SUSPENDED SEDIMENTS AND THE DISTRIBUTION OF BOTTOM SEDIMENTS IN THE NIAGARA RIVER

by

Alena Mudroch

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Lakes Research Branch
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario, Canada L7R 4A6

Environment Canada

EXECUTIVE SUMMARY

During the comprehensive investigation of the Niagara River pollution initiated in 1981 bottom sediment samples collected in different sections of the river were mainly sandy silt and coarse grained material. All attempts to recover a sediment core from the river failed due to either strong currents or a limited quantity of fine-grained sediments on the river bottom. Consequently, to obtain more information on the character and distribution of sediments in the Niagara River, a geophysical survey was conducted in 1983/84. The results of the survey confirmed the lack of deposition of fine-grained sediments on the river bottom. Fine-grained sediments were located only at a few areas in the lower part of the Niagara River. The estimated thickness of these deposits was about 10 cm within areas smaller than 1 m^2. It was concluded that the lack of depositional areas for fine-grained particles in the Niagara River results in the transport of fine-particle associated contaminants originating from the sources along the river into depositional zones of Lake Ontario. The survey was carried out through a contract to McOuest Marine Sciences Ltd., Burlington, Ontario. The work was jointly funded by Environment Canada and the Great Lakes National Programs Office, U.S. Environmental Protection Agency, Region V, Chicago, Illinois.

RÉSUMÉ

Au cours de l'étude d'ensemble de la pollution de la rivière Niagara, entreprise en 1981, les échantillons de sédiments de fond prélevés dans divers segments de la rivière étaient constitués essentiellement de silt sableux et de matériaux grossiers. Il a été impossible de récupérer une carotte de sédiments de la rivière, à cause des courants trop puissants ou d'une quantité faible de sédiments fins sur le fond du lit. C'est pourquoi, afin d'obtenir plus de renseignements sur les caractéristiques et la distribution des sédiments dans la rivière Niagara, un levé géophysique a été réalisé en 1983-1984. Les résultats du levé ont permis de confirmer que les sédiments ne s'accumulaient pas sur le fond de la rivière; ils ont été observés seulement à quelques endroits dans le cours inférieur de la rivière Niagara. L'épaisseur de ces dépôts, étalés en plaques de moins de 1 m^2 de superficie, a été estimée à environ 10 cm. D'après le levé, à cause de la rareté des zones d'accumulation de particules fines dans la rivière Niagara, les contaminants fixés à ces particules et provenant de sources le long de la rivière s'accumulent plutôt dans le lac Ontario. Le levé a été réalisé à contrat par McQuest Marine Sciences Ltd. de Burlington en Ontario et a été subventionné conjointement par Environnement Canada et le Great Lakes National Programs Office, U.S. Environmental Protection Agency, Region V, Chicago, Illinois.

ABSTRACT

A geophysical survey was conducted in 1983/84 to obtain information on the character and distribution of bottom sediments in the Niagara River. A combination side-scan sonar and sub-bottom profiler was used in the survey of the river bed. The results of the survey showed a lack of deposition of fine-grained sediments on the river bed. Coarse sand, gravel, glacio-lacustrine clay and till, and bedrock were major components of the bottom deposits in the river. Fine-grained sediments were located only at a few areas in the lower part of the Niagara River. The estimated thickness of these deposits was about 10 cm and they occurred as small patches, often <1 m^2. Many contaminants entering the Niagara River, in a soluble or particulate form, become associated with the suspended load, consisting mainly of fine-grained particles. The lack of depositional areas for fine-grained particles in the Niagara River results in the transport of particle-associated contaminants into the depositional zones of Lake Ontario.

Additional Index Words: Contaminants, Transport, Lake Ontario

RÉSUMÉ

Un levé géophysique a été réalisé en 1983-1984 en vue d'obtenir des données sur les caractéristiques de la distribution des sédiments de fond de la rivière Niagara. Un sonar latéral et un profilomètre de fond ont été utilisés. Le résultat du levé a montré l'absence d'accumulation de sédiments fins sur le lit de la rivière alors que les sables grossiers, les graviers, les argiles et les tills glacio-lacustres et le substrat constituaient les principales composantes des dépôts de fond. Les sédiments fins n'ont été observés qu'à quelques endroits dans le cours inférieur de la rivière Niagara, en petites plaques de superficie parfois inférieure à 1 m^2; leur épaisseur a été estimée à 10 cm. Nombre de contaminants qui pénètrent dans la rivière Niagara, sous forme soluble ou particulaire, se fixent à la charge en suspension, essentiellement constituée de particules à grains fins. À cause de la rareté des zones d'accumulation de sédiments fins dans la rivière Niagara, les contaminants fixés aux particules s'accumulent dans le lac Ontario.

Autres mots clés : contaminants, transport, lac Ontario

MANAGEMENT PERSPECTIVE

The survey of the bottom sediments of the Niagara River confirmed the results of the comprehensive investigation of the Niagara River pollution and showed limited deposition of fine-grained sediment on the river bottom. It was concluded that the lack of deposition of fine-grained sediments in the Niagara River results in the transport of fine particles associated contaminants originating from the sources along the river into depositional zones of Lake Ontario.

PERSPECTIVE DE GESTION

Le levé réalisé sur les sédiments de fond de la rivière Niagara a confirmé les résultats d'une étude d'ensemble de la pollution de la rivière Niagara et révélé qu'il y avait une faible accumulation de sédiments à granulométrie fine sur le lit de la rivière. Le levé permet donc de conclure que l'absence d'accumulation de sédiments fins dans la rivière Niagara résulte du transport de contaminants fixés à des particules fines provenant de sources le long de la rivière, vers les zones d'accumulation du lac Ontario.

INTRODUCTION

The Niagara River, a connecting channel between Lakes Erie and Ontario, with an average flow of 5,800 m^3/sec (Yee and Lloyd, 1985), provides more than 84% of the total tributary inflow to Lake Ontario.

Steel, petrochemical and chemical manufacturing industries located along the river have created environmental problems, particularly contamination of water, sediments and biota, by the discharge of toxic chemicals in municipal and industrial effluents and the leakage waste disposal sites located adjacent to the river.

