stems and leaves of corn were analyzed together. According to methods of Ward and Johnston (1962) all specific plant organs were weighed, their water content determined and then analyzed for potassium, calcium, magnesium, manganese, iron, copper, molybdenum, zinc, arsen, chromium, nickel, lead, cadmium, strontium, cobalt and mercury.

6.4 RESULTS AND DISCUSSION

Chemical composition of sediment

Results of chemical analyses are listed in Table 7 (Benthos cores) and Table 8 (Shipek samples). Tables show the element contents of collected sediments in a decreasing order. It is obvious that the Hamilton Harbour sediment has a greater quantities of nearly all elements than the other sediments.

Leaching experiments

The quantities of elements determined in the sediment and in the filtrate in leaching experiments as well as the percentage ratios of the concentration of elements in the sediment and that of the filtrate are shown in Table 11.

Calcium, magnesium, sodium, potassium, iron, manganese, copper, nickel, zinc, nitrogen and reactive PO_4-phosphorus were released from the sediments and determined quantitatively in the water. Cobalt, cadmium, mercury, and organic carbon were not detected in the water.

The contents of calcium, magnesium, iron, sodium, zinc, nickel, phosphorus released from air dried sediments were higher than those from wet sediments. The ratio of these two contents was different for each element and sediment. There were negligible quantitative differences between the amounts of organic carbon, copper, nitrogen, potassium and manganese released from air dried and wet sediments.

The amounts of elements released from Hamilton Harbour dry sediment were generally higher than those from Lake St. Clair dry sediment. On the other hand, on the percentage basis, calcium, magnesium, potassium and manganese percentage ratios of the Hamilton Harbour sediment and leaching water were higher than those of the Lake St. Clair sediment and leaching water: percentage ratios were nearly equal for sodium and iron. Zinc, nickel and copper percentage ratios of the Lake St. Clair sediment and leaching water were higher than those of the Hamilton Harbour sediment and leaching water.

The quantities of elements released in leaching experiments were many times higher than those determined in lysimeter percolates. In a leaching experiment all solid particles are in a continuous contact with water. On the other hand, in a lysimeter porosity and permeability are the factors that decide about the frequency of contact between water and sediments.

Concentrations of elements detected in leaching experiments were lower than those recommended for water for public use but for manganese and nickel concentrations. Consequently, it may be assumed that the bottom sediments disposed of in a landfill or used as agricultural soil do not present any potential hazard to the environment, in particular, to the groundwater.

TABLE 12

Metal concentrations released from bottom sediments and detected in water in lysimeter and leaching experiments

Metal	Concentration permitted by Health Standards (mg/l)	Concentrations determined in water from air dried sediments in:	
		Lysimeters (mg/l)	leaching experiments (mg/l)
Cadmium	0.01	< 0.001	< 0.001
Chromium	0.05	< 0.2 μg/l	< 0.2 μg/l
Copper	1.0	0.006	0.08
Iron	0.3	0.001	0.08
Lead	0.05	< 0.001	< 0.001
Manganese	0.05	0.001	0.07 Lake St. Clair
			2.9 Hamilton Harbour
Mercury	0.005	< 0.05 μg/l	< 0.05 μg/l
Nickel	0.03	0.004	0.07
Zinc	5	0.047	1.1

Detection Limits using solvent extraction

Cd - 0.001 mg/l

Cr - 0.2 μg/l

Cu - 0.001 mg/l

Fe - 0.05 mg/l

Pb - 0.001 mg/l

Mn - 0.001 mg/l

Ni - 0.001 mg/l

Zn - 0.001 mg/l

Hg - 0.05 μg/l

Lysimeters

The quantities of elements released by the three different eluants were nearly the same, therefore, only the results from experiments with distilled water were evaluated. Quantities of elements detected in the percolate along with the appropriate quantities in sediments and the percentage ratios

$$\frac{\text{quantity of elements in the percolate x 100}}{\text{quantity of elements in wet or dry sediments}}$$

are shown in Tables 9 and 10.

Marked differences were found in quantities of elements released from wet and dry sediments. Water in wet samples suppressed any larger chemical and mineralogical changes. Conversely, at air drying, extractability and mobilization capacities of a number of elements were changed, and, consequently, greater quantities of those elements were detected in the effluents.

The amounts of calcium in the effluents were small and different for tested sediments. The percentage ratios were constant for Hamilton Harbour, Detroit River, Lake St. Clair, being 0.1 for wet sediments, and approximately 1.0 for dry sediments. The percentage ratios for Port Stanley sediments were completely different being 0.05 for wet sediments and 0.20 for dry sediment respectively. The amounts released from dry sediments were significantly higher than those from wet sediments.

The magnesium contents released were small and varied widely. The amounts released from dry sediments were higher than those from wet sediments. There was no correlation between the magnesium contents in wet or dry sediments and in the effluents. Although the magnesium content in the Hamilton Harbour sediment was the lowest, the magnesium content detected in the effluent from wet and dry sediments was highest with the exception of the Detroit River dry sediment. The percentage ratios were equal for the Lake St. Clair, Detroit River, Port Stanley sediments but significantly lower than the Hamilton Harbour ratio. The percentage ratios descended in this order: Hamilton Harbour, Detroit River, Lake St. Clair and Port Stanley dry sediments.

Only minute quantities of sodium were detected in all effluents. The highest quantity was released from the Hamilton Harbour sediment. The quantities of sodium released from dry sediments were slightly higher, by 20 - 50 per cent, than those from wet sediments.

Potassium was released in minute quantities from wet and dry sediments. The amounts released from dry sediments were higher by a factor of two than those from wet sediments. No big differences in percentage ratios for wet and dry sediments were established.

Although the content of iron was large in all sediments the quantities released from wet and dry sediments and detected in the effluent were extremely small, practically the same for all sediments. The percentage ratios were in the range of 10^{-6}.

The amounts of manganese were extremely small in effluents from wet and dry sediments and different for various locations.

Minute amounts of copper were detected, same quantities for wet and dry sediments taken from the same location, slightly different for all locations. The percentage ratios for wet and dry sediments were practically equal for wet and dry sediments from the same locations but differ for all locations.

Only minor quantities of zinc were detected. They were different for all sediments. Zinc amounts released from dry sediments were approximately twice higher than those from wet sediments. There was poor correlation between the amounts of zinc in sediments and those in effluents.

The amounts of nickel detected in the effluents from various sediments were small and varied widely. The amounts of nickel released from dry sediments were smaller than those from wet sediments.

Although the amounts of lead were almost the same in the Lake St. Clair, Detroit River, Port Stanley sediments, very high in the Hamilton Harbour sediment the amounts of lead released were at the levels of detectability. No lead was detected in the percolate from Lake St. Clair and Port Stanley sediments. Only a minute amount of lead was detected in the dry Hamilton Harbour and Detroit River sediments.

The contents of cobalt, cadmium, mercury, and organic carbon were below detectable levels in the percolating water.

The amounts of nitrogen released from all sediments were small, in particular, for Detroit River, Lake St. Clair and Port Stanley sediments. The quantity of nitrogen released from dry sediments was slightly greater than that from wet sediments by about 25%. The nitrogen content of the Hamilton Harbour sediment deviated significantly from those of other sediments, by nearly three degrees of magnitude.

More phosphorus was released from dry than wet sediments but in both cases total phosphorus quantities were extremely small. The percentage ratio, of order of the 10^{-4} demonstrated the small extractability and mobilization of phosphorus in sediment columns.

The amounts of elements released from all sediments and detected in water were lower than those permitted by Health Standards (Table 12).

Lehman and Wilson (1971) found that the concentrations of iron, manganese, nickel, copper, zinc, lead, and cadmium in a domestic sewage effluent were effectively reduced during percolation through càlcareous soil. However, after a longer period of time larger quantities of iron, manganese, and copper were detected, indicating the possible saturation of the soil with these metals. From the aspect of saturation bottom sediments may be classified from unsaturated to saturated with major, minor, and trace elements. The degree of saturation depends on a number of factors such as the composition, structure and particle size distribution of the original uncontaminated bottom sediments, the impact of winds, waves, currents, and the availability of contaminating metal compounds etc. The extremely small amount of elements released from wet sediments indicated that the sediments were unsaturated with some elements and saturated with other elements. An oversaturation was caused by air drying of sediments.

Permeability

Calculated permeability values of dry, wet, and frozen sediments to water as well as their classification after O'Neal are shown in Table 13. Permeability of bottom sediments to water could be classified as very slow (3×10^{-10}) and only for the Hamilton Harbour and Humber Bay dry sediments as slow (3×10^{-10} to 15×10^{-10}). Wet sediment taken in Humber Bay was impermeable.

The pretreatment of the sediments had a definite impact on permeability. When the sediments were air dried their structural properties changed probably due to aggregation. Permeability of dry sediments was always greater than that of wet and frozen sediments. No definite relationship was established between wet and frozen sediments

Sediment location	Permeability decrease
Hamilton Harbour	dry - frozen - wet
Detroit River	dry - wet - frozen
Port Stanley	dry - wet - frozen
Lake St. Clair	dry - frozen - wet
Humber Bay	dry - frozen - wet (impermeable)

Very low permeability of bottom sediments indicates that during a torrential rainfall the bulk of water will run off from a landfill site rather than percolate through the sediment.

Clay Mineralogy

The results of the mineralogical analyses of the sediments were summarized in Table 14. The results were given to the nearest percent but the precision was in the order of 5 per cent of the reported value.

The $< 2\mu$ fraction of sediments contained in addition to clay minerals substantial amounts of non-clay minerals such as quartz, feldspars and carbonates. The most abundant clay mineral in collected sediments is illite ranging from 35 to 55 per cent of the total $< 2\mu$ fraction. Other clay minerals present are: expandable clay minerals, 0 to 2 per cent; chlorite, 2 to 6 per cent: vermiculite, 1 to 4 per cent:

a mixed-layer 10-14 Å clay mineral, 5 to 9 per cent and kaolinite, 1 to 5 per cent.

Non-clay minerals in the 2u fraction are quartz, 11 to 35 per cent; potash feldspar, 3 to 7 per cent; plagioclase feldspar, 2 to 5 per cent; calcite, 0 to 17 per cent and dolomite, 0.5 to 8 per cent.

The intensity of diffraction from investigated bottom sediments was obviously affected, in addition to the concentration of the minerals, crystal size and crystal perfection, by a number of factors such as organic matter, the abundance of various elements, and amorphous substances which acted as nondiffracting dilutents. The deviations in results could be ascribed to all these factors.

Cation exchange capacity

The cation exchange capacity and the content of exchangeable cations for all sediments in wet, dry and frozen states are shown in Table 15 and 16. The percentage ratios of element contents in sediments and contents of exchangeable cations were calculated and are presented in Tables 17 and 18.

The replaceability of the exchangeable cations varied in various sediments and among wet, air dried and frozen samples. The greatest cation exchange capacity was found for Hamilton Harbour sediment and Humber Bay sediment, the lowest for Lake St. Clair and Port Stanley sediments.

No definite relationship could be established between dry, wet, and frozen sediments and cation exchange capacity. This is in complete disagreement with Toth's (1970) observations. Factors responsible might be sediment composition, types of minerals present in sediments and many others:-

Location	Cation	Exchange	Capacity
Hamilton Harbour	dry 14.16	frozen 14.11	wet 10.55
Humber Bay	frozen 14.66	wet 12.77	dry 12.66
Detroit River	dry 10.16	frozen 9.10	wet 7.50
Port Stanley	frozen 9.55	wet 6.22	dry 6.22
Lake St. Clair	frozen 7.33	dry 6.0	wet 4.69

Air drying and freezing changed the exchangeable characteristics.

Air drying at ambient temperature:-

(a) tended to fix iron and manganese in an unreplaceable form;

(b) did not affect the replaceability of magnesium, sodium (in Hamilton Harbour sediment), potassium (in Port Stanley and Detroit River sediments);

(c) increased the replaceability of calcium, copper, zinc, sodium (in Lake St. Clair and Humber Bay sediments), potassium (in Hamilton Harbour, Lake St. Clair and Humber Bay Sediments).

Freezing and melting of sediments:-

(a) decreased the replaceability of potassium, sodium iron, manganese, zinc (except for Port Stanley and Humber Bay), copper (in Hamilton Harbour, Humber Bay sediments);

(b) did not affect the replaceability of magnesium (in Hamilton Harbour, Port Stanley and Humber Bay sediments), copper (in Port Stanley sediment), zinc (in Port Stanley sediment);

(c) . increased the replaceability of calcium and magnesium (in Detroit River and Lake St. Clair sediments), copper (in Detroit River and Lake St. Clair sediments), zinc (in Humber Bay sediment).

The greatest availability of iron and manganese was in wet sediments. By air drying and by freezing considerable fixation of iron and manganese occured in all sediments. Iron fixation was more extensive for the Hamilton Harbour and Humber Bay sediments than for the other three. Drying of bottom sediments reduced exchangeable iron to almost trace levels. Ferrous and manganous ions are rapidly oxidized in air to ferric and manganic ions and tend to precipitate as insoluble oxides.

When considered as percentage ratios the exchangeable zinc ratios were extremely variable in all sediments. Although the zinc concentration of the Hamilton Harbour sediment was relatively high the exchangeable zinc value of the wet sediment was small. Drying the bottom sediment caused obviously such a chemical change that the exchangeable zinc increased to an extremely high value, from 0.24%

to 8.2% of the total zinc content of the sediment.

Clay materials affect significantly the cation exchange capacity of sediments and soils. An attempt was made to evaluate indirectly the cation exchange capacity values using known cation exchange capacity ranges for individual clay minerals, (Grim, 1968) and mineralogical composition of the $<2\mu$ fraction of the investigated sediments determined by X-ray diffraction, (Table 14). Low and high cation exchange capacity values were used for organic matter (100 and 150 meq/100 g) as well as for clay minerals. Particle size distribution (Table 22) yielded the percentage of clay material in the sediments. The cation exchange capacity values determined experimentally and those evaluated indirectly are summarized in Table 19. The same orders of cation exchange capacity values were obtained for those determined experimentally and those obtained by using low cation exchange capacity values for individual clay minerals and average values for organic matter (100 to 150 meq/100 g). However, both orders were different with the exception of cation exchange capacity values for Lake St. Clair sediment which were the lowest in all evaluations.

The indirectly evaluated lower values of the Humber Bay sediment were caused probably by a great amount of amorphous organic matter, which had a greater CEC than 150 meq/100g.

It has been repeatedly claimed that the capacity of a soil, and obviously of a bottom sediment, to exchange cations, is the best single index of potential soil (sediment) fertility, (Donahue et al, 1971). With regard to this statement the Hamilton Harbour and Humber Bay sediments should be the most fertile, the Detroit River, Lake St. Clair, and Port Stanley sediments should show a significantly lower fertility. Algal bioassay verified this statement, however, in greenhouse experiments Humber Bay sediment gave a double yield in tomato stems, leaves and fruits than the Hamilton Harbour and Detroit River sediments. Consequently, caution should be exercised in the interpretation of the results of cation exchange capacity.

The knowledge of the effect of drying on cation exchange capacity and exchangeable cation contents is very important. The dredged sediment will be stored in a pile or spread on fields where they will slowly dry under aerobic conditions.

Bioassay

The results from the determination of algal growth are shown in Table 20. There were differneces between the Hamilton Harbour and Humber Bay sediments and all other sediments, and small differences between the Lake St. Clair, Port Stanley and Detroit River sediments. There were no large differences among the wet, air dried and frozen sediments. The deviation of the Hamilton Harbour air dried sediment was probably caused by a thin layer on the water surface containing unwettable particles that prevented light penetration to the sediment and algal cultures. However, correlation was established among the algal bioassay, cation exchange capacity, total porosity and greenhouse experiments. The growth rate of tomatoes and corn was observed in this degree: Humber Bay sediment > Hamilton Harbour sediment > Detroit River sediment.

The bioassay tests in which algal cultures were grown on the harbour and open lake sediments and changes in optical density recorded gave some insight into the possible effect of sediments on selected genera of algae. Supplemented by other tests they could be useful for evaluating the bottom sediment fertility and toxicity.

However, more research is needed to establish definite relationship between growth rates of algae and plants in bottom sediments.

Bulk density, particle density, total porosity

Bulk density, particle density and total porosity of all sediments are shown in Table 21. With respect to the low particle density of 2.43 the Humber Bay sediment could be characterized as sediment containing a large amount of organic matter. The Hamilton Harbour sediment contained a great amount of fines and organic matter. The bulk density of wet and air-dried sediments was significantly lower than that of the other sediments. The bulk density of the dry sediment was nearly twice greater than the bulk density of the wet sediment.

The sediments collected from the Detroit River and Lake St. Clair were similar in properties and could be characterized as typical mineral sediments. The Port Stanley sediment containing the smallest content of organic carbon had the greatest bulk density and lowest porosity.

After planting the seedlings in the sediments in the greenhouse the growth rate was directly proportional to the total porosity of the sediments: Hamilton Harbour > Humber Bay > Detroit River. However later (about 10-12 weeks), the plant growth changed significantly and Humber Bay sediment became the most productive: Humber Bay > Hamilton Harbour > Detroit River.

It was impossible to decide whether observed differences in plant growth were attributable to the changes in the sediment pore system.

Donahue et al (1971), stated that normal root growth is severely restricted in fine-textured horizons when the bulk density is greater than 1.4, and in coarse-textured soil of bulk density above 1.6. In this investigation the sediments used in greenhouse experiments had lower bulk density, Hamilton Harbour - 0.97 g/cm^3; Humber Bay 1.02 g/cm^3, and Detroit River 1.21 g/cm^3 respectively.

More research work is required to draw a definite conclusion about the relation between total porosity and the growth rate of plants.

Particle size distribution

Particle size distribution diagrams for the individual sediments were plotted from the data calculated by a CCIW computer program (Figure 12, 13). The basic statistical values along with the sand, silt, and clay percentages are shown in Table 22. Sediments collected from Lake St. Clair, the Detroit River, and Port Stanley had a greater mean grain size than Hamilton Harbour and Humber Bay sediments, suggesting a possible higher energy environment. Hamilton Harbour sediment contained the highest amount of clay size particles whereas Lake St. Clair sediment had the lowest.

Using the soil texture classification and particle size distribution data the sediment could be classified as follows:-

Hamilton Harbour	silty clay
Humber Bay	silty clay
Lake St. Clair	silty loam
Detroit River	silty clay
Port Stanley	silty clay loam.

Particle size distribution aids characterization of sediments with regard to their use in agriculture.

Greenhouse experiments

After starting, plants seedlings in Hamilton Harbour sediments had the fastest growth rate. The sediment seemed to supply the required nutrients in the right proportions. However, two months later the growth rate slowed down significantly.

By contrast, the tomato plants in Humber Bay sediment made continuous appreciable growth progress and surpassed all other tomato plants. The tomato plants in Detroit River sediment grew slower than the other tomato plants during the whole period.

Initially, the colour of leaves was dark green on the tomato plant grown in Hamilton Harbour sediment, green in Humber Bay sediment and pale green in Detroit River sediment. Three months later there was no colour difference between Hamilton Harbour and Humber Bay leaves and only a slight difference between these two and Detroit River leaves. Humber Bay leaves were wider and longer than Hamilton Harbour and Detroit River leaves in the following order:-

Humber Bay leaves	Detroit River leaves	Hamilton Harbour leaves
138 mm long	115 mm long	110 mm long
84 mm wide	71 mm wide	61 mm wide

Table 23 shows the fresh and dried weights of roots, stems, leaves, and fruits of tomato plants grown in Hamilton Harbour, Humber Bay and Detroit River sediments. Table 21 shows the water contents in tomato parts. Stems, leaves and fruits from Humber Bay sediment weighed twice as much as those from Hamilton Harbour but the roots of the Hamilton Harbour tomato plant were heavier than those of the Humber Bay tomato. The crop yield of the Humber Bay tomato fruit was best, (100 per cent) followed by Hamilton Harbour (48 per cent) and Detroit River crop yields (30 per cent). The greatest variation in water content was found in roots, the smallest in fruits.

The results of chemical analyses of the corresponding plant organs expressed in concentration mg/kg were summarized in table 25. The quantities of elements in specific organs of one plant were calculated and tabulated, Table 26. The concentrations of individual elements in the sediment roots, stems, leaves, and fruits were arranged in graphs. Individual scales were provided to illustrate the differences in concentrations. (Figures 15, 1-13)

Tomato plants did not take up the various elements in the proportions in which the elements occured in the sediments. They took up major, minor and trace elements only to a certain limiting concentration characteristic for individual plant organs. Generally, the smallest element concentrations were found in the fruits. These facts were presented schematically in Table 27. The concentrations were comparable with those found by soil scientists investigating the uptake of elements from soils, Table 29.

The effect of the concentration of the elements in the sediments on their concentration in the tomato plants was evaluated, (Figure 14) and the following conclusions drawn:

1. The greater the element concentration in the sediment the greater its concentration in the tomato plant: lead, iron, zinc, manganese.

2. The greater the element concentration in the sediment the lower its concentration in the tomato plant: copper, strontium,, cobalt (only partially valid)

3. The element concentration in the plant approaches a concentration limit: arsen.

4. In addition to the element concentration in the sediment other factors affect it concentration in the tomato plant and cause great discrepancies:-

   (a) With increasing element concentration in the sediment its concentration in the tomato plant increases (Humber Bay) as well as decreases (Hamilton Harbour) nickel, cadmium, chromium (see also item b)

(b) The element concentration has hardly any effect on its concentration in the tomato plant: chromium (see also item a).

Uptake of specific elements by tomato plants

Calcium

The calcium content was very high in all organs of the tomatoes indicating an easy release of claclum from calcium bearing minerals (calcium carbonate) in the sediments. (Figure 15.1) The highest amount of calcium accumulated in the leaves, four times that of the sediments, followed by the calcium contents of stems, roots and fruits. Calcium concentrations in roots, stems and leaves were of 10,000 mg per kg dry basis magnitude. The individual concentrations seemed to be limiting values. There was no correlation between the calcium quantity in the sediments and calcium quantities in the various tomato organs. For example, although the calcium content of the sediment was twice that of Detroit River sediment the calcium contents of the roots and leaves were practically the same, the calcium contents of Detroit River stems and fruits were higher than those of Hamilton Harbour tomato.

Magnesium

There was no correlation between the magnesium quantity in the sediment and the magnesium quantities in tomato organs, (Figure 15.2). The dominant factor seemed to be the availability of magnesium in the sediments. Magnesium occurred in dolomitic limestone, see Table 13. Since dolomitic limestone is not so readily decomposed as is calcite the amount of exchangeable magnesium was less than that of exchangeable calcium.

The Hamilton Harbour sediment had the lowest magnesium concentration but the magnesium concentrations in roots, stems and leaves were greater than those from Humber Bay and Detroit River sediments. The magnesium concentrations in the fruits and roots from all three sediments were almost equal and appeared to be converging to a definite value range, approximately 6000 mg per kg dry weight for roots, and 2000 mg per kg dry weight for fruits. The concentrations of magnesium in leaves and stems ranging from 5200 to 19,000 mg per kg corresponded to the nutrient levels determined by the Soil Science Department, Michigan State University, 1968.

Potassium

The uptake of potassium by all tomato organs was high and represented one of the most important factors in tomato planting and had a direct impact on potassium deficiency, (Figure 15.3).

Potassium deficiency symptons:-

(a) plants woody and slow-growing (observed mainly on tomato planted in Detroit River sediment, to a lesser extent in Hamilton Harbour sediment).

(b) Some leaves are dary bluish-green. There was a marked difference in colour of the leaves mentioned before: suspected potassium deficiency as one of the possible causes;

(c) Fruit often fail to ripen evenly (not observed);

(d) Curling, yellowing, scorching, browning of leaf margins and tips (not observed);

(e) Stems are weak (observed on Detroit River tomato)

The potassium concentrations varied widely in stems and leaves of the individual plants, but were the same in the fruits, approximately 37,0000mg per kg.

Although the potassium concentrations were nearly the same in the sediments and fruits, the uptake of potassium for one plant grown in individual sediments were different: 929 mg for Hamilton Harbour plant, 4014 mg for Humber Bay plant, and 840 mg for Detroit River plant.

J.C. Shicluna (1962) proposed a following classification of potassium minerals:

Relatively unavailable potassium	feldspar, muscovite
Fixed or slowly available potassium	biotite, hydrous mica illite
Readily available potassium	exchangeable and water soluble potassium

Table 14 showed that the sediments differed mainly in illite (Humber Bay 35%, Hamilton Harbour 37%, Detroit River 50%) and in feldspar (Humber Bay 12%, Hamilton Harbour 6%, Detroit River 5%). It was proven in leaching experiments that no significant amount of water soluble potassium was available, see Table 11. Potassium was present in an exchangeable form in amounts stated in Tables 15, 16.

Hamilton Harbour sediment:

0.60 meq/100 g = 234 mg/kg = 14.5 % of the total potassium

Humber Bay sediment:

0.18 meq/100 g = 70 mg/kg = 3.9 % of the total potassium

Detroit River sediment:

0.02 meq/100 g = 8 mg/kg = 0.53 % of the total potassium

Upon drying the cation exchange capacity of the sediments did not change; therefore, not potassium fixation in forms unavailable to plants was suspected.

