NWRI CONTRIBUTION 90-120

IMPACT OF RUBBLEMOUND BREAKWATER AT GODERICH

by

Craig T. Bishop and Phil Zrymiak

Research and Applications Branch
National Water Research Institute
Canada Centre for Inland Waters
867 Lakeshore Rd., P.O. Box 5050
Burlington, Ontario L7R 4A6

Sediment Survey Section
Water Resources Branch
Water Survey of Canada
Ottawa, Ontario
K1A 0H3

MARCH 1990

MANAGEMENT PERSPECTIVE

This study has been conducted at the request of an inter-Departmental client, Environmental Protection, Ontario Region. It provides valuable information for the management of waterfront resources at Goderich. An interesting discovery resulting from the hydrographic surveys is that the lake bottom in the vicinity of the harbour is subsiding significantly due to subsurface salt mining activity. This subsidence has profound implications for the future maintenance of the harbour structures. This data base of pre- and post-construction surveys will allow future assessments of impacts over longer time periods.

John Lawrence
Director
Research and Applications Branch

December 1989

PERSPECTIVE DE GESTION

Cette étude a été effectuée à la demande d'un client inter-ministériel de la Protection de l'environnement, région de l'Ontario. Elle renferme une information précieuse pour la gestion des ressources du secteur riverain à Goderich. Les levés hydrographiques effectués ont permis une découverte intéressante, soit que dans les environs du port le fond du lac s'affaise de manière importante en raison de l'activité d'exploitation minière souterraine du sel. Cette subsidence a d'importantes répercussions sur l'entretien futur des ouvrages portuaires. Cette base de données sur les levés avant et après construction permettra des évaluations futures des incidences à plus long terme.

John Lawrence
Directeur
Direction de la recherche et des applications

décembre 1989

Impact of Rubblemound Breakwater at Goderich

by
Craig T. Bishop and Phil Zrymiak

Research and Applications Branch
National Water Research Institute
Canada Centre for Inland Waters
867 Lakeshore Rd., P.O. Box 5050
Burlington, Ontario L7R 4A6

Sediment Survey Section
Water Resources Branch
Water Survey of Canada
Ottawa, Ontario
K1A 0H3

ABSTRACT

To assess the impacts of a new breakwater on coastal and fluvial processes at Goderich, a five-year environmental monitoring program has now been completed. It consisted of four surveys to collect hydrographic data and bed material samples. From the hydrographic survey results, subsidence of approximately 0.5 m was found to have occurred between 1984 and 1988 over most of the survey area. This is attributed to the subsurface salt-mining activity at Goderich. The impact of the new breakwater on downdrift erosion is considered to be negligible, and its impact on navigability at the mouth of the Maitland River appears to be beneficial.

RÉSUMÉ

Afin d'évaluer les incidences d'un nouveau brise-lames sur les processus littoraux et fluviaux à Goderich, un programme quinquennal de surveillance environnementale a maintenant été complété. Il consistait en quatre relevés de collecte de données hydrographiques et d'échantillons de matériaux du fond. D'après les résultats des levés hydrographiques, une subsidence d'approximativement 0,5 m de la plus grande partie de l'aire du levé a été constatée entre 1984 et 1988. Elle est attribuée à l'activité d'exploitation minière du sel sous la surface à Goderich. L'incidence du nouveau brise-lames sur l'érosion à l'aval est considérée négligeable et son incidence sur la navigabilité à l'embouchure de la rivière Maitland semble bénéfique.

1.0 BACKGROUND

In 1984-85 Transport Canada expanded Goderich Harbour in order to provide a new wharf for Domtar Ltd. As part of the project, a 610 m long rubblemound breakwater was designed and constructed by Public Works Canada (PWC) (Figures 1 and 2). Prior to approval of the project, environmental concerns were raised about the possibility of the breakwater causing increased sediment deposition at the mouth of the Maitland River and increased erosion rates south of the Harbour. River mouth deposition might aggravate flooding problems on the Maitland River and might lessen the navigability of the mouth of the Maitland River for pleasure craft. Accordingly, Transport Canada agreed to fund a five-year monitoring program at Goderich in order to assess the new breakwater's impact on coastal and fluvial processes.

The Hydraulics Division (now Research and Applications Branch) of the National Water Research Institute was asked to design the monitoring program, analyze the results and prepare reports on the findings. This report summarizes the results of the five-year monitoring program (preliminary results are available in an earlier report by Bishop (1987)).

Construction of the breakwater began in November 1984 and final armouring was completed in December 1985. By the end of January 1985 the partially built breakwater extended lakeward about half its final length (PWC, Progress Chart, 1985) and can be assumed to have been acting as a substantial, if not total, barrier to the southward littoral drift from that time onward.

The predominant direction of littoral transport at Goderich is southward. The existing entrance channel structures and offshore breakwaters have been in their present configuration since 1916. Prior to the construction of the rubblemound breakwater, sand was transported into the harbour entrance channel from which it was dredged periodically and dumped offshore and, therefore, was lost to the littoral system. Now, with the rubblemound breakwater in place, sand is expected to accrete on the north side of the harbour. "It is estimated that this accretion will occur for about 500 years before the nearshore area north of the harbour is filled with sand and sand starts to bypass the harbour" (Reinders 1989). Therefore, since at least 1916, the Goderich Harbour structures have formed a man-made littoral cell boundary, thereby creating two cells, within the natural littoral cell from Point Clark to Kettle Point (Reinders 1989).

