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COMPARISON OF GROWTH AND METAL UPTAKE OF *CYPERUS ESCULENTUS*, *TYPHA LATIFOLIA* AND *PHRAGMITES COMMUNIS* GROWN ON CONTAMINATED SEDIMENTS FROM TWO GREAT LAKES' HARBOURS

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COMPARISON OF GROWTH AND METAL UPTAKE OF *CYPERUS ESCULENTUS*, *TYPHA LATIFOLIA* AND *PHRAGMITES COMMUNIS* GROWN ON CONTAMINATED SEDIMENTS FROM TWO GREAT LAKES HARBOURS

by

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MANAGEMENT PERSPECTIVE

This report provides information on the availability of metals in contaminated sediments to some plant species. The information can be used in planning of a proper design of Confined Disposal Facilities used for the disposal of contaminated sediments dredged from the Great Lakes waterways.

It can also be used in assessing an alternative for a remedial action plan for the treatment of contaminated sediments at the Areas of Concern in the Great Lakes Basin.

COMPARAISON DE LA CROISSANCE ET DE L'ABSORPTION DE MÉTAUX
PAR
CYPERUS ESCULENTUS, *TYPHA LATIFOLIA* ET
PHRAGMITES COMMUNIS POUSSANT SUR
LES SÉDIMENTS CONTAMINÉS DANS DEUX PORTS DES GRANDS LACS

PERSPECTIVE DE GESTION

Cet exposé fournit des informations sur la disponibilité des métaux des sédiments contaminés pour certaines espèces de plantes. Ces informations peuvent être utilisées dans la planification des installations d'élimination restreinte utilisées pour l'élimination des sédiments contaminés dragués dans les voies navigables des Grands Lacs.

EXECUTIVE SUMMARY

A bioassay was carried out to investigate the availability of metals in contaminated sediments collected from Hamilton Harbour, Ontario, and Times Beach, Buffalo, N.Y. Both sediments were heavily contaminated with metals, in particular, Zn, Cu and Pb.

The objective of the study was to evaluate the suitability of different plants for colonizing contaminated sediments dredged from the Great Lakes waterways and disposed at Confined Disposal Facilities (CDF's) along the shoreline. The growth and metal uptake by two macrophytes (*Typha latifolia* and *Phragmites communis*) was compared to *Cyperus esculentus*, a plant designated as "index plant" in past studies by the scientists from U.S.A. and The Netherlands. The experiment was designed to simulate the growth of the plants in a marsh (flooded sediment under reduced conditions) and at an upland condition (oxidized sediment with a regular field moisture capacity). The uptake of metals by *Typha* and *Phragmites* indicated that both plants are suitable to colonize CDF's containing sediments with high metal concentrations. The suitability of the "index" plant for the prediction of metal availability from contaminated sediment was confirmed by the experiments.

The study was funded by the Environmental Laboratory, Waterways Experiment Station, Department of the Army, U.S. Corps of Engineers, Vicksburg, Mississippi, and was carried out under ECD-236 study.

RÉSUMÉ

On a effectué un bio-essai pour étudier la disponibilité des métaux dans les sédiments contaminés prélevés dans le port de Hamilton en Ontario et à Times Beach, Buffalo, dans l'État de New York. Ces deux sédiments ont été fortement contaminés par les métaux, particulièrement le zinc, le cuivre et le plomb.

L'objectif de cette étude était d'évaluer la possibilité de diverses plantes à établir des colonies dans les sédiments contaminés dragués dans les voies navigables des Grands Lacs et déposés dans des installations d'élimination restreinte (IER) sur la rive. La croissance et l'absorption des métaux de deux plantes macrophytes (<u>Typha latifolia</u> et <u>Phragmites communis</u>) ont été comparées à celles de <u>Cyperus esculentus</u>, reconnue comme "plante indicatrice" au cours d'études antérieures effectuées par des scientifiques des États-Unis et des Pavs-Bas. L'expérience a été conçue pour simuler la croissance des plantes dans un marais (sédiments inondés dans des conditions réductrices) et dans les conditions des bas-plateaux (sédiments oxydés avec une capacité d'humidité normale des champs). L'absorption de métaux par <u>Typha</u> et <u>Phragmites</u> a indiqué que ces deux plantes étaient appropriées pour la colonisation des IER contenant des sédiments à forte teneur en métaux. Ces expériences ont permis de confirmer l'utilité de la plante indicatrice pour prévoir la disponibilité des métaux dans les sédiments contaminés.

L'étude a été financée par l'Environmental Laboratory, Waterways Experiment Station, Department of the Army, U.S. Corps of Engineers, Vicksburg, Missisipi, selon le contrat ECD-236.

INTRODUCTION

La prise de conscience des effets néfastes pour l'environnement associés à l'élimination en eau libre des déblais de dragage contaminés a entraîné l'augmentation de l'élimination de ces déblais dans des installations d'élimination restreintes (IER) dans les Grands Lacs. Une fois les déblais de dragage déposés dans les IER, les plantes peuvent établir une colonie sur le site. Les déblais de dragage finement granulés contiennent de grandes quantités d'éléments nutritifs qui favorisent une croissance vigoureuse des plantes. La création d'un marais ou celle d'une zone de restauration de la végétation naturelle constituent deux des solutions possibles pour la gestion des IER. De nombreux sites d'élimination sont de plus en plus utilisés par les poissons et la faune. Plus de 145 espèces d'oiseaux ont été observées dans les IER des Grands Lacs (U.S. Army Engineers Waterways Experiment Station, Vicksburg, 1985). Cependant, des contaminants peuvent passer des déblais de dragage disposés à ces endroits aux plantes et ensuite à la chaîne alimentaire. Un test a été mis au point à la Waterways Experiment Station (WES), Vicksburg, Mississippi, É.-U., afin d'évaluer la consommation par les plantes des contaminants contenus dans les sédiments. Ce procédé a été appliqué pour tester un certain nombre de sédiments contaminés et a donné des résultats et des renseignements précieux pour prévoir l'absorption possible par les plantes de contaminants provenant des déblais de dragage (Van Driel et al, 1985; Lee et al , 1983; Folsom et al, 1981). Ce procédé consiste à faire pousser une plante indicatrice, *Cyperus esculentus*, dans des sédiments testés dans des conditions simulant des milieux de terres humides et de bas-plateaux. La croissance des plantes, la phytotoxicité et la bioaccumulation des contaminants sont surveillées. Dans les sédiments contaminés, un rapport a été observé entre

INTRODUCTION

The awareness of adverse environmental impact associated with the open water disposal of contaminated dredged material brought about increased disposal into confined disposal facilities (CDF's) in the Great Lakes. After dredged material has been placed in a CDF, plants can invade and colonize the size. Fine-grained dredged material contains great quantities of nutrients which promote a vigorous growth of plants. The creation of a marsh or natural revegetation are two of the available alternatives for the management of a CDF. Many of the disposal sites become extensively used by fish and wildlife. Over 145 species of birds have been found at the Great Lakes CDF's (U.S. Army Engineers Waterways Experiment Station, Vicksburg, 1985). However, contaminants may move from disposed dredged material into plants and subsequently into the food chain. A test was developed at Waterways Experiment Station (WES), Vicksburg, Mississippi, USA, to evaluate the uptake of contaminants from sediments by plants. This procedure has been applied to testing a number of contaminated sediments and has given valuable results and information to predict the potential for plant uptake of contaminants from dredged material (Van Driel et al., 1985; Lee et al., 1983; Folsom et al., 1981). The procedure involves growing an index plant Cyperus esculentus in tested sediments under conditions of both wetland and upland environments. Plant growth, phytotoxicity and bioaccumulation of contaminants are monitored. A relationship was observed between the uptake of some metals by Cyperus esculentus and other plants, including agronomic crops, in a contaminated sediment under similar conditions in a greenhouse. Consequently, the test results obtained by the plant bioassay can be used to design appropriate management strategies of CDF's to minimize the mobility of contaminants through the ecosystem developing at the new disposal area.