Considering the results from X-ray diffraction, leaching experiments and cation exchange capacity measurements the theoretical conditions were totally unfavourable for the tomato growth. The potassium amounts determined by cation exchange capacity were completely insufficient. Most of the potassium was in the form of the relatively unavailable and slowly available potassium and only a minor part was in a readily available form.

The discrepancy between potassium uptake and available exchangeable potassium could be explained only in such a way that during the growing season, a major part of potassium absorbed by the plants had to come from the relatively unavailable potassium that decomposed and thereby released their potassium.

Iron

Iron availability to the plants is related to many factors, e.g. the proportion of ferrous and ferric ions, type of plant, pH, and aeration of the soil. Iron released from ferromagnesium minerals may be absorbed on humus and clays by ion exchange and become unavailable. Aeration makes iron unavailable as proven by the determination of cation exchange capacity of wet and dry sediments. (Table 27). The mechanisms by which ferrous ions are absorbed by roots and translocated to stems, leaves, and fruits are poorly understood.

In all plants the highest amount of iron was found in the roots. (Figure 15.4). The roots from Hamilton Harbour sediment with the greatest sediment iron amount contained the greatest amount of iron. However, there was no correlation between the iron quantities in sediments and roots of Humber Bay and Detroit River sediments.

Translocation of iron from the roots to the other plant organs was interesting. The stems seemed to function as a valve allowing only a definite maximum iron concentration, 25 mg per kg. Iron accumulated in leaves, in the range from 300 to 500 mg per kg. Only minute amounts of iron were transferred from leaves to fruits. A definite maximum iron concentration, about 5 mg/kg, was found in the fruits.

Nickel

No correlation was established between the nickel content of the sediments and nickel content of the plant organs. (Figure 15.5) Disregarding certain deviations, nickel distribution in the roots, stems and leaves was equal. No nickel was translocated from the stem to the fruits.

Chromium

No correlation was established between the chromium content of the sediments and chromium content of the plant organs. (Figure 15.6) The chromium concentration in all tomato organs seemed to achieve definite values, for roots about 20 mg/kg, for stems 50-80 mg/kg and for leaves about 10 mg/kg. The stems seemed to be the storage area for chromium. Chromium appeared to be unavailable to the fruits, i.e. no chromium was detected in fruits.

Lead

The effect of lead content in the sediment on the lead contents of the plant organs was negligible. (Figure 15.7). The concentrations of lead converged to definite ranges: 30-45 mg/kg for roots, 10-12 mg/kg for stems, 25-34 mg/kg for leaves, and 2-3 mg/kg for fruits.

Cadmium

Since the cadmium concentrations were small in both the sediments and the tomato plants, the analytical values deviated. (Figure 15.8). The greatest cadmium concentration was determined in leaves, nearly equal in roots and stems and the smallest in the fruits. Cadmium was translocated from the Humber Bay sediment in greater amounts that from the Hamilton Harbour and Detroit River sediments.

The initial cadmium concentration of the sediment had no effect on cadmium concentration of the specific organs of the tomato plants.

Zinc

Zinc contents per tomato plant was 7.2 mg in Hamilton Harbour sediment, 4.1 mg for Humber Bay and 2.8 mg for Detroit River. (Figure 15.9). The maximum zinc concentrations were in the roots, 240-440 mg/kg; and stems, 200-360 mg/kg; and fruits, 25-40 mg/kg;

The initial zinc content in the sediments affected the zinc contents of the roots, stems, and leaves, but did not affect the zinc content of the fruit. The Hamilton Harbour sediment with an extremely high zinc amount had greatest zinc content than tomato plants grown in Humber Bay sediment and both had a greater zinc content than tomatoes in Detroit River Sediment. The irregularity in the zinc content of the stem was disregarded.

The zinc concentrations of the fruits were practically equal, 25-40 mg/kg dry basis, for all sediments. The percentage ratios of the transferred zinc from the sediments and the zinc amounts in the roots varied widely, from 10 per cent for Hamilton Harbour sediment to 76 per cent for Humber Bay sediment to 205 per cent for Detroit River sediment. The zinc concentrations of Hamilton Harbour and Humber Bay sediments were greater than those of roots. On the other hand, the zinc concentration of Detroit River sediment was less than that of roots as well as leaves.

Strontium

Strontium translocated easily from the sediments into the tomato plants. Strontium concentrations of roots, stems, and leaves were higher than those of the sediments but significantly lower than those of the fruits. (Figure 15.10). An interesting relationship was found between the strontium concentrations of the Detroit River sediments and tomato plants and Hamilton Harbour and Humber Bay sediments and tomato plants. The lower the strontium concentration of the sediments the higher the strontium concentration of the individual portions of the tomato plants. However, the reverse relationship was established between Hamilton Harbour and Humber Bay sediments and tomato plants. The higher the strontium concentration of the sediment, the higher the strontium concentration of tomato plants.

Cobalt

Cobalt concentration in the sediments ranged from about 10 to 17 mg per kg. (Figure 15.11). With the exception of the cobalt concentration in the Detroit River sediment the cobalt content regularly diminished in the order:- sediment-roots-stems-fruit. However, the leaves accumulated cobalt and their cobalt content approached that of the sediment.

Manganese

The manganese uptake by plants with the exception of fruit seemed to match the manganese concentrations in sediments. (Figure 15.12). On the other hand, there seemed to be a definite limit for the manganese contents in roots (300 mg/kg) and stems (400 mg/kg). Whatever the initial manganese content in the sediment the uptake of manganese by tomato fruit was minute, less than 1 mg per kg dry weight. The uptake of manganese by leaves was always 15 per cent of the initial manganese quantity in sediments, and thus the manganese amount in leaves varied. Hamilton Harbour tomato had the highest total manganese content.

Copper

The initial copper in the sediment:-

(a) seemed to have an inverse relationship to the copper content of the roots and leaves, i.e., the higher the copper content in the sediments the lower content in the roots and leaves. (Figure 15.13)

(b) had not effect on the copper content in the stems; it was consistently in the range of 20-25 mg/kg,

(c) had no effect on the copper content in the fruits; it was consistently about 20 mg per kg.

The copper contents of the roots and leaves were always higher than those of the stems and fruits.

Uptake of elements for plant growth and sediment exhaustion

The plant roots take up during the growing period certain amounts of macronutrients, micronutriens and trace elements. Consequently the sediment becomes exhausted, the individual elements are taken up in different proportions.

An attempt was made to evaluate the over-all sediment exhaustion by calculating the loss of elements from a given mass of sediment during the growing season. Arbitrarily, the sediment mass was taken to be 1000 g.

Two simplifying assumptions were made:

1. every element is in available form and,
2. the plant takes up only that portion which it needs for its growth under prevailing conditions.

The element concentrations in the sediments determined analytically were base values expressed in mg/kg or mg/1000 g (Value A),(Table 28).

The quantities of elements translocated from the sediment to the plants were determined analytically and expressed in mg per one plant (Value B), Table 26.

The exhaustion value (EV) was calculated as follows and expressed in g:

EV = B/A

The calculated value was plotted on the logarithmic scale 1 - 3000.

The following examples can illustrate the calculation of the exhaustion values:

The iron concentration in Humber Bay sediment (A)	28,000 mg/1000 g
The iron concentration in the plant (B)	21 mg
Hypothetical exhaustion of the sediment for the growth of one tomato plant (EV=B/A)	0.75 g

In other words, 1 kg sediment could provide iron for 1330 tomato plants (28,000 mg/kg : 21mg)

The potassium concentration in Humber Bay sediment	1,800 mg/1000 g
The potassium concentration in the plant	4,014 mg
Hypothetical exhaustion of the sediment for the growth of one tomato	2,250 g

In other words, 2.25 kg sediment is required for one tomato plant.

The exhaustion values for the studied elements were plotted for Hamilton Harbour, Humber Bay and Detroit River sediments for one plant using a logarithmic scale (Figure 16.)

To assess the accuracy of cation exchange capacity values of calcium, magnesium, potassium, zinc, manganese, copper, and iron, the appropriate values for element uptake amount, element content in sediment, exchangeable cation quantity together with the amounts of sediment required to cover the element quantities taken up were summarized in Table 28.

Considering the root extension the mass of the sediment required for one plant was estimated between one and four kg (Figures 17, 18, 19).

If the mass of sediment required to supply the quantities of elements consumed for the plant growth were calculated from the element content in studied sediments one kilogram of each sediment would be sufficient for all elements except potassium in Humber Bay sediment where 2.22 kg sediment was needed.

If exchangeable cation quantity were used for the calculation of the required mass of the sediment then 1 kg sediment would be required to cover the uptake of zinc, manganese, copper, and iron; 4 kg sediment would be needed for calcium and magnesium with the exception of Humber Bay sediment, where 4.5 kg is required. However, extremely high and obviously unrealistic quantities of sediment would be needed to cover the loss of potassium from Humber Bay (38 kg) and the Detroit River sediment (105 kg).

From these calculations a conclusion could be drawn that the standard method for the determination of cation exchange capacity rendered incorrect values for potassium.

7. SUMMARY

(1) The suitability of contaminated bottom sediments collected in Hamilton Harbour, Humber Bay and Detroit River Mouth as agricultural soil was verified in greenhouse experiments by planting tomato and corn with a good crop yield. The crop yield of the Humber Bay tomato plants was best (100 per cent), followed by those of Hamilton Harbour (48 per cent) and Detroit River (30 per cent). The Eh of the cropped sediment was over 250 mV.

(2) For all investigated sediments the quantities of elements released in leaching experiments were many times higher than those determined in lysimeter percolates but were lower than those recommended for water for public use (values in parentheses) with the exception of manganese and nickel. The highest values were determined for Hamilton Harbour dry sediment:

Cd < 0.001 mg/l (0.01 mg/l), Cr < 0.2 mg/l (0.05 mg/l), Cu 0.08 mg/l (1.0 mg/l), Fe 0.08 mg/l (0.3 mg/l), Pb < 0.001 mg/l (0.05 mg/l), Mn 2.9 mg/l (0.05 mg/l), Hg < 0.05 mg/l (5 mg/l), Ni 0.07 mg/l (0.03 mg/l), Zn 1.1 mg/l (5 mg/l).

Consequently, it may be assumed that the bottom sediments disposed of in a landfill or used as agricultural soil will not present any potential hazard to the environment, in particular, groundwater.

(3) Tomato plants and corn did not take up various elements in the proportions in which the elements occurred in the sediments or were determined as available in cation exchange capacity measurement,

leaching experiments or lysimeters. Tomato plants took up major and minor nutrients and trace elements only to a certain limiting concentration characteristic for individual plant organs. Following maximum concentrations were determined for tomato fruit: K 37,000 mg/kg, Mg 2,100 mg/kg, Ca 1,700 mg/kg, Zn 40 mg/kg, Sr 30 mg/kg, Cu 23 mg/kg, Pb 12 mg/kg, Co 7 mg/kg, Cd 2 mg/kg. Arsenic, molybdenum, manganese, chromium, nickel and mercury were not detected in tomato fruit.

(4) The required sediment mass to cover the uptake of elements by one tomato plant varied from one sediment to the other, for example for Humber Bay sediment it was evaluated as follows for specific elements: K 2,240 g, Ca 240 g, Sr 130 g, Mg 120 g, Cd 80 g, Cu 50 g, Co 48 g, Cr 17 g, Ni 14 g, Zn 10 g, Mn 9 g, Pb 6 g, Fe < 1 g.

RECOMMENDATIONS

(1) The present investigation ended with successful growing of tomato plants and corn in sediments in a greenhouse. Field tests, however, are required to evaluate all problems encountered from the transport of dredged sediments and spreading on the fields to the changes which may occur in the sediments during and after the growing season.

(2) To continue the greenhouse experiments for different plants in order to assess the overall utilization of sediments in agriculture.

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TABLE 1

List of 1973 - 1974 Dredging Projects scheduled for the Province of Ontario

(Prepared by Department of Public Works of Canada - Ontario Region

PLACE	ZONE	PROJECT	VALUE	YARDAGE	DISPOSAL
Maintenance Dredging:					
Colchester	London	Dredging	$ 20,000	9,200	Land Disposal
Port Burwell	London	Redredging	61,500	12,000	Not known
Leamington	London	Redredging	51,300	10,000	Not confirmed
Kingsville	London	Redredging	100,200	23,300	Shoreline disposal
Rondeau (Erieau)	London	Dredging	41,000	10,000	Land disposal
Thunder Bay	Northern	Mission River Entrance Channel	191,000	145,000	Lake disposal
Capital Dredging					
Brechin (Lake Simcoe)	Toronto	Marina Entrance	45,000	10,500	Beach Disposal (Sand). Land Disposal (Organic).
Oshawa	Toronto	Dredging	220,000	140,000	Land Disposal
Lefroy (Lake Simcoe)	Toronto	Marina Approach	6,400	1,380	Land
Mitchell Bay	London	c/o Marina Approach Channel	54,000	60,000	Part in lake Part on land
Port Stanley	London	Redredging	200,000	120,000	Part land Part Lake
Turtle Portage	Northern	Widening and Deepening Channel	25,750	3,100	Land disposal

TABLE 2

Changes in Composition of Bottom Sediments Collected from Lake Erie and Lake Ontario

Element Content % or ppm	LAKE ERIE		LAKE ONTARIO	
	surface sediment (0-1 cm)	before industrialization	surface sediment (0-1 cm)	before industrialization
Ca %	2.27	2.45	5.76	1.33
Na %	0.68	0.71	1.18	0.79
Fe%	4.52	3.80	3.86	4.38
Mg %	2.21	2.28	1.78	1.84
P %	0.111	0.068	0.142	0.053
Mn %	0.13	0.07	0.38	0.10
Si %	27.07	27.17	25.11	27.95
K %	2.71	2.62	2.32	2.87
Al %	5.94	5.75	5.15	6.50
Ti %	0.39	0.41	0.37	0.38
ppb Hg	927	663	2,302	85
Pb ppm	100	41	230	30
Cu ppm	55	36	90	36
Zn ppm	270	123	369	98
Ni ppm	102	60	120	74
Co ppm	21	22	28	25
Cr ppm	163	80	228	118

TABLE 3

Nitrogen, Phosphoric Acid and Potash Contained in Fertilizers Sold during the Years 1971 and 1972

Province	1971				1972			
	Tonnage sold Total	Contained			Tonnage sold Total	Contained		
		Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash= (K_2O)		Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)
aterial:								
rio	364,960	101,563	30,462	32,729	379,608	99,279	33,319	32,292
al, anada	1,112,999	277,236	189,424	46,831	1,171,355	285,037	199,803	43,340
ixtures:								
ario	529,789	42,215	98,815	84,942	525,408	42,831	100,400	86,579
al, anada	997,979	78,904	170,357	156,362	1,003,875	82,814	174,294	158,568
al:								
ario	894,749	143,778	129,277	117,671	905,016	142,110	133,719	118,871
, ada	2,110,978	356,140	359,781	203,193	2,175,230	367,851	374,097	206,908

TABLE 4

SAMPLE LOCATIONS

Sampling locations	Latitude	Longitude	Water Depth (m)	Chart Figure #
Hamilton Harbor	43°16.8'N	79°48.5'W	10	6
Port Stanley	inside harbour see chart		4	7
Detroit River	42°oo'N	83°03'W	5	8
Lake St. Clair	42°29.5'N	82°42.5'W	5	9
Humber Bay	43°37.7'N	79°27.7'W	12	10

Factors affecting the properties and composition of bottom sediments in the selected sample locations

Sampling location	Population of the local areas	Major Industry	Minor Industry	Farming	River, Creek	Municipal waters - treatment
Hamilton Harbour	300,000	Primary metal industry	Metal fabricating electrical products machinery, food, beverages	negligible	few small creeks	Hamilton (activated sludge) (primary sed.)
Port Stanley	approx. 25,000	Machinery (St. Thomas)	Metal fabricating, Transport equipment	Extensive	Kettle Creek	St. Thomas (activated sludge) Port Stanley (prim.)
Detroit River	2 millions	Transportation Equipment	Petroleum and coal products, Fabricated metal pr., primary metal pr., chemicals, machinery	Extensive	Detroit River	Windsor (activated sludge)
Lake St. Clair	100,000	Chemicals and chemical products	Petroleum, coal products transportation equipment	Extensive	St. Clair River	Sarnia (primary sedimentation) Few small towns without any treatment; septic tanks
Humber Bay	approx. 500,000	Metal fabricating	Machinery Electrical products	negligible	Humber River Mimico Creek	Toronto (activated sludge; septic tanks with land treatment)

TABLE 7

Chemical composition of core sections 0-3cm and 15-20cm collected by Benthos Corer

		Hamilton Harbour		Humber Bay		Detroit River		Port Stanley		Lake St. Clair	
		0-3	15-20	0-3	15-20	0-3	15-20	0-3	15-20	0-3	15-20
. C	%	5.05	6.10	3.05	2.45	2.99	1.45	1.95		2.57	1.30
al C	%	10.62	9.12	6.72	4.65	7.18	4.28	6.20		8.52	4.04
al P	ppm	6,000	1,730	2,400	1,600	1,600	330	1,400		2,000	39
al N	ppm	3,200	3,250	2,500	1,900	1,450	1,050	1,010		1,400	1,30
	ppm	121,300	26,100	51,500	12,500	63,000	9,800	69,000		81,000	14,75
	ppm	11,800	4,800	7,000	6,600	21,180	8,800	9,800		27,400	11,40
	ppm	1,440	1,200	1,700	1,950	2,400	1,600	2,750		2,750	2,70
	ppm	7,100	6,950	2,650	2,400	3,300	2,800	3,600		4,200	3,80
	ppm	70,500	35,500	27,000	27,500	31,900	31,100	21,950		19,500	23,00
	ppm	1,200	3,000	430	410	460	210	545		420	41
	ppm	4,700	4,500	3,500	5,300	1,200	950	1,020		800	95
	ppb	6,100	2,000	3,950	2,100	2,800	1,750	2,300		2,850	2,50
t r s,)	ppm	0.28	0.25	0.2	0.15	0.12	0.10	0.18		0.09	0.08
	ppm	10,760	4,840	520	402	235	120	70		90	70
	ppm	330	75	30	29	33	42	25		42	54
	ppm	250	278	220	210	135	173	210		130	170
	ppm	820	132	450	250	150	50	78		119	60
	ppm	475	77	46	46	58	32	21		29	42
	ppm	1,005	127	81	65	65	32	30		55	32
	ppm	173	17	15	15	14	10	8		8	10
	ppm	2,610	290	160	130	86	50	33		22	36
	ppm	48	0.5	7	7	3	2	3		1	2
	ppm	6	2	1	1	1	1	1		2	2

TABLE 8

Chemical composition of bottom sediments collected by Shipek sampler

		Hamilton Harbour	Humber Bay	Detroit River	Port Stanley	Lake St. Clair
rg. C	%	4.97	2.74	2.72	1.76	2.21
otal C	%	7.54	4.87	5.42	4.26	5.12
otal P	ppm	4,000	1,785	700	545	500
otal N.	ppm	3,255	2,140	1,277	830	1,260
a	ppm	21,750	13,250	11,700	16,750	12,100
g	ppm	4,600	6,100	11,600	9,300	12,750
K	ppm	1,600	1,800	1,500	2,400	2,300
Na	ppm	6,800	2,800	2,950	3,900	3,900
Fe	ppm	40,500	28,000	32,900	22,200	22,200
Mn	ppm	1,600	400	410	620	405
S	ppm	5,500	8,200	800	980	900
Hg	ppb	5,300	3,300	2,500	1,900	2,500
B(hot water sol)	ppm	0.32	0.15	0.10	0.14	0.12
Zn	ppm	4,160	408	117	68	78
V	ppm	45	30	24	27	25
Sr	ppm	236	248	138	230	128
Pb	ppm	1,100	269	85	93	88
Ni	ppm	66	50	35	28	27
Cu	ppm	136	75	32	29	38
Co	ppm	17	14	10	11	10
Cr	ppm	330	124	40	39	26
Cd	ppm	15	8	2	2	2
Be	ppm	2	1	1	1	1

TABLE 9

Quantities of elements detected in the Lysimeter percolate and percentage ratios

CALCIUM

	WET	DRY	WET	DRY
Sample	mg in effluent	% of dry weight	mg. in effluent	% of dry weight
Hamilton Harbour	23	0.10	186	0.85
Lake St. Clair	15	0.12	120	1.0
Detroit River	13	0.11	115	0.98
Port Stanley	8	0.05	34	0.20

POTASSIUM

	WET	DRY	WET	DRY
Sample	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight
	1	0.06	1	0.06
	1	0.05	2	0.10
	1	0.07	2.5	0.17
	1.5	0.06	2	0.08

MAGNESIUM

Sample	mg in effluent	% of dry weight	mg. in effluent	% of dry weight
Hamilton Harbour	8	0.17	14	0.30
Lake St. Clair	4	0.03	8	0.06
Detroit River	4	0.03	18	0.16
Port Stanley	3	0.03	5	0.05

COPPER

mg. in effluent	% of dry weight	mg. in effluent	% of dry weight
0.006	0.004	0.006	0.004
0.004	0.011	0.003	0.009
0.005	0.016	0.005	0.016
0.007	0.024	0.007	0.024

SODIUM

Sample	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight
Hamilton Harbour	7	0.105	9	0.13
Lake St. Clair	2	0.05	3	0.08
Detroit River	4	0.14	5	0.17
Port Stanley	2	0.05	3	0.08

ZINC

mg. in effluent	% of dry weight	mg. in effluent	% of dry weight
0.016	4×10^{-3}	0.047	1.5×10^{-3}
0.006	8×10^{-3}	0.010	0.013
0.008	7.1×10^{-3}	0.017	0.015
0.005	8×10^{-3}	0.007	0.010

Quantities of elements detected in the Lysimeter percolate and percentage ratios

	IRON				MANGANESE			
	WET	DRY	WET	DRY	WET	DRY	WET	DRY
mple	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight
milton rbour	0.001	2×10^{-6}	0.001	2×10^{-6}	1×10^{-3}	6×10^{-5}	1×10^{-3}	6×10^{-5}
ke St. air	0.001	4×10^{-6}	0.001	4×10^{-6}	3×10^{-4}	7×10^{-5}	3×10^{-4}	7×10^{-5}
troit ver	0.001	3×10^{-6}	0.001	3×10^{-6}	1×10^{-3}	2×10^{-4}	1×10^{-3}	2×10^{-4}
rt anley	0.0003	1.1×10^{-6}	0.0003	1.1×10^{-6}	5×10^{-4}	8×10^{-5}	5 x 10-4	8×10^{-5}

	LEAD				TOTAL NITROGEN			
mple	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight
milton rbour	nd	nd	5×10^{-4}	5×10^{-5}	1.5	0.046	2	0.061
ke St. air	nd	nd	nd	nd	6×10^{-3}	5×10^{-4}	8×10^{-3}	6×10^{-4}
troit ver	nd	nd	8×10^{-4}	9×10^{-4}	8×10^{-3}	6.1×10^{-4}	11×10^{-3}	9×10^{-4}
rt anley	nd	nd	nd	nd	4×10^{-3}	5×10^{-4}	4×10^{-3}	5×10^{-4}

	NICKEL				REACTIVE PHOSPHORUS			
mple	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight	mg. in effluent	% of dry weight
milton rbour	1×10^{-3}	1.5×10^{-3}	2×10^{-3}	3×10^{-3}	3.5×10^{-3}	9×10^{-5}	4×10^{-3}	1×10^{-4}
ke . Clair	8×10^{-4}	3×10^{-3}	4×10^{-3}	1.5×10^{-2}	1.7×10^{-3}	2×10^{-4}	3×10^{-3}	5×10^{-4}
troit ver	6×10^{-4}	1.7×10^{-3}	3×10^{-3}	8×10^{-3}	2.5×10^{-3}	4×10^{-4}	3×10^{-3}	5×10^{-4}
rt anley	5×10^{-4}	1.7×10^{-3}	1×10^{-3}	3.5×10^{-3}	1.5×10^{-3}	3×10^{-4}	1.8×10^{-3}	4×10^{-4}

Quantities of elements released from Hamilton Harbour and
sediments and detected in the water in leaching experiments