2.0 MONITORING PROGRAM

The monitoring surveys were conducted by the Water Resources Branch, Water Survey of Canada, Environment Canada. The three components of the program included:

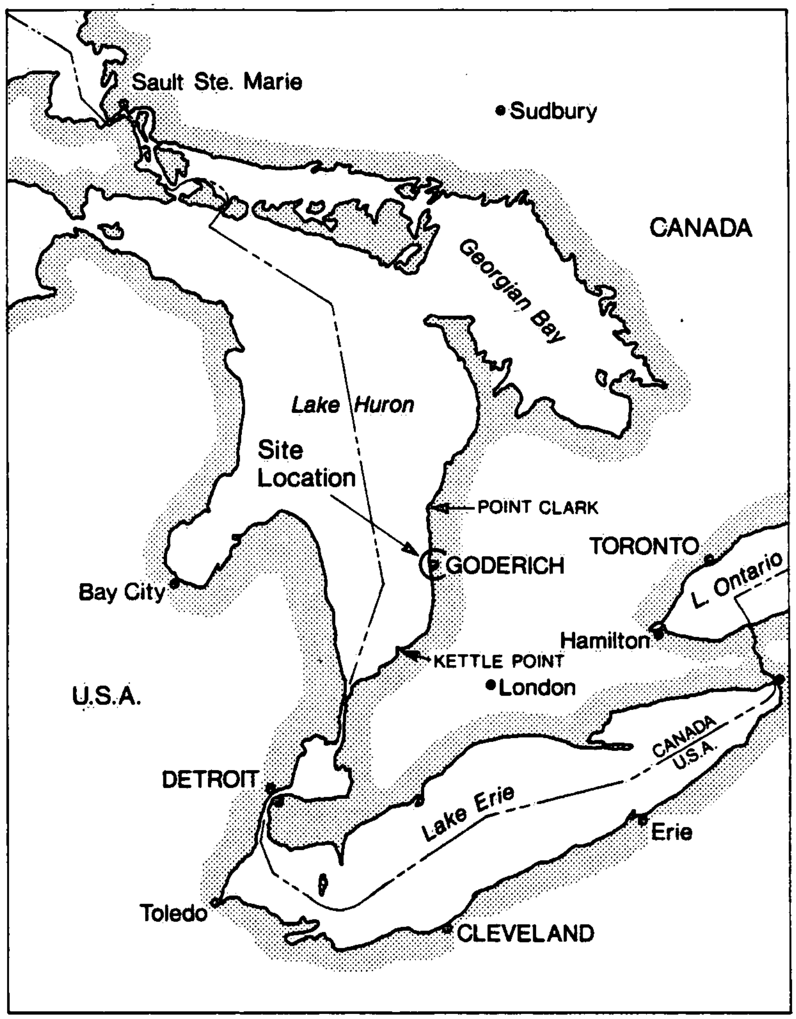

Figure 1 Site Location Plan

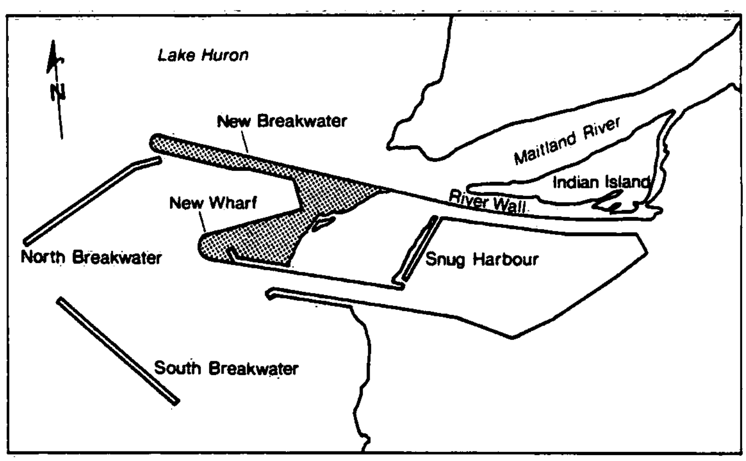

Figure 2 Locations of new breakwater and wharf at Goderich Harbour.

i) Hydrographic survey of the Goderich Harbour area, including the Maitland River estuary.
ii) Hydrographic survey of 5 range lines.
iii) Bed material survey of nearshore and estuary deposits (Figure 3).

Four surveys have been conducted:

- September 28 - October 1, 1984
- September 10 - 19, 1985
- September 3 - 17, 1986
- September 6 - 16, 1988

No survey was conducted in 1987 because preliminary survey results (Bishop 1987) did not indicate any serious adverse environmental impacts.

The hydrographic surveys were conducted using an automated Hydrographic Data Acquisition System, designated as HYDAC-100 (Durette and Zrymiak 1978). Bottom surface sediment samples were collected using a Shipek 860 sampler. PWC provided assistance by locating, establishing and checking some of the control points used in the survey portion of the study.