A three-year joint Canada/U.S.A. investigation of toxic chemicals entering and present in the river, with the simultaneous identification of sources of these chemicals, was initiated in 1981. Bottom sediment samples collected in different sections of the Niagara River were mainly composed of sandy silt and coarse grained material. Surface sediments consisting of fine sand with some silt were collected only in some nearshore areas. However, all attempts to recover a sediment core from the river failed due to either strong currents or the lack of fine-grained river bed material. Consequently, concentrations of contaminants were obtained by analyzing sediments collected by a Shipek grab sampler at numerous widely separated locations in the nearshore areas of the river. The results of these analyses have been published (The Niagara River Toxics Committee, 1984).

The study was supplemented by a comprehensive research program at the outlet of the river and in the Western Basin of Lake Ontario to assess the historical input, pathways and fate of contaminants entering the lake from the Niagara River. Results of this research have been published by Allan et al. (1983).

To obtain more information about the character and distribution of bottom sediments in the Niagara River, a detailed geophysical survey was conducted in 1983/84 by Environment Canada through a contract to McQuest Marine Sciences Ltd., Burlington, Ontario. The contract was jointly funded by Environment Canada and the Great Lakes National Program Office, U.S. Environmental Protection Service, Region V, Chicago, Illinois. A combination side-scan sonar and sub-bottom profiler was used in the survey of the river bed. This paper presents the results of the 1983/84 survey and discusses their relevance to the Niagara River pollution issue.

MATERIALS AND METHODS

The Niagara River was divided into five sections for the geophysical survey (Fig. 1): section 1 covered the river from Lake Erie downstream to the southern tip of Grand Island; section 2 covered the Tonawanda Channel from the southern limit of Grand Island downstream to Tonawanda Creek; section 3, also in the Tonawanda Channel, extended from Tonawanda Creek to Cayuga Island; section 4 covered the Chippawa Channel, and section 5 covered the lower Niagara

River downstream from the Queenston Bridge to Lake Ontario; the upper river, from just above the falls to just below the power plants in the great gorge, was not surveyed. The survey was conducted in two phases; a feasibility survey was run in section 2, only, during January 1983. This was used to determine the suitability of survey methods. The remaining sections were surveyed during February 1984.

A set of aerial photographs was used to locate landmarks on the shore which would serve as fix locations for positioning from a small survey craft. Selected locations were transferred from the photographs to an overlay for use in the field. In the field, some additional points were located and more details were added to the shoreline description. All fix points were given numbers which, during the course of each run, were noted on all records simultaneously. Optical position fixing was successfully used. Traverse lines were generally run in both directions, upstream and downstream, with a minimum of three lines at the 1/4, 1/2 and 3/4 width points depending on the width of the river section. The number of lines run was based on the need to provide 10 to 20% overlap coverage by the side-scan sonar. The only variable was current velocity. Lines were run at 50 m and 75 m from each shoreline with the aid of the horizontal scale on the side-scan sonar and were considered to be located accurately. The centre line was also considered reasonably accurate, being relatively simple to estimate the mid-point of the river. The estimated distance from shore was less certain for all other survey lines. The survey did not cover the river nearshore at depths of less than 3 m.

The instrumentation used for the survey consisted of a Klein Model 531T three-channel side-scan sonar system operating at a frequency of 500 kHz. Two channels were used for side-scan display and the third was used to provide a 3.6 kHz sub-bottom profiler display. Depending on the depth of bedrock beneath the river bed and the nature of the bottom sediments, channel three could image both bottom and sub-bottom profiles. A Kelvin Hughes MS26 echosounder was used to provide qualitative sub-bottom information (Sly and Prior, 1984). The river bed bathymetry was recorded on a Raytheon DE719BM echosounder operating at 200 kHz and calibrated to a speed of sound in water of 1463 m/sec. All equipment was mounted on board an eight-meter fibreglass boat.

On completion of the geophysical survey, sediment sampling was carried out in the upper river at fifteen stations(Figs. 4 and 5) using a double-Shipek grab sampler (Sly, 1981). Station selection was based on the use of different bottom relief types that were established following the interpretation of the geophysical data.

RESULTS

The positioning system used in this survey was not considered to be of sufficient accuracy to attempt contouring of the bottom elevation. The bottom relief was categorized into six different types: (1) smooth, (2) gently undulating, (3) undulating minor relief, (4) minor but irregular relief, (5) major irregularities, (6) gully. Typical examples of each category are presented in Fig. 2. The distribution of relief types detected in the river are presented in Figs. 3 to 6. From the inspection of all available records, implications were drawn about the types of bed material that were characteristic of different relief types.

The bedrock forms a predominantly flat surface but with local areas of significant relief. The thickness of overburden can change rapidly and is generally inversely proportional to local water depth. However, it was not practical to map this thickness with the positioning systems used in the survey. The overburden thickness may be up to 15 m. Two distinct layers were apparent in the thicker overburden sequences. The upper layer consisted of coarse sand and gravel (lag deposits from which all fine material has been winnowed) and a deeper layer with the seismic signature (Thomas et al., 1973; Sly and Prior, 1984) of glacio-lacustrine or varved clay. The lower river is significantly deeper than the section above the falls. In the lower river, significant overburden thickness occur only at the river mouth in Lake Ontario.

The side-scan sonar image of the river bed was consistent with the interpretation based on bottom relief, generally indicating a coarse grained or bouldery material on the river bed with a higher proportion of debris (such as wood branches, leaves) adjacent to the river banks. Evidence of dredging and shipping channel maintenance operations were apparent in the upper river.

Figures 3 to 6 show the bed profile along the centre line in each section and the type of exposed bottom sediment, based on echo-sounder records and interpretations of side-scan sonar signatures. There was no evidence of extensive deposits of fine-grained materials such as silt or clay. Small patches of fine-grained sediment, generally $< 1\ m^2$ in area and 10 cm thick, were detected at a few locations and only in the lower Niagara River. These areas have been indicated by a bar on Fig. 6. Grab sampling for fine-grained sediment may be carried out in these areas with some difficulty, given their size and the high flow velocity of the river. The sediment thickness was not sufficient to allow bottom coring.

Results from sediment sampling at 15 sites, representative of the relief categories (except "gully"), generally confirmed the interpretation of the side-scan sonar data. Sediments consisted principally of coarse-grained, poorly sorted sand and gravel. Some silt and fine sand were found at one sampling station located about 10 m from the western shore in section 2 (Fig. 1).

