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Inner Harbor Improvements Interim Report
Evaluation of Wave Protection Alternatives
Port Washington, Wisconsin

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The Wisconsin Coastal Management Program, part of the Wisconsin Department of Administration, and overseen by Wisconsin Coastal Management Council, was established in 1978 to preserve, protect and develop the resources of the Lake Michigan and Lake Superior coastline for this and future generations. The Wisconsin Coastal Management Program analyzes state policy on Great Lakes issues, coordinates government programs that affect the coast, and provides grants to stimulate better state and local coastal management.

This study is the first phase of a larger project entitled "Inner Harbor Improvements - Port Washington, Wisconsin". The project is being performed by W.F. Baird & Associates, Ltd. (Baird) for the City of Port Washington. In addition to the work under this study, the project includes physical model testing and preliminary engineering design of wave protection solutions. The project is funded by the City of Port Washington and the Wisconsin Waterways Commission in addition to this portion funded by Wisconsin Coastal Zone Management. A design report which includes the information contained in this report and presents the findings of the model testing and preliminary design will be prepared upon completion of the project.

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1.0 INTRODUCTION

Port Washington Harbor is an extremely valuable asset to both the City of Port Washington and the State of Wisconsin. Functionally, the harbor has facilitated beneficial industry such as shipping in the past, and commercial fishing, power generation and recreational boating which continue today. Aesthetically, the harbor and town that has grown up around it have a unique maritime flavor. The related waterfront experiences are a great benefit to the residents of the community and a significant tourist attraction. The harbor has special historical importance for the State in that it is the oldest man-made harbor in North America created in a non-natural harbor setting.

Preservation and development of this resource is threatened by the inner harbor's unique configuration (Figure 1). The north and west slips are defined by steel sheetpile walls along their entire perimeter. East-southeast waves which propagate through the outer harbor entrance and directly into the inner harbor produce reflected and standing waves in the slips. The resulting damage to the perimeter walls and landside facilities has been costly in the past. Future damage could be even more costly, given the aging condition of the walls. The wave action in the slips also creates navigation and mooring conditions that are unacceptable to most boaters.

The problem at the inner harbor has been studied in the past (U.S. Army Corps of Engineers, 1976 and Warzyn Engineering Inc., 1987) and a number of conceptual solutions have been proposed. This study expands upon the past studies by:

1) establishing the criteria for successful protection of the slips;
2) refining and updating the site environmental conditions based on state-of-the-art analytical tools and recent information;
3) developing a current understanding of construction methods and costs;
4) and reviewing, revising and developing proposed engineering solutions.

This interim report provides a recommended strategy for physical model testing of proposed solutions, and documents the activities above which form the basis for the recommended strategy.

2.0 ESTABLISHING PROJECT CRITERIA

An important first step in developing a solution to any problem involves establishing criteria which proposed solutions can be measured against. Ideally, a solution to the wave problems in the inner slips would meet all elements of the four criteria presented below.

2.1 Project Criteria

Criteria 1: reduce the wave climate in the north and west slips to manageable levels.
During a 20 year storm event (a storm of severity which on average would occur once in 20 years) there should be no damage to the perimeter walls in the slips, or to adjacent facilities. Wave heights should not exceed one foot during a 20 year storm event occuring during the boating season, to allow for safe navigation and mooring.

Criteria 2: control the power plant cooling water discharge.
Proposed structures should maintain the de-icing and flushing benefits associated with the cooling water discharge flowing into the slips and through the marina. Access to the discharge for fishing should also be maintained. However, the discharge should be deflected to minimize navigation impacts, and reduce the quantity of floating debris from Sauk Creek entering the slips and marina.

Criteria 3: minimize the impacts to existing facilities.
Implementing the proposed solution should not alter or damage the existing facilities elsewhere in the harbor. Access to and function of the City's park should be enhanced, or at least maintained in its present condition. Marina infrastructure and operations should not be negatively impacted. Wisconsin Electric Power Company's (WEPCO) dock should remain detached and inaccessible to the public. Proposed structures should not interfere with WEPCO coal boat unloading procedures. Current use of the slips for commercial and charter fishing should not be disrupted. Siltation and related dredging requirements should not increase in the harbor.

Criteria 4. do not impede future opportunities related to the harbor.
Proposed solutions must recognize the host of opportunities associated with the harbor.

- available land for sale around the west slip represents potential new downtown waterfront area;
- a stable, attractive waterfront can attract downtown development and produce related economic benefits;
- the infrastructure and institutional framework are in place to allow boating opportunities to expand with minimal difficulty;
- transient boating demand is high, and transient experience is positive and profitable in Port Washington;
- existing vertical walls allow boat mooring and preserve space;
- the inner harbor is dredged to a depth that allows the largest of pleasure craft as well as commercial boats and specialty craft;
- excellent shore fishing exists within the harbor;
- WEPCO is both cooperative and interested in the project.