	HAMILTON HARBOUR									LAKE ST. CLAIR				
		Wet Sediment				Dry Sediment					Wet Sediment		Dry Sediment	
	Sediment Content	Mixing 24hr		48hr		Mixing 24hr		48hr		Sediment Content	Mixing 48hr		Mixing 48hr	
	ppm	ppm	%	ppm	%	ppm	%	ppm	%	ppm	ppm	%	ppm	%
Ca	21,750	190	0.9	230	1.1	1,230	5.6	1,320	6.1	12,100	170	1.41	500	4.2
Mg	4,600	110	2.5	90	2.3	190	4.0	200	4.4	12,750	16	0.24	39	0.31
K	1,600	18	1.1	20	1.3	19	1.2	19	1.3	2,300	5	0.21	8	0.35
Na	6,800	18	0.34	74	1.1	26	0.4	25	0.4	3,900	12	0.31	16	0.4
Fe	40,500	0.041	$9x10^{-5}$	0.06	$1.4x10^{-4}$	0.06	$1x10^{-4}$	0.08	$2x10^{-4}$	22,200	0.02	$7x10^{-5}$	0.04	$1.3x10^{-4}$
Mn	1,600	1.6	0.1	2.7	0.17	1.8	0.11	2.9	0.18	405	0.08	0.02	0.07	0.02
Zn	4,160	0.2	0.06	0.8	0.13	0.7	0.17	1.1	0.27	78	0.07	0.09	0.27	0.35
Pb	1,100	nd		nd		nd		nd		88	nd			
Ni	66	0.03	0.04	0.05	0.07	0.04	0.06	0.07	0.11	27	0.02	0.09	0.04	0.17
Cu	136	0.05	0.04	0.08	0.06	0.07	0.05	0.08	0.06	38	0.08	0.2	0.07	0.18
Co	17	nd		nd		nd		nd		10	nd		nd	
Cr	330	nd		nd		nd		nd		26	nd		nd	
C (Org.)	4,970	2.2	0.05	2.7	0.05	2.7	0.05	3.2	0.06	2,210	- - - - not analysed - - - - - -			
P	4,000	0.04	$9x10^{-4}$	0.07	$2x10^{-3}$	0.07	$2x10^{-3}$	0.1	$2x10^{-3}$	500		"	"	
N	3,255	0.03	$9x10^{-4}$	0.04	$1.1x10^{-3}$	0.04	$1x10^{-3}$	0.04	$2x10^{-3}$	1,260		"	"	
Hg	5.3	nd		nd		nd		nd		2.5	nd		nd	
Cd	15	nd		nd		nd		nd		2	nd		nd	

TABLE 13

SEDIMENT PERMEABILITY

SAMPLE	CONDITIONS	PERMEABILITY IN cm^2	RATE *
HAMILTON HARBOUR	dry	3×10^{-10}	slow
	frozen	1×10^{-10}	very slow
	wet	6×10^{-11}	very slow
DETROIT RIVER	dry	1.1×10^{-10}	very slow
	frozen	8×10^{-11}	very slow
	wet	2×10^{-11}	very slow
LAKE ST. CLAIR	dry	2×10^{-10}	ver slow
	frozen	7×10^{-11}	very slow
	wet	3×10^{-11}	very slow
PORT STANLEY	dry	5×10^{-11}	very slow
	frozen	3×10^{-11}	very slow
	wet	1×10^{-11}	very slow
HUMBER BAY	dry	6×10^{-10}	slow
	frozen	2×10^{-11}	very slow
	wet	----	----

*classification after O'Neal (published in Methods of soil analyses)

Mineralogical composition of the $<2\ \mu m$ of bottom sediments determined by X-ray diffraction

% of minerals

Sample	Expand minerals	Chlorite	Vermiculite	Mixed layer 10 - 14Å	Illite	Kaolinite	Quartz	Potash Feldspar	Plagioclase Feldspar	Calcite	Dolomite
LAKE ST. CLAIR	1	4	1	5	47	5	19	6	5		7
DETROIT RIVER	1	5	2	9	50	5	22	3	2	0.5	0.5
PORT STANLEY	2	2	4	8	55	1	11	5	3	7	2
HAMILTON HARBOUR	0	6	1	6	37	1	35	3	3		8
HUMBER BAY	1	3	3	5	35	1	20	7	5	17	3

TABLE 15

Cation exchange capacity and exchangeable cations of the collected bottom sediment samples

Sample	Conditions	C.E.C. meq/100g	(Exchangeable cations (meq/100g)							
			Ca	Mg	K	Na	Mn	Fe	Cu	Zn	H
HAMILTON HARBOUR	dry	14.16	4.10	1.05	0.66	0.26	0.64	0.013	0.04	1.10	6.3
	wet	10.55	3.47	1.00	0.60	0.30	1.30	3.80	0.02	0.03	--
	frozen	14.11	3.70	1.00	0.58	0.25	1.02	2.49	0.01	0.01	5.05
DETROIT RIVER	dry	10.16	3.46	0.68	0.02	trace	0.13	trace	0.04	0.03	5.80
	wet	7.50	2.65	0.60	0.02	trace	0.40	0.10	trace	0.05	3.68
	frozen	9.10	3.05	0.70	0.01	trace	0.35	0.05	0.01	trace	4.93
LAKE ST. CLAIR	dry	6.00	3.35	0.78	0.59	0.39	0.14	trace	0.04	0.02	0.73
	wet	4.69	2.50	0.60	0.40	0.20	0.30	0.05	trace	0.01	0.69
	frozen	7.33	3.56	0.71	0.02	trace	0.20	0.01	0.01	trace	2.82
PORT STANLEY	dry	6.22	2.83	0.60	0.02	trace	0.24	0.01	0.02	0.006	2.50
	wet	6.22	2.50	0.61	0.018	trace	0.65	0.018	0.013	0.007	2.41
	frozen	9.55	2.55	0.62	0.016	trace	0.57	trace	0.01	0.007	5.78
HUMBER BAY	dry	12.66	3.60	0.81	0.21	0.40	0.31	trace	0.04	0.23	7.06
	wet	12.77	2.80	0.80	0.18	0.05	0.74	0.55	0.016	0.01	6.83
	frozen	14.66	3.14	0.82	0.02	0.01	0.73	0.044	0.01	0.018	9.87

TABLE 16

EXCHANGEABLE CATIONS - TRACES

Sample	Conditions	Cr	Cd	Pb	Hg	Mo	Ni	V	Be	Co
HAMILTON HARBOUR	dry	+	-	+	+	+	+	+	+	+
	wet	+	-	+	+	+	+	+	+	+
	frozen	+	-	+	+	+	+	+	+	+
DETROIT RIVER	dry	+	-	+	+	+	+	+	+	+
	wet	+	-	+	+	+	+	+	+	+
	frozen	+	-	+	+	+	+	+	+	+
LAKE ST. CLAIR	dry	+	-	+	+	+	+	+	+	+
	wet	+	-	+	+	+	-	+	+	+
	frozen	+	-	+	+	+	+	+	+	+
PORT STANLEY	dry	+	+	-	+	+	+	+	+	+
	wet	+	+	+	+	+	+	+	+	+
	frozen	+	+	+	+	+	+	+	+	+
HUMBER BAY	dry	+	+	+	+	+	+	+	+	+
	wet	+	-	+	+	+	+	+	+	+
	frozen	+	-	+	+	+	+	+	+	+

TABLE 17

Contents of exchangeable cations in ppm and percentage ratios of element contents in sediments and contents of exchangeable cations - calcium, magnesium, potassium and sodium

Sediment	cond.	Total Ca ppm	Exchange Ca ppm	% from total Ca	Total Mg ppm	Exchange Mg ppm	% from Total Mg	Total K ppm	Exchange Kppm	% from Total K	Total Na ppm	Exchange Na ppm	% from Total Na
Hamilton Harbor	dry	21,750	820	3.7	4,600	126	2.7	1,600	257	16	6,800	60	0.9
	wet		690	3.2		120	2.6		234	14.5		69	1.0
	frozen		740	3.4		120	2.6		230	14.3		60	0.9
Detroit River	dry	11,700	690	5.9	11,600	82	0.7	1,500	8	0.5	2,950	traces	
	wet		530	4.5		72	0.6		8	0.5			
	frozen		610	5.2		89	0.7		4	0.3			
Lake St. Clair	dry	12,100	670	5.5	12,750	94	0.7	2,300	234	10.2	3,900	90	2.3
	wet		500	4.1		72	0.6		156	6.8		46	1.2
	frozen		710	5.8		90	0.7		8	0.3		trace	trace
Port Stanley	dry	16,750	560	3.3	9,300	72	0.8	2,400	8	0.3	3,900	trace	trace
	wet		500	2.9		72			8	0.3			
	frozen		510	3.8		72			7	0.3			
Humber Bay	dry	13,250	720	5.4	6,100	96	1.6	1,800	82	4.5	2,800	92	3.3
	wet		580	4.3					70	3.9		11	0.4
	frozen		630	4.7					8	0.5		2	0.07

TABLE 18

Contents of exchangeable cations in ppm and percentage ratios of element contents in sediments and contents of exchangeable cations - manganese, iron, copper and zinc

Sediment	condition	Total Mn ppm	Exchange Mn ppm	% from Total Mn	Total Fe ppm	Exchange Fe ppm	% from Total Fe	Total Cu ppm	Exchange Cu ppm	% from Total Cu	Total Zn ppm	Exchange Zn ppm	% from Total Zn
Hamilton Harbour	dry	1,600	176	11.0	40,500	4	0.01	136	25	18.4	4,160	363	8.7
	wet		350	22.4		1,060	2.6		12	9.2		10	0.2
	frozen		280	17.5		695	1.7		6	4.6		3	0.08
Detroit River	dry	410	36	8.8	32,900	trace	-	32	25	78.5	117	10	8.5
	wet		110	26.9		30	0.09		trace	trace		17	14.5
	frozen		96	23.4		15	0.05		6	19.7		trace	trace
Lake St. Clair	dry	405	36	8.9	22,200	trace	-	38	25	65.8	78	7	8.9
	wet		83	20.6		15	0.07		trace	-		3	3.8
	frozen		55	13.5		3	0.01		6	16.0		trace	-
Port Stanley	dry	620	66	10.6	22,200	3	0.01	29	12	43.3	68	2	2.9
	wet		178	28.6		4	0.01		6	22.4		2	
	frozen		157	25.4		trace	-		6	22.2		2	
Humber Bay	dry	400	83	20.7	28,000	trace	-	75	25	33.4	408	8	1.7
	wet		202	50.5		162	0.6		10	13.3		3	0.8
	frozen		202	50.5		12	0.04		6	8.4		7	1.7

TABLE 19

Cation Exchange Capacity of the collected bottom sediment samples

erimentally determined CEC			CEC Evaluated from Clay Mineralogy							
			CEC of org. matter = 100 meg/100g				CEC of org. matter = 150meg/100g			
			CEC clay values				CEC clay values			
Wet iment	Dry Sediment		Low		High		Low		High	
10.6	HH	14.2	HH	11.6	DR	18.2	HH	15.3	HH	21.3
12.8	HB	12.7	HB	8.8	HH	17.6	HB	11.7	DR	20.5
7.5	DR	10.2	DR	8.6	PS	15.1	DR	10.9	HB	17.8
6.2	PS	6.2	PS	6.9	HB	14.9	PS	8.4	PS	16.6
4.7	LC	6.0	LC	5.3	LC	9.6	LC	7.1	LC	11.4

Hamilton Harbour

Humber Bay

Detroit River

Port Stanley

Lake St. Clair

TABLE 20

Green Pigment Determination in Collected Bottom Sediment Samples

(absorbancy at 665 mμ)

SAMPLE	DRY SEDIMENT D_{665}	WET SEDIMENT D_{665}	FROZEN SEDIMENT D_{665}
HAMILTON HARBOUR	.236	.374	.368
HUMBER BAY	.149	.143	.141
LAKE ST. CLAIR	.075	.075	.075
PORT STANLEY	.085	.069	.064
DETROIT RIVER	.067	.065	.064

TABLE 21

Water content, bulk density, particle density and porosity of collected sediment samples

SAMPLE	WATER CONTENT (%)	BULK DENSITY (g/cm^3)		PARTICLE DENSITY (g/cm^3)	POROSITY (%)
		Wet	Dry		
HAMILTON HARBOUR	55.79	0.51	0.97	2.55	61.83
DETROIT RIVER	40.23	1.02	1.21	2.66	54.46
LAKE ST. CLAIR	41.68	0.95	1.15	2.65	56.56
PORT STANLEY	28.21	1.34	1.41	2.60	45.48
HUMBER BAY	45.80	0.79	1.02	2.43	58.0

TABLE 22

Particle size distribution of collected sediment samples

SEDIMENT	MEAN GRAIN SIZE (phi)	STANDARD DEVIATION	MEDIAN GRAIN SIZE (phi)	COMPOSITION		
				sand %	silt %	clay size %
HAMILTON HARBOUR	7.44	1.89	8.23	1.00	46.50	52.50
HUMBER BAY	7.19	1.58	7.48	1.00	57.50	41.50
LAKE ST. CLAIR	6.41	1.35	6.48	0.00	76.00	24.00
DETROIT RIVER	6.69	1.74	7.61	4.00	49.50	46.50
PORT STANLEY	6.63	1.49	7.13	2.00	60.50	37.50

TABLE 23

Weight of fresh and dried tomato organs grown in Hamilton Harbour, Humber Bay and Detroit River sediments

SEDIMENT	Tomato Organs	roots g	stems g	leaves g	fruit g	TOTAL (g)
HAMILTON	Fresh	8.8	133.6	126.0	110.6	369.0
HARBOUR	dry	1.9	13.3	14.5	8.2	38.0
HUMBER	Fresh	7.8	473.5	400.3	233.5	1115.1
BAY	dry	1.4	32.1	38.5	17.2	89.2
DETROIT	Fresh	3.6	99.3	85.0	81.1	269.0
RIVER	dry	0.9	8.1	8.1	5.2	23.3

TABLE 24

Water content of tomato organs grown in Hamilton Harbour, Humber Bay and Detroit River sediments

SEDIMENT	roots %	stems %	leaves %	fruit %
HAMILTON HARBOUR	78.0	90.3	88.5	92.5
HUMBER BAY	81.8	93.2	90.4	92.7
DETROIT RIVER	75.2	91.8	90.5	93.7

TABLE 25

Composition of tomato organs and corn (ppm in dry wight - mg/kg)

TOMATOES		Ca	Mg	K	Fe	As	Mo	Cr	Ni	Pb	Zn	Cs	Sr	Co	Mn	Cu	Hg (μg)
HAMILTON	Sedim.	21,800	4,600	1,600	40,500	1		330	66	1,100	4,160	15	240	17	1,600	136	5,300
HARBOUR	roots	18,900	6,400	12,000	4,750	7	3	15	5	46	440	2	350	15	300	41	210
	stem	26,000	19,000	28,000	25	.2	1	50	2	10	360	2	270	9	100	20	140
	leaves	60,000	16,000	17,000	490	.8	2	12	7	31	90	4	380	17	240	50	80
	fruit	500	1,700	35,000	5	n.d.	< 0.5	n.d.	n.d.	12	31	1	13	5	< 1	20	< 5
Corn - H.H.	whole plant	5,400	2,850	9,300	437	< 0.1	< 0.1	< 0.1	< 0.1	8	355	1	82	< 0.1	67	13	45
HUMBER	Sedim.	13,250	6,100	1,800	28,000	1		120	50	270	410	8	250	14	400	75	3,300
BAY	roots	25,300	5,500	23,000	1,500	4	2	25	10	32	310	4	440	10	100	47	180
	stem	34,000	12,000	60,000	25	.2	1	80	7	12	200	3	430	7	35	25	200
	leaves	54,000	8,700	37,000	480	.5	2	8	9	34	60	16	530	11	60	69	140
	fruit	1,500	1,700	37,000	3.0	n.d.	< 0.1	n.d.	n.d.	2	40	2	27	n.d.	< 1	23	< 5
Corn - H.B.	whole plant	4,900	2,000	14,500	260	< 0.1	< 0.1	< 0.1	< 0.1	7	200	5	75	< 0.1	22	18	50
DETROIT	Sedim.	11,750	11,600	1,600	32,800	n.d.		40	35	85	117	2	138	10	410	32	2,500
RIVER	roots	18,200	5,200	22,000	2,000	2	2	20	7	30	240	2	470	34	200	94	230
	stem	36,000	5,200	48,000	25	.2	1	50	7	12	270	4	530	6	90	23	160
	leaves	55,000	7,300	30,000	300	.5	2	7	7	25	30	6	600	12	60	87	140
	fruit	1,750	2,100	37,000	5	n.d.	< 0.1	n.d.	n.d.	3	25	1	30	7	< 1	20	< 5
Corn - D.R.	whole plant	4,300	2,000	13,300	185	< 0.1	< 0.1	< 0.1	< 0.1	5	167	2	70	< 0.1	32	21	35

TABLE 26

Quantities of elements contained in specific organs of tomato plant grown in Hamilton Harbour, Humber Bay and Detroit River sediments

(mg per one plant)

		Ca	Mg	K	Fe	As	Mo	Cr	Ni	Pb	Zn	Cd	Sr	Co	Mn	Cu	Hg
HAMILTON	Roots	36	12	23	9.29	14*	52*	29*	4*	89*	850*	4*	680*	29*	580*	79*	0.4*
HARBOUR	Stem	440	252	370	0.3	3*	13*	665*	26*	133*	4,800*	27*	3,600*	520*	1,330*	266*	1.86*
	Leaves	870	232	246	7.1	12*	29*	174*	101*	450*	1,300*	58*	5,500*	246*	3,400*	725*	1.24*
	Fruit	4	13	290	-	-	-	-	-	100*	260*	8*	100*	4*	-	166*	0.04*
	mg	1,350	509	929	16.7	0.029	0.094	0.87	0.13	0.77	7.2	0.097	9.9	0.74	5.3	1.2	
SEDIMENT	mg/kg	21,800	4,600	1,600	40,500	1	-	330	66	1,100	4,160	15	240	17	1,600	136	5.3
HUMBER	Roots	35	8	33	2.1	56*	28*	21*	147*	47*	440*	6*	0.6	14*	142*	67	0.25*
BAY	Stem	1,100	385	1,926	0.6	6*	32*	1,600*	224*	385*	642*	96*	13.8	224*	1,130*	800*	6.42*
	Leaves	2,080	334	1,430	18.6	19*	77*	410*	342*	1,300*	2,300*	620*	20.4	422*	2,300*	2,660*	5.4*
	Fruit	25	3	635	-	-	-	-	-	34*	690*	34*	0.5	-	-	400*	0.09*
	MG	3,240	730	4,014	21.3	0.08	0.137	2.0	0.58	1.8	4.1	0.76	35.3	0.66	3.6	3.9	
SEDIMENT	mg/kg	13,250	6,100	1,800	28,000	1		120	50	270	410	8	250	14	400	75	3.3
DETROIT	Roots	16	5	20	1.8	-	2*	18*	6*	29*	215*	2*	0.8	30*	180*	0.2	0.2*
	Stems	292	42	390	0.2	-	8*	405*	56*	96*	480*	32*	4.3	48*	729*	186*	1.3*
	Leaves	440	58	240	2.4	-	16*	56*	56*	200*	240*	48*	4.8	96*	480*	696*	1.1*
	Fruit	9	10	192	0.03	-	-	-	-	15*	130*	5*	0.2	36*		104*	0.03*
	mg	758	115	840	4.4	-	0.026	0.5	0.12	0.34	2.8	0.09	10.0	0.21	1.4	1.1	
SEDIMENT	mg/kg	11,750	11,600	1,600	32,800	n.d.	-	40	35	85	117	2	138	10	410	32	2.5

* x 10^{-3}

TABLE 27

	Element concentration gradient in tomato organs	Element concentration range in tomato fruit
Ca	L > S > R > F	500 - 1,750 mg/kg
Mg	S = L > S > F	1,700 - 2,100 mg/kg
K	S > F ⩾ L > R	35,000 - 37,000 mg/kg
Fe	R = L > S > F	3 - 5 mg/kg
Cr	S > R > L > F (n.d.)	n.d.
Ni	R = S = L > F (n.d.)	n.d.
Pb	R ⩾ L > S > F	2 - 12 mg/kg
Zn	R > S > L > F	25 - 40 mg/kg
Cd	L > S ⩾ R > F	1 - 2 mg/kg
Sr	L > S > R > F	13 - 30 mg/kg
Co	R = L > S = F	0 - 7 mg/kg
Mn	R > L > S > F	n.d.
Cu	L > R > S = F	20 mg/kg
As	R > S = L > F	n.d.
Mo	R > S = L > F	< 0.1 mg/kg
Hg	R > S > L > F	< 5 mg/kg

TABLE 28

Required amount of sediment to supply the amounts of elements consumed for the plant growth

A) evaluated from the element content in sediment

B) evaluated from the exchangeable amount

	HAMILTON HARBOUR					DETROIT RIVER					HUMBER BAY				
		A		B			A		B			A		B	
	Uptake mg/plant	Element content in sedi. mg/kg	Required amount kg	Exchangeable mg/kg	Required amount kg	Uptake mg/plant	Element content in sedi. mg/kg	Required amount kg	Exchangeable mg/kg	Required amount kg	Uptake mg/plant	Element content in sedi. mg/kg	Required amount kg	Exchangeable mg/kg	Required amount of sedi. kg
CALCIUM	1,350	21,800	0.06	820	1.6	758	11,700	0.07	602	1.3	3,240	13,250	0.24	720	4.5
MAGNESIUM	509	4,600	0.1	126	4.0	115	11,600	0.01	82	1.4	730	6,100	0.12	96	7.6
POTASSIUM	929	1,600	0.6	257	3.6	840	1,600	0.5	8	105	4,014	1,800	2.22	82	38
ZINC	7.2	4,100	0.002	363	0.02	2.8	117	0.02	10	0.3	4.1	410	0.01	8	0.5
MANGANESE	5.3	1,600	0.004	176	0.03	1.4	410	0.004	36	0.04	3.6	400	0.009	83	0.4
COPPER	1.2	136	0.009	25	0.05	1.1	32 32	0.04	25	0.04	3.9	75	0.05	25	0.15
IRON	6.7	40,500	0.0004	4	4.1	4.4	32,800	0.0001	trace (1)	4.4	21.3	28,000	0.0008	trace (1)	21

TABLE 29

Total concentrations of trace elements typically found in soils and plants

Element	Conc. in Soils (μg/g) Common	Range	Conc. in Plants (μg/g) Normal	Toxic
As	6	0.1 - 40	0.1 - 5	-
B	10	2 - 100	30-75	>75
Cd	0.06	0.01- 7	0.2 - 0.8	-
Cr	100	5 - 3000	0.2 - 1.0	-
Co	8	1 - 40	0.05- 0.5	-
Cu	20	2 - 100	4 - 15	>20
Pb	10	2 - 200	0.1 - 10	-
Mn	850	100 - 4000	15 - 100	-
Mo	2	0.2 - 5	1 - 100	-
Ni	40	10 - 1000	1	>50
Se	0.5	0.1 - 2.0	0.02- 2.0	50 - 100
V	100	20 - 500	0.1 - 10	>10
Zn	50	10 - 300	15 - 200	>200

FROM: Page, A. L. (1973)

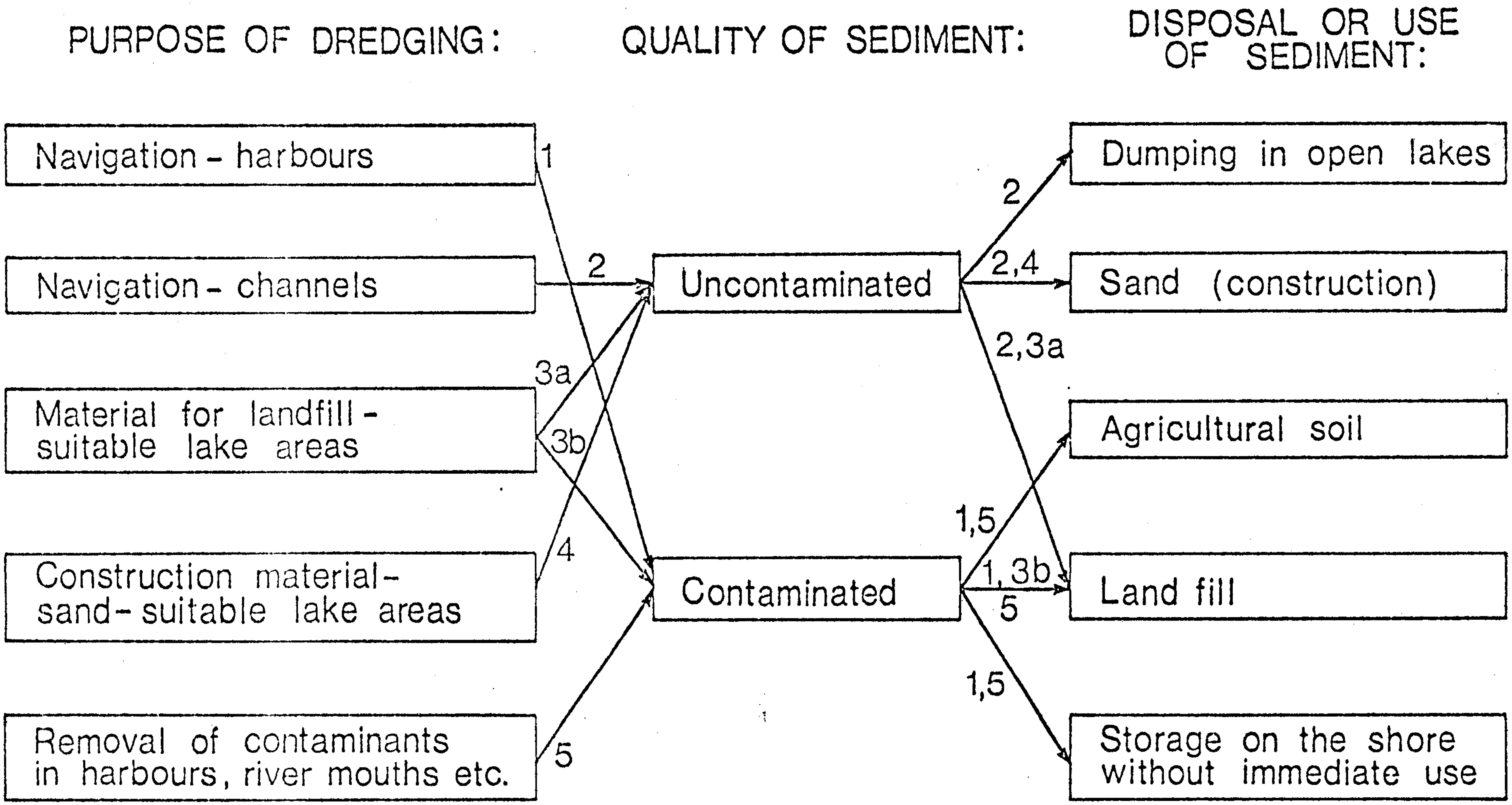


Figure 1. Relationship between the purpose of dredging, quality of sediments and disposal or use of sediments