DISCUSSION

Kemp and Harper (1976) estimated that the Niagara River contributes about 50% or 4.56 million tonnes per year of the silt and clay-size grained material to Lake Ontario. They concluded that most of the fine-grained sediment entering Lake Ontario from the Niagara River originates from Lake Erie. A more recent determination of 1.54 million tonnes (range 0.4 to 8.3 x 10^6) per annum based on suspended sediment concentrations and flow data of Kuntz and Warry (1983) agrees well with this estimate. The results of the geophysical survey indicated that with the exception of a few isolated patches in the lower Niagara River, the river bottom is essentially swept clean of any fine-grained sediments. Furthermore, nearshore sediments sampled during the 1981-83 intensive investigation of the Niagara River consisted mainly of sandy silt and coarser material (Niagara River Toxics Committee, 1984). Several studies have demonstrated correlations between the quantities of suspended sediment at the river outflow into Lake Ontario (at Niagara-on-the-Lake) and at the outflow from Lake Erie (at Fort Erie). Increased quantities of suspended sediment may be brought about by resuspension of Lake Erie bottom sediments during storm events. In addition, large quantities of suspended sediment were observed at the outflow during the winters of 1984-85 and 1985-86, during periods of extremely low river flow. These were thought to be brought about by ice-scouring of bottom sediments in Lake Erie (Kuntz and Chan, 1982; Kuntz and Warry, 1983; Kauss, 1983; Data Interpretation Group, 1986). On an annual basis, the quantity of suspended sediment measured at the Niagara-on-the-Lake station was only slightly greater than at Fort Erie. This difference is due to tributary inputs along the river and the effects of bank erosion.

To visualize the amount of suspended sediment carried annually through the Niagara River, we calculated the thickness of a layer of fine-grained sediment which would be deposited on the river bed under hydrological conditions permitting sedimentation. In this calculation we used river dimensions given by the International Niagara River Working Committee (1987) and values for the average and maximum loading calculated by Kuntz and Warry (1983). The thickness of the hypothetical sediment layer deposited annually on the river bottom would be 3.5 cm and 18.6 cm (for average and maximum loading, respectively). The calculation illustrates that there is enough material in suspension to form a significant layer of bottom sediment, if deposited. However, prevailing hydrological conditions, in particular strong currents and ice scouring, prevent sediment accumulation on the river bed.

Many contaminants in the aquatic environment become associated with particulate material, especially the fine-grained (silt/clay-sized) sediments (Allan, 1986). Several studies, including those cited above, have demonstrated that substantial quantities of metals and man-made organic chemicals enter Lake Ontario from the Niagara River on the suspended sediment fraction (Thomas <u>et</u> <u>al</u>., 1987). Municipal and industrial point sources as well as non-point sources such as leaking waste sites and tributaries along the Niagara River, increase contaminant loadings to Lake Ontario. Our results, which covered most of the river bed, suggested resuspension of contaminated sediment is probably insignificant throughout most of the river's channel.

Contaminants transported from Lake Erie contribute to Lake Ontario loadings. Two stations, one at the head and the other at the mouth of the river, were used to determine the differences in concentrations in both the dissolved and particulate phases of chemicals entering the Niagara River from Lake Erie, and those entering Lake Ontario from the Niagara River. Analyses of the data have shown statistically significant increases in concentrations for a number of metals, pesticides, PAH's and other industrial chemicals. This implies that there are significant inputs of these substances from the sources along the river (El-Shaarawi et al., 1985; Data Interpretation Group, 1986). Because of the high dilution capacity of the river and the low solubility of many of the organics in water the in-river and outflow concentrations of such substances are often below analytical detection limits. However, because of the affinity of many of these chemicals to sorb onto particulate matter, most increases are observed in association with the suspended sediment in the water column.

To determine if particular substances are cause for concern, part of the traditional regulatory approach is to compare their concentrations in receiving waters with a variety of specified water quality objectives, guidelines, standards, etc. We question whether such an approach is either meaningful or sufficient in the context of the Niagara River. In particular, the high flow (5800 m^3/sec) and large volume of water in the river greatly dilute even large inputs of contaminants from point and non-point sources to concentrations which will not exceed most water quality criteria. Furthermore, even though statistically significant increases in concentrations of some substances in water occur between the head and mouth of the river, as noted above, these differences are relatively small and tend not to adequately reflect the true magnitude of the contaminant loads entering along the river. In both cases, the ultimate result is that the impact of the often substantial loadings to Lake Ontario from the Niagara River, tends to be ignored because the concentrations in the water are considered to be more important than loadings.

For example, Warry et al. (1986) calculated the mean annual loading of Cu, other metals and organic contaminants from the Niagara River to Lake Ontario on data collected from 1983-85. Both the total load to Lake Ontario (including Lake Erie input) and the portion of the load originating from sources along the river were calculated using data from two stations at the inflow and outflow of the river. The proportion of the load in the "dissolved" and "suspended" fraction was also calculated. The results suggest that 357,000 kg of Cu enter Lake Ontario annually from the Niagara River of which 71,540 kg, or about 20%, originates from sources along the river. Despite these substantial loadings, the mean concentration of total Cu in river water was only 2 µg/L and, at this concentration, Cu did not exceed the specific objective of the 1978 Great Lakes Water Quality Agreement of 5 μg/L for the protection of aquatic life. Similar observations can be made for other metals and organic contaminants.

The above estimates for the loading of Cu to Lake Ontario are based on its total concentration in water, this includes both dissolved and particulate fractions. Of the 357,000 kg of total Cu entering the lake, only about 13% was associated with the particulate fraction. However, Cu entering the river in the dissolved phase may be further adsorbed onto particulate matter in Lake Ontario. Indeed, Oliver (1986) suggested that because of the short residence time of water in the river (about 19 hrs) due to the high flow rates, thermodynamic equilibrium between dissolved and particulate phases in the water column may not have been established by the time the river water reaches Lake Ontario. While this data applies to organic contaminants, one could postulate that a similar process will apply to some metals. After association with suspended sediments in Lake Ontario, the additional particulate fraction of Cu becomes deposited on the lake bottom along with particles enriched with Cu and other contaminants entering the lake from the river (as noted by Sly, 1983).

Table 1 presents mean concentrations of Pb, Zn, Cu, PCB's, DDT and Mirex in surficial bottom sediments of Lakes Erie and Ontario, and the Niagara River. Table 2 presents similar information for the same parameters in suspended sediment collected from the water column of Lake Erie and the Niagara River. The mean concentrations of many contaminants in Lake Ontario sediments were up to ten times higher than those in Lake Erie.