In this study a plant bioassay was carried out with contaminated sediments from two Great Lakes harbours, the index plant *Cyperus esculentus* and two macrophyte species common in the Great Lakes coastal marshes, *Typha latifolia* and *Phragmites communis*.

Scope of Work

A study of uptake of Cd, Co, Cr, Cu, Ni, Pb and Zn by the freshwater marsh plants *Typha latifolia* and *Phragmites communis* was conducted with sediments under extreme oxidized (upland) and reduced (flooded) conditions. *Cyperus esculentus* was used as the index plant in the experiments. Sediments were analysed for total and DTPA-extractable metals.

The specific objectives of the study were:

1. To assess the accumulation of metal by *Typha latifolia* and *Phragmites communis*, common species growing in the Great Lakes marshes;
2. To determine the suitability of the greenhouse double-bucket technique for the assessment of the growth/contaminant uptake by these, and similar, plant species.

Experimental Design

Sediments/soils used in the experiment were:

a) Times Beach sediment, Buffalo, Lake Erie

b) Hamilton Harbour sediment, Lake Ontario

c) reference soil (sandy loam) supplied by the Waterways Experiment Station (WES) Vicksburg, Mississippi, U.S.A.

- Plants used in the experiment were Cyperus esculentus, Typha latifolia and Phragmites communis.
- All three plants were grown under upland (oxidized) and flooded (reduced) conditions.
- Under flooded conditions each plant/sediment combination was replicated four times, except WES reference soil, which was replicated two times.
- Under upland conditions plant/sediment combination was replicated four times in Hamilton Harbour, three times in Times Beach and two times in WES reference soil. (The reason for fewer replicates was the lack of the sediment shipped from Buffalo, and the soil supplied by Vicksburg.)
- There were 57 pots, 30 under flooded conditions and 27 under upland conditions.

Sediment Selection

One of the objectives of the bioassay experiment was to test contaminated Great Lakes sediments. Sediments from two sites were chosen for the experiment. The sites are located in the lower Great Lakes and the general geochemical composition of the sediment is similar. The sediments from both localities are contaminated mainly by metals from local industrial wastes, and are not suitable for open water diposal. Confined disposal facilities already exist at both sites. Localities of selected sites shown in Figure 1 are following:

- Times Beach, Buffalo
- Hamilton Harbour

WES reference soil was described by Folsom et al. (1981).

Plant Selection

The other objective of the experiment was to assess the growth and metal uptake by macrophytes common in the Great Lakes marshes. *Typha latifolia* and *Phragmites communis* are dominant wetland macrophytes in the Great Lakes Basin and both are virtually cosmopolitan in distribution. In the Great Lakes Basin, *Phragmites* occupies drier sites than *Typha latifolia*. In addition, both species grow naturally at the Buffalo's Times Beach disposal area. *Cyperus esculentus* was used as an index plant to compare the uptake of metals from sediments by *Typha* and *Phragmites*. *Cyperus esculentus* also grows in the Great Lakes Basin in nature wetland habitats as well as cultivated field as weeds.

EXPERIMENTAL PROCEDURES

Treatment of Sediments and Reference Soil

Times Beach sediment obtained from the upland conditions at the disposal site and WES reference soil were shipped in plastic buckets to Burlington, Ontario. Upon arrival, the sediment and soil were divided into two portions. One portion was distributed into the inner containers of the double buckets, filled with demineralized water and maintained under 5 cm layer of water. Hamilton Harbour sediment was collected using a box corer. The flooded conditions were created as described above. The second portion of both, the Times Beach and Hamilton Harbour sediments and the WES reference soil were air-dried in thin layers on trays lined with polyethylene sheets. The dry material was ground to pass through a 2 mm sieve. Sieved sediments and soil were transferred into inner containers of double buckets and moistened to 70% of field capacity. The "double bucket" construction for upland conditions was described by Folsom et al., 1981. Sediments and soils prepared under flooded and upland conditions were maintained in the greenhouse for four weeks prior to planting.

Plant Species

Cyperus esculentus tubers used in the experiment originated from the same source as tubers used in corresponding experiments by Folsom *et al*. (1981).

Typha latifolia seeds were obtained from a marsh located at the western end of Lake Ontario. A small experiment was also conducted using Hamilton Harbour sediment and *Typha* rhizomes and plants. *Phragmites communis* seeds were obtained from the same location as those of *Typha*. *Phragmites* rhizomes were also included in the small experiment mentioned above.

Greenhouse Environment

Cyperus esculentus was grown in the greenhouse from 14.August to 28.September 1986, *Phragmites communis* from 14.August to 31.October 1986, and *Typha latifolia* from 15.August to 7.November 1986. The average day and night temperatures during the experiments were the following:

August 15 - August 30:	Day average 33°C; night average 25°C
September 2 - September 15:	Day average 29°C; night average 25°C
September 16 - September 30:	Day average 27°C; night average 24°C
October 1 - October 15:	Day average 25°C; night average 24°C
October 16 - October 30:	Day average 27°C; night average 25°C

Relative humidity ranged from 65% to 90%.

The average day length in August was 14 hours, in September 12.5 hours in October 11 hours.

Germination, Planting, Growing and Harvesting

Cyperus esculentus

Five presprouted *Cyperus* tubers were planted in each container with sediments and soil. The growing period in the sediment was 45 days. No flowering occurred during this period. After 45 days the plants were harvested. All aboveground tissues, roots and tubers were collected from each pot, rinsed with demineralized water, blotted dry with filter paper and dried to constant weight at 70°C. Aboveground tissue and roots were ground to a powder in an automatic grinder using an achate grinding dish to avoid metal contamination. Tubers were stored unground.

Typha latifolia

Seeds of *T. latifolia* were germinated in the greenhouse in a plastic tray filled with a 1:1 mixture of peat and vermiculite, saturated with deionized water. The seedlings were grown in the peat: vermiculite mixture for ten days when they reached about 2 cm height.

Five plants were then planted in each container with sediments and soil. The growing period in the sediment was 84 days. Aboveground tissues, roots and rhizomes were collected from each pot, rinsed with demineralized water (sediment particles adhering to the roots and rhizomes were removed with a plastic brush), blotted dry with filter paper, and dried and ground by the same technique described for Cyperus.

Phragmites communis

Seeds of P. communis were germinated in a plastic tray filled with about 4 cm thick layer of sediment from an uncontaminated lake in Ontario. Germinated seeds were grown in moist sediment for 165 days when they reached a height between 5 and 19 cm. Before planting into the containers with tested sediments, roots of each seedling were washed with deionized water to remove the growing substrate. Five seedlings were planted into each container. At the time of planting each seedling had an additional small shoot (about 1 cm long). Since the plants differed in size, five seedlings of comparables sizes (1 taller, 3 medium size and 1 shorter) were planted in each container. The growing period in tested sediments was 78 days. All above ground parts and roots were collected, rinsed with demineralized water, blotted dry with filter paper, and dried and ground as described for Cyperus.

ANALYTICAL METHODS

Plant Samples

The concentrations of Pb, Zn, Cu, and Ni were determined in all pulverized aboveground tissue samples by Inductively Coupled Plasma spectrometry following the method described by Mclaren and Berman (1981). The concentrations of Cd, Co and Cr were determined in the plant extracts by flameless atomic absorption spectrometry. The accuracy of the procedures was verified regularly by subjecting a standard sample to the overall analytical procedure (U.S. National Bureau of Standards, Standard Reference Material 1571, Orchard Leaves). The analytical precision as determined by replicate analysis of several samples of C. Esculentus, T. latifolia and P. communis was generally <15%.