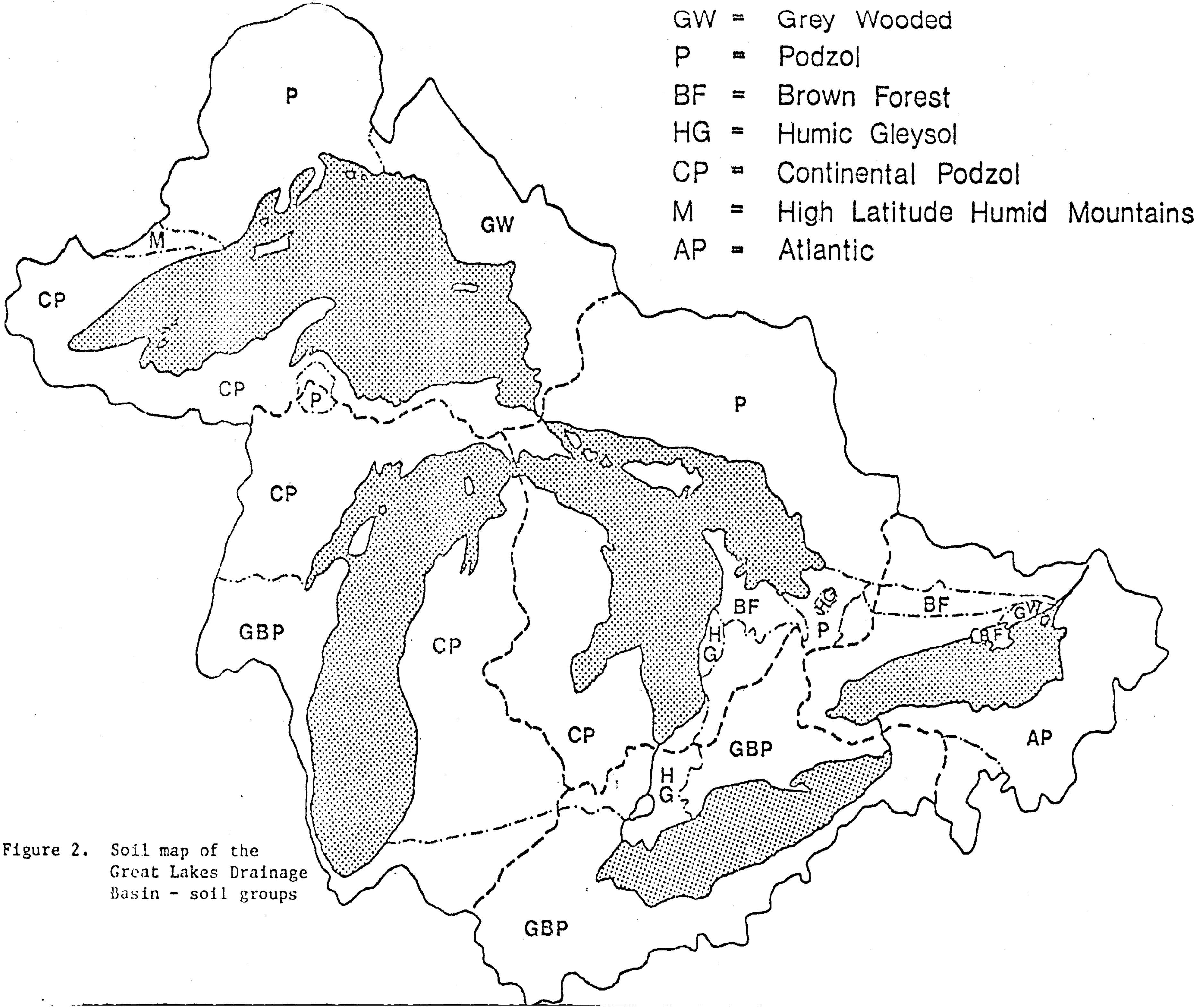
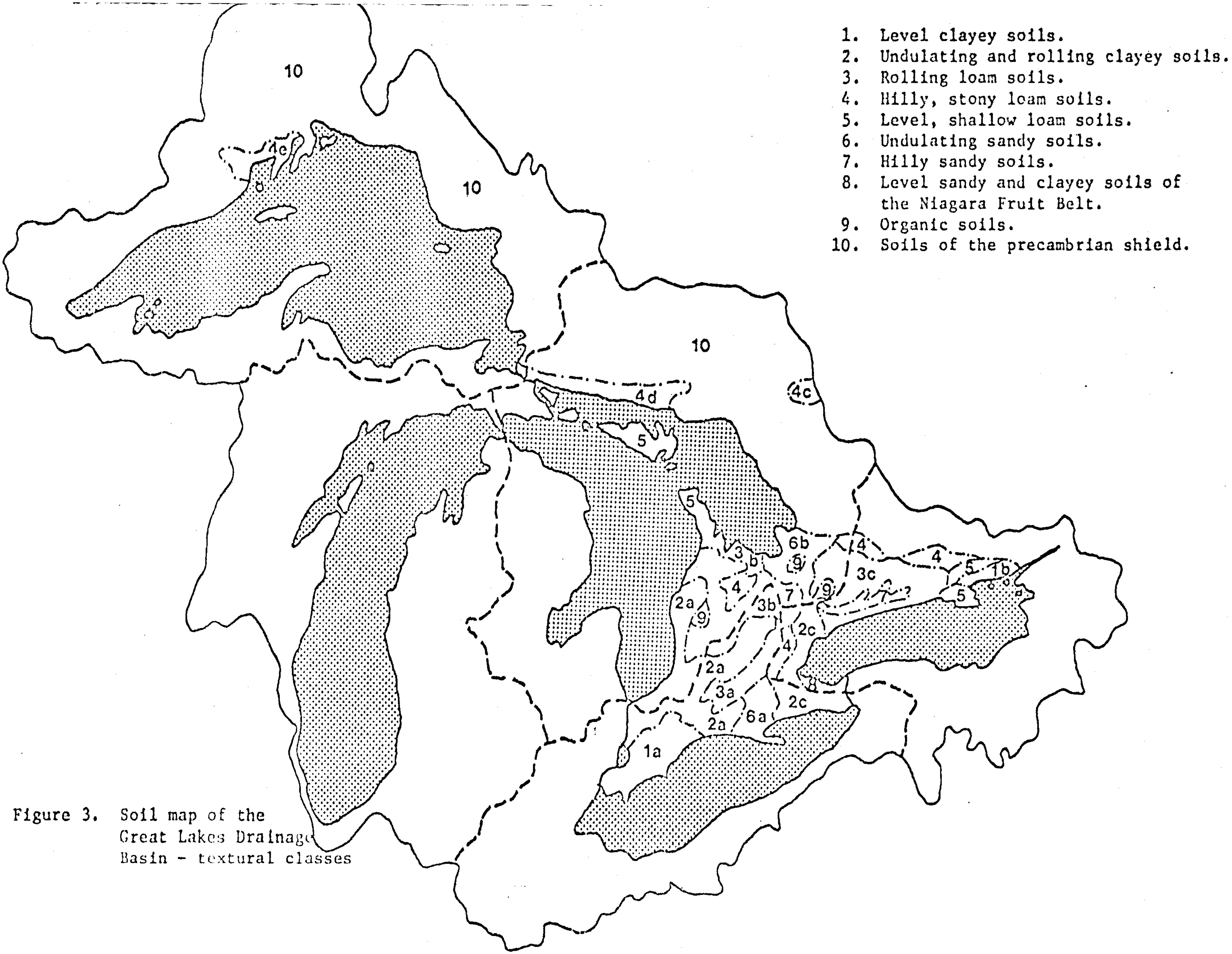
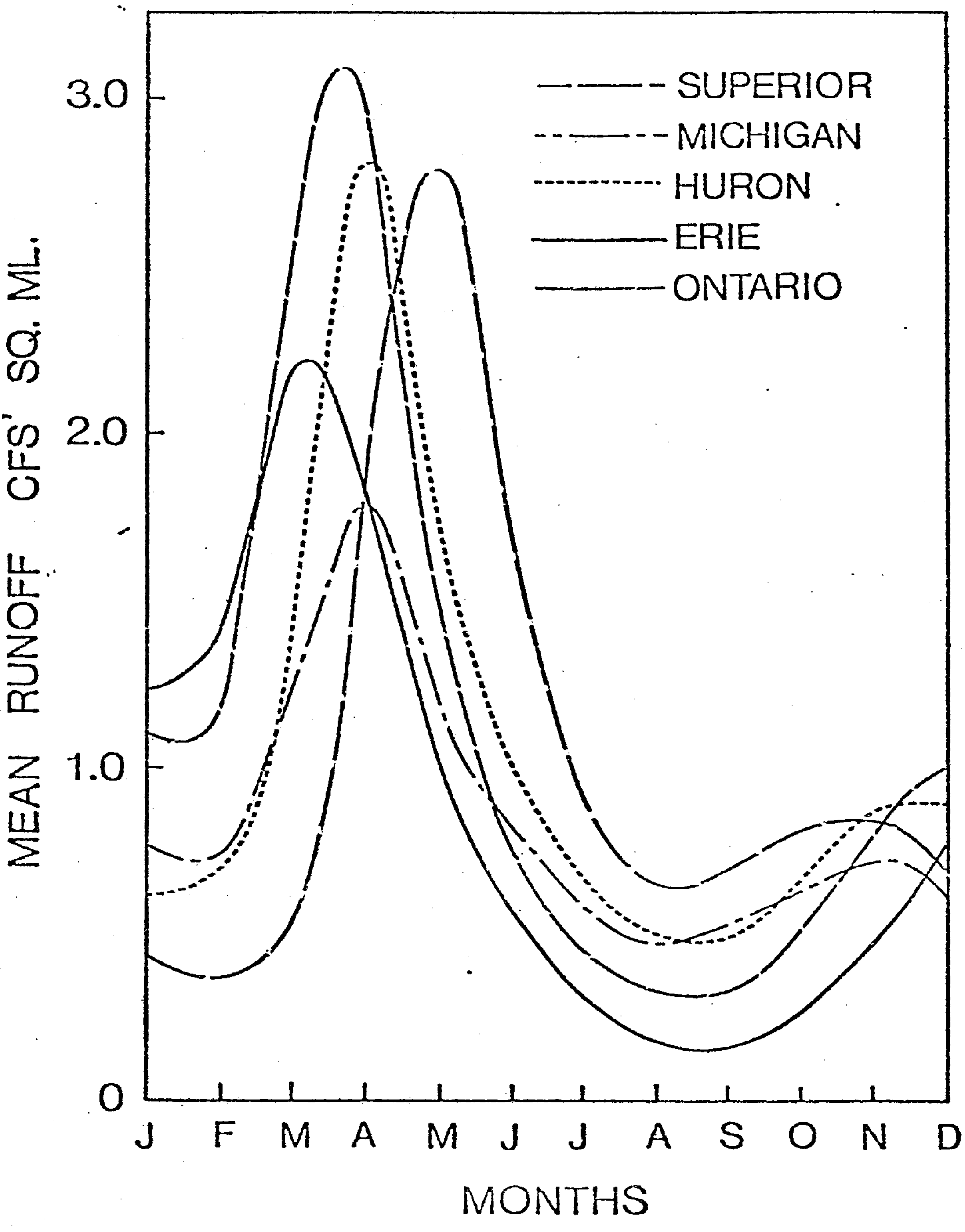


Figure 2. Soil map of the Great Lakes Drainage Basin - soil groups



1. Level clayey soils.
2. Undulating and rolling clayey soils.
3. Rolling loam soils.
4. Hilly, stony loam soils.
5. Level, shallow loam soils.
6. Undulating sandy soils.
7. Hilly sandy soils.
8. Level sandy and clayey soils of the Niagara Fruit Belt.
9. Organic soils.
10. Soils of the precambrian shield.