The concentrations of inorganic contaminants, particularly Pb, Cu and Zn in the river sediments, although variable from site to site, were lower than those found in fine-grained sediments of both Lake Ontario and Lake Erie. On the other hand, the concentrations of organic contaminants in the Niagara River bottom sediments exceeded those in Lake Erie sediments (Table 1). This indicates that organic contaminants from different sources become associated even with coarse grained bottom sediments in the river.

With the exception of DDT the concentrations of inorganic and organic contaminants in suspended sediments collected at various river sections were greater than those collected at Fort Erie. On a relative basis, the concentrations of Pb, Cu and Zn in suspended sediments rose from 43, 25 and 76 µg/g, respectively, at the Lake Erie outflow to 133, 102 and 350 µg/g, respectively, in the lower Niagara River. The concentrations of these elements in suspended sediments of the lower Niagara River were of the same magnitude as in bottom sediments from the Western Basin of Lake Ontario. Estimates by Thomas et al. (1987) suggest that the Niagara River contributes 46%, 68%, 86% and 33% of sediment bound Pb, Cu, Zn and PCB's, respectively, to Lake Ontario. It was also suggested that the Niagara River is the largest source of Mirex to Lake Ontario (Holdrinet et al., 1978).

CONCLUSIONS

Bottom sediment samples recovered during a comprehensive investigation of Niagara River pollution in 1981-83 consisted mainly of sandy silt and coarser material. Results of 1983/84 geophysical surveys of the distribution of bottom sediments confirmed a lack of deposition of fine-grained sediments in both upper and lower parts of the river. Fine-grained sediments were located in only a few areas of the lower Niagara River. The estimated thickness of these deposits was about 10 cm within areas $<1\ m^2$.

Concentrations of many contaminants in the river sediments were lower than those found in fine-grained sediments of Lake Ontario. However, concentrations of contaminants in suspended sediments were many times higher than those found in bottom sediments from the river. Many contaminants entering the Niagara River in a soluble or particulate form become associated with the fine-grained suspended material and are transported into the depositional areas of Lake Ontario. In addition, the results of the geophysical surveys support the conclusions of many previous studies which showed that the Niagara River is a primary source of contaminants found in fine-grained sediments deposited in western Lake Ontario.

REFERENCES

Allan, R.J. 1986. The role of particulate matter in the fate of contaminants in aquatic ecosystems. Inland Waters Directorate, National Water Research institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada, Scientific Series No. 142.

Allan, R.J., Mudroch, A. and Munawar, M. 1983. The Niagara River-Lake Ontario pollution problem. J. Great Lakes Res. 9 (Special Issue).

Data Interpretation Group. 1986. Joint evaluation of upstream/downstream Niagara River monitoring data, 1984-1986. Prepared by the Data Interpretation Group for the Niagara River Toxics Management Plan, October 1986.

El-Shaarawi, A.H., Esterby, S.R., Warry, N.D. and Kuntz, K.W. 1985. Evidence of contaminant loading to Lake Ontario from the Niagara River. Can. J. Fish. Aquat. Sci. 42: 1278-1289.

Frank, R., Thomas, R.L., Holdrinet, M., Kemp, A.L.W., Braun, H.E. and Jaquet, J.-M. 1977. Organochlorine insecticides and PCB in sediment of Lake St. Clair and Lake Erie. Science of the Total Environment 8: 205-277.

Frank, R., Thomas, R.L., Holdrinet, M., Kemp, A.L.W. and Braun, H.E. 1979. Organochlorine insecticides and PCB in surficial sediments (1968) and sediment cores (1976) from Lake Ontario. J. Great Lakes Res. 5: 18-27.

Holdrinet, M., Frank, R., Thomas, R.L. and Hetling, L.J. 1978. Mirex in the sediments of Lake Ontario. J. Great Lakes Res. 4: 69-74.

International Niagara River Working Committee. 1987. 1986-1987 operation of the Lake Erie-Niagara River ice boom. Report to the International Niagara Board of Control.

Kauss, P.B. 1983. Studies of trace contaminants, nutrients and bacterial levels in the Niagara River. J. Great Lakes Res. 9: 249-273.

Kuntz, K.W. and Chan, C.H. 1982. Water quality of the upper Niagara River, 1975 to 1979. Report Series No. 129. Inland Waters Directorate, Water Quality Branch, Ontario Region, Burlington, Ontario, Canada.

Kuntz, K.W. and Warry, N.D. 1983. Chlorinated organic contaminants in water and suspended sediments in the lower Niagara River. J. Great Lakes Res. 9: 241-248.

Oliver, B.G. 1986. Partitioning relationships for chlorinated organics between water and particulates in the St. Clair, Detroit and Niagara Rivers. In: QSAR in Environmental Toxicology,II, K.L.E. Kaiser (Ed.), D. Reidel Publ. Co., Dordrecht, Holland.

Sly, P.G. 1981. Equipment and techniques for offshore survey and site investigations. Can. Geotech. Jour. 18: 230-249.

Sly, P.G. 1983. Sedimentology and geochemistry of recent sediments of the Niagara River, Lake Ontario. J. Great Lakes Res. 9: 134-159.

Sly, P.G. and Prior, J.W. 1984. Late glacial and postglacial geology in the Lake Ontario basin. Can. J. Earth Sci. 21: 802-821.

The Niagara River Toxics Committee. 1984. Report. Environment Canada, NY State Dept. of Environmental Conseration, Ontario Ministry of the Environment, and U.S. Environmental Protection Agency.

Thomas, R.L., Kemp, A.L. and Lewis, C.F.M. 1973. The surficial sediments of Lake Huron. Can. J. Earth Sci. 10: 226-271.

Thomas, R.L. and Mudroch, A. 1979. Small Craft Harbours - sediment survey. Lakes Ontario, Erie and St. Clair. Dredging and Summary Protocol. Report to Small Craft Harbours, Ontario Region, Fisheries and Oceans, Canada.

Thomas, R.L., Williams, D.J., Whittle, D.M., Gannon, J.E. and Hartig, J.H. 1987. Contaminants in Lake Ontario - a case study. Proc. of World Conference on Large Lakes, May 18-21, 1986, Mackinac Island, Michigan (In Press).

Warry, N.D., Kuntz, K.W. and Bieberhofer, J. 1986. Evidence of contaminant loading to the Niagara River between Fort Erie and Niagara-on-the-Lake. Inland Waters Directorate, Water Quality Branch, Ontario Region, Burlington, Ontario, Canada.