Sediments and Reference Soil

Total concentrations of major elements (Si, Al, Fe, Ca, Mg, K, Na, Mn, P and Ti) and trace elements (Cu, Cr, Co, Pb, Ni, Zn, As) were determined by X-ray fluorescence spectrometry using the method described by Mudroch (1977). The precision of the analyses was determined by analysing five pellets made from a homogenized sediment sample. Relative deviations for major elements in samples can be expected at the following levels: SiO_2 2%; K_2O and Al_2O_3 4%; Fe_2O_3 and

CaO 2%; and MgO and Na_2O 10%. Absolute deviations of 0.01% to 0.02% were found for MnO, TiO_2 and P_2O_5. Depending on their content absolute deviations for trace elements (Cu, Cr, Co, Pb, Ni, Zn and As) are to be expected in the range of 1 to 15 µg/g. The accuracy of the analyses was checked by running Canadian Reference Standards Syenite SY-2 an soils SO-2 and SO-4 and comparing the results with the stated reference values for major and trace elements. Total Cd was determined by atomic absorption spectrometry using graphite furnace after digestion of sediment and soil samples with fuming HNO3 (five times to dryness on a water bath).

The concentration of Hg was determined by a gold film mercury analyzer after digestion of sediment and soil samples by HNO3:HCl (20:1) using procedure described by Mudroch and Kokotich (1987). DTPA extractable metals were determined in dry, homogenized sediment and soil samples prepared for planting and in sediments and soil samples maintained under flooded conditions for four weeks prior to planting. One composite sediment or soil sample was obtained for each tested substrate. Flooded samples were taken with all precautions necessary to avoid aeration of the sediment. DTPA extracts were prepared according to Lee _et al_. (1983). Concentrations of Cu, Zn, Cr, Ni, Cd and Pb were measured in the extracts with flame atomic absorption spectrometry and compared with standard solutions of these elements dissolved in the same extractant. Background correction was made.

Total C, organic C and inorganic C were determined in dry sediment and soil samples by a Leco Carbon Analyzer. Organic C was determined after decomposition of inorganic carbon by hydrochloric acid, and inorganic C is the calculated difference between total C and organic C.

pH of flooded sediment or soil was measured by a combination glass electrode (Metrohm) inserted directly into the wet sediments. pH of upland sediment or soil was measured in a 1:2 sediment or soil - water suspension using the air dried samples.

Particle size distribution was measured by a sedigraph using the method described by Duncan and LaHaie (1979).

Mineralogical composition of sediments was determined qualitatively by a powder X-ray diffraction using the Cu-target and the Ni filter.

RESULTS

Sediments

Physical and chemical properties of the sediments and the reference soil are presented in Table 1. Although Hamilton Harbour and Times Beach sediments originated from the lower Great Lakes drainage basin, the input from local industries affected the composition of each sediment. The greatest difference was the concentration of Ca (16.91% and 3.82% CaO in Hamilton Harbour and Times Beach sediments, respectively). Calcium in Hamilton Harbour was present mainly as $CaCO_3$ (high inorganic C content and presence of mineral calcite), and originated most likely from the lime used by the steel industry in Hamilton. Times Beach sediment contained greater quantities of organic C and K than Hamilton Harbour sediment. On the other hand, the concentration of P was greater in Hamilton Harbour sediment. Particle size distribution was similar in both sediments, and with the exception of calcite in Hamilton Harbour, both sediments had similar mineralogical composition. Most common minerals were illite, feldspar, quartz and chlorite. These minerals are common in lower Great Lakes sediments (Mudroch, 1983). The WES reference soil, classified as sandy loam, had much smaller concentration of $CaCO_3$, organic C and P than both sediments.

Concentrations of trace elements in the sediments and reference soil are presented in Table 2. Trace elements (Ni, Co, Cr, Cu, As and Cd) were present in similar concentrations in Hamilton Harbour and Times Beach sediments. Hamilton Harbour sediment contained greater concentrations of Zn and a smaller concentration of Pb and Hg than Times Beach sediment. Concentrations of trace elements in sediments from both localities are compared to those found in the sediments from different areas of the lower Great Lakes in Table 2.

Concentrations of Cd, Co, Cr, Cu, Ni, Pb, Fe, Mn and Zn extracted by DTPA from Times Beach and Hamilton Harbour sediments and WES reference soil under upland and flooded conditions are shown in Table 2. The ratio of DTPA-extractable to total element concentrations (Table 3) indicated the mobile fraction of these elements in the sediments. This fraction was associated in previous experiments (Van Driel *et al.*, 1985; Lee *et al.*, 1983) with the plant-available fraction. The ratio was highest for Cd in both sediments under upland conditions, followed by Cd under flooded conditions. However, the ratio was different for other elements in Hamilton Harbour and Times Beach sediments. Under flooded conditions, Cu and Pb appeared to be more available in Times Beach sediment than in Hamilton Harbour sediment, and Zn and Ni were more available in Hamilton Harbour than in Times Beach sediment. Under upland conditions, greater quantities of Cu, Ni, Pb and Zn were extracted from Hamilton Harbour sediment than from Times Beach sediment. Only small portions of Cr, Co, Fe and Mn were extracted from both sediments by the DTPA extraction procedure.

Plant Growth

Cyperus exculentus

The *C. esculentus* experiment was conducted on Hamilton Harbour and Times Beach sediments and on the reference soil supplied by WES. *Cyperus* performed best in Hamilton Harbour sediment under flooded conditions (Table 3). The poorest growth was obtained in Times Beach sediment under flooded conditions. However, there was a small difference between the yield of *Cyperus* grown in Hamilton Harbour and Times Beach sediments under upland conditions. *Cyperus* grown in

Hamilton Harbour under flooded conditions developed the greatest root system, and the total weight of tubers was similar to that of *Cyperus* grown in WES soil.

Phragmites communis

P. communis were grown on Hamilton Harbour and Times Beach sediments and WES reference soil. *Phragmites* performed best in Hamilton Harbour sediment under flooded conditions, followed closely by those grown in WES soil also under flooded conditions (Table 3). The growth was very poor in Times Beach sediment under flooded conditions. However, *Phragmites* produced similar quantities of aboveground tissue in both sediments and soil under upland conditions. The difference between the growth of *Phragmites* under flooded and upland conditions suggest that this species performs better under the flooded conditions designed for the *Cyperus esculentus* bioassay. Low yields of plants in Times Beach sediment indicated suppression of growth which may be due to either toxicity or nutrient limitation.

Typha latifolia

T. latifolia performed well in Times Beach sediment and WES soil under flooded conditions (Table 3). Poor performance of *Typha* under upland conditions indicated that the small seedlings used were not suitable for an upland bioassay experiment designed for *Cyperus esculentus*. A poor growth existed in Hamilton Harbour sediment under flooded conditions. This sediment contained up to 0.2% of oil and grease (Mudroch and Sandilands, 1980). An oil slick developed on the surface of the water in containers maintained under flooded conditions in the greenhouse experiment, most likely inhibited the growth of the *Typha* seedlings. However, rhizomes and plants of *Typha latifolia* planted in a plastic container (about 1 m x 1 m) filled with a wet Hamilton Harbour sediment and maintained in an upland condition produced healthy looking plants, about 1 m tall after 75 days of growth.

Plant Chemical Composition

Results of chemical analyses of the aboveground tissues of all plants are presented in Table 5. Under upland conditions *Cyperus* grown in Hamilton Harbour and Times Beach sediments accumulated greater quantities of Zn and Cd than that grown in these sediments under flooded conditions. Under both conditions *Cyperus* grown in Hamilton Harbour accumulated more Zn than that in Times Beach sediment. In Hamilton Harbour *Cyperus* accumulated more Cu under upland than flooded conditions.

Under upland conditions *P. communis* grown in Hamilton Harbour and Times Beach sediments accumulated greater quantities of Zn and Cu than that grown in these sediments under flooded conditions. There was no difference in the uptake of Cd by Phragmites grown under upland and flooded conditions on both Times Beach and Hamilton Harbour sediments. Under both conditions P. communis grown in Hamilton Harbour accumulated more Zn than that in Times Beach sediment. Under upland conditions plants growing in Hamilton Harbour accumulated greater quanitites of Zn, Cu and Pb than those in Times Beach sediment.