3.0 AREA SURVEYS

In order to assess the impact of the new breakwater in the immediate area of Goderich Harbour, hydrographic surveys were scheduled on an annual basis. The limits selected for the study area were: 1.0 km north of the breakwater (to a depth of 5 metres), 1.8 km south of the breakwater (to a depth of 5 metres), 1.0 km west of the harbour to a depth of 10 metres and east within the estuary to the railway bridge (Zrymiak 1986). Figure 4 shows the coverage of the area surveys conducted over the four years.

Analysis of the data by the Water Resources Branch included use of a software package to smooth and average the raw data. It derived corner elevations on a 30 m x 30 m grid. These computed grid corner elevations were then used in all subsequent analysis and plot generation (i.e. contour plots, grid corner elevation plots, elevation-capacity tables). The capacity refers to the water volume between the lake or river bed and a given elevation.

Results from each of the area surveys are available as:

1) points plots of soundings
2) plots of grid corner elevations of the bed
3) contour plots of bed elevations
4) elevation-capacity tables

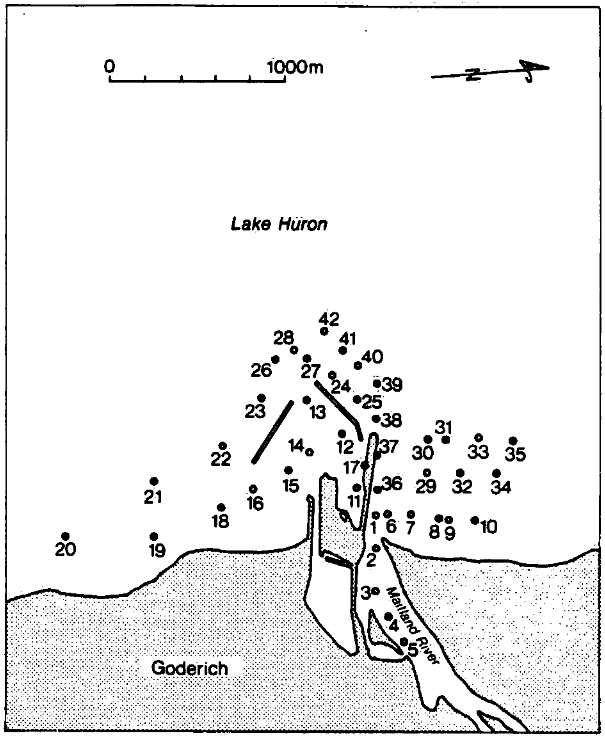

Figure 3 Bed Material Sample Locations

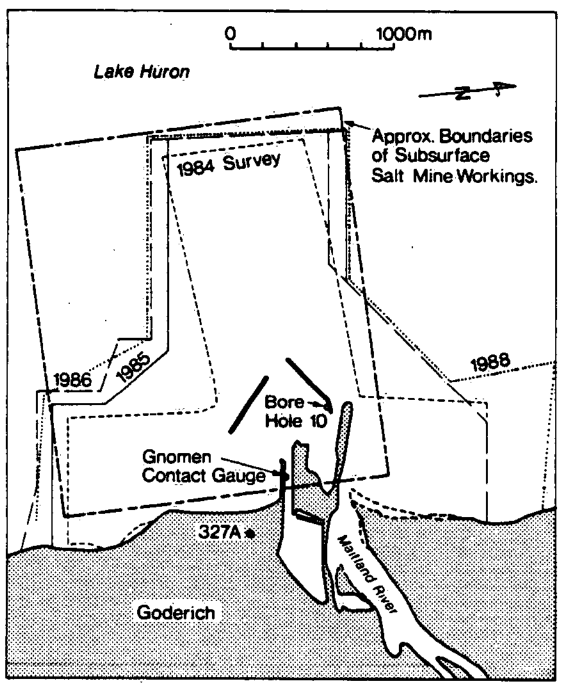

Figure 4 Hydrographic Survey Areas

For visual interpretation, contour plots of differences in elevation between pairs of surveys are available (Bishop and Zrymiak 1990) over common survey areas between the following years.

i) 1984 and 1985
ii) 1984 and 1986
iii) 1985 and 1986
iv) 1984 and 1988
v) 1985 and 1988
vi) 1986 and 1988

Grid corner elevation difference plots are available for comparing between the same years as those above.

4.0 RANGE LINE SURVEYS

In order to establish a data base from which to assess the effects of the new breakwater on downdrift erosion, range line surveys were measured at 5 locations (Figure 5). These locations were chosen to be the same as those of stations H86 to H90 in the Coastal Zone Atlas (Haras and Tsui 1976) for which estimates of subaerial recession rates are available. In 1984, time and weather constraints prevented the Water Resource Branch from collecting any range line data. However, a PWC survey boat did collect profile data at these five locations. The Water Resources Branch collected profile data at all 5 locations using HYDAC in 1985 and 1986, however, in 1988 data were collected at H86 and H87 only due to time and weather constraints. Although starting from the same baseline markers onshore, the orientations of some of the PWC and HYDAC profiles differ slightly. The PWC profiles were oriented approximately perpendicular to shore (D. Carr, 1987, personal communication), while the HYDAC profiles were oriented accurately in an east-west direction.