Figure 3. Soil map of the Great Lakes Drainage Basin - textural classes



RUNOFF CHARACTERISTICS

Figure 4. Great Lakes seasonal runoff distribution

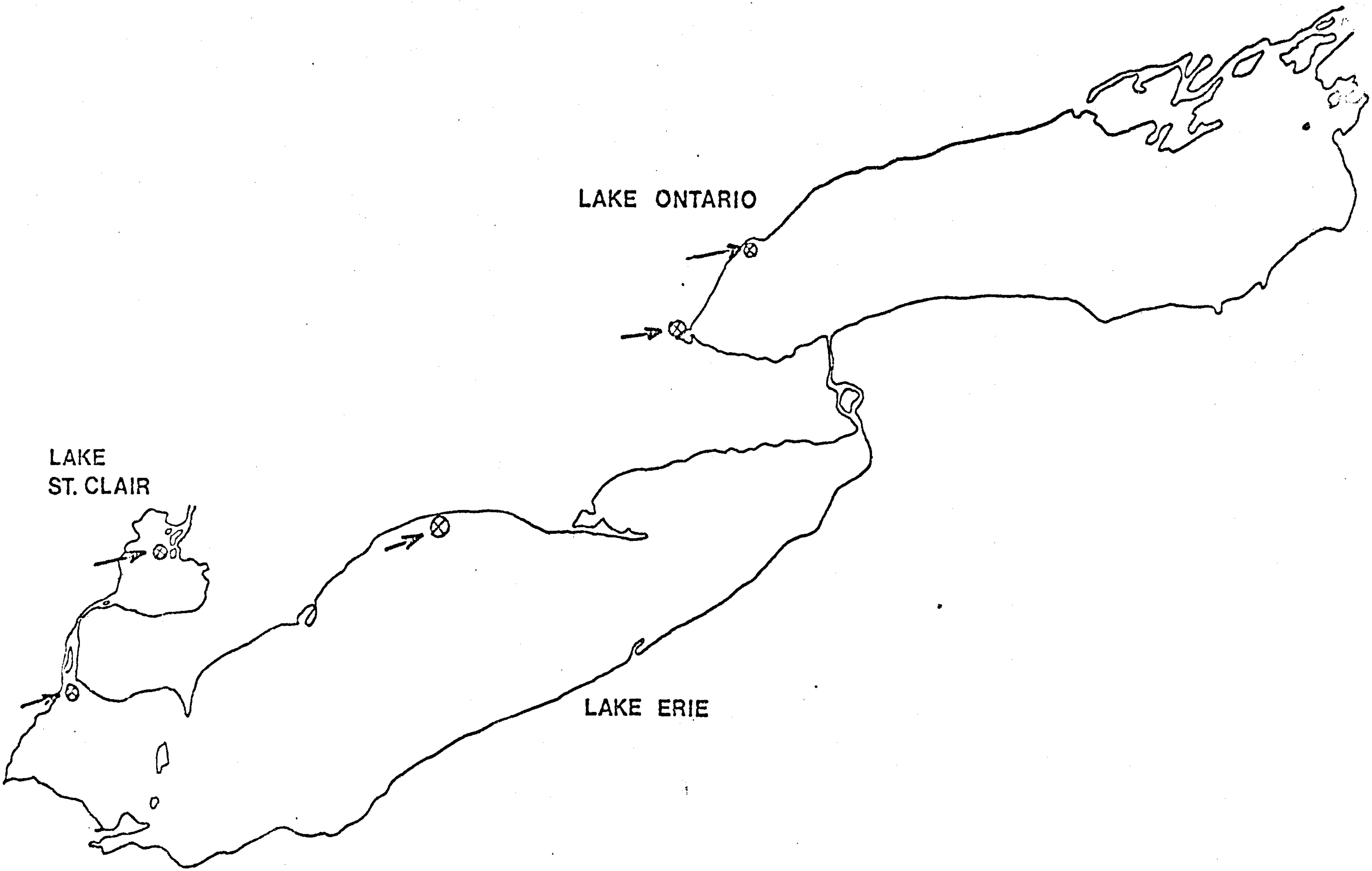


Figure 5. Sampling locations - general

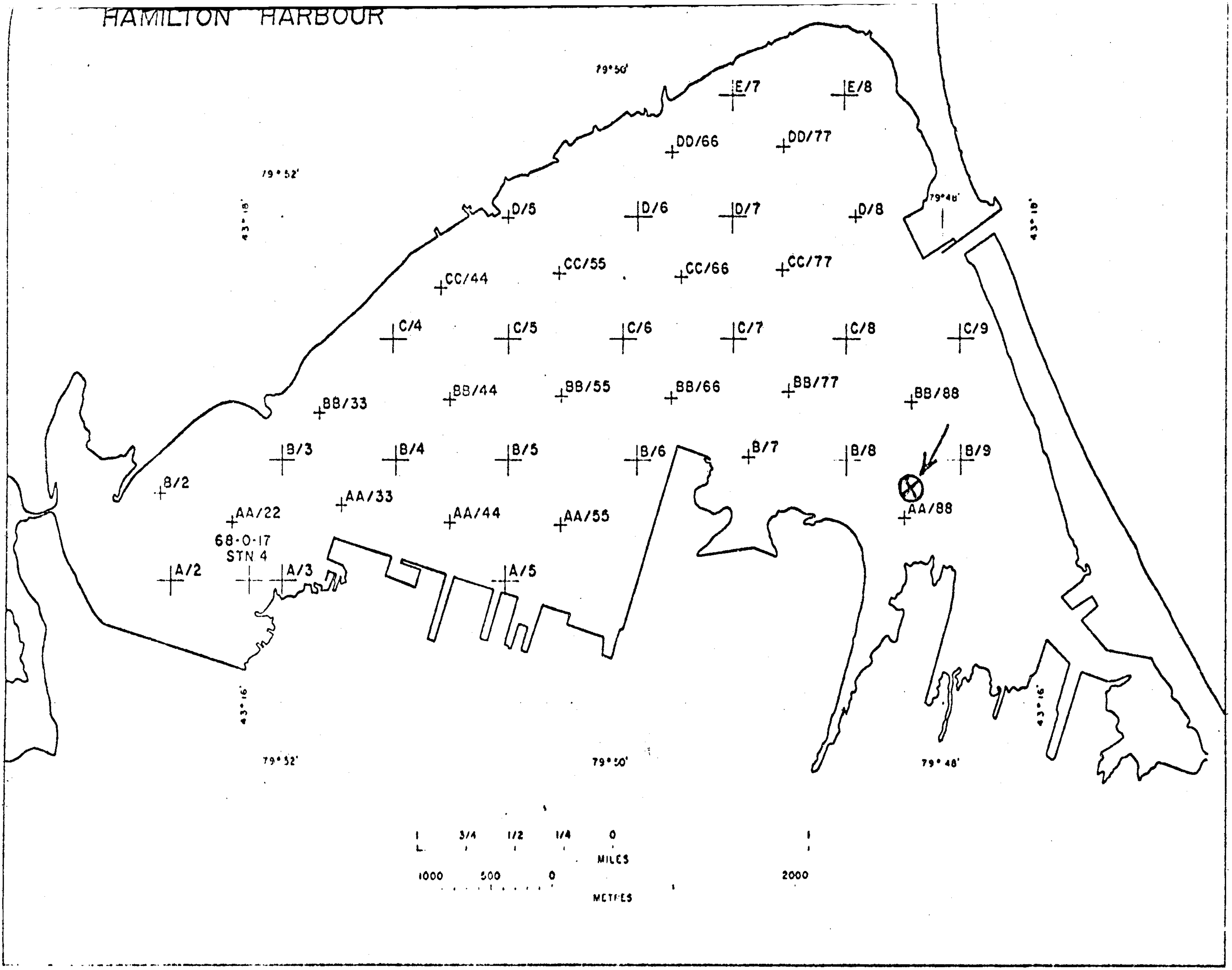


Figure 6. Sampling location - Hamilton Harbour

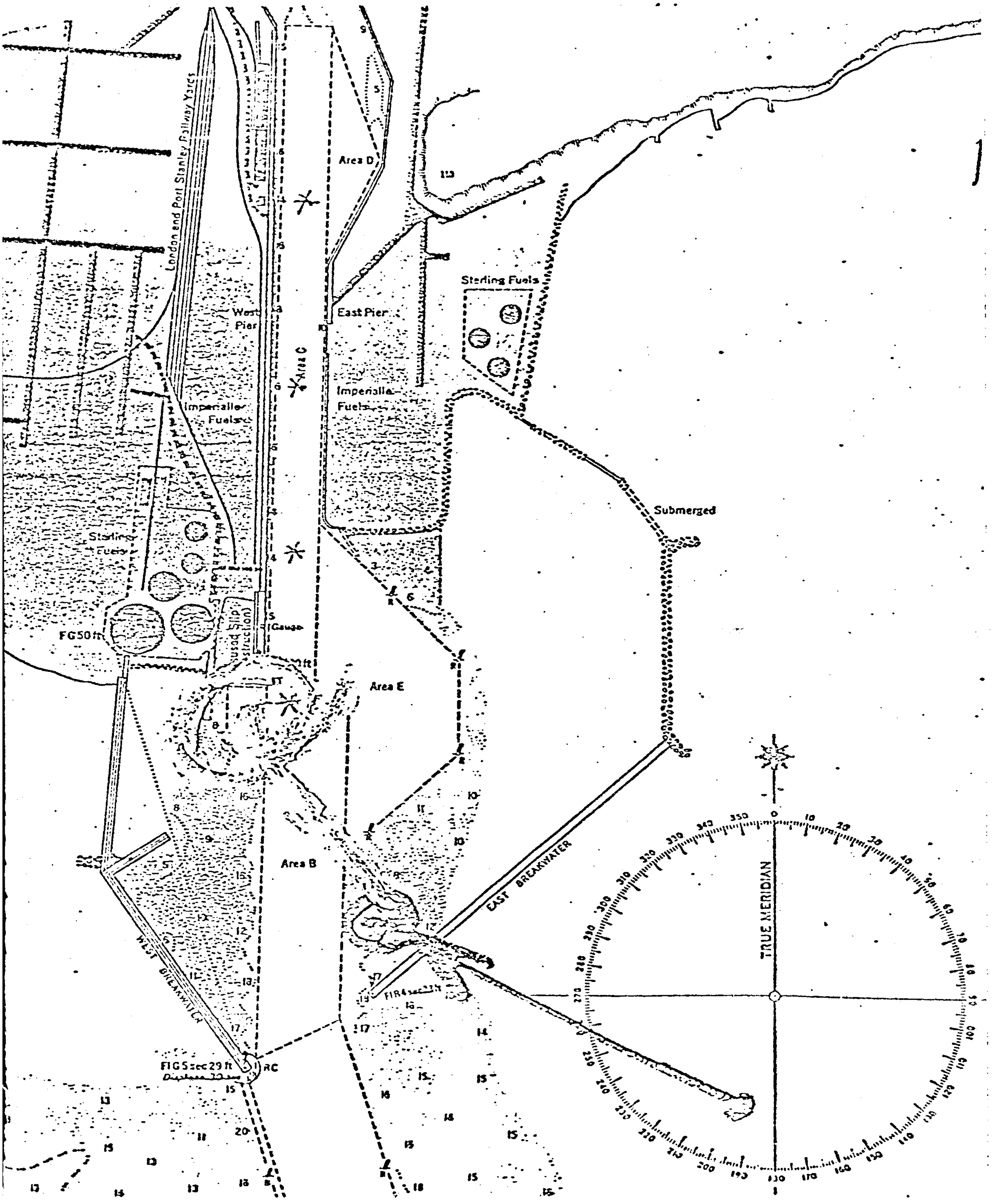


Figure 7. Sampling location - Port Stanley

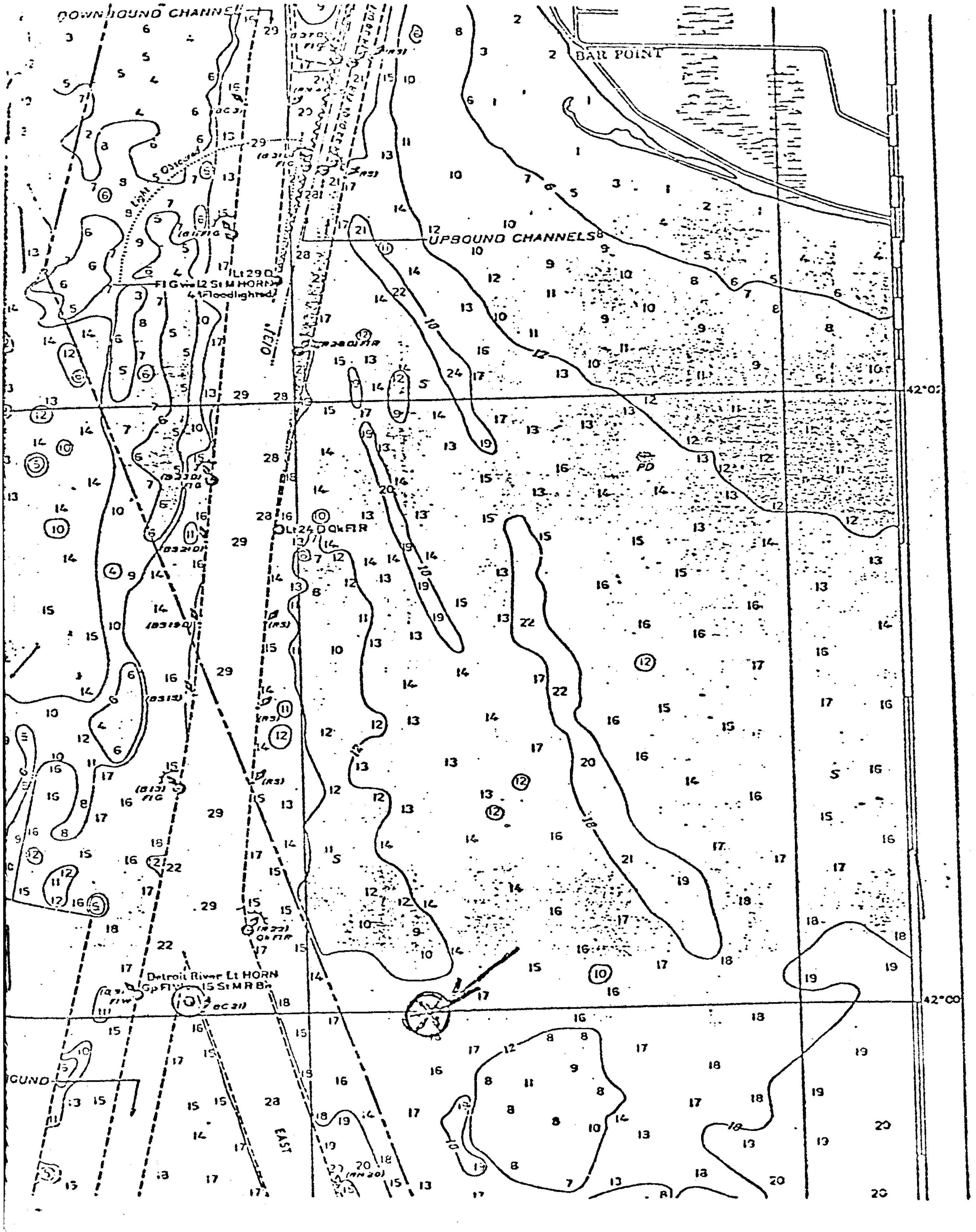


Figure 8. Sampling location - Detroit River Mouth

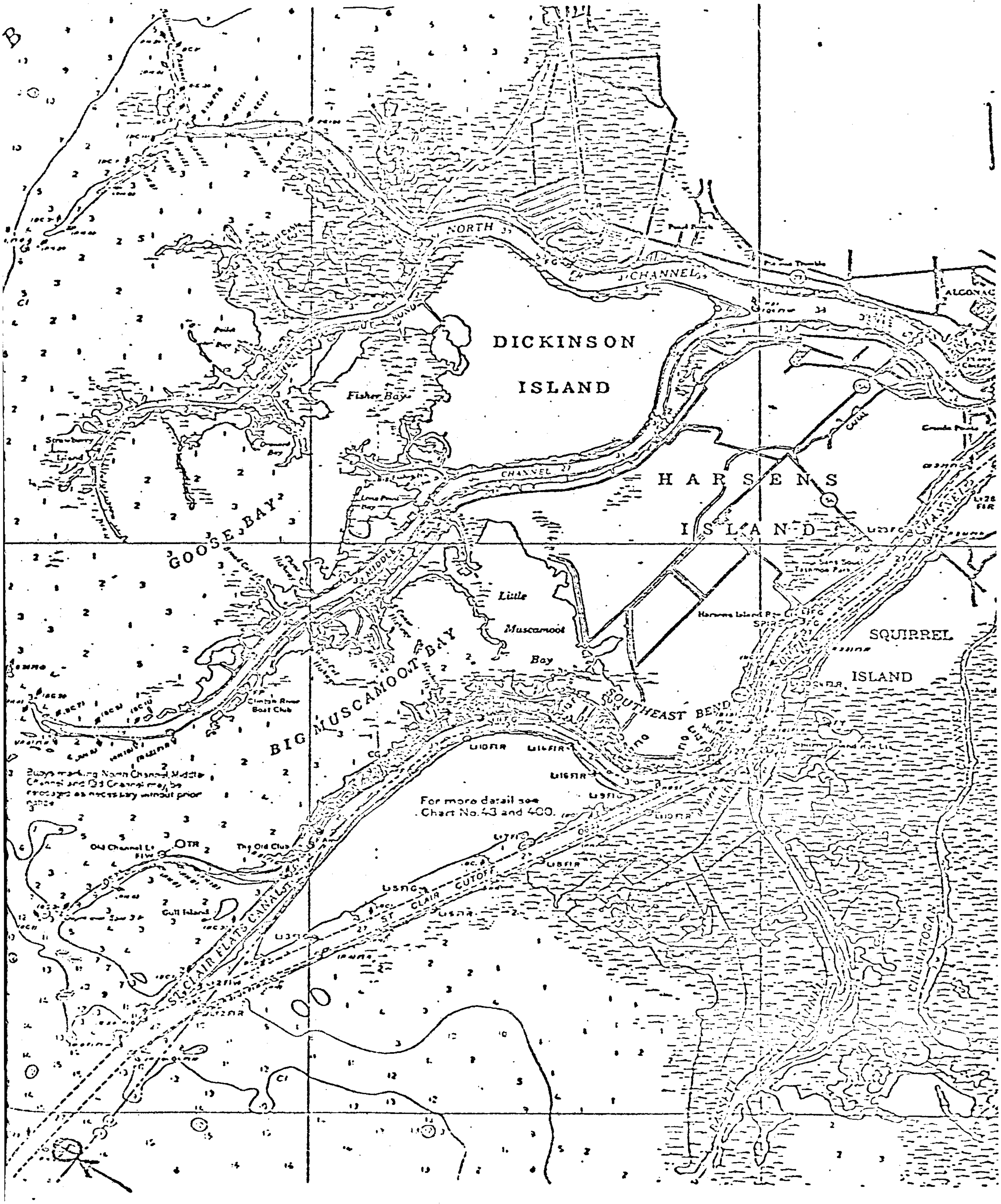


Figure 9. Sampling location - Lake St. Clair

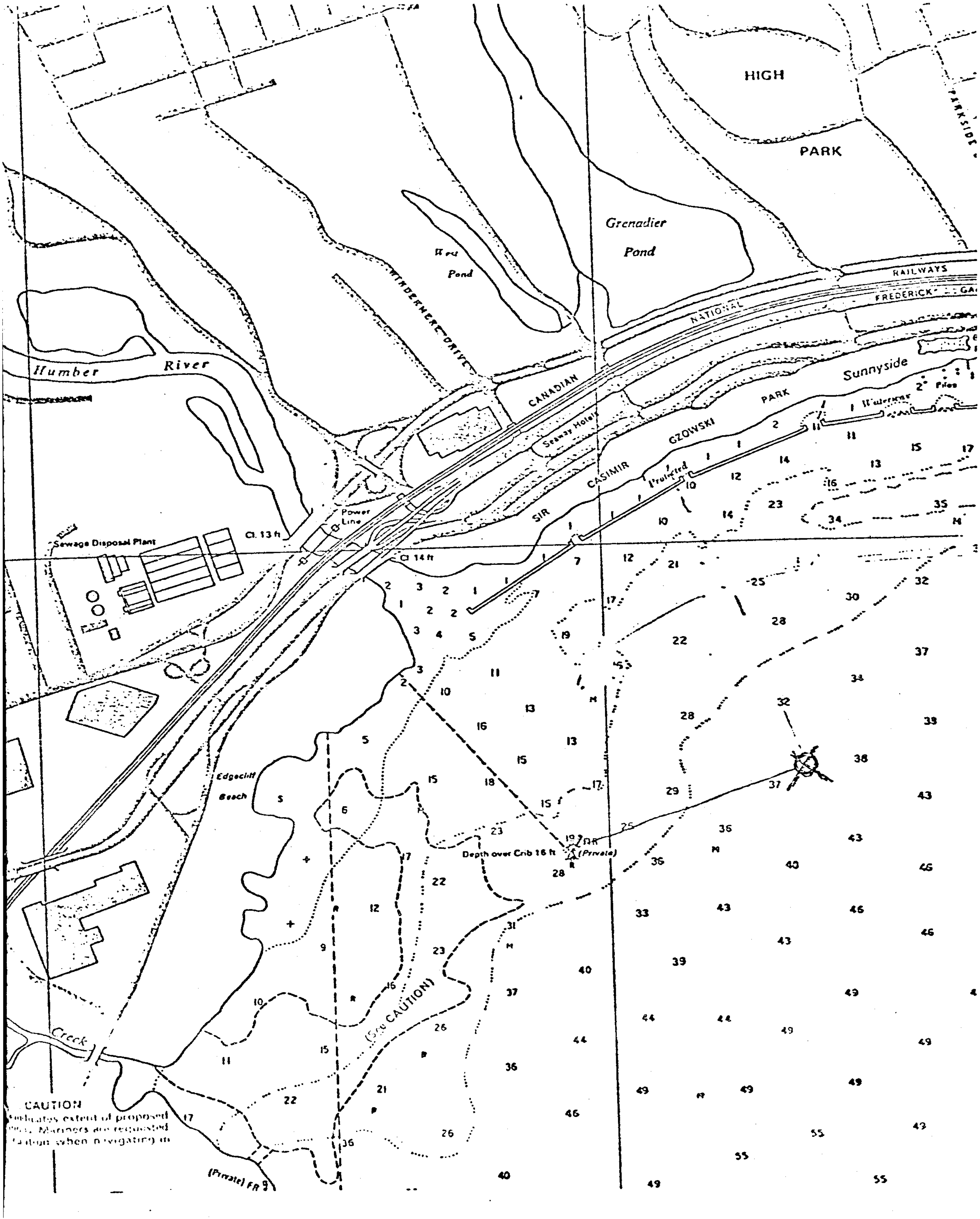


Figure 10. Sampling location - Humber Bay

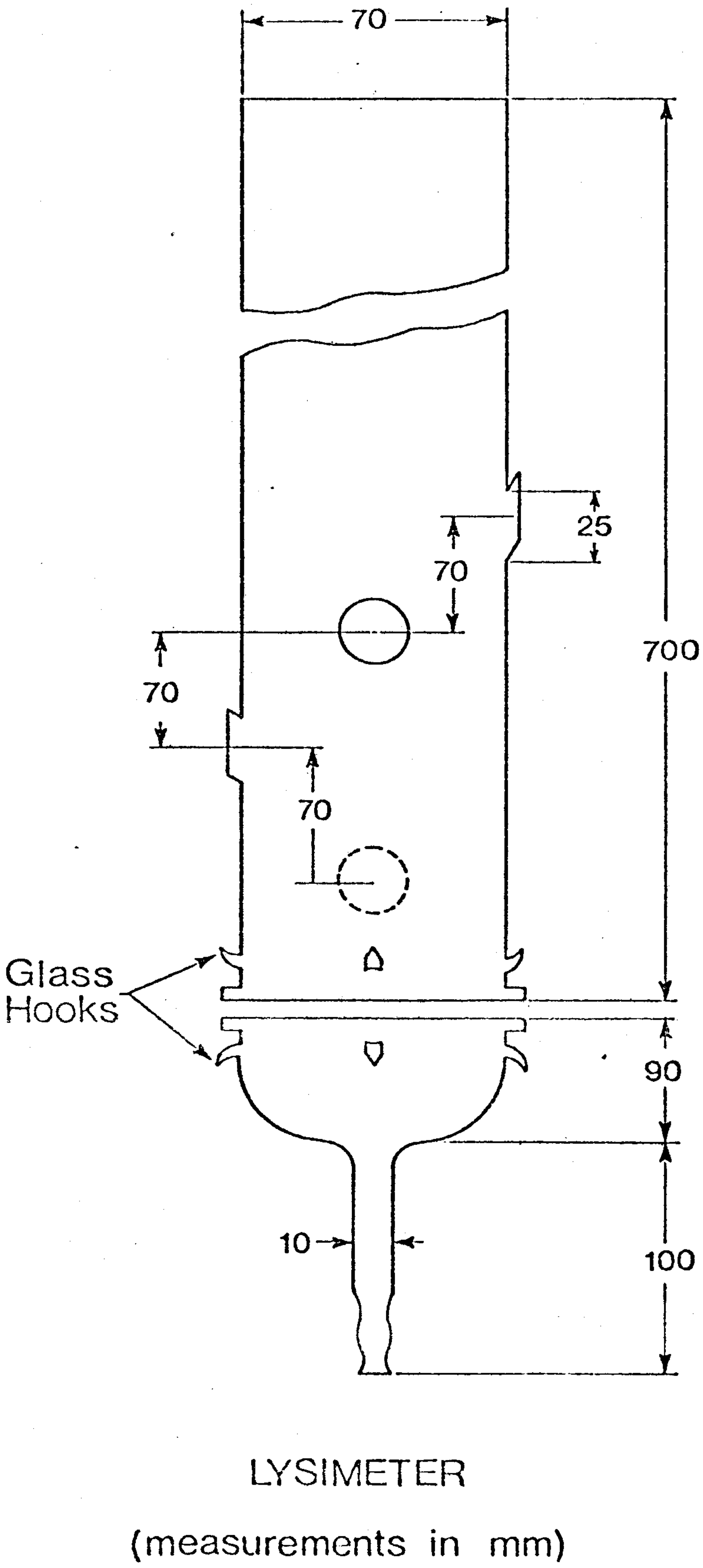


Figure 11. Schema of a lysimeter

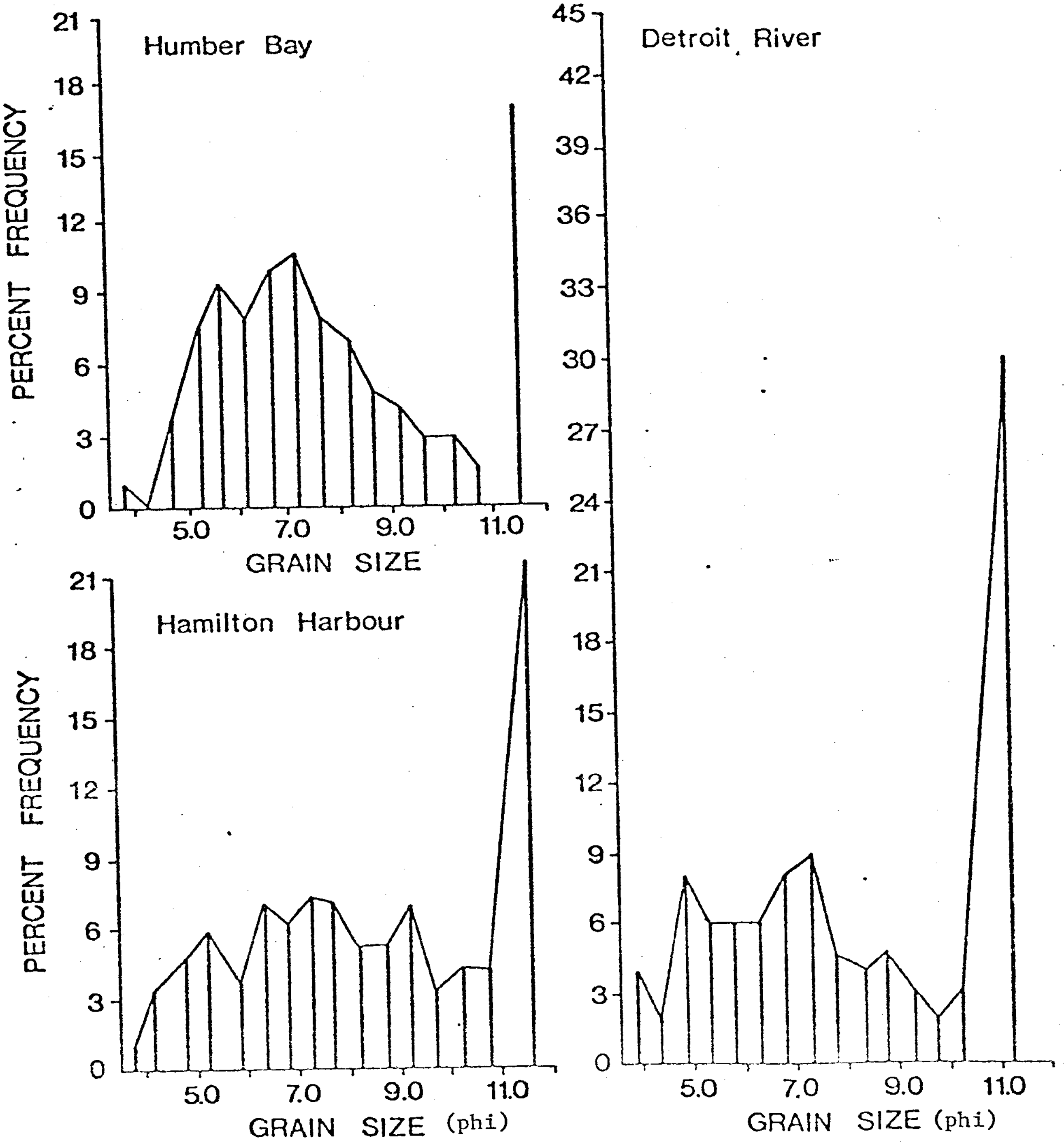


Figure 12. Particle size distribution of collected sediments

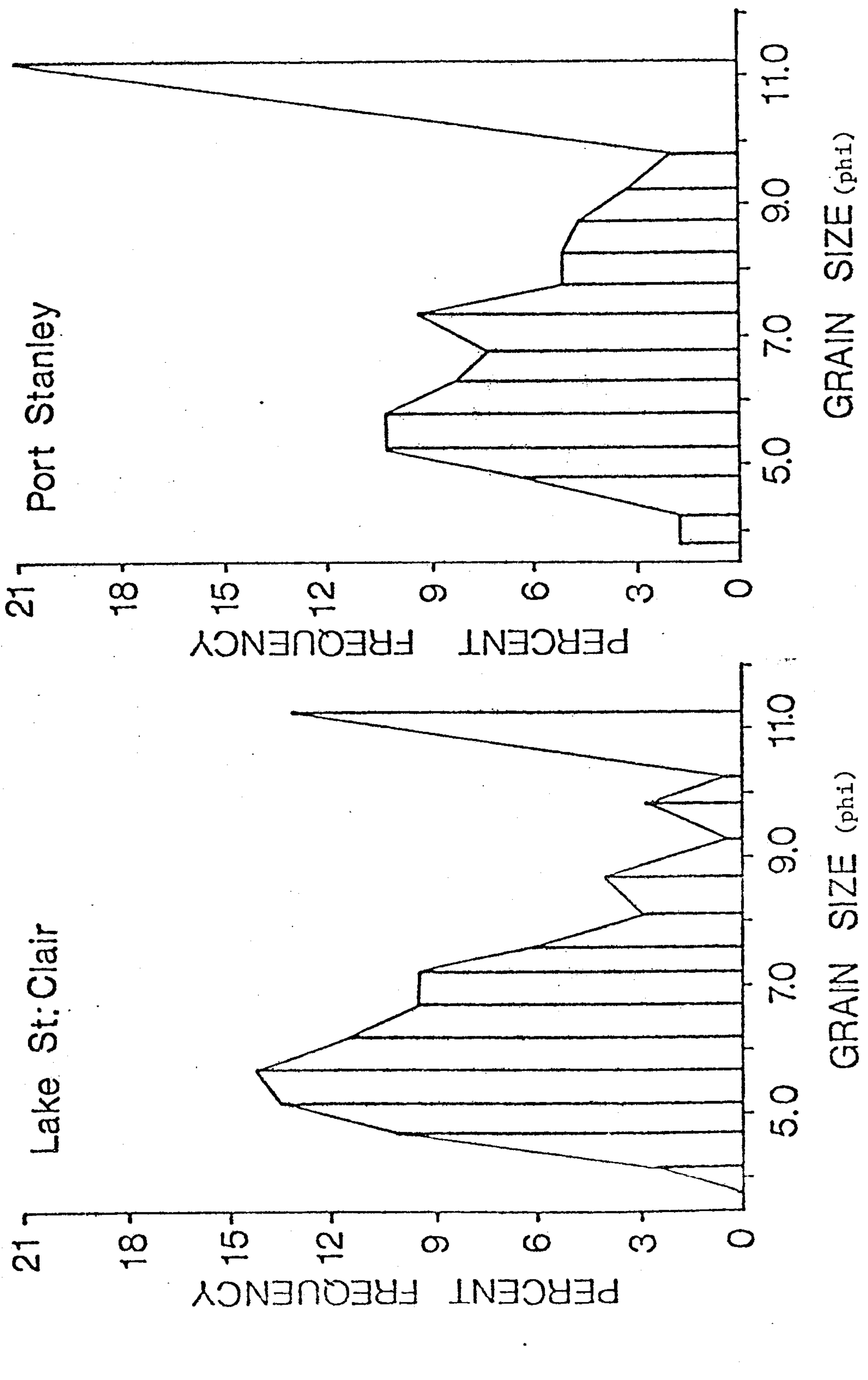


Figure 13. Particle size distribution of collected sediments

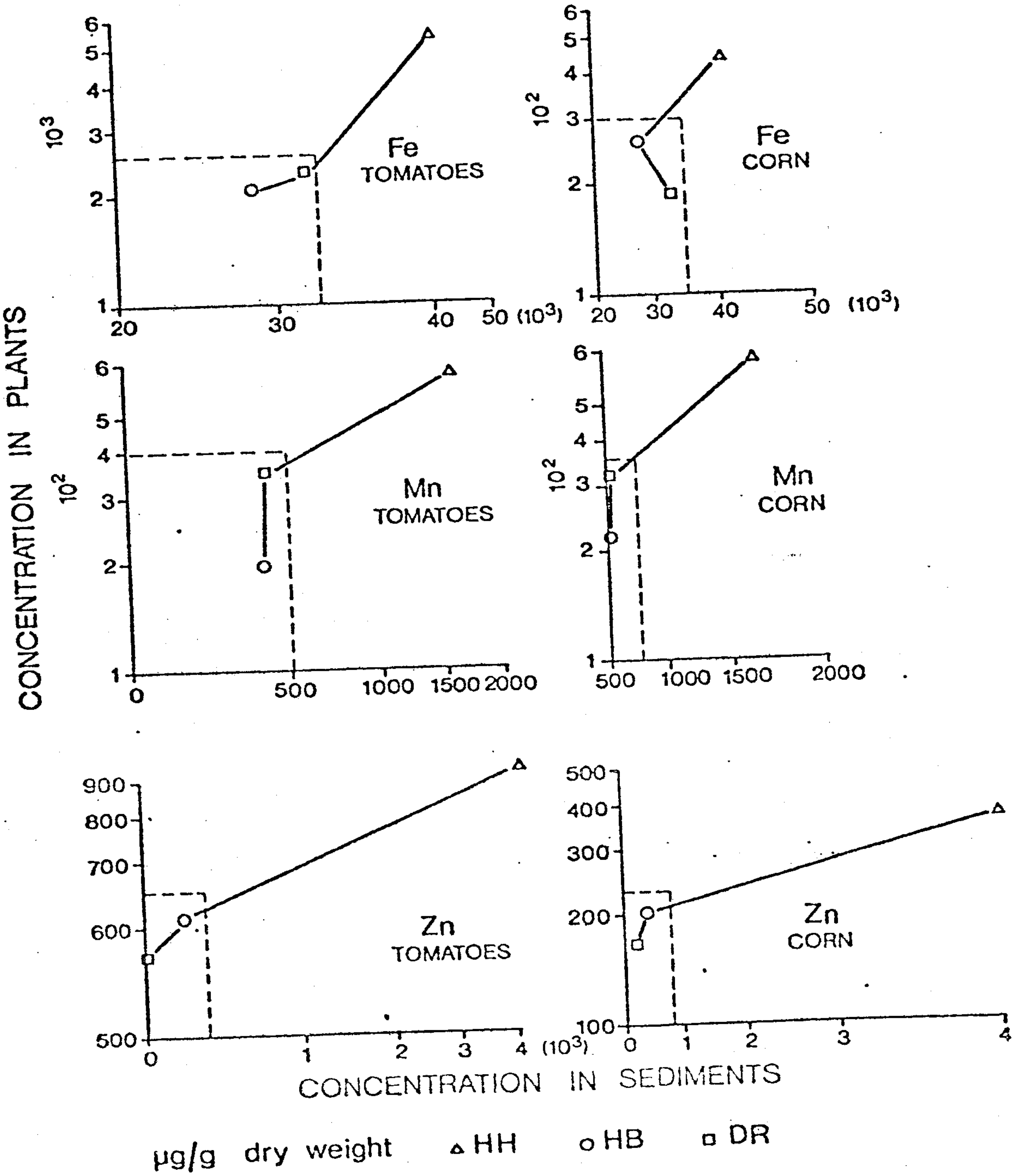


Figure 14. Relationship between the element concentration in Hamilton Harbour, Humber Bay and Detroit River sediments and its concentration in the tomato fruit and corn