Only one plant of Typha latifolia succeeded in Hamilton Harbour sediment under flooded conditions. This plant accumulated greater concentrations of Zn than the plants growing in Times Beach sediment. The uptake of Cu, Pb and Zn by T. latifolia was greater under upland than flooded conditions in Times Beach sediment. The uptake of Cd was similar by Typha grown on both Times Beach and Hamilton Harbour sediments.

The relationship between the concentrations of metals in the aboveground tissue of Cyperus esculentus and that of Phragmites communis and Typha latifolia is shown in Table 6. The data indicate a good potential for using Cyperus esculentus as an indicator species to predict the uptake of Co, Cr, Cu and Zn by Phragmites communis, and the uptake of Zn by Typha latifolia growing on contaminated sediments. However, this relationship derived from a controlled greenhouse experiment needs to be verified under field conditions with sediments contaminated to a different degree with these metals. Details of the results obtained in the experiments are in the Appendix.

DISCUSSION

Cyperus esculentus

The yield of aboveground tissue of Cyperus esculentus varied from 7.34 to 12.50 g dry matter/pot under upland, and from 7.23 to 17.70 g dry matter/pot under flooded conditions. The greatest yield was obtained on Hamilton Harbour sediment. The diffence in the yield may be due to different nutrient levels of the substrates (Table 1). There is no obvious relationship between yield and metal status of the substrates, whether expressed as total or as DTPA-extractable (Tables 2 and 3). Hamilton Harbour and Buffalo sediments were contaminated with similar concentrations of metals and had similar quantities of silt and clay particles. Greater quantities of Zn were extracted by DTPA under both conditions from Hamilton Harbour sediment than from Times Beach sediment, indicating that Zn was in more plant-available form in Hamilton Harbour. Greater quantities of Cu were extracted from Times Beach than from Hamilton Harbour sediment under flooded conditions. There was not a great difference between concentrations of the rest of the metals extracted by DTPA from both sediments (Table 2).

The yield of aboveground tissues of Cyperus esculentus grown in contaminated sediments in The Netherlands ranged from 13.4 to 22.7 g dry matter/pot under flooded conditions, and from 14.6 to 35.5 g dry matter/pot under upland conditions (Van Driel et al., 1985). The highest "upland" yield was obtained on the most contaminated sediment. A greater yield of Cyperus esculentus grown in sediments in The Netherlands than that observed in Times Beach and Hamilton Harbour sediments could be due to a longer day length (average 16 hours and 25 minutes). About 25% of Cyperus esculentus grown in The Netherlands sediments started flowering after 36 days, and a week later 75% of the plants were flowering. C. esculentus grown in our experiments did not flower in 45 days. The yield of aboveground tissue of Cyperus esculentus grown at WES greenhouse in 15 highly contaminated sediments from the Great Lakes waterways (Folsom et al., 1981) ranged from 3.0 to 231 g dry matter/pot under flooded conditions, and from 8.7 to 102.9 g dry matter/pot under upland conditions. However, the growing period was 90 days (from June to November).

The average metal concentrations in Cyperus esculentus grown on Hamilton Harbour and Times Beach sediments are compared to those obtained by the experiments conducted with contaminated sediments from The Netherlands and different localities in the Great Lakes in Table 5. The data show that C. esculentus grown in Hamilton Harbour and Times Beach sediments accumulated greater concentrations of Zn, Cr, Cu and Pb than that grown in other sediments from the Great Lakes and The Netherlands. Plants growing in Hamilton Harbour sediments accumulated the greatest quantity of Zn. The ratios between DTPA-extractable and total concentrations of Zn and Cr were greater in Hamilton Harbour and Times Beach sediments than those in the sediments from The Netherlands. These ratios were generally similar for Cu, Ni, Pb and Cd for all sediments.

Typha latifolia and Phragmites communis

The uptake of metals by aboveground tissues of Typha latifolia, Phragmites communis and Cyperus esculentus grown on Times Beach and Hamilton Harbour sediments is compared in Figures 2 and 3. Under both upland and flooded conditions, T. latifolia and P. communis accumulated smaller quantities of Zn and Cu than C. esculentus. Typha grown on Times Beach sediment accumulated greater quantities of Pb than the other plants under upland conditions. Typha and Phragmites grown under both upland and flooded conditions on Times Beach and Hamilton Harbour sediments accumulated smaller quantities of Cd than Cyperus esculentus (Table 5).

Concentrations of Zn, Cu and Cd in aboveground tissues of Typha sp. and Phragmites sp. grown in the Times Beach sediment in the greenhouse are compared to those found in these species growing at Times Beach, Buffalo, in Table 5. Concentrations of Zn were similar in Phragmites sp. collected at site C, Times Beach, and those grown under upland conditions in the greenhouse experiment. Similar concentrations of Zn were found in Phragmites sp. collected at site D, Times Beach and those grown under flooded conditions in the greenhouse. The accumulation of Cu was higher by Phragmites sp. growing under upland conditions in the greenhouse than in those collected in the field. However, a similar concentration of Cu was found in Phragmites sp. grown in the greenhouse under flooded conditions and those in the same species collected in the field.

Aboveground tissues of Typha latifolia accumulated greater quantities of Zn and Cu under both conditions in the greenhouse than that collected at Times Beach sites D and G. The concentration of Cd was similar in aboveground tissues of both species grown in the greenhouse and those collected in the field.

Use of Results for Estimating the Uptake of Metals at the Disposal Site

The data indicated that Typha and Phragmites sp. bioassay in a greenhouse can be used for the prediction of the uptake of metals at a disposal site. In addition, the greenhouse experiment showed that aboveground tissues of both macrophytes accumulated less Zn, Cu and Cd than that of Cyperus esculentus, particularly when growing under flooded conditions. However, in a marsh mature Typha and Phragmites would produce a greater biomass than Cyperus, and therefore would contribute more leaf litter containing the metals. Data presented in Table 5 show that aboveground tissues of Phragmites sp. and Typha sp. grown in Times Beach sediment had similar concentrations of metals to those found in the Great Lakes marshes and other areas. Consequently, the contribution of metals from the leaf litter from these macrophytes would be similar at a disposal site and natural marsh. The greenhouse experiment demonstrated that both plants preferred flooded conditions. In the marshes, the dry aboveground tissues of both species don't decompose completely in the fall. Stands of dry plants last until next growing season (end of April to May in the Great Lakes area) in the marsh, contributing limited quantities of leaf litter from fall to spring. It has to be also considered that _Typha_ sp. and _Phragmites_ sp. dont contribute to the waterfowl diet. They produce dense stands usually not inhabited by waterfowl and other animals. Muskarats are the only animals grazing on rhizomes of _Typha_. It appears that both macrophyte species may be a good vegetation cover for contaminated sediments disposed in a confined facility until the final capacity and design of that facility is reached, which may take a few years.

Suitability of the Bioassay Procedure

A greenhouse bioassay of _Typha_ sp. and _Phragmites_ sp. is longer than that of _Cyperus_ _esculentus_. Ideally, the plants for the bioassay should be started from seeds, and selected seedlings of similar size should be planted into experimental containers. However, it takes about three months to obtain sufficiently strong seedings of _Phragmites_ _communis_ which can be transplanted into tested sediments. In addition, only about 25% of _Phragmites_ seeds germinate. Similar germination procedure should be used for a bioassay with _Typha_ sp. We tested the use of rhizomes of _Phragmites_ and rhizomes and plants of _Typha_. However, each rhizome section produced a different number of shoots of unequal size. Mortality of the rhizomes and plants was greater than 80%, and Phragmites shoots obtained from rhizomes were sensitive to transplanting shock. Our experiments showed that both macrophytes had a different moisture requirement than Cyperus esculentus. Typha latifolia did not grow well under upland conditions suitable for C. esculentus. Both, Typha and Phragmites were taller and developed a greater root system than Cyperus. Consequently, a larger container would be desirable if the plants have to grow to their maturity. In marshes, these plants usually grow in soil which is more often under "flooded" than "upland" conditions, and the effect of waterlevel fluctuation on the uptake of metals is not known. Similar conditions may apply to other macrophyte species which are important in the waterfowl diet and may grow at CDF's in the Great Lakes area.