The range line profiles for H86 and H87 are shown in Figures 6 and 7 (H88 to H90 can be seen in Bishop and Zrymiak 1990). Differences at profiles H86 and H88 are minor, however, significant differences do appear between PWC and HYDAC surveys for profiles H87, H89 and H90. At these locations the shore perpendiculars are considerably off a due east-west direction. These directional differences are thought to be the main reason for the differences in the profiles between 1984 and 1985.

5.0 BED MATERIAL

In order to identify initial bed material conditions, and to document changes that might be attributable to the new breakwater, bottom surface sediment samples were collected and analyzed in 1984, 85, 86 and 88. Results of sediment size analyses, undertaken by the Water Resources Branch, of the bed material samples are summarized in Bishop and Zrymiak (1990). All samples are sand-size or coarser.

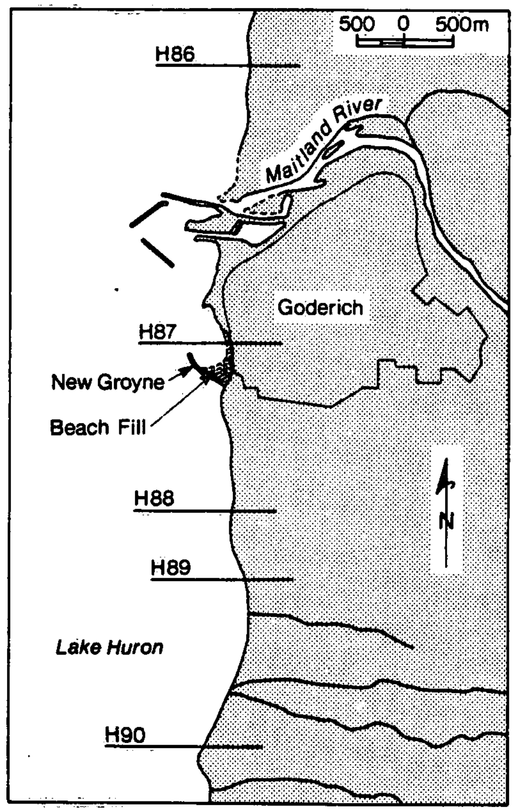

Figure 5 Range Line Locations

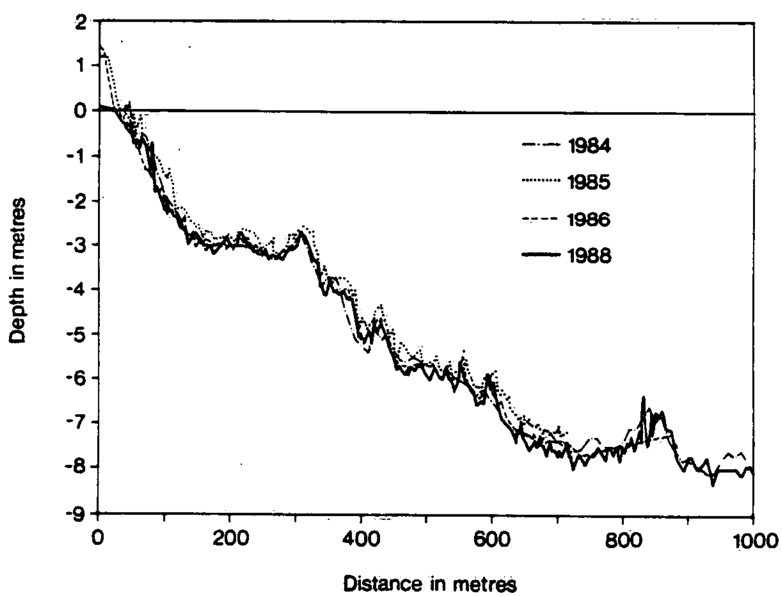

Figure 6 Profiles of H86

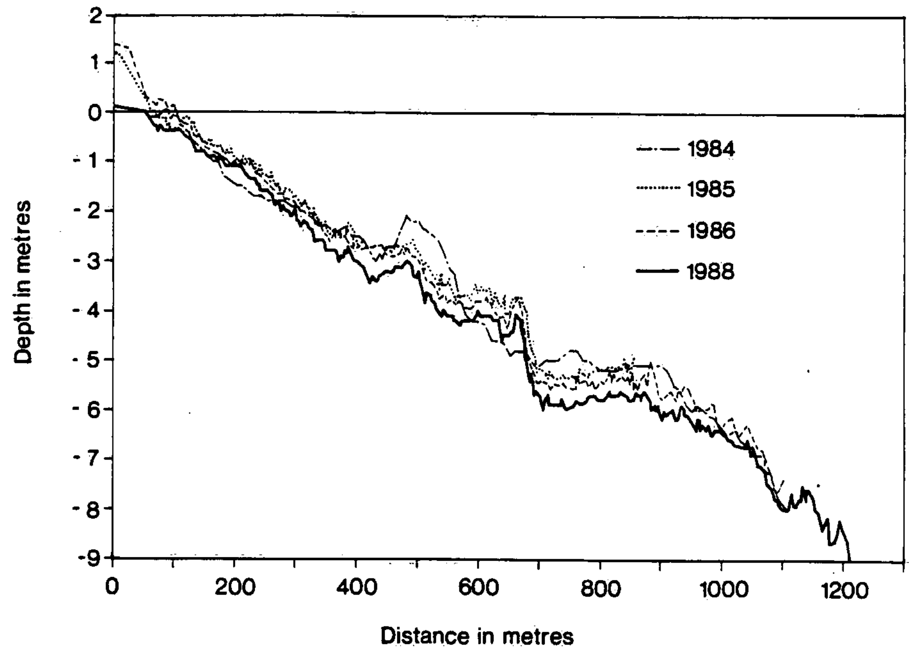

Figure 7 Profiles of H87

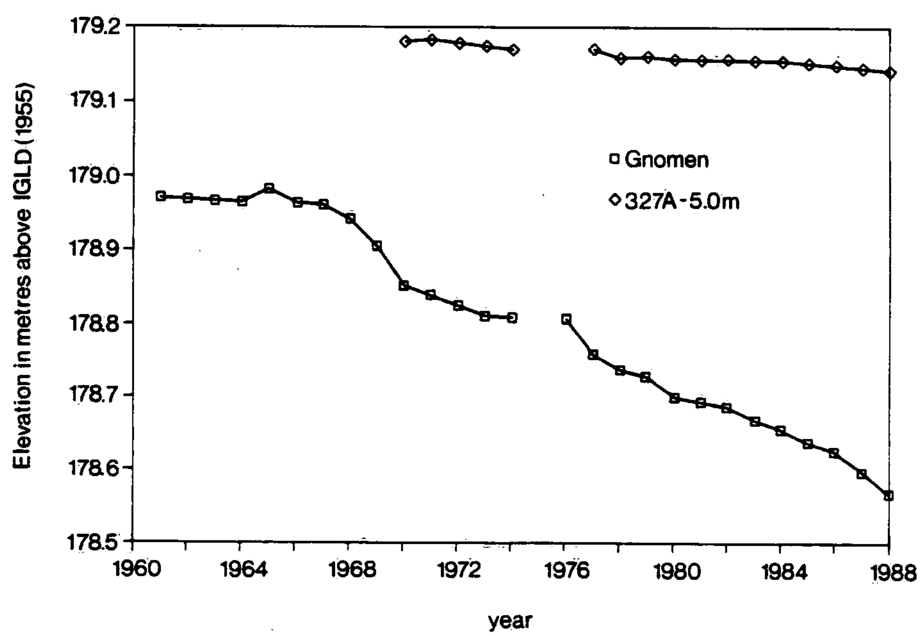

Figure 8 Goderich Bench Marks

Boyd (1977) reports on sediment samples taken at Goderich in 1975 and 1976. His results for 4 locations north of the new breakwater are in good agreement with the results from 1984-88, indicating relatively minor changes in surface sediment size from 1975 to 1988.

6.0 SUBSIDENCE

The contour plots of differences in bottom elevation clearly indicate a lowering trend over most of the survey area, even in water depths of 10 m where little change would be expected. After checking the analysis of the water level and HYDAC data, this trend was confirmed as being real. At this point, the authors contacted the Domtar Chemicals Group, Sifto Salt Division, Goderich Mine to inquire about the effects of underground salt mining on the lake bottom. Subsequently, discussions were held with the mine engineer, Neil Crocker.

The Goderich salt mine began operations in 1959. Salt is excavated from 13 m high caverns about 540 m below the surface. About one-half of the rock volume in the mining layer is removed. Subsidence of the ground surface, in this case the lake bottom, starts when stresses on the rock pillars between the caverns become supercritical. In the opinion of Mr. Crocker, this occurred in 1978 after which a period of accelerated subsidence occurred