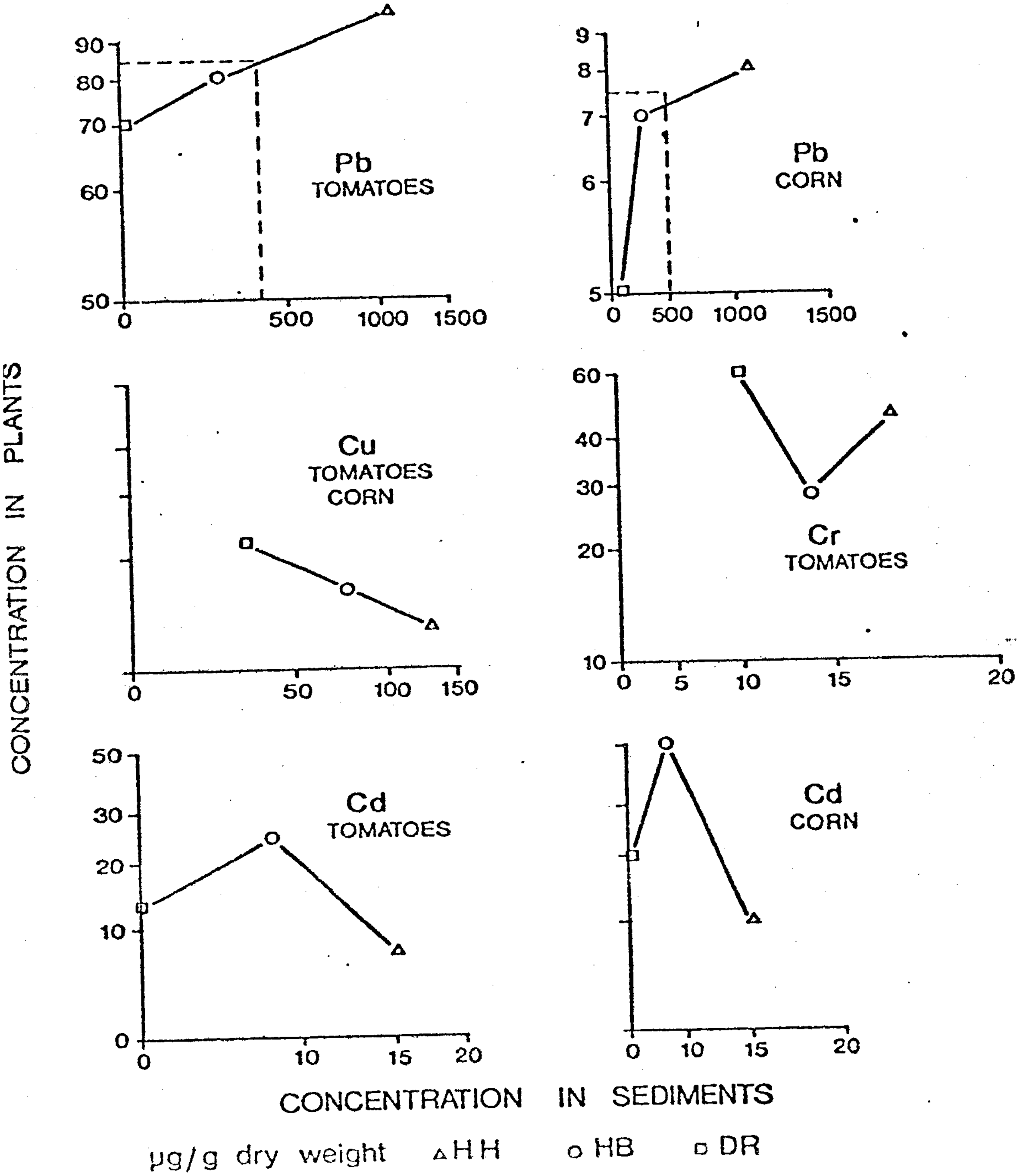


Figure 14 (Cont.) Relationship between the element concentration in Hamilton Harbour, Humber Bay and Detroit River sediments and its concentration in the tomato fruit and corn

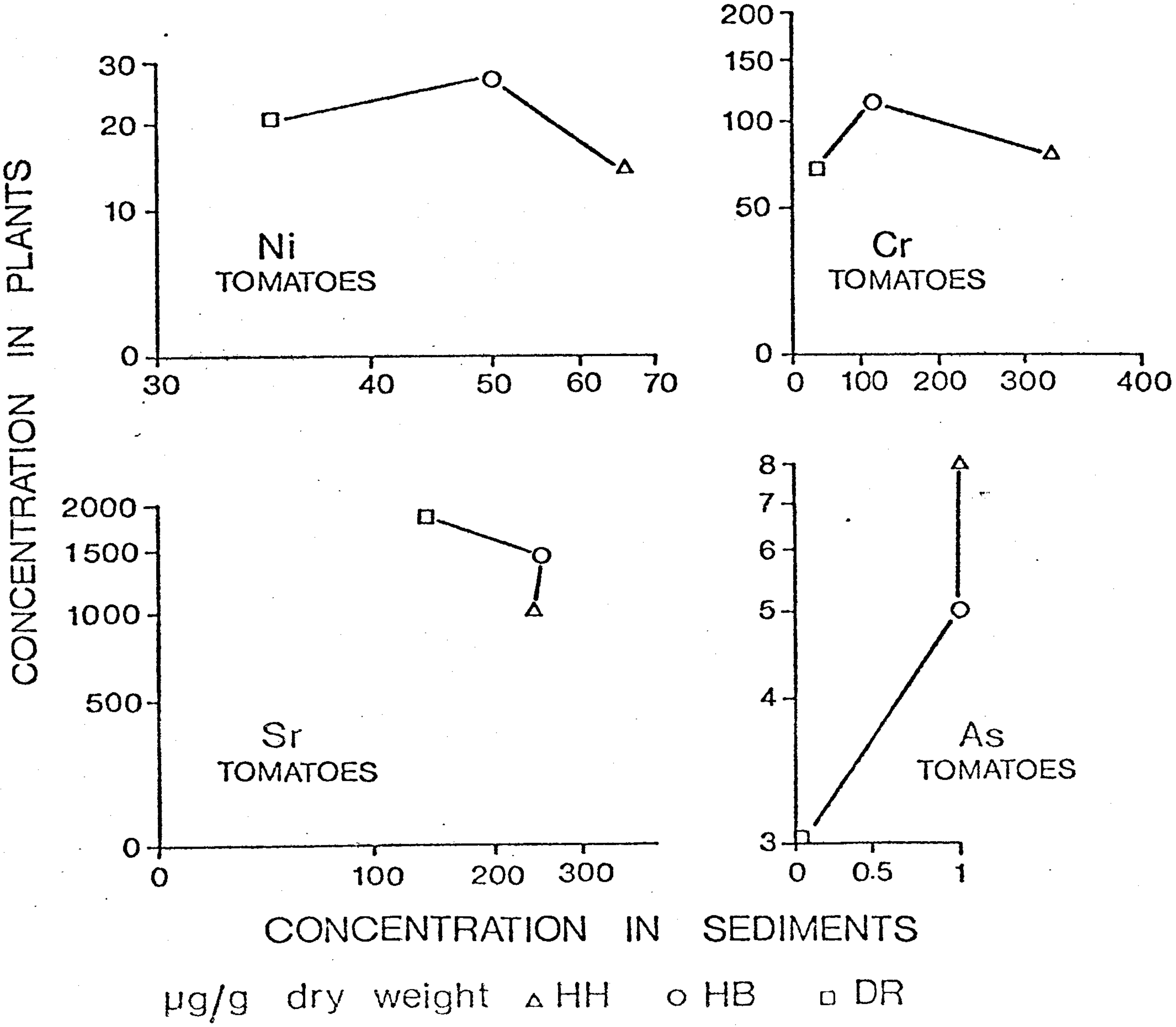


Figure 14 (Cont.) Relationship between the element concentration in Hamilton Harbour, Humber Bay and Detroit River sediments and its concentration in the tomato fruit and corn

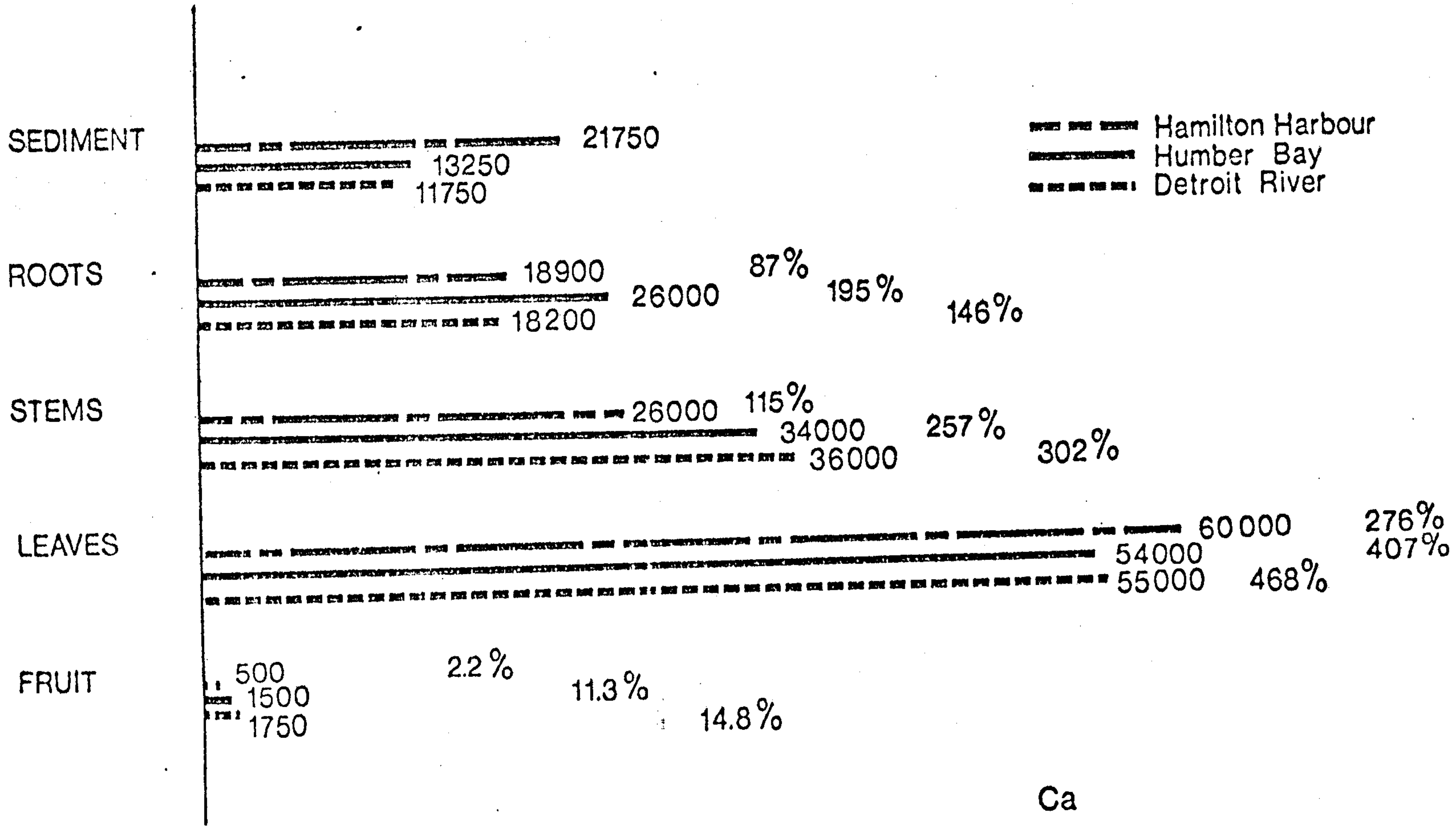


Figure 15.1. Calcium concentration in sediments and organs of tomato grown in these sediments

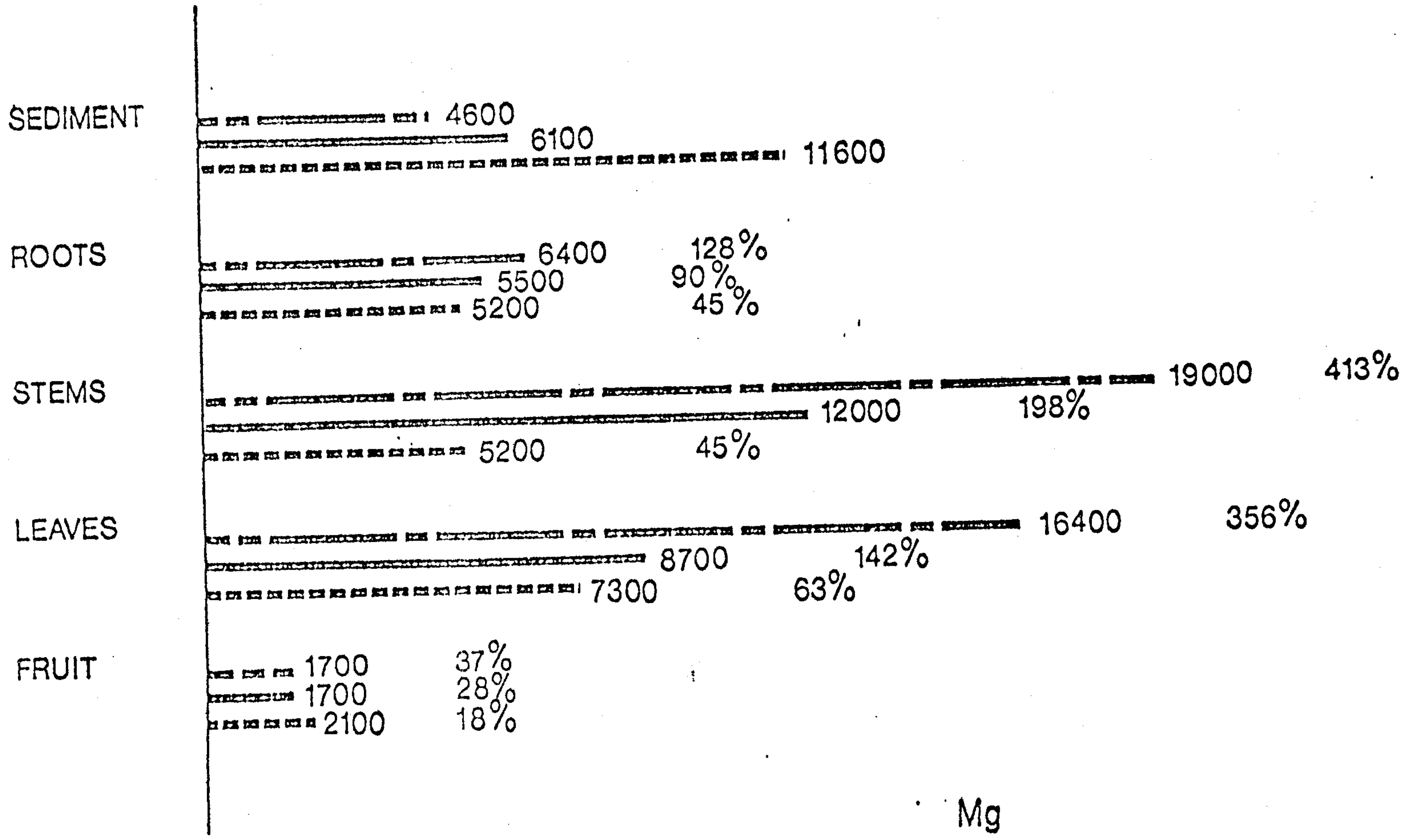


Figure 15.2. Magnesium concentration in sediments and organs of tomato grown in these sediments

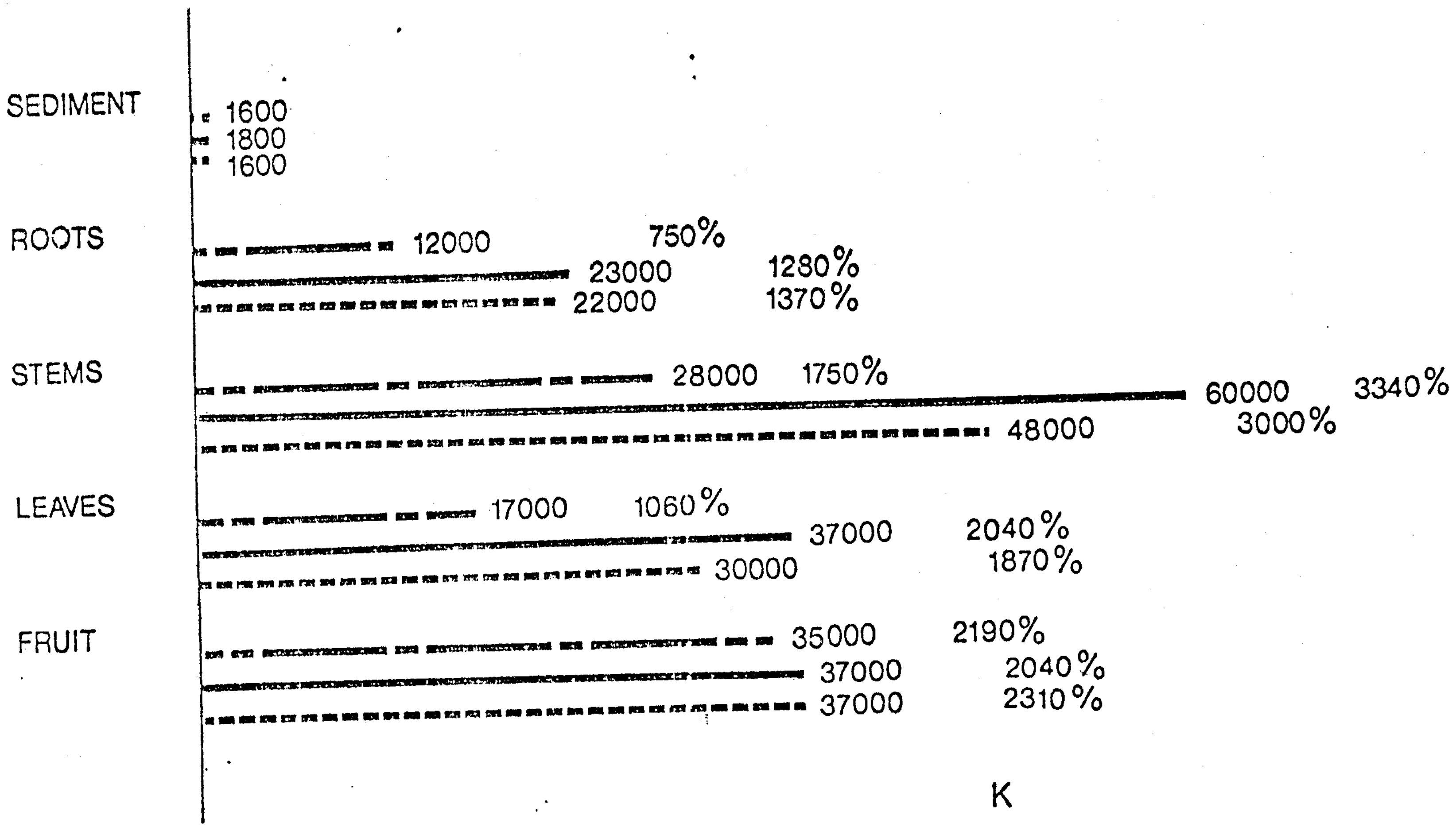


Figure 15.3. Potassium concentration in sediments and organs of tomato grown in these sediments

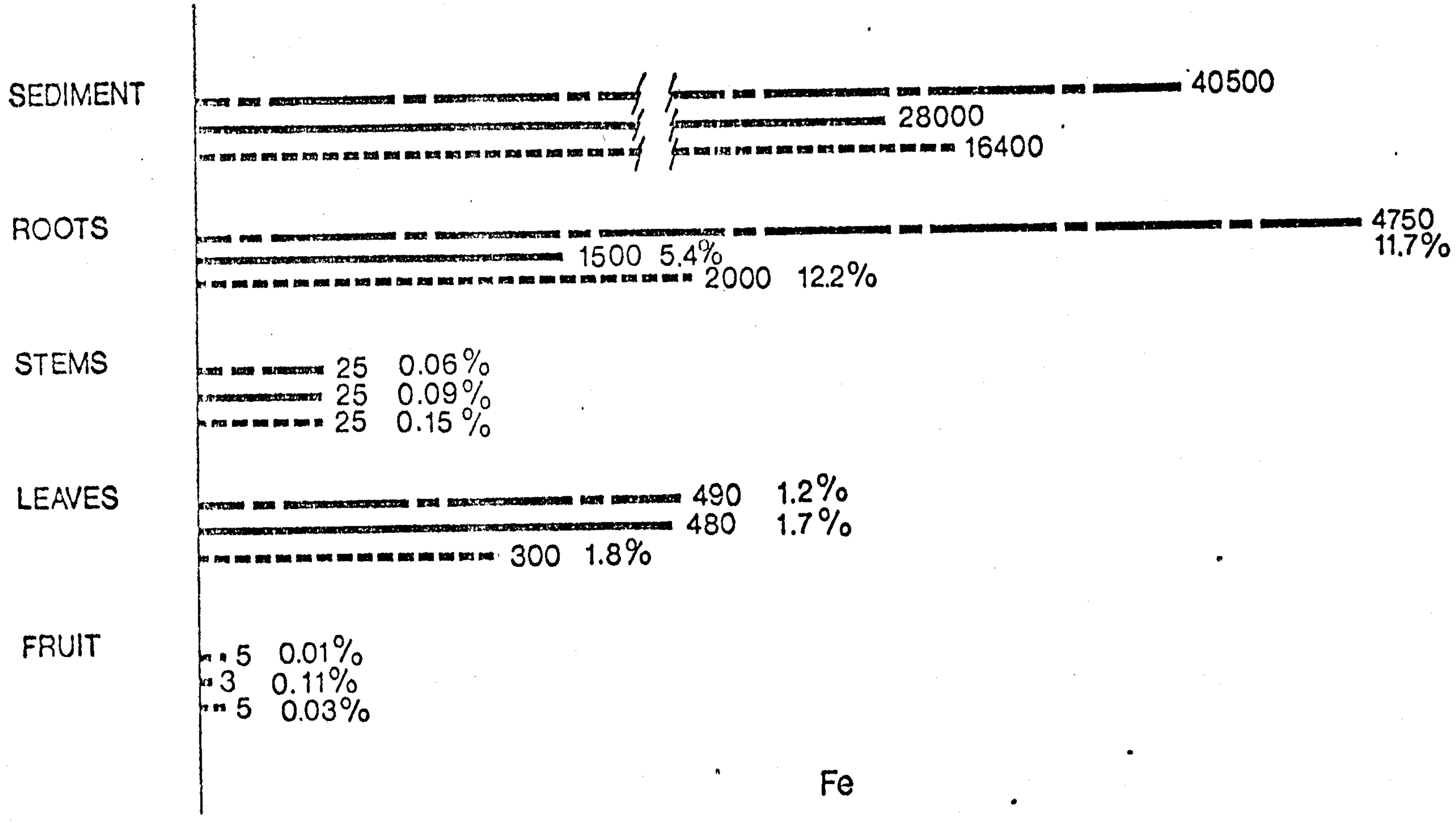


Figure 15.4. Iron concentration in sediments and organs of tomato grown in these sediments