SUMMARY

1. A series of experiments were carried out to investigate the growth and uptake of metals by the macrophytes Cyperus esculentus, Typha latifolia and Phragmites communis from contaminated sediments collected at two Great Lakes harbours. One sediment was from the confined disposal facility located at Times Beach, Buffalo (Lake Erie), and the other from Hamilton Harbour (Lake Ontario). Both sediments were contaminated with similar quantities of heavy metals from local industries. An uncontaminated fluvial sediment was used as a reference soil.

2. All plants were grown on oxidized (upland) and reduced (flooded) sediment under greenhouse conditions. Cyperus esculentus grown in Hamilton Harbour sediment produced a greater quantity of aboveground tissue than that grown on Times Beach under upland and flooded conditions. Phragmites communis grown on Hamilton Harbour and Times Beach sediments produced a similar quantity of aboveground tissue under upland conditions. However, the growth was poor on Times Beach sediment under flooded conditions. Typha latifolia did not grow in Hamilton Harbour sediment under upland conditions. Under flooded conditions, Typha produced a greater quantity of aboveground tissue on Times Beach than on Hamilton Harbour sediment.

3. Under both, flooded and upland conditions, Typha latifolia and Phragmites communis accumulated smaller quantities of Zn, Cu and Cd than Cyperus esculentus. With few exceptions, small quantities of Cr, Co and Ni were found in aboveground tissues of the plants.

4. Concentrations of Zn, Cd and Cu were similar in aboveground tissues of Phragmites grown in Times Beach sediment under upland and flooded conditions in the greenhouse and those at the disposal area in Buffalo. The aboveground tissue of Typha grown in the greenhouse under upland and flooded conditions contained greater quantities of Zn and Cu than that collected at the Buffalo disposal site. However, the concentration of Cd was similar in Typha grown under both conditions in the greenhouse and that at the disposal site.

5. A good relationship between the concentrations of metals in the aboveground tissue of *Cyperus esculentus* and that of *Phragmites communis* and *Typha latifolia* indicated a good potential for using *Cyperus esculentus* as an indicator species to predict the uptake of Co, Cr, Cu and Zn by *Phragmites* and *Typha* growing on contaminated sediments.
6. Some problems were experienced with the germination and transplanting of *Typha* and *Phragmites* during the experiments. Only a small percentage (about 25%) of the planted seeds germinated. It was suggested to grow the seedlings for about 2-3 months before transplanting into tested sediments. In addition, *Typha* did not grow well under upland conditions designed for the index plant *Cyperus esculentus*. *Typha* and *Phragmites* developed a greater root system than *Cyperus*, and, consequently, it appears that a larger container should be used than that designed for the *Cyperus* bioassay.

ACKNOWLEDGEMENT

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Table 1 Chemical and Physical Properties of Sediments and Reference Soil

	Times Beach	Hamilton Harbour	WES Soil
Major Elements (% Dry Weight)			
SiO_2	64.3	36.1	79.7
Al_2O_3	12.5	6.9	12.4
Fe_2O_3	7.27	8.90	2.60
CaO	3.82	16.91	0.42
Na_2O	0.62	0.53	1.03
K_2O	2.32	1.85	2.08
TiO_2	0.65	0.30	0.73
MnO	0.13	0.17	0.19
P_2O_5	0.25	0.35	0.08
MgO	1.94	3.30	0.81
Total C	5.06	6.59	0.49
Org. C	3.26	2.32	0.32
Inorg. C	1.80	4.27	0.17
Particle Size:			
Clay	22.1	20.2	sandy
Silt	35.8	33.8	loam
Sand	42.1	46.0	
pH (wet)	7.01	6.85	5.90
pH (dry)	7.58	7.60	6.75

Table 2 Concentrations of trace elements in sediments and soils (µg/g dry weight)

Sediment	Cd	Co	Cr	Cu	Ni	Pb	V	Zn	As	Hg	Fe	Mn
Times Beach												
Total	2.9	12	188	165	46	410	76	610	15	2.15	50000	950
DTPA Upland	2.63	1.65	3.00	30.4	2.15	60.8		92.66			195	88
DTPA Flooded	1.80	1.31	3.44	56.59	4.83	41.65		23.8			912	126
Upland % of Total	90%	13%	1.6%	18.4%	4.7%	14.8%		15.2%			0.4%	0.8%
Flooded % of Total	69%	11%	1.8%	34.3%	10.6%	10.2%		3.9%			1.8%	12.6%
Hamilton Harbour												
Total	2.7	12	149	122	48	225	16	820	11	0.53	62000	1240
DTPA Upland	2.1	<0.1	3.2	27.7	7.0	40.7		329.0			323	89
DTPA Flooded	1.49	1.53	<0.1	0.76	9.55	14.4		279.0			359	87
Upland % of Total	78%	0.8%	2.1%	22.3%	14.6%	18.1%		40.9%			0.5%	6.8%
Flooded % of Total	55%	12%	0.1%	0.7%	19.9%	6.5%		34.0%			0.6%	6.7%
WES Soil												
Total	0.1	8	85	14	37	18	39	78	8	0.02	18100	1380
DTPA Upland	0.1	0.5	<0.1	0.55	<0.1	0.85		1.85			24	356
DTPA Flooded	<0.1	0.86	0.1	0.53	0.1	0.46		1.16			12	289
Upland % of Total	100%	6.2%	<0.1%	3.9%	<0.2%	4.7%		2.3%				
Flooded % of Total	<100%	10.7%	0.1%	3.8%	0.27%	2.5%		1.4%				
L. Ontario Deep	0.1-6.2		8-133	26-109	29-99	7-285		87-3507	0.2-17.0	0.14-3.95		
L. Ontario Shallow	<0.2-20.6		3-500	2-200	4-160	1.8-287		6-1120	0.2-26.0	<0.01-7.76		
L. Ontario Harbours	<0.5-10.0		<0.3-390	1-860	<1-75	<1-1600		5-2010	N/A	<0.01-7.00		
L. Erie Deep	0.8-13.7		12-362	5-207	16-150	6-299		18-536	0.45-12.3	0.045-450		
L. Erie Shallow	0.1-8.3		N/A	3-138	9-69	9-221		16-351	N/A	0.08-1.88		
L. Erie Harbours	N/A		13-150	2-100	2-90	<1-192		12-650	N/A	0.015-2.20		
OME Guidelines *	1.0		25	25	25	50		100	8.0	0.3		

N/A - not available

*The Ontario Ministry of The Environmentl guidelines for open water disposal of dredged material.

Table 3 Ratio between DTPA-extractable and total trace elements, Fe and Mn concentrations in sediment.