Yee, P. and Lloyd, J. 1985. Great Lakes water levels. Inland Waters Directorate, Water Quality Branch, Ontario Region, Burlington, Ontario, Canada.

FIGURE CAPTIONS

Figure 1. Surveyed sections of the Niagara River.

Figure 2. Different reliefs of the Niagara River bottom.

Figure 3. Bottom relief of sections 1 and 3 of the Niagara River.

Figure 4. Bottom relief of section 2 of the Niagara River.

Figure 5. Bottom relief of section 4 of the Niaraga River.

Figure 6. Bottom relief of section 5 of the Niagara River.

TABLE 1. Mean concentrations of contaminants in surficial sediments of Lakes Erie and Ontario and the Niagara River.

	Lake Erie	Niagara River[4]			Lake Ontario
		Upper River			
	Eastern Basin[1,2,3]	Chippawa Channel	Tonawanda Channel	Lower River	Western Basin[1,2,3]
Inorganics (μg/g dry weight)					
Pb	81	7.5	37	20	157
Cu	34	11	22	17	77
Zn	178	56	153	101	300
Organics (μg/g dry weight)					
PCB	86	27	415	576	612
ΣDDT	30	4	7	53	50
Mirex	ND	ND	3	86	10

[1] Thomas and Mudroch (1979).
[2] Frank *et al*. (1977; 1979).
[3] Holdrinet *et al*. (1978).
[4] Kauss (1983).
ND = less than detection limit.

TABLE 2. Mean concentrations of contaminants in suspended sediments from Lake Erie and the Niagara River.

		Niagara River[2]		
		Upper River		
	Lake Erie[1] (at Fort Erie)	Chippawa Channel	Tonawanda Channel	Lower River
Inorganics (μg/g dry weight)				
Pb	43	50	170	133
Cu	25	190	290	102
Zn	76	180	870	350
Organics (μg/g dry weight)				
PCB	40	160	660	136
ΣDDT	27	42	43	11
Mirex	ND	8	15	55

[1] Warry et al. (1986).
[2] Kauss (1983).
ND = less than detection limit.

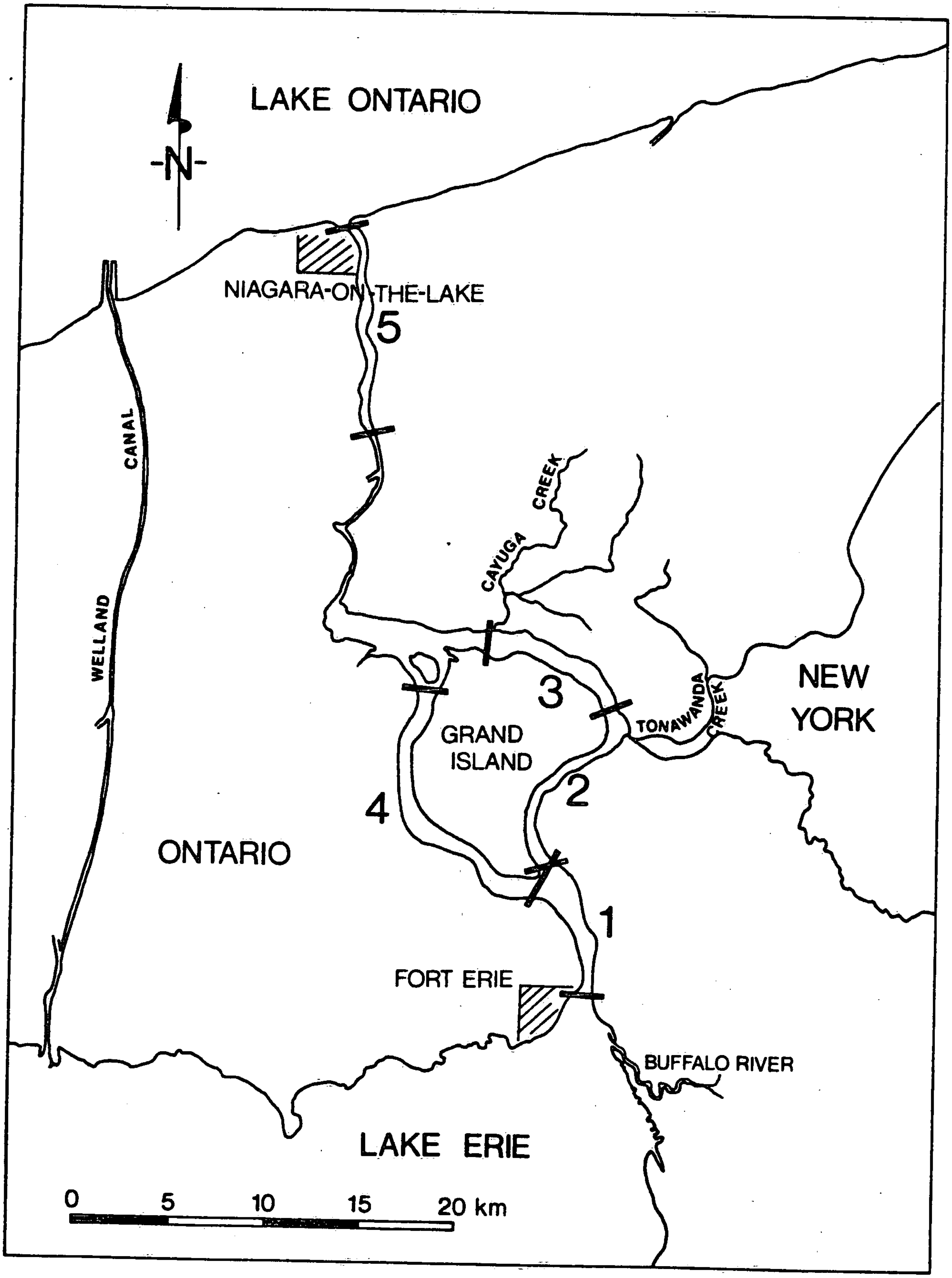
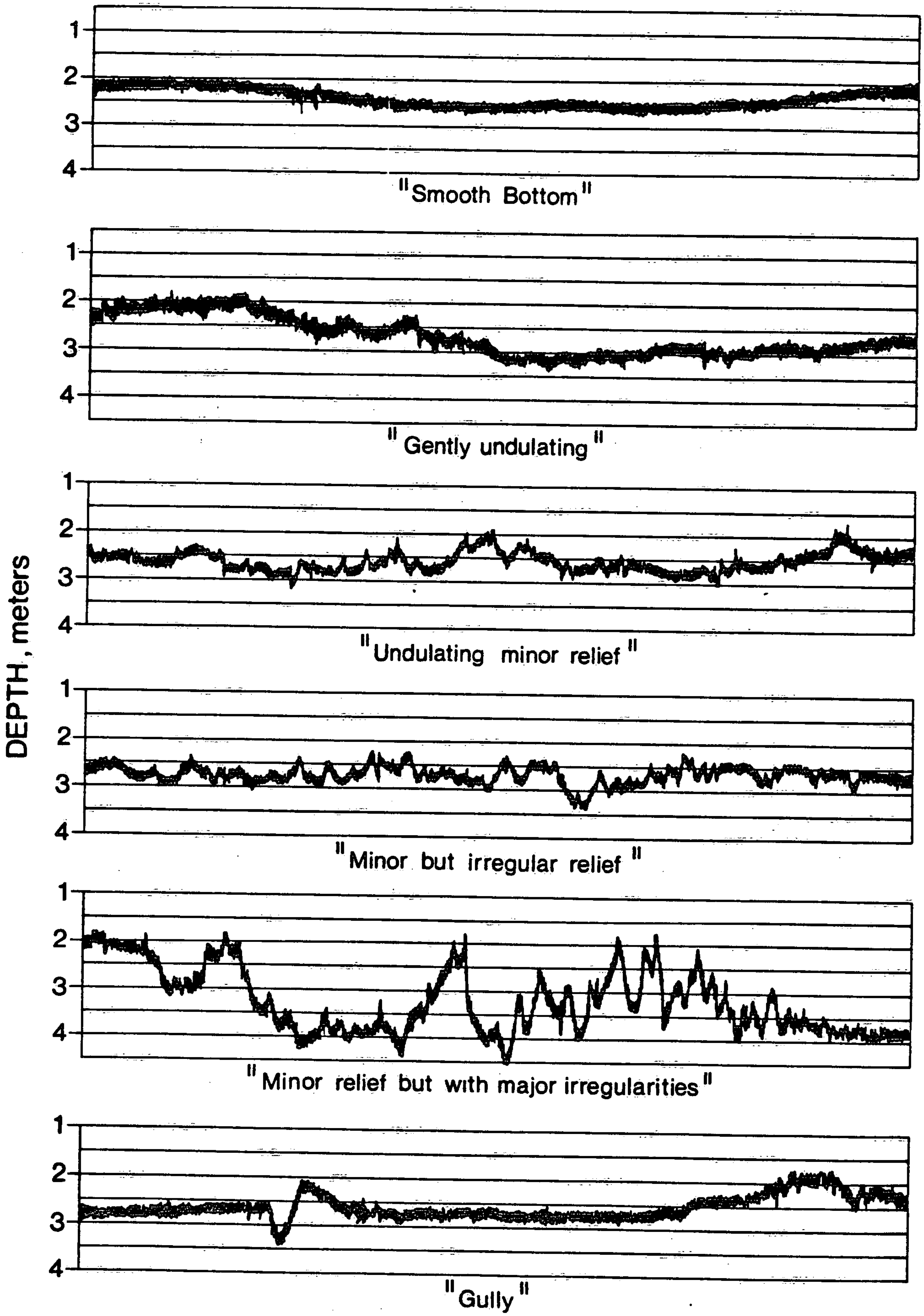