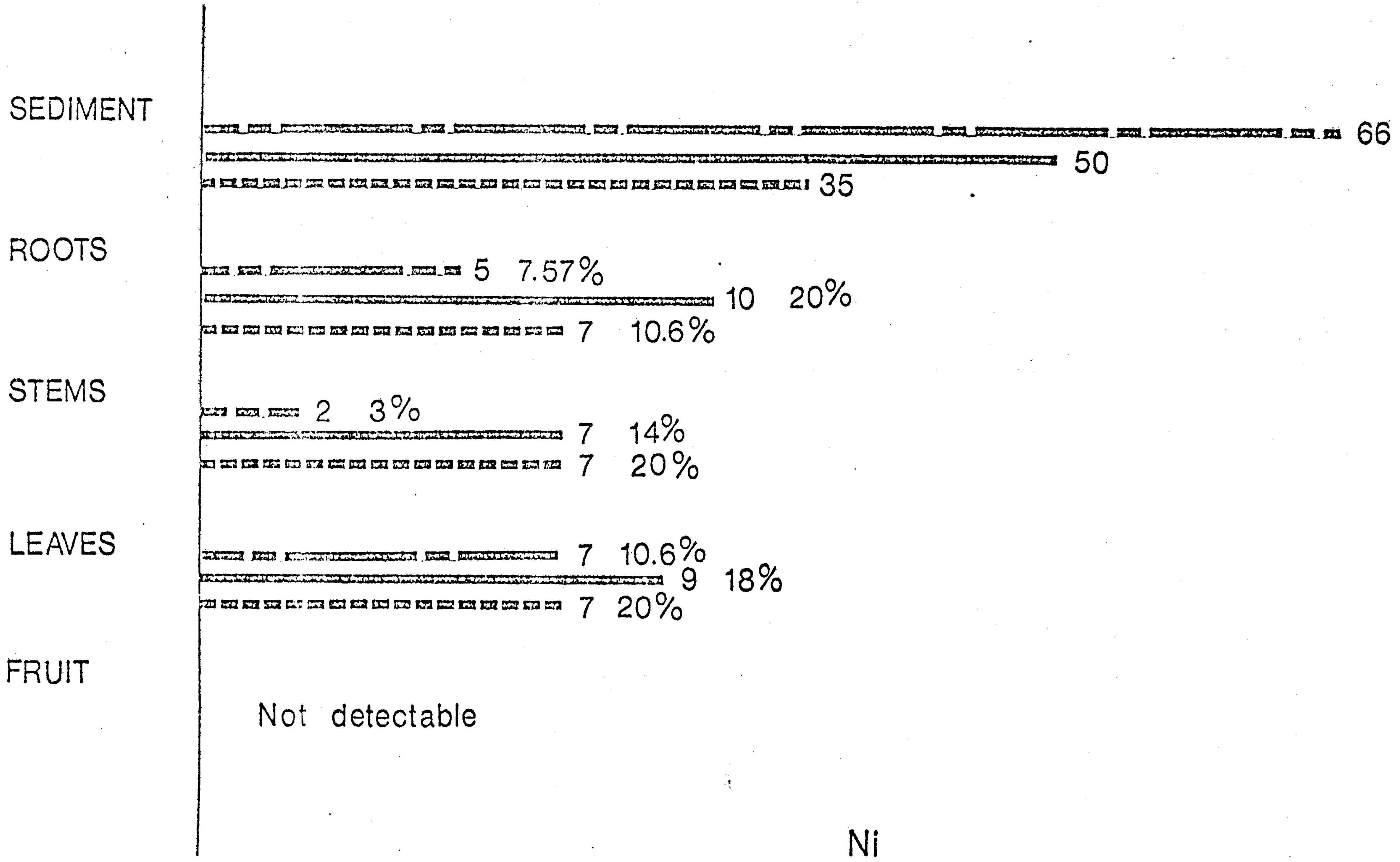


Figure 15.5. Nickel concentration in sediments and organs of tomato grown in these sediments

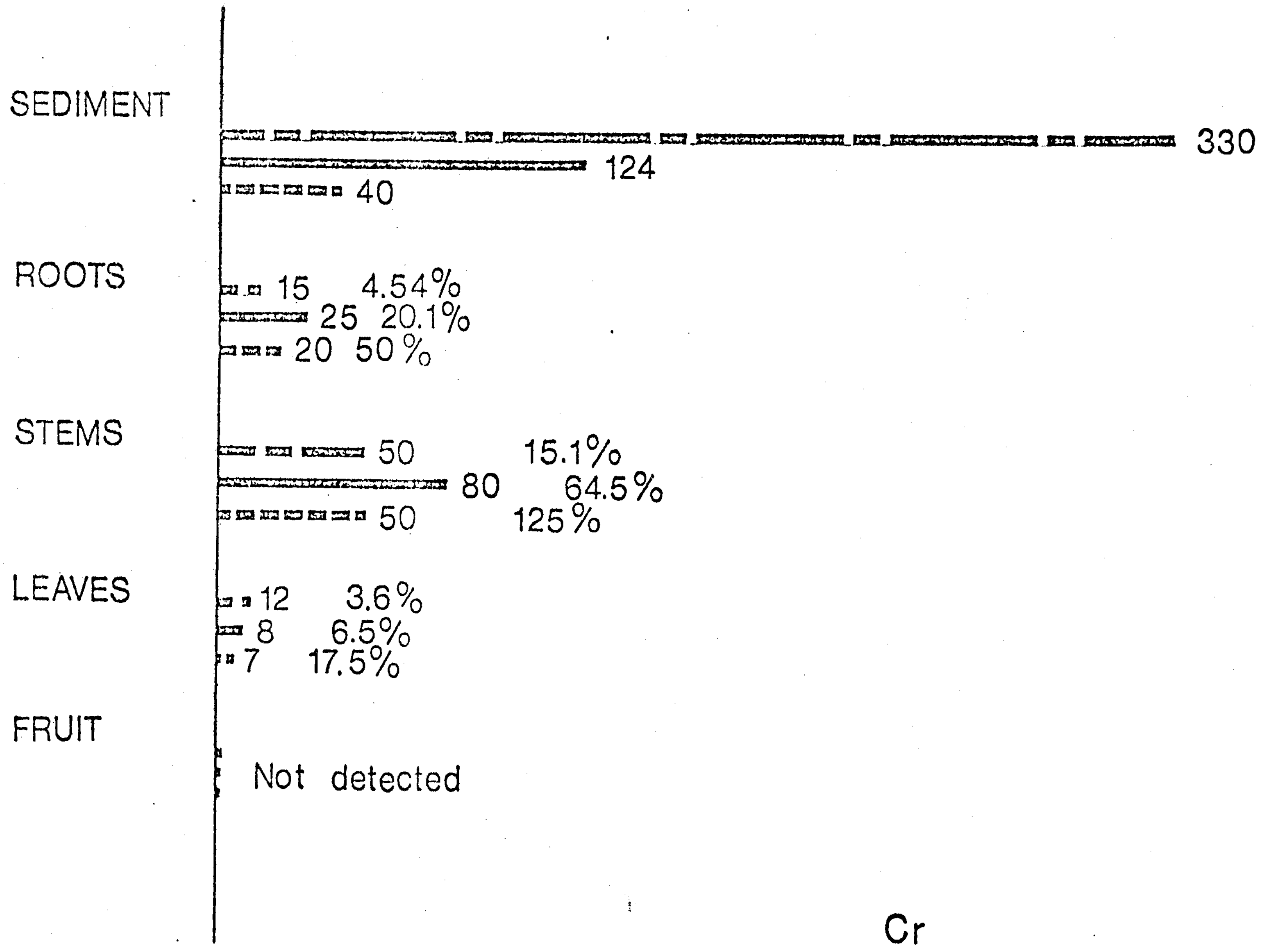


Figure 15.6. Chromium concentration in sediments and organs of tomato grown in these sediments

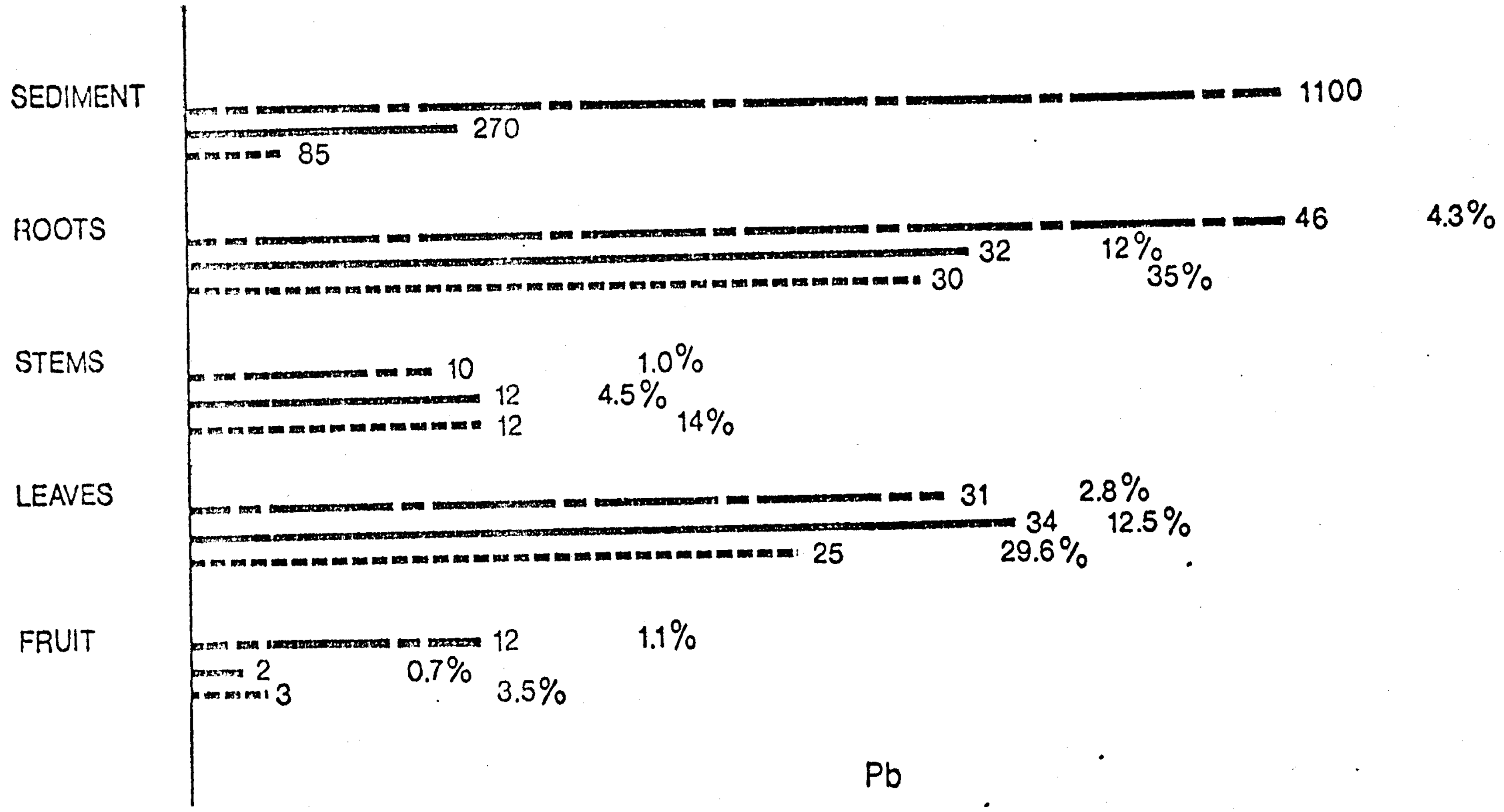


Figure 15.7. Lead concentration in sediments and organs of tomato grown in these sediments

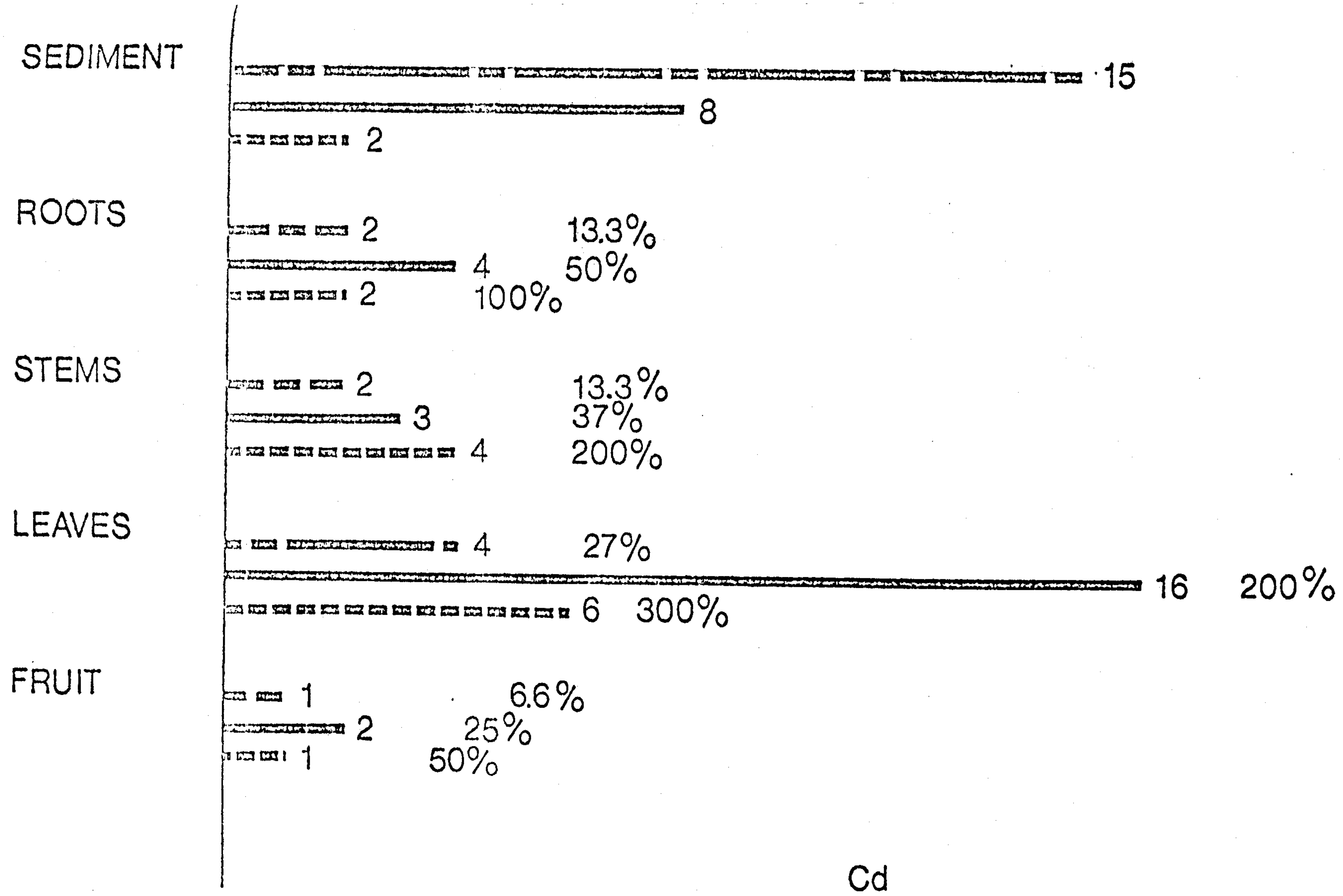


Figure 15.8. Cadmium concentration in sediments and organs of tomato grown in these sediments

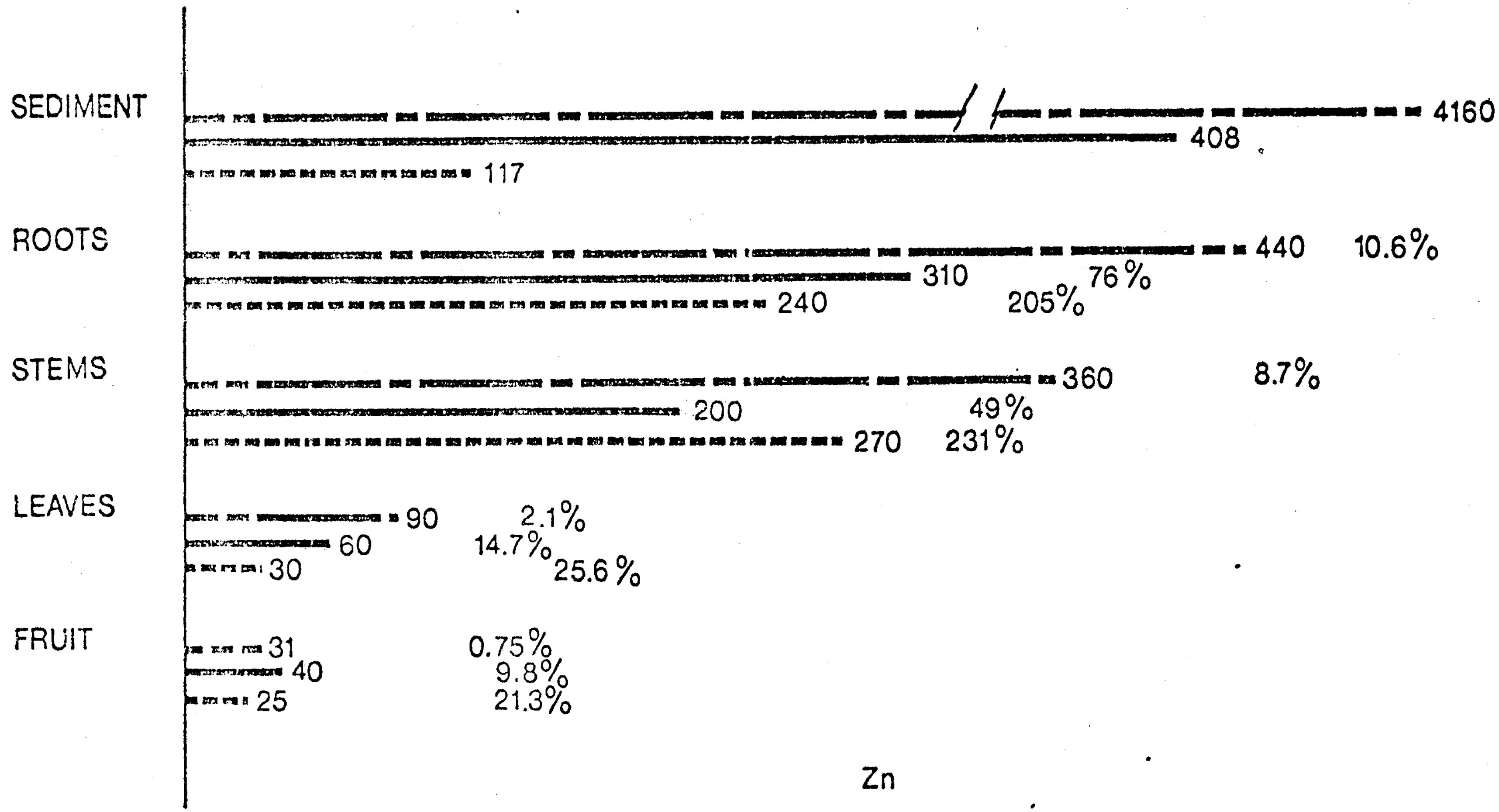


Figure 15.9. Zinc concentration in sediments and organs of tomato grown in these sediments

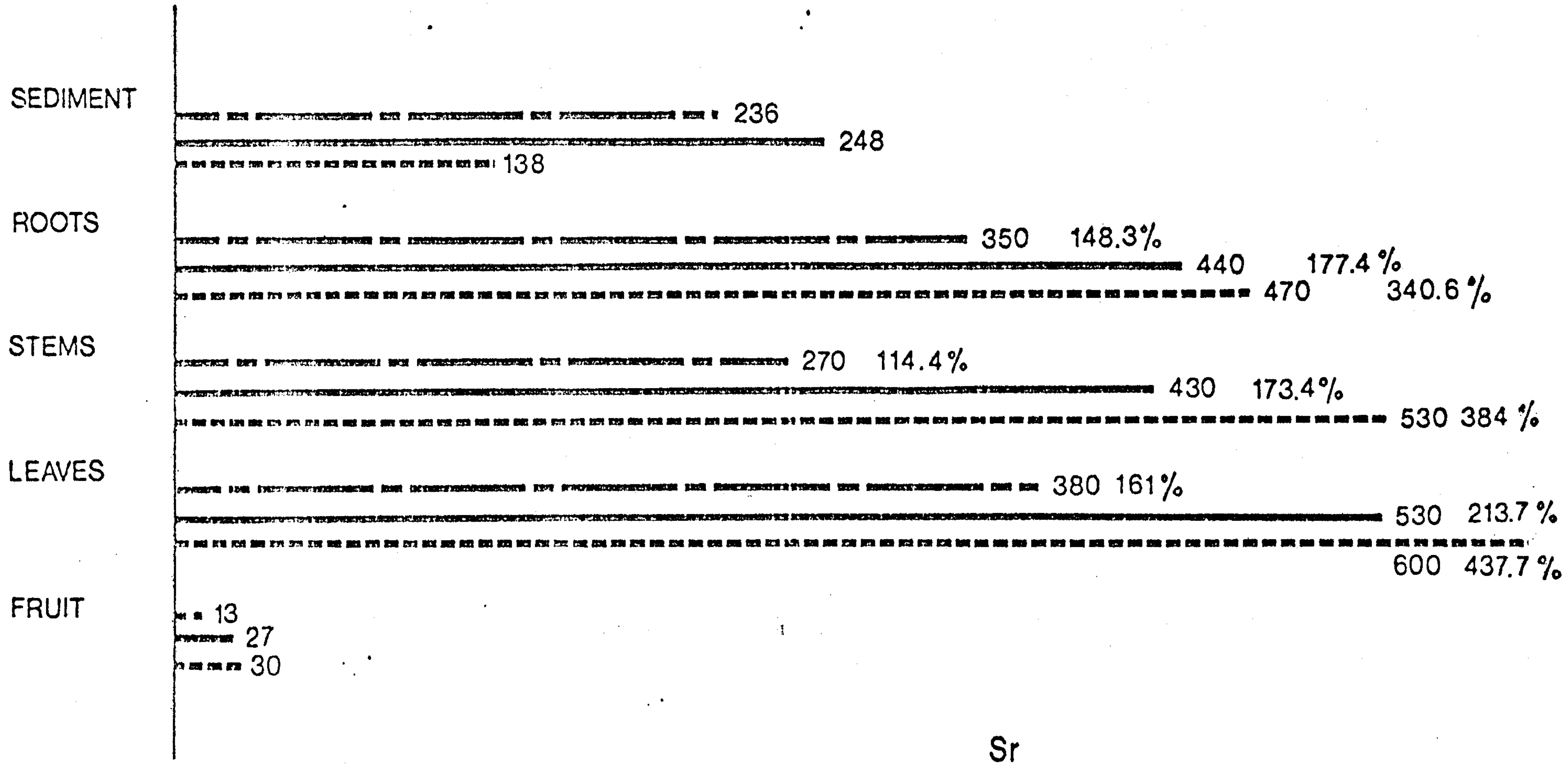


Figure 15.10. Strontium concentration in sediments and organs of tomato grown in these sediments

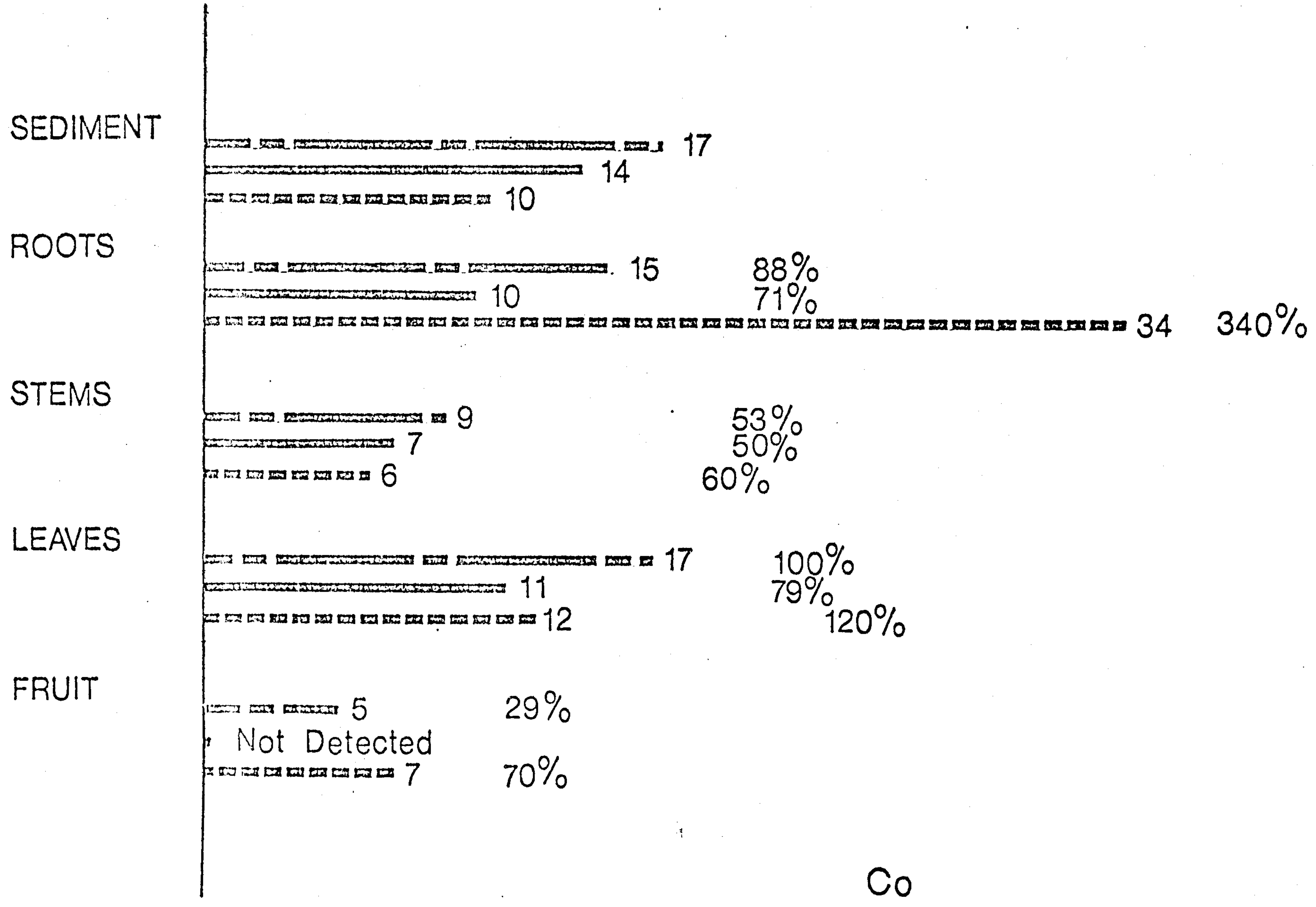


Figure 15.11. Cobalt concentration in sediments and organs of tomato grown in these sediments