Sediment	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
<u>Times Beach</u>									
Upland	0.90	0.13	0.016	0.184	0.004	0.008	0.047	0.148	0.152
<u>Times Beach</u>									
Flooded	0.69	0.11	0.018	0.343	0.018	0.126	0.106	0.102	0.039
<u>Hamilton Harbour</u>									
Upland	0.78	0.008	0.021	0.223	0.005	0.068	0.146	0.181	0.409
<u>Hamilton Harbour</u>									
Flooded	0.55	0.12	0.001	0.007	0.006	0.067	0.199	0.064	0.340

Table 4 Plant Yield (g dry weight/pot)

Sediment	Upland			Flooded		
	Shoots	Roots	Tubers	Shoots	Roots	Tubers
Cyperus						
Times Beach	9.10	2.12	2.00	7.23	3.0	1.00
Hamilton Harbour	12.50	2.56	1.95	17.70	8.39	5.77
WES Soil	7.34	2.62	2.69	13.42	3.26	6.20
Phragmites						
Times Beach	3.36	2.63		0.91	1.15	
Hamilton Harbour	3.23	1.19		12.77	12.26	
WES Soil	2.59	0.87		9.61	8.56	
Typha						
Times Beach	0.42	0.18		3.89	1.66	
Hamilton Harbour	N/A	N/A		0.35	0.11	
WES Soil	1.53	1.06		4.38	1.68	

Table 5 Plant Trace Element Concentrations (µg dry weight)

Sediment		Cd u.	Cd f.	Co u.	Co f.	Cr u.	Cr f.	Cu u.	Cu f.	Ni u.	Ni f.	Pb u.	Pb f.	Zn u.	Zn f.
Cyperus															
Times Beach		1.13	0.31	.1	.1	.9	1.5	38	36	2	3	14	19	152	88
Hamilton Harbour		0.98	0.26	.2	.2	1.5	2.6	52	37	4	7	16	17	782	283
Phragmites															
Times Beach		<.1	<.1	.2	.2	.3	.5	12	8	3	3	14	13	42	28
Hamilton Harbour		<.1	<.1	.3	.1	.5	.4	18	6	4	3	19	10	201	42
Typha															
Times Beach		<.1	<.1	.3	.2	1.1	1.0	22	12	6	4	33	20	96	36
Hamilton Harbour		NA	<.1	NA	.2	NA	.8	NA	12	NA	5	NA	17	NA	61
Cyperus (Other Studies)															
Great Lakes[1]	Min	0.9	0.2			<0.03	0.08	2.1	0.2	<0.08	<0.08	0.9	0.5	17.3	0.2
(10 Sediments)	Max	20.8	2.8			5.2	4.5	6.5	8.4	3.4	2.7	1.6	2.3	259.6	151.5
The Netherlands[2]	Min	0.6	0.1			<0.25	<0.25	11.7	6.1	0.5	0.3	0.2	0.4	78	34
(4 sediments)	Max	4.8	1.0					12.3	11.1	1.0	0.5	0.3	0.8	113	37
Phragmites (Other Studies)															
Site C Times Beach[3]		<0.13						7.5						39	
Site D Times Beach		<0.13						7.0						27	
Phragmites sp.															
New Jersey[6]								26.1						37.8	
USSR[7,8]								25.0-52.4						40.3	
Canada, lake[9]								3.0						112	
Compiled from literature[5]								1-26						15-38	
Germany, wastewater pond[11,12]					0.62			4.2		1.53					37
USSR, reservoir[7]					0.2-0.42			1.5-3.4						18-53	

u. = upland conditions f. = flooded conditions NA = no plant available for analyses

Table 5 Plant Trace Element Concentrations (μg dry weight)
<u>continued</u>

Sediment	Cd	Co	Cr	Cu	Ni	Pb	Zn
	u. f.	u. f.	u. f.	u. f.	u. f.	u. f.	u. f.
				Typha (Other Studies			
Site D Times Beach[3]	<0.13			5.1			20
Site G Times Beach	<0.13			4.0			16
Typha sp.							
Great Lakes marshes[4]	<0.5	<1-3	<1-6	<1-6	<1-5	3-6	7-20
Compiled from literature[5]				1-37			18-150
New Jersey[6]				5.0-6.3			23.5-50.5
USSR[7,8]		0.7-1.0		3.6-24.3			22-40
Canada, marsh [9]				8.0			14
Canada, meadow[10]				8.0			97
Germany, wastewater system[11,12]		0.44		4.7	1.86		43

[1]Lee *et al*. (1983)
[2]Van Driel *et al*. (1985)
[3]Dr. J. Simmers Env. Lab Wes. (Pers. Comm.)
[4]Mudroch, A. (1981)
[5]Boyce, C.E. and E. Scarsbrook (1975)
[6]Riemer, D.N. and S.J. Toth (1968)
[7]Varenko, N.I. and V.T. Chuiko (1971)
[8]Petkova, L.M. and I.P. Lubyanov (1969)
[9]Auclair, A.N.D. (1979)
[10]Auclair, A.N.D. (1977)
[11]Seidel, K. (1966)
[12]Seidel, K. (1976)

u. = upland conditions f. = flooded conditions

Table 6 Relationship between concentrations of metals in aboveground tissue of *Cyperus esculentus*, *Phragmites communis* and *Typha latifolia*. (linear correlation coefficient r^2)

Metal	*C. esculentus* - *P. communis* (no. of samples = 7) Upland	*C. esculentus* - *P. communis* (no. of samples = 7) Flooded	*C. esculentus* - *T. latifolia* (no. of samples = 5) Flooded
Co	.745	-.600	-
Cr	.887	-.611	-.769
Cu	.868	-.147	-.971
Ni	.592	-.115	.202
Pb	.433	-.038	.205
Zn	.922	-.742	.941

FIGURE 1. Location of Times Beach, Buffalo and Hamilton Harbour.

FIGURE 2. Concentrations of metals in plants grown on Times Beach sediment.