for a few years followed by a rate which will reduce over time. He estimates that the average ultimate subsidence will be about 5 m. The time period over which this will occur is not known, but Mr. Crocker estimates several centuries, maybe a thousand years. A capability exists for predicting subsidence by using a rock mechanics computer model. The Goderich Mine has a proprietary model that might be made available for such predictions.

The areal extent of the salt mine is compared to the HYDAC survey areas in Figure 4. This shows that virtually all of the HYDAC survey area, except the Maitland River estuary and part of the nearshore area north of the rubblemound breakwater, is underlain by the salt mine. According to Mr. Crocker, the surface subsidence is not expected to be uniform over the area, but rather is probably "bowl-shaped", with the greatest subsidence close to the centre of the mine.

Several estimates of subsidence can be made. The top of the north concrete breakwater was surveyed in 1959 and again in 1988 (N. Crocker, 1989, personal communication). Over this time, the elevation at borehole 10 (see Figure 4) subsided by about 0.61 m. In addition, Water Survey of Canada maintains several bench marks in the vicinity of the Harbour. The Gnomen Contact Gauge (GCG) record from 1961 to 1988 is shown in Figure 8, along with data from Gauge 327A from 1970 to 1988. The GCG data indicates subsidence of 0.40 m between 1961 and 1988, with most occurring since 1967. However, the 327A data indicates subsidence of only 0.039 m between 1970 and 1988. As seen in Figure 4, borehole 10 is well within the mining area, while the GCG is very close to the edge and 327A is well outside. The trend to lesser amounts of subsidence with distance from the centre of the mining area agrees with expectations.

The elevation-capacity tables can also be used to provide estimates of subsidence. Capacities must be compared to the same reference elevation, so the computed capacities in the tables have been adjusted for differences in maximum elevation. Using the area common to all four surveys from 1984 to 1988, and adjusting the capacities from the maximum elevations given in the elevation-capacity tables to the 1 m elevation, gives the results shown in Table 1. The precision of the HYDAC survey is estimated (J. McIlhinney, 1987, personal communication) to be +/- 2 percent of the capacity. The total survey area is shown on Figure 4.