Figure 1. Surveyed sections of the Niagara River.



TYPES OF BOTTOM RELIEF OF THE NIAGARA RIVER

Figure 2. Different reliefs of the Niagara River bottom.

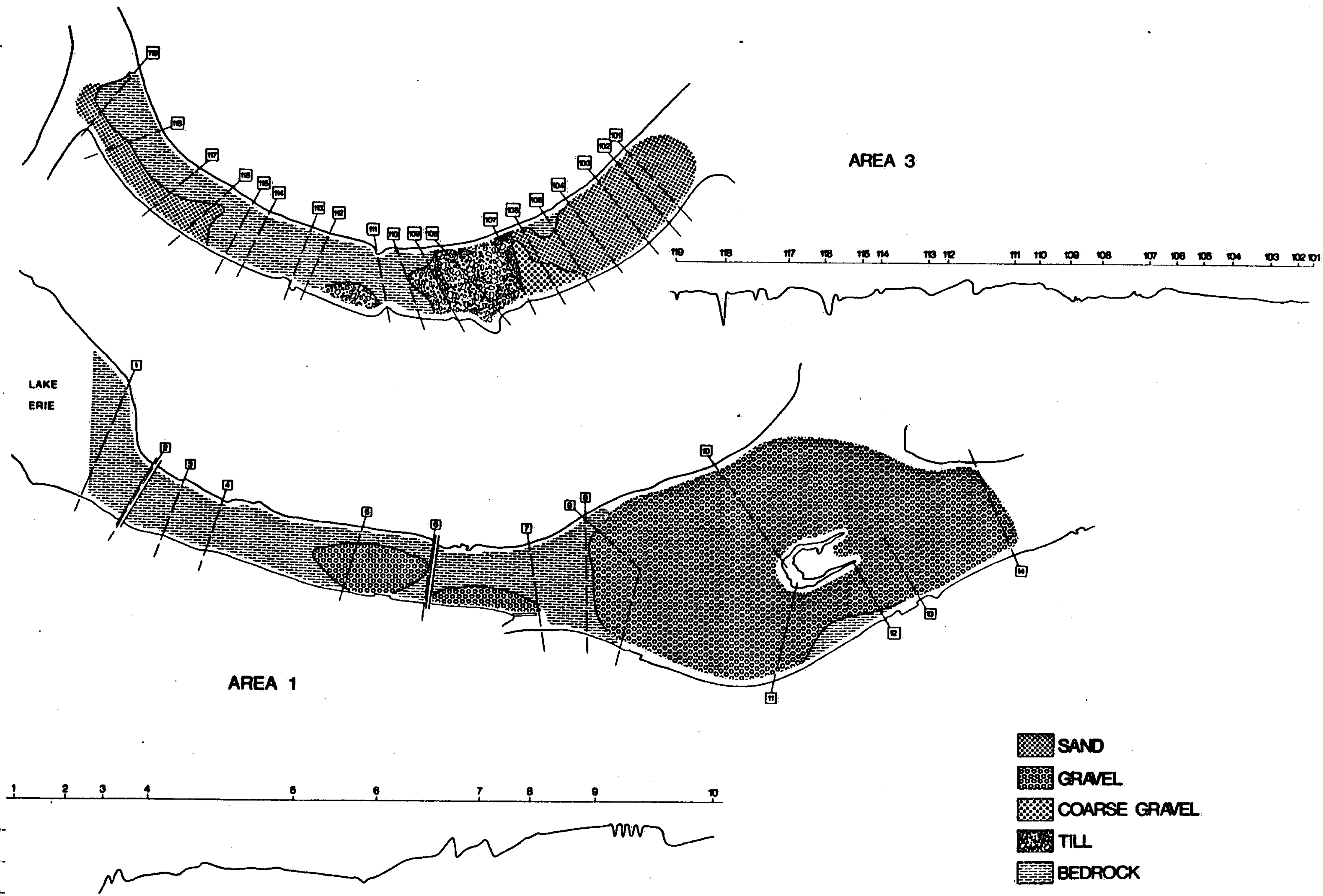
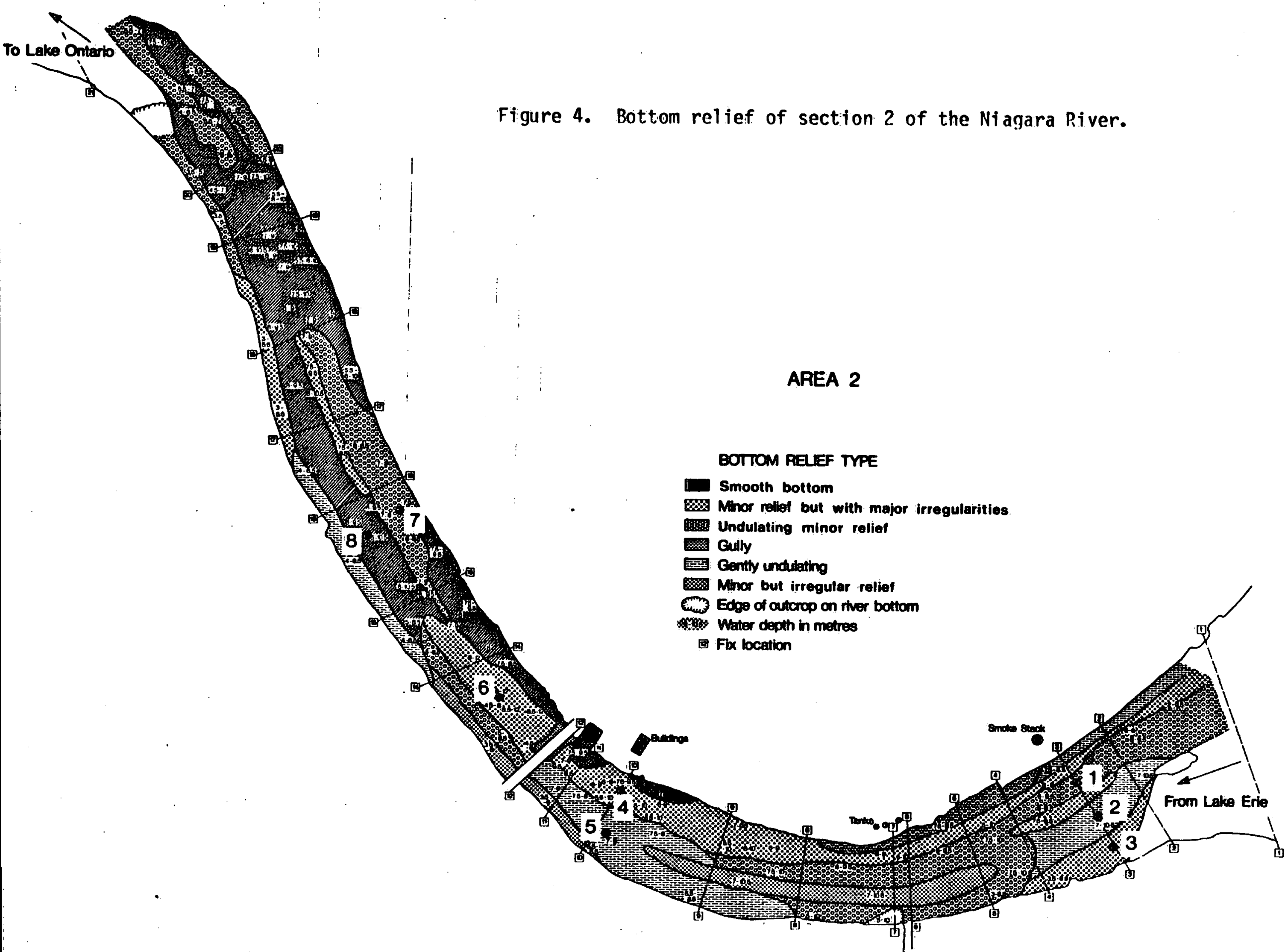


Figure 3. Bottom relief of sections 1 and 3 of the Niagara River.

Figure 4. Bottom relief of section 2 of the Niagara River.