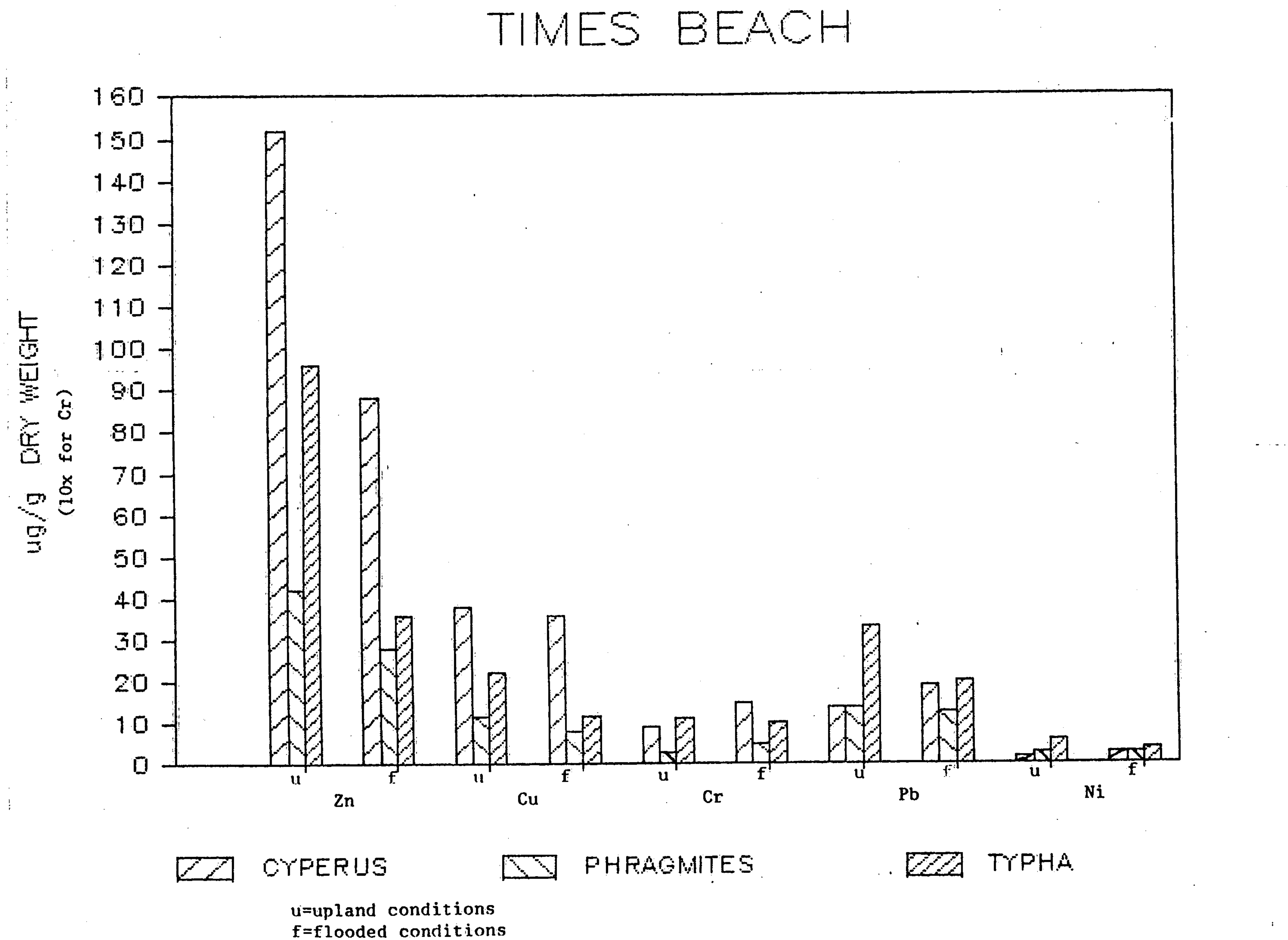
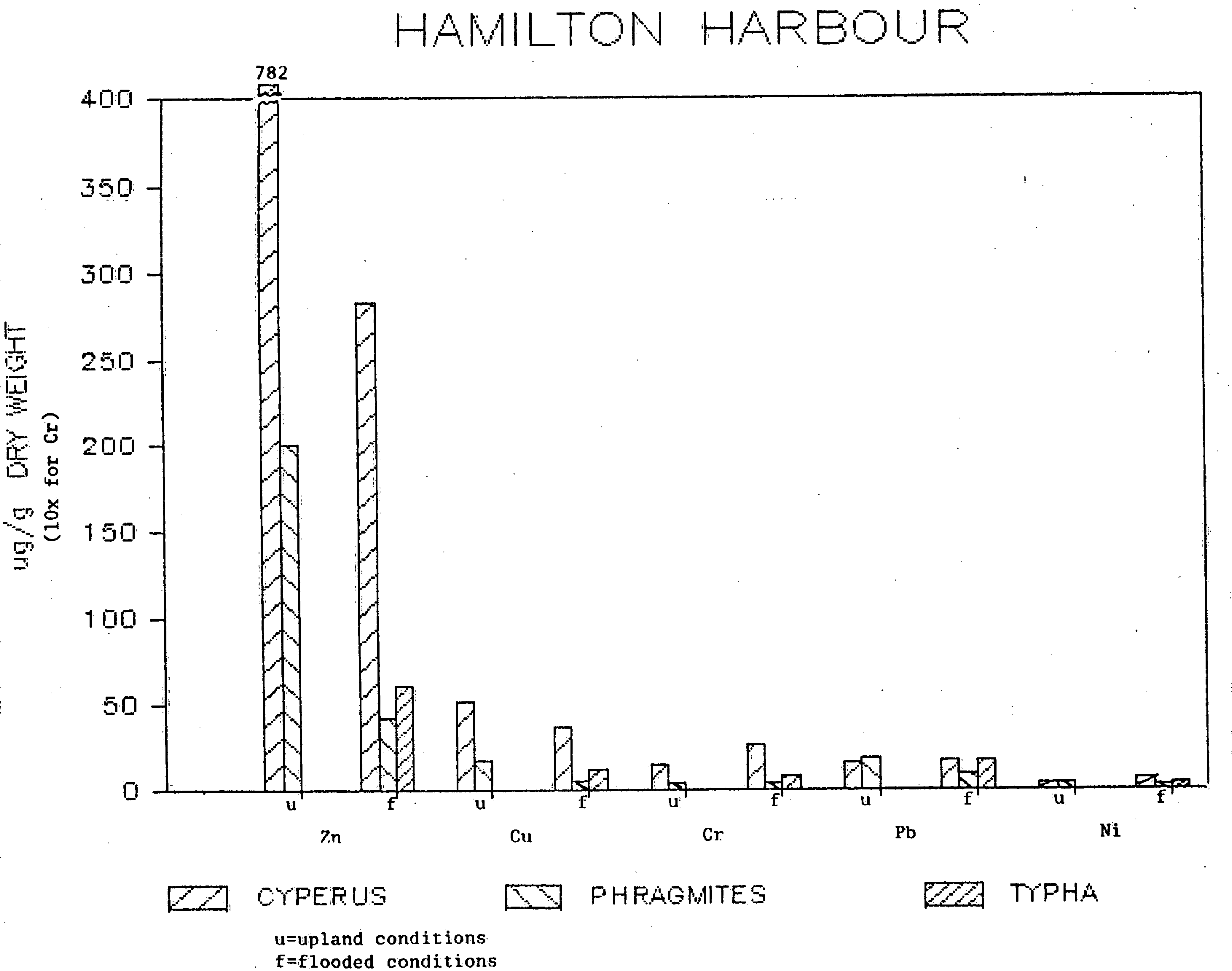


FIGURE 3. Concentrations of metals in plants grown on Hamilton Harbour sediment.



APPENDIX

LIST OF TABLES IN THE APPENDIX

Table 1 Chemical and physical properties of sediments and reference soil

Sediment/Soil	Major Elements (% dry weight)														
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	MgO	Total C	Org C	Inorg C	pH (wet)	pH (dry)
Times Beach Buffalo	64.3	12.5	7.27	3.82	0.62	2.32	0.65	0.13	0.25	1.94	5.06	3.26	1.80	7.01	7.58
Hamilton Harbour	36.1	6.9	8.90	16.91	0.53	1.85	0.30	0.17	0.35	3.30	6.59	2.32	4.27	6.85	7.60
WES Soil	79.7	12.4	2.60	0.42	1.03	2.08	0.73	0.19	0.08	0.81	0.49	0.32	0.17	5.90	6.75

	Particle Size Distribution		
	Clay %	Silt %	Sand %
Times Beach Buffalo	22.1	35.8	42.1
Hamilton Harbour	20.2	33.8	46.0

Table 2 Concentrations of trace elements in sediments and soil (μg/g dry weight)

Sediment/Soil	Cd	Co	Cr	Cu	Ni	Pb	V	Zn	As	Hg
Times Beach Buffalo	2.9	12	188	165	46	410	76	610	15	2.15
Hamilton Harbour	2.7	12	149	122	48	225	16	820	11	0.53
WES Soil	0.1	8	85	14	37	18	39	78	8	0.02

Table 3 Concentrations of trace elements in surface sediments of Lakes Ontario and Erie*. (μg/g dry weight)

Element/Lake		Depositional Basins	Nondepositional Zones	Harbours	OME Guidelines**	Times Beach	Hamilton Harbour
As	Ontario	0.20 - 17.00	0.20 - 26.00	n.d.	8	15	11
	Erie	0.45 - 12.30	n.d.	n.d.			
Cd	Ontario	0.10 - 6.20	<0.20 - 20.60	<0.50 - 10.00	1.0	2.9	2.7
	Erie	0.80 - 13.70	0.10 - 8.30	n.d.			
Cr	Ontario	8 - 133	3 - 500	<0.3 - 390	25	188	149
	Erie	12 - 362	n.d.	13 - 150			
Cu	Ontario	26 - 109	2 - 200	1 - 860	25	165	122
	Erie	5 - 207	3 - 138	2 - 100			
Pb	Ontario	7 - 285	1.8 - 287	<1 - 1600	50	410	225
	Erie	6 - 299	9 - 221	<1 - 192			
Hg	Ontario	0.14 - 3.95	<0.01 - 7.76	<0.01 - 7.00	0.30		
	Erie	0.045 - 4.80	0.08 - 1.88	0.015 - 2.20			
Ni	Ontario	29 - 99	4 - 160	<1 - 75	25	46	48
	Erie	16 - 150	9 - 69	2 - 90			
Zn	Ontario	87 - 507	6 - 1120	5 - 2010	100	610	820
	Erie	18 - 536	16 - 351	12 - 650			

* Summary of concentration reported in different journals and reports (Mudroch et al., 1985)

** The Ontario Ministry of the Environment guidelines for dredged material open meter disposal

n.d. no data available

Table 4 DTPA-extractable trace elements, Fe and Mn (µg/g dry weight)