The northshore area referred to in Table 1 consists of the area north of the new rubblemound breakwater, excluding the river estuary and the area west of a line running north from the western end of the rubblemound breakwater. This northshore area traps most of the southerly alongshore transport of littoral material and the material transported downstream by the Maitland River. The most recent supply-based estimate of this southerly sediment (grain size of 0.06 mm or greater) transport rate at Goderich is 26,770 m^3/yr (Reinders 1989). According to the report by Reinders (1989), the Goderich Harbour structures present a complete barrier to the alongshore transport of sand and will continue to do so for hundreds of years. Assuming this to be true, the capacities in Table 1 have been adjusted by increasing the capacity by 26,770 m^3/yr in order to estimate subsidence. Interestingly, the results for both the total survey area and for the northshore area (adjusted) show almost no change in capacity between 1984 and 1985, but then show a linear subsidence from 1985 to 1988.

The northshore area shows a subsidence of 0.36 m over the four year period, while the total survey area less the northshore area shows a subsidence of 0.49 m. As expected, the northshore area shows less subsidence because the bulk of it is outside the boundaries of the mine (Figure 4). The sensitivity of the subsidence calculation to the assumed rate (Q) of southerly sediment transport was checked for the northshore area by using different values of Q with the following results:

Q (m^3/yr)	Subsidence (m)
20,000	0.31
26,770	0.36
30,000	0.38
35,000	0.41
40,000	0.45

These estimates of subsidence can also be compared to the bench mark data which show drops of 0.087 m at the Gnomen Gauge and 0.013 m at Gauge 327A from 1984 to 1988.

TABLE 1

Estimates of Subsidence for Total Survey Area and Northshore Area

Total Area Common to 84, 85, 86 and 88 Surveys (2,426,400 m^2)

Year	Capacity (m^3) to Max. Elev.	Max. Elev. (m)	Adj. Capacity to +1.0 m elev.	Avg. Diff (m) in Elev. from 1984	Avg. Diff (m) Adjusting for Sediment transp
84	16,331,400	0.08	18,563,688	-	
85	16,545,400	0.17	18,559,312	+ 0.002	
86	17,737,900	0.53	18,878,308	- 0.13	
88	15,996,700	-0.47	19,563,508	- 0.41	
Northshore Area (563,400 m^2)					
84	2,220,900	-0.26	2,930,784	-	-
85	2,307,300	-0.06	2,904,504	+ 0.05	0.00
86	2,691,500	0.53	2,956,298	- 0.05	- 0.14
88	2,190,600	-0.48	3,024,432	- 0.17	- 0.36
Total Survey Area less Northshore Area (1,863,000 m^2)					
84			15,632,904	-	
85			15,654,808	- 0.01	
86			15,922,010	- 0.16	
88			16,539,076	- 0.49	

TABLE 2

Estimates of Accretion in Maitland River Estuary Common to 84, 85, 86 and 88 Surveys (35,100 m^2)

Year	Capacity (m^3) to Max. Elev.	Max. Elev. (m)	Adj. Capacity to + 0.5 m Elev.	Adj. Diff (m) in Elev. from 1984
84	46,000	- 0.27	73,027	-
85	49,900	- 0.06	69,556	+ 0.10
86	59,100	0.26	67,524	+ 0.16
88	37,900	- 0.48	72,298	+ 0.02

The sensitivity calculations indicate that the calculated subsidence is not very sensitive to Q. Therefore, given the uncertainties in the magnitude and spatial variation of the subsidence, any estimate of Q from the adjusted volume of accretion north of the rubblemound breakwater is prone to considerable error.

As seen from the range line surveys, there has been very little change in the profiles at H86. From Figure 5, H86 is at the northern edge of the northshore area, well beyond the boundaries of the mine. Therefore, it is not surprising that subsidence there is negligible. However, profile H87 in Figure 7 shows clear evidence of progressive subsidence. Assuming a linear subsidence of 0.5 m from 1984 to 1988, the HYDAC profiles have been adjusted by adding 0.125 m to the 1986 profile elevations and 0.375 m to the 1988 profile elevations in order to compare them with the 1985 profile (the 1984 profile differences are believed to be due to differences in profile orientation). The resulting profiles are shown in Figure 9. Clearly, these adjustments bring the profiles into much closer agreement. As expected, after adjustment for subsidence, there is no evidence of systematic erosion due to the rubblemound breakwater at profile H87. The Goderich Harbour structures have been acting as a man-made littoral cell boundary ever since their construction and, therefore, the littoral regime south of the harbour has not been affected by the construction of the rubblemound breakwater.

7.0 MAITLAND RIVER ESTUARY

The zones of accretion of littoral sediments are generally as anticipated (Hall and Baird 1984) when a predominantly southward littoral drift has been interrupted by a structure such as the new rubblemound breakwater. Classical littoral drift theory suggests that a fillet beach of sand would form updrift of the breakwater. This has, in fact, occurred but is complicated by flushing of the deposits at the river mouth by the river currents. Material eroded from the zone at the river mouth has probably been displaced westward to the zones of accretion along the rubblemound breakwater and the north concrete breakwater, furthermore, some material may be transported into deeper water offshore.