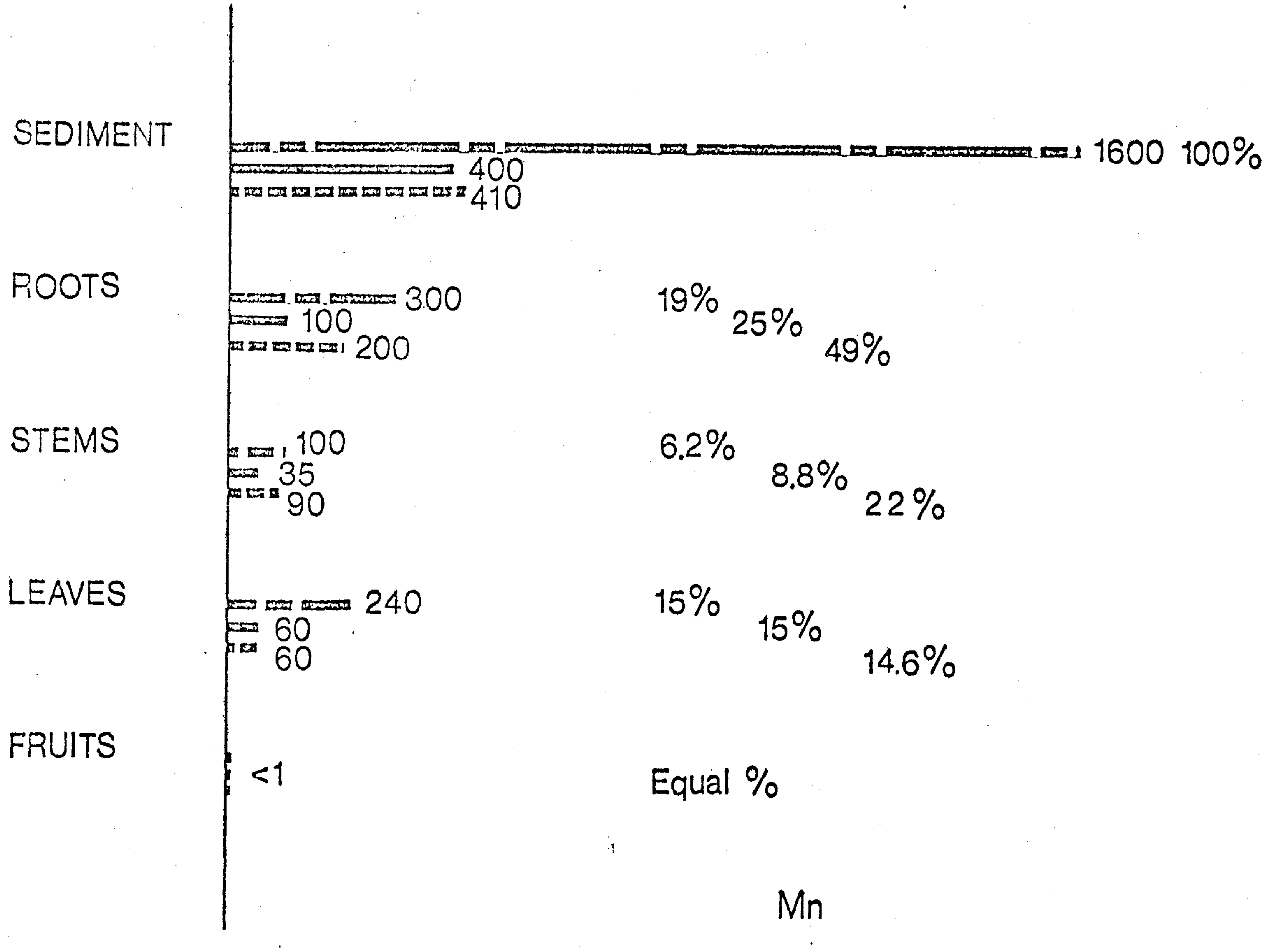


Figure 15.12. Manganese concentration in sediments and organs of tomato grown in these sediments

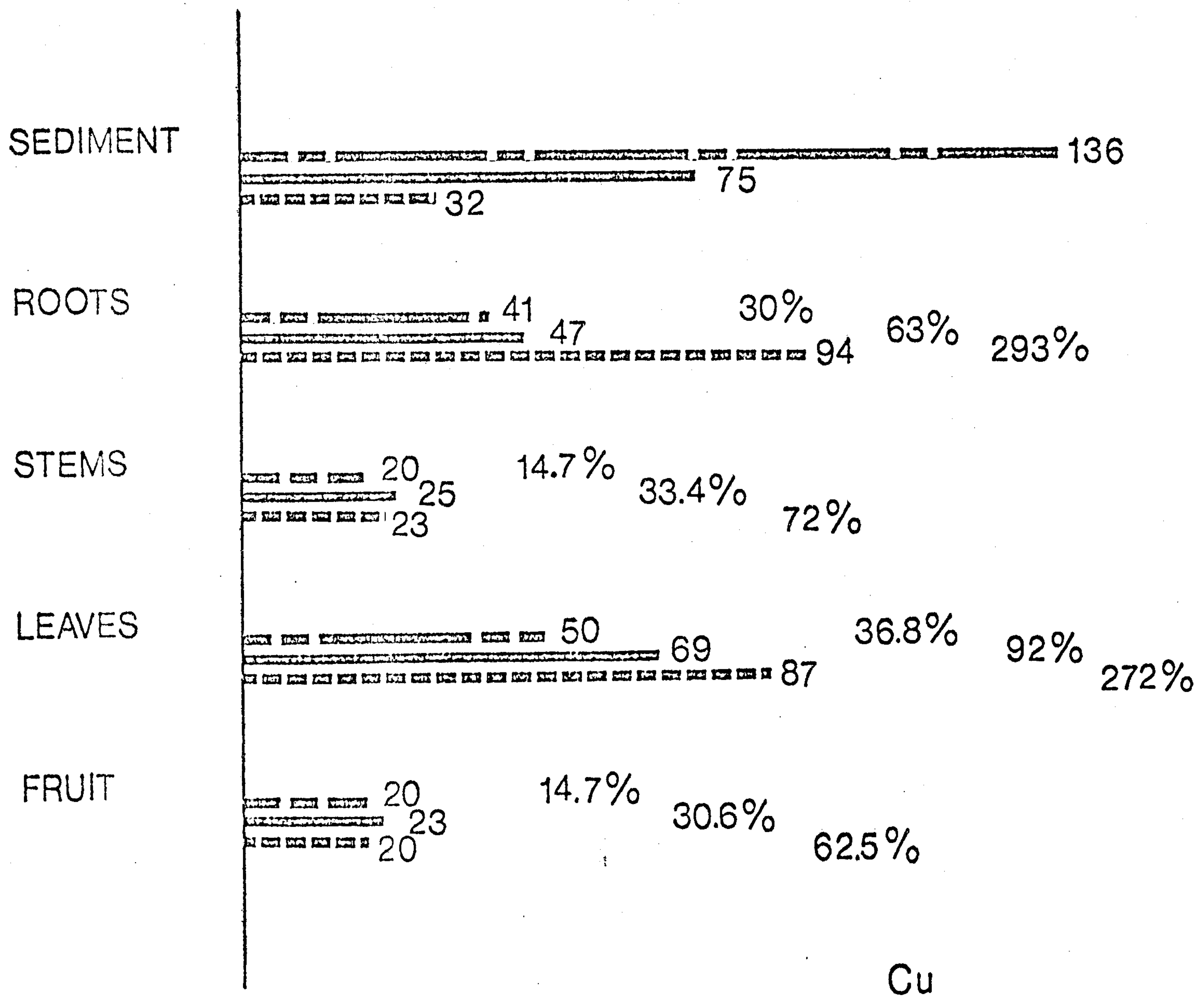


Figure 15.13. Copper concentration in sediments and organs of tomato grown in these sediments

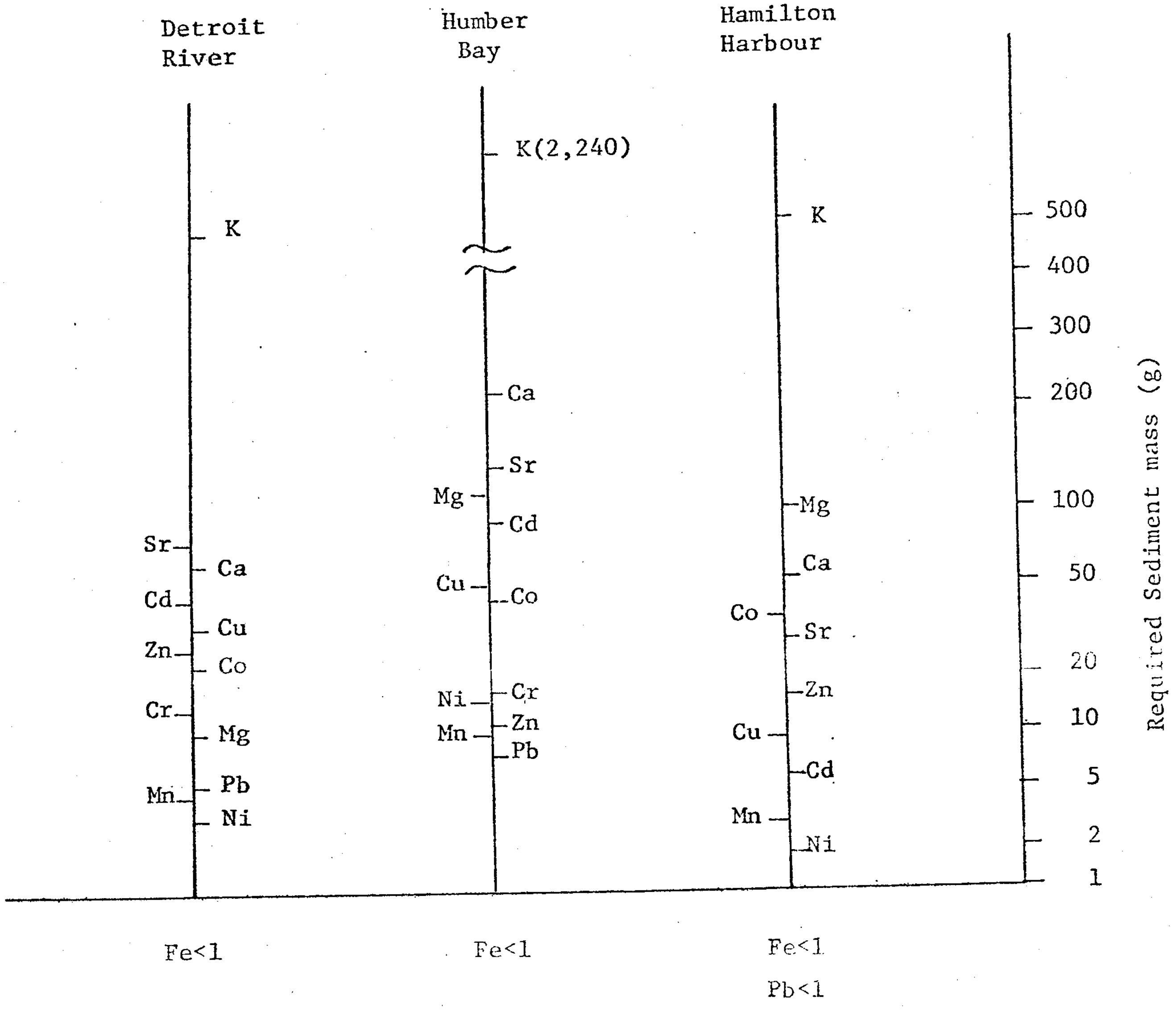


Figure 16. Required Sediment mass to cover the uptake of elements by one tomato plant.

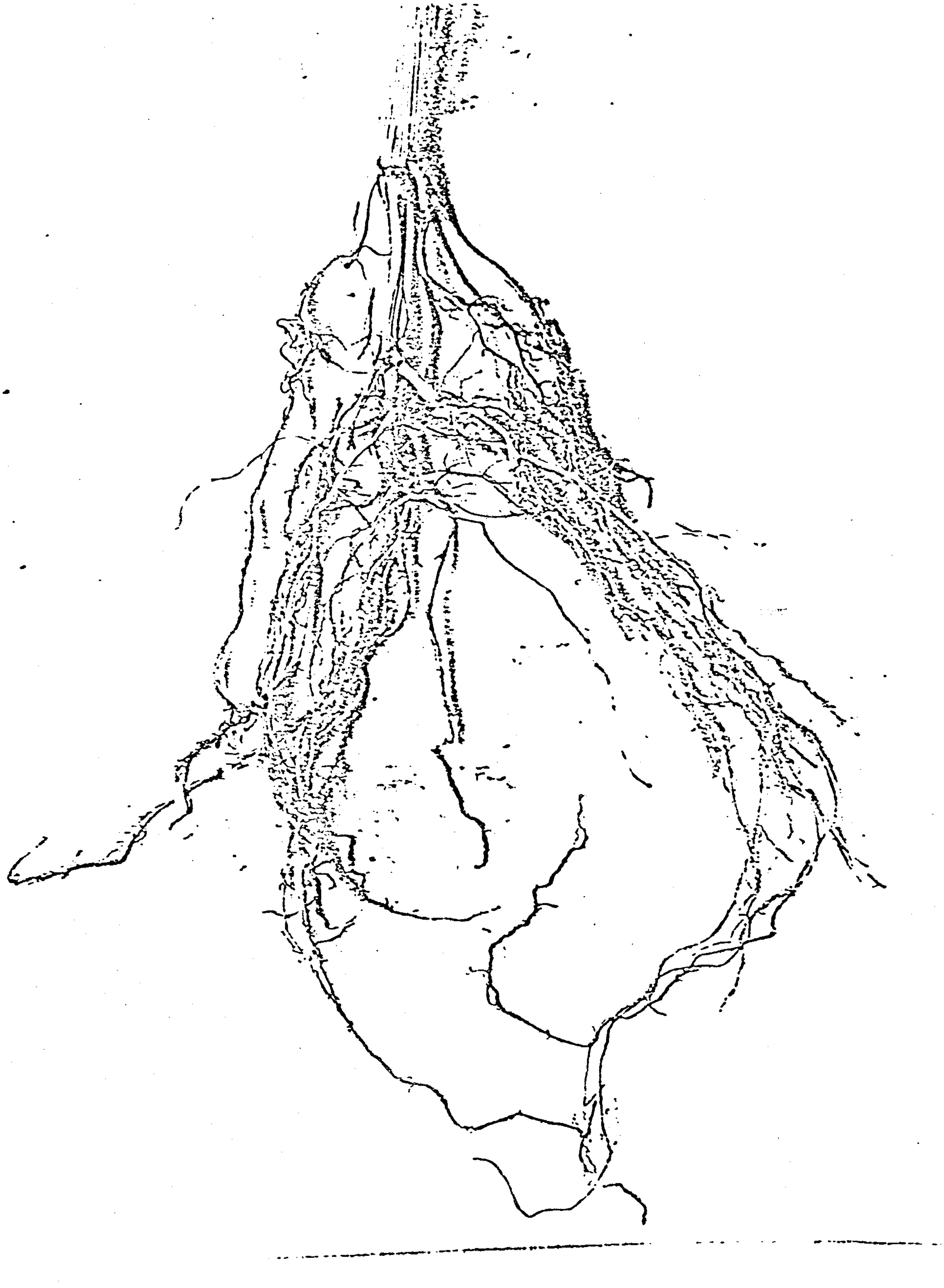


Figure 17. Roots of a tomato plant grown in Hamilton Harbour sediment

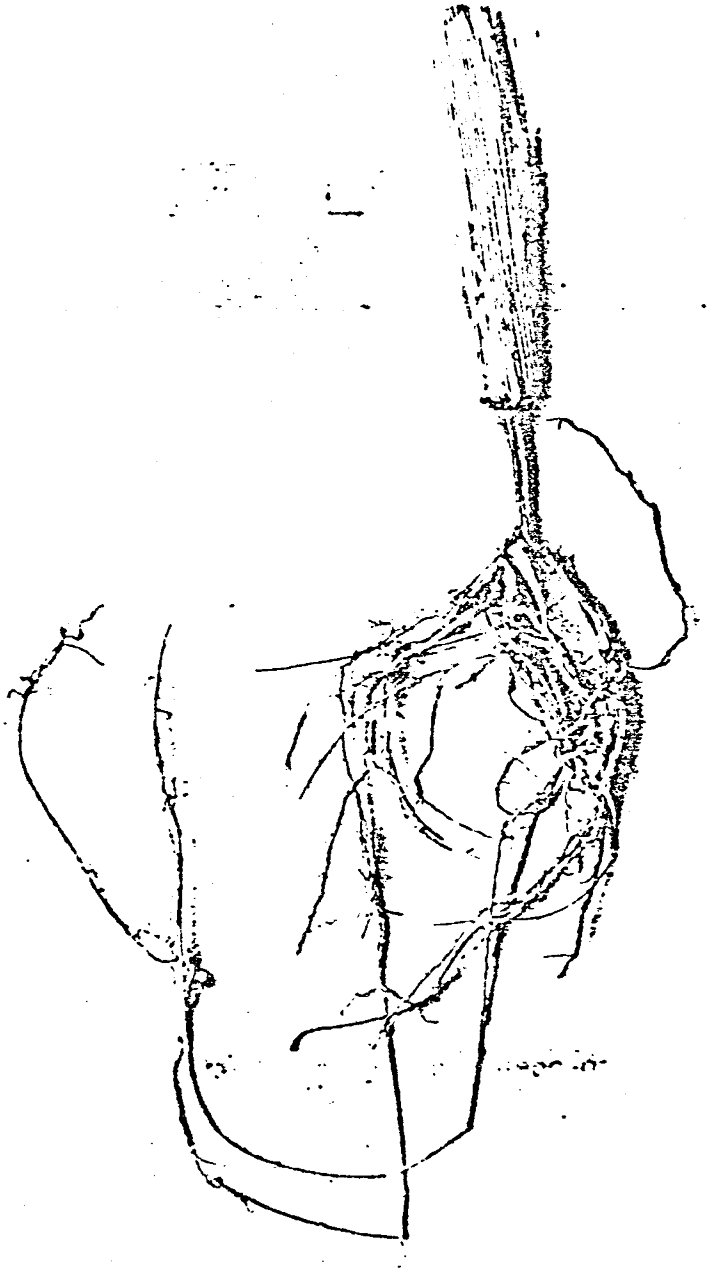


Figure 18. Roots of a tomato plant grown in Humber Bay sediment

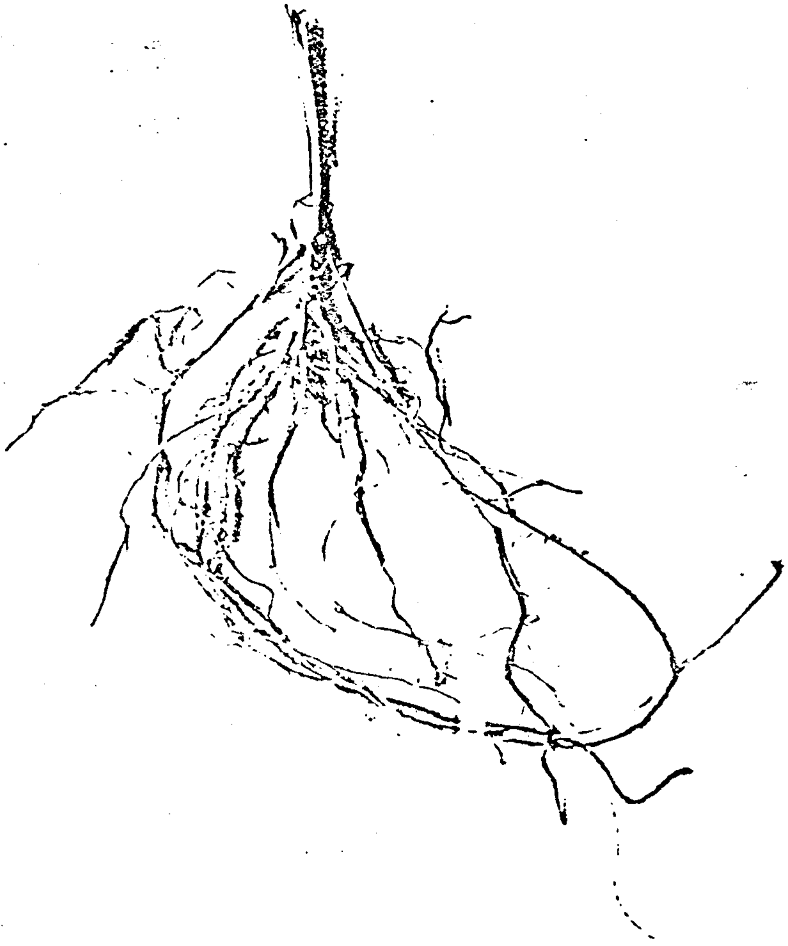
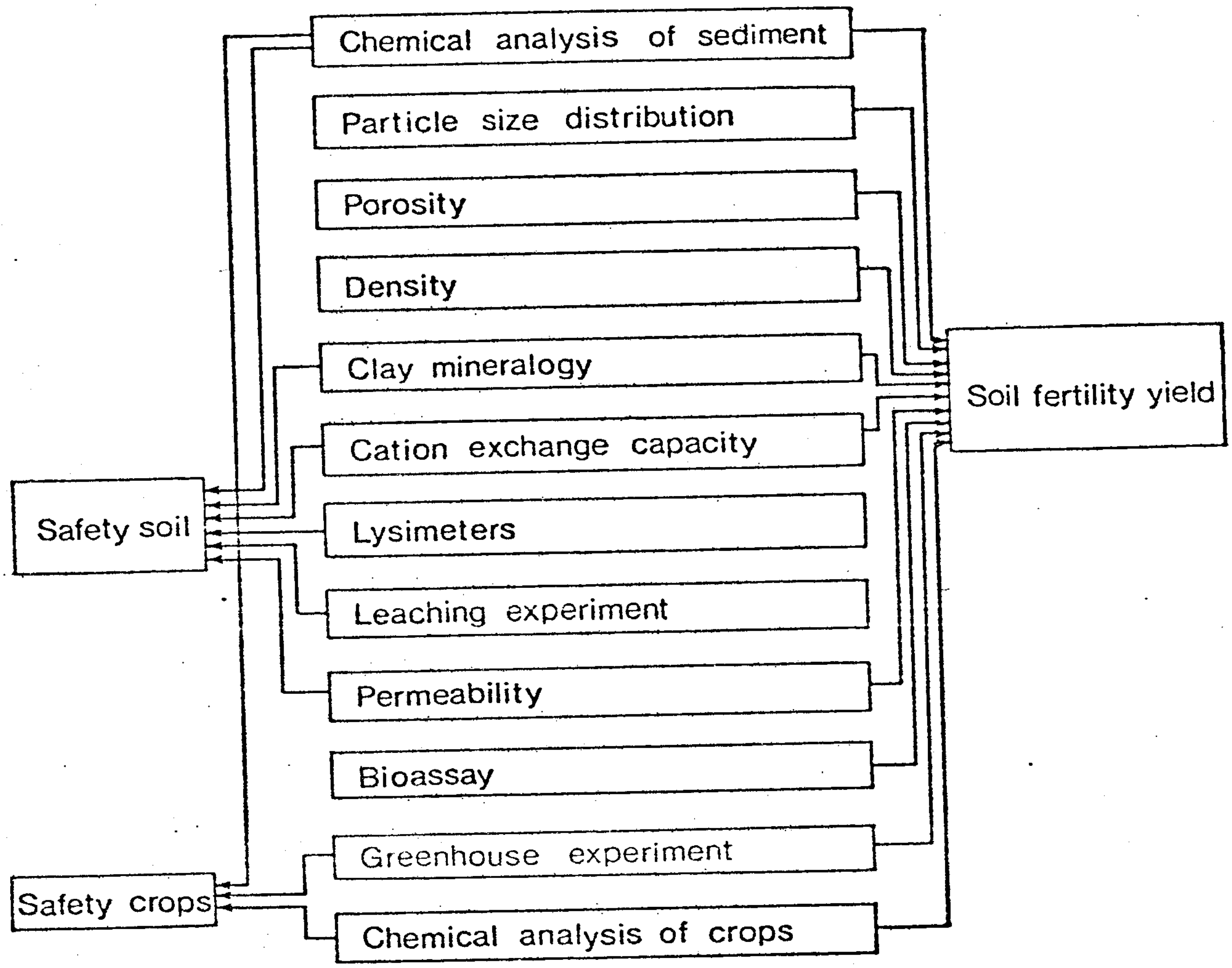


Figure 19. Roots of a tomato plant grown in Detroit River sediment



INTERRELATIONSHIP BETWEEN CHEMICAL AND PHYSICAL PROPERTIES, THE SAFETY ASPECTS AND FERTILITY OF THE SEDIMENTS

Figure 20. Interrelationship among chemical and physical properties, safety aspects and fertility of the sediments