Sediment/Soil	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
<u>Times Beach</u>									
Upland	2.63	1.65	3.00	30.40	195	88	2.15	60.80	92.66
<u>Times Beach</u>									
Flooded	1.80	1.31	3.44	56.59	912	126	4.83	41.65	23.80
<u>Hamilton Harbour</u>									
Upland	2.10	$<$0.10	3.20	27.70	323	89	7.00	40.70	329.0
<u>Hamilton Harbour</u>									
Flooded	1.49	1.53	$<$0.10	0.76	359	87	9.55	14.40	279.0
<u>WES Soil</u>									
Upland	0.10	0.50	$<$0.10	0.55	24	356	$<$0.10	0.85	1.85
<u>WES Soil</u>									
Flooded	$<$0.10	0.86	0.10	0.53	12	289	0.10	0.46	1.16

Table 5 Ratio between DTPA-extractable and total trace elements

Sediment/Soil	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
<u>Times Beach</u>									
Upland	0.90	0.13	0.016	0.184	0.004	0.008	0.047	0.148	0.152
<u>Times Beach</u>									
Flooded	0.69	0.11	0.018	0.343	0.018	0.126	0.106	0.102	0.039
<u>Hamilton Harbour</u>									
Upland	0.78	0.008	0.021	0.223	0.005	0.068	0.146	0.181	0.409
<u>Hamilton Harbour</u>									
Flooded	0.55	0.12	0.001	0.007	0.006	0.067	0.199	0.064	0.340

Table 6 Average yield of *Cyperus esculentus* (g dry matter/pot)

	Upland			Flooded		
Sediment/Soil	Aboveground	Roots	Tubers	Aboveground	Roots	Tubers
Times Beach Buffalo	9.10	2.12	2.00	7.23	3.00	1.00
Hamilton Harbour	12.50	2.56	1.95	17.70	8.39	5.77
WES Soil	7.34	2.62	2.69	13.42	3.26	6.20

Table 7 Average yield of *Phragmites communis* (g dry matter/pot)

	Upland		Flooded	
Sediment/Soil	Aboveground	Roots	Aboveground	Roots
Times Beach Buffalo	3.36	2.63	0.91	1.15
Hamilton Harbour	3.23	1.19	12.77	12.26
WES Soil	2.59	0.87	9.61	8.56

Table 8 Average yield of Typha latifolia (g dry matter/pot)

	Upland		Flooded	
Sediment/Soil	Aboveground	Roots	Aboveground	Roots
Times Beach Buffalo	0.42	0.18	3.89	1.66
Hamilton Harbour	No plants available		0.35	0.11
WES Soil	1.53	1.06	4.38	1.68

Table 9 Average metal concentrations in aboveground tissue of <u>Cyperus</u> <u>esuclentus</u> (μg dry weight)

Sediment	Cd		Co		Cr		Cu		Ni		Pb		Zn	
	f.	u.	f.	u.	f.	u.	f.	u.	f.	u.	f.	u.	f.	u.
Times Beach Buffalo	.31	1.13	.1	.1	1.5	.9	36	38	3	2	19	14	88	152
Hamilton Harbour	.26	.98	.2	.2	2.6	1.5	37	52	7	4	17	16	283	782

f. = flooded conditions
u. = upland conditions

Table 10 Average metal concentrations in aboveground tissue of <u>Phragmites communis</u> (μg dry weight)

Sediment	Cd		Co		Cr		Cu		Ni		Pb		Zn	
	f.	u.	f.	u.	f.	u.	f.	u.	f.	u.	f.	u.	f.	u.
Times Beach Buffalo	<0.1	<0.1	.2	.2	.5	.3	8	12	3	3	13	14	28	42
Hamilton Harbour	<0.1	<0.1	.1	.3	.4	.5	6	18	3	4	10	19	42	201

f. = flooded conditions
u. = upland conditions

Table 11 Average metal concentrations in aboveground tissue of _Typha latifolia_ (µg dry weight)

Sediment	Cd		Co		Cr		Cu		Ni		Pb		Zn	
	f.	u.	f.	u.	f.	u.	f.	u.	f.	u.	f.	u.	f.	u.
Times Beach Buffalo	<0.1	<0.1	.2	.3	1.0	1.1	12	22	4	6	20	33	36	96
Hamilton Harbour	<0.1	*	.2	*	.8	*	12	*	5	*	17	*	61	*

f. = flooded conditions
u. = upland conditions
* no plants available for analysis

Table 12 Range of average concentrations of metals in aboveground tissue of <u>Cyperus esculentus</u> grown in different contaminated sediments from the Great Lakes and The Netherlands (μg/g dry matter)

Location:	Cd		Cr		Cu		Ni		Pb		Zn	
	flooded	upland	flooded	upland	flooded	upland	flooded	upland	flooded	upland	flooded	upland
Times Beach[1]	.31	1.13	1.5	.9	36	38	3	2	19	14	88	152
Hamilton Harbour[1]	.26	.98	2.6	1.5	37	52	7	4	17	16	283	782
Great Lakes[2] (10-sediments)	0.19-2.81	0.87-20.84	0.08-4.53	<0.03-5.21	0.23-8.4	2.10-6.53	<0.08-2.70	<0.08-3.41	0.54-2.25	0.87-1.63	0.2-151.5	17.3-259.6
The Netherlands[3] (4 sediments)	0.16-0.95	0.65-4.75	<0.25	<0.25	6.1-11.1	11.7-12.3	0.35-0.51	0.45-0.95	0.36-0.83	0.19-0.32	34-37	78-132

[1]average concentration (this report)
[2]Lee *et al*. (1983)
[3]Van Driel *et al*. (1983)

Table 13 Concentrations of Zn, Cu and Cd in aboveground tissue of *Typha* sp. and *Phragmites* sp. grown in the greenhouse and collected at Times Beach, Buffalo (µg dry weight)

	Zn	Cu	Cd
Field:[1]			
(site C, Times Beach)	39	7.5	<0.13
Phragmites australis (site D, Times Beach)	27	7.0	<0.13
Greenhouse:			
Phragmites communis			
Times Beach sediment:			
upland conditions	42	12	
flooded conditions	28	8	
Field:[1]			
Typha latifolia			
(side D, Times Beach)	20	5.1	<0.10
Typha latifolia (site G, Times Beach	16	4.0	<0.10
Greenhouse:			
Typha latifolia			
Times Beach sediment			
upland conditions	96	22	<0.10
flooded conditions	36	12	<0.10

[1]Dr. J. Simmers, Environmental Laboratory, WES (personal communication)

Table 14 Concentratio of metals in aboveground tissue of <u>Typha</u> sp. and <u>Phragmites</u> sp. collected at different areas (μg/g dry weight).

Sediment/Soil	Cd	Co	Cr	Cu	Ni	Pb	Zn
<u>Typha sp.</u>							
Great Lakes marshes[1]	<0.5	<1-3	<1-6	<1-6	<1-5	3-6	7-20
Compiled from literature[2]				1-37			18-150
New Jersey[3]				5.0-6.3			23.5-50.5
USSR[4,5]		0.7-1.0		3.6-24.3			22-40
Canada, marsh[6]				8.0			14
Canada, meadow[7]				8.0			97
Germany, wastewater system[8,9]		0.44		4.7	1.86		43
<u>Phragmites sp.</u>							
New Jersey[3]				26.1			37.8
USSR[4,5]				25.0-52.4			40.3
Canada, lake[6]				3.0			112
Compiled from literature[2]				1-26			15-38
Germany, wastewater pond[8,9]		0.62		4.2	1.53		37
USSR, reservoir[4]		0.2-0.42		1.5-3.4			18-53

[1]Mudroch, A. (1981)
[2]Boyd, C.E. and E. Scarsbrook (1975)
[3]Riemer, D.N. and S.J. Toth (1968)
[4]Varenko, N.I. and V.T. Chuiko (1971)
[5]Petkova, L.M. and I.P. Lubyanov (1969)
[6]Auclair, A.N.D. (1979)
[7]Auclair, A.N.D. (1977)
[8]Seidel, K. (1966)
[9]Seidel, K. (1976)