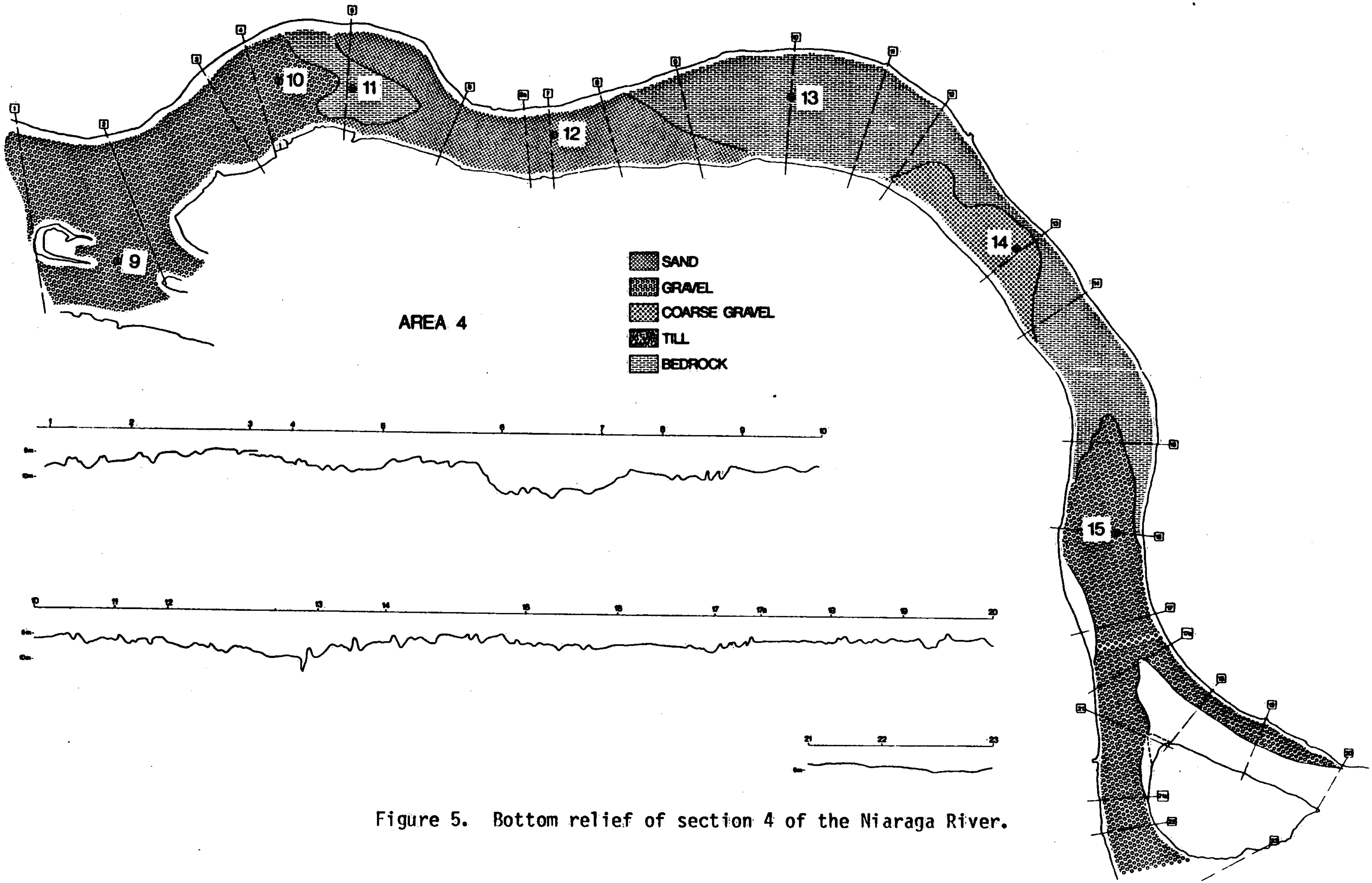


Figure 5. Bottom relief of section 4 of the Niaraga River.

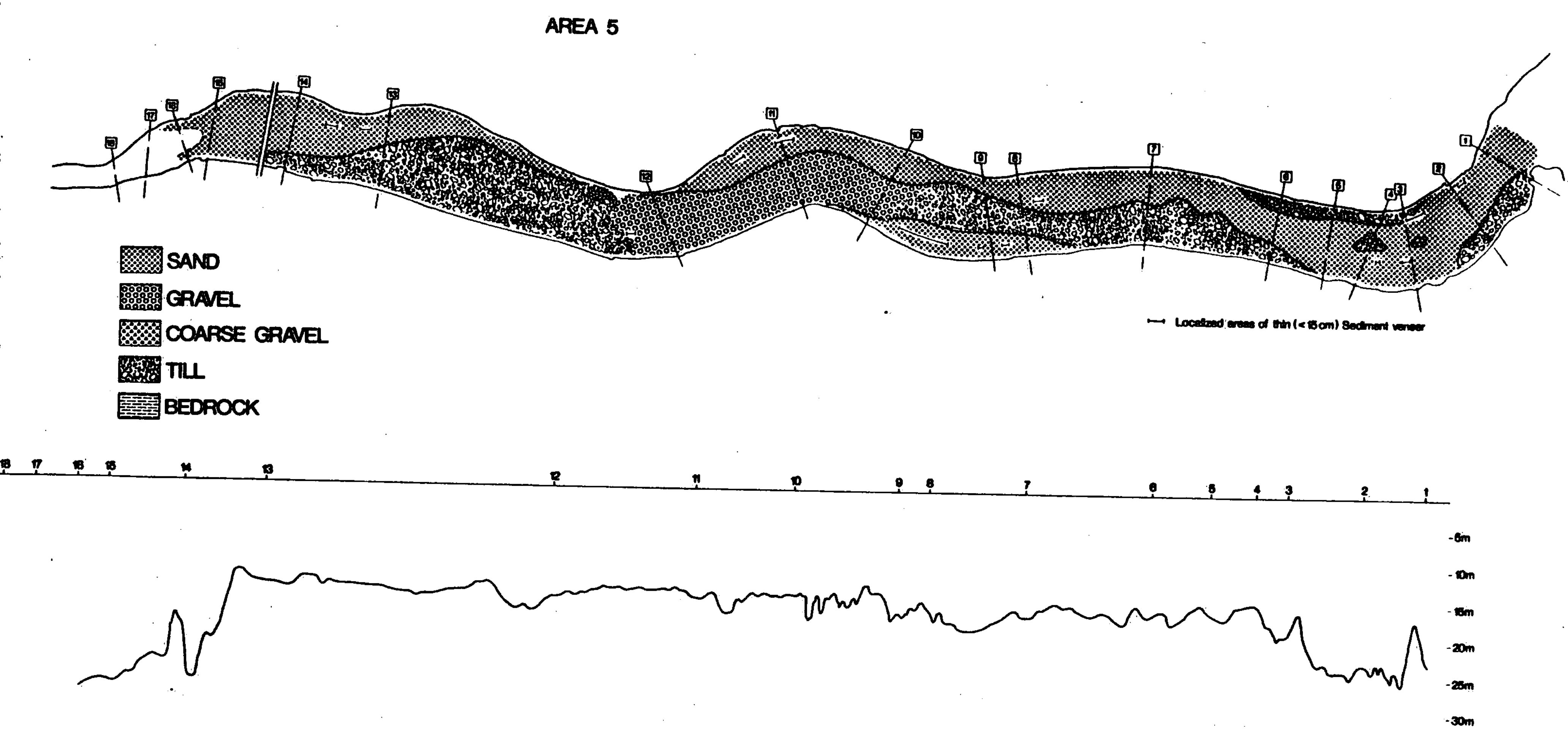


Figure 6. Bottom relief of section 5 of the Niagara River.