Elevation-capacity tables for 1984, 1985, 1986 and 1988 for the estuary are given in Bishop and Zrymiak (1990). Using the area common to all four surveys (35,100 m^2), and adjusting the capacities from the maximum elevations given in the Tables to the 0.5 m elevation, gives the results shown in Table 2. This shows a mean increase in bed elevation between 1984 and 1985 of 0.10 m, between 1984 and 1986 of 0.16 m, and between 1984 and 1988 of only 0.02 m. Based on relative locations, subsidence over this survey area may be somewhat less than at the Gnomen Gauge and somewhat more than that at Gauge 327A. If it is assumed to be about 0.05 m between 1984 and 1988, the estimates of accretion increase to 0.11 m, 0.18 m and 0.07 m, respectively.

The accretion of sediment in the estuary from 1984 to 1986 can be attributed to the decreased sediment transport capacity of the river resulting from lower river speeds. Erosion of the lake bottom at the river mouth indicates that the accretion in the estuary cannot be

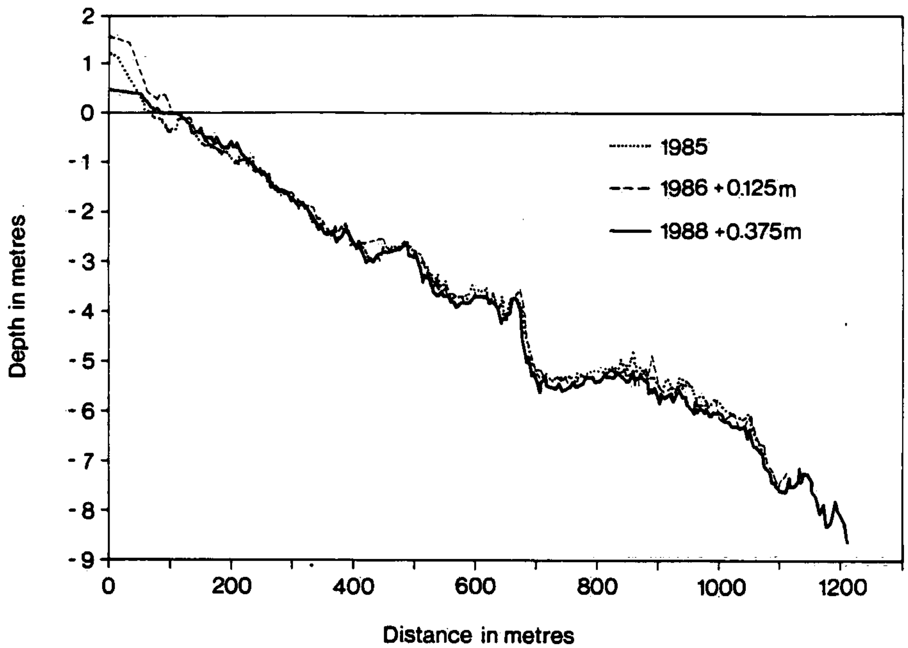

Figure 9 Profiles of H87 with adjustments for subsidence

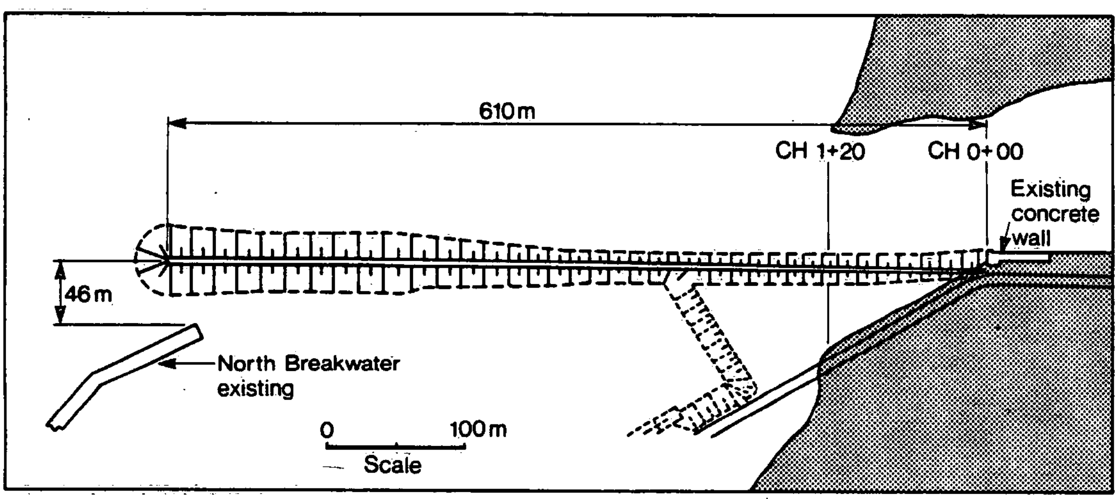

Figure 10 Detail at Maitland River Mouth

due to littoral deposits blocking the river mouth. After the lake returned to average levels in 1988, the mean bed level in the estuary returned to a level 0.04 m lower than it was in post-construction 1985.

The traditional problems of sand bar formation at the river mouth (Boyd 1977) and of water depths too shallow for navigation by keel boats have not occurred since 1984. This may be due, in part, to the higher than average lake levels during this period. The mean annual level increased each year from 176.39 m IGLD (1955) in 1982 to 177.10 m in 1986. The mean monthly level of 177.29 m measured in October 1986 is the highest monthly level in 100 years.

One of the impacts of higher lake levels is to reduce the average speed of the Maitland River discharge in the estuary. Using the results of a PWC sounding survey in June 1985, the river cross-sectional area below datum at the mouth (station 1+20) has been estimated at 200 m^2 with a top width of 92 m (Figure 10). At another cross-section 240 m upstream (station -1+20) the area has been estimated at 215 m^2 with a top width of 123 m. From WSC flow measurements at Donnybrook and Summerhill, the maximum instantaneous discharge at the mouth in 1985 has been estimated at 700 m^3/s on April 6. The daily mean lake level for April 6, 1985, was 1.11 m above datum. This results in mean river speeds of 2.3 m/s at the mouth and 2.0 m/s at station -1+20. If the lake level had been at its average level, about 0.65 m lower, the corresponding velocities would have been significantly higher at 2.9 m/s and 2.6 m/s respectively.

In addition, it appears that the restriction of the cross-sectional area at the river mouth, caused by the construction of the new breakwater, may be enough to keep the river mouth free of the troublesome sediment deposition of the past. Using the pre-construction sounding results from an October 1984 PCW survey, the cross-sectional area below datum at station 1+20 has been estimated at 195 m^2 with a top width of 128 m. The April 6, 1985 peak discharge of 700 m^3/s would have produced a mean current of about 2.1 m/s. This is the approximate location of traditional sand bar formation. As mentioned already, the mean current for a discharge of 700 m^3/s after breakwater construction was estimated at 2.3 m/s. Currents in this area scoured the toe of the breakwater's armour layer, necessitating scour restoration work and an extra row of armour stone at the toe from station 0+80 to 1+70 (PWC, As Built Drawing, 1986).

Consequently, the anticipated adverse impacts of the new breakwater, namely decreased navigability of the river mouth and increased upstream flooding due to blockage at the river mouth, have not materialized to date.

8.0 CONCLUSIONS

Evidence to date shows that the main environmental concern of the project, namely increased sediment deposition at the mouth of the Maitland River, has not occurred. Restriction of the cross-sectional area at the river mouth by the presence of the new rubblemound breakwater seems to have increased river velocities sufficiently to have actually deepened the channel there. This has occurred in spite of a general fillet beach type accretion of sediment north of the new breakwater.

The Goderich Harbour structures existing prior to 1984 already formed a man-made littoral cell boundary. Therefore, the construction of the rubblemound breakwater on the Harbour's north side has had no incremental impact on the south, or downdrift, side. In the past, PWC has performed regular maintenance dredging of the Harbour entrance channel. Now, the sediments that filled the channel will accrete on the updrift side of the rubblemound breakwater.

Results from hydrographic area and range line surveys indicate an average subsidence of the lake bottom in the vicinity of the Goderich salt mine of about 0.5 m between 1984 and 1988. This has important ramifications for the future maintenance of both the new rubblemound breakwater and the older harbour structures.

REFERENCES

Bishop, C.T. 1987. A preliminary assessment of the Goderich Harbour rubblemound breakwater's effects on coastal and fluvial processes. NWRI Contribution 87-119, National Water Research Institute, Burlington, Ontario.

Bishop, C.T. and Zrymiak, P. 1990. Impact of the rubblemound breakwater at Goderich Harbour on coastal and fluvial processes. NWRI Contribution 90-121, National Water Research Institute, Burlington, Ontario.

Boyd, G.L. 1977. The siltation problem at the Maitland River mouth, Goderich, Ontario: preliminary review. Unpublished report prepared by Shore Properties Studies, Fisheries and Marine Service, Burlington, Ontario for the Maitland Valley Conservation Authority. 58 pages.

Durette, Y.J. and Zrymiak, P. 1978. HYDAC-100 An automated system for hydrographic data acquisition and analysis. Technical Bulletin 105, Inland Waters Directorate, Ottawa. 44 pages.

Hall, K.R. and Baird, W.F. 1984. A preliminary review of the coastal processes at Goderich, Ontario. Unpublished report prepared by W.F. Baird & Associates Coastal Engineers Ltd. for Public Works Canada, Ontario Region. 18 pages + 5 figures + 13 tables.

Haras, W.S. and Tsui, K.K. (Editors) 1976. Coastal Zone Atlas. Canada/Ontario Great Lakes Shore Damage Survey. Environment Canada and Ontario Ministry of Natural Resources.

Public Works Canada and Transport Canada 1984. Goderich Harbour Expansion. Engineering Report. 26 pages + 25 figures.

Reinders, F.J. and Associates Ltd. 1989. Lake Huron Shoreline Processes Study, McRae Point to Sarnia. Unpublished report for the St. Clair River, Ausable-Bayfield, Maitland Valley and Saugeen Valley Conservation Authorities, Ontario.

Zrymiak, P. 1986. 1985 Goderich Harbour Survey Trip Report. Unpublished Report. Sediment Survey Section, Water Resources Branch, Water Survey of Canada, Ottawa.