A successful protection solution will also allow the City to capitalize on these possibilities.

2.2 Basis for Project Criteria

The project criteria were established based on review of past studies of the problem, experience with typical performance criteria for similar facilities, and workshop meetings and discussions with representatives of the City, WEPCO, and Mr. Philip Keillor of the University of Wisconsin Sea Grant Institute. Mr. Keillor initially worked with the City in 1985 to begin the process of developing solutions to the wave problems at the inner harbor. Additional input was received at an open meeting of the Port Washington Harbor Commission on August 30, 1993.

2.3 Conflicting Objectives and Constraints

The ideal criteria set presented in Section 2.1 contains several conflicting objectives and criteria with different levels of importance. The situation at the inner harbor is further complicated by additional constraints.

- Space for coastal structures is limited.
- Deep water increases the costs of these structures.
- Funds for construction are limited.
- The inner harbor is part of a federally authorized navigation project.

Structures capable of protecting the inner harbor are very likely to fall within the federal project limits. De-authorization of the affected part of the harbor through an act of Congress will probably be required. However, the City's Lakebed Grant from the State of Wisconsin should provide more flexibility with respect to land form alterations than would be possible without this grant.

As is the case with virtually any public project, the successful solution will necessitate compromise. It is important to note that two key parties, the City and WEPCO, have expressed a common goal of improving the harbor and surrounding area, while minimizing impacts to existing facilities and operations.

3.0 SITE ANALYSIS

Existing data for the harbor was gathered and analyzed to develop an understanding of the inner harbor and the technical factors that will affect the performance of proposed protection solutions. Limited field data collection and observations were undertaken to support this analysis when existing data was not available.

3.1 Location/Condition of Existing Facilities

A base map of existing conditions was developed for the study (Figure 2). Site features were digitized from a Southeastern Wisconsin Regional Planning Commission (SWRPC) topographic map of section 28, township 11 north, range 22 east dated September, 1991. Bathymetry was digitized from a U.S. Army Corps of Engineers condition of channel survey dated September 21, 1992.

The following additional existing information was obtained for purposes of laying out the physical model:

- construction drawings for the existing marina;
- an oblique aerial photograph of the site;
- 1" = 400' aerial photograph of the site dated March, 1990;
- detailed drawings of the WEPCO emergency intake and cooling water discharge.

A field visit was conducted to verify stone sizes and structure dimensions for the existing rubblemound breakwaters, and to photograph all structures related to the inner harbor.

3.2 Offshore Wave Climate

A detailed description of the offshore wave climate at Port Washington has been developed using the results of the Great Lakes Wave Information Study (WIS), which was recently completed (1991) by the Waterways Experiment Station (WES) of the U.S. Army Corps of Engineers (USACOE). The WIS hindcast study utilized a state-of-the-art two dimensional wind-wave hindcast model to simulate the generation of waves on each of the Great Lakes. The resulting data, archived at locations around the perimeter of each lake, consist of a 32 year long time series (with data every three hours) of wave height, period and direction.

WIS Station M11 is the closest station to Port Washington, and these data were obtained on diskette from the USACOE for detailed review and analyses. A detailed statistical summary of the wave climate at this location is included in Appendix A. Given the layout and exposure of Port Washington harbor, the critical wave directions with respect to wave agitation in the inner harbor are from the East through Southeast. This fact is confirmed by the results of a previous physical model investigation of this harbor undertaken by WES (1977). For this reason, the analyses of the WIS hindcast wave data focused on waves from these directions only.

For example, wave height distributions were estimated for the full year, as well as for three different "boating seasons". Table 1 on the following page summarizes the percent exceedance of selected wave heights at a location offshore of Port Washington, considering waves from the East through Southeast only (azimuth range from 79 to 146°).

The results in Table 1 illustrate the increase in the severity of the wave climate when one considers longer boating seasons. For example, during a typical boating season, waves come from the East through Southeast directions approximately twelve per cent of the time. Assuming a boating season which extends from May 1 to October 15, these waves exceed a height of 1.6 ft approximately one-third (33.3 %) of the time; this exceedance drops to approximately one-quarter (26.5%) of the time assuming a June 1 to September 15 boating season.

Table 1

Wave Height Exceedances
WIS Station M11
(E through SE directions only)

Significant Wave Height (ft)	Full Year	Percent Exceedance Apr. 1 - Nov. 15	May 1 - Oct. 15	Jun. 1 - Sep. 15
0.0	100.0	100.0	100.0	100.0
0.8	80.3	74.6	70.4	65.2
1.6	51.2	40.0	33.3	26.5
2.5	29.9	18.1	12.4	7.8
3.3	19.8	9.9	5.5	2.6
4.1	12.1	4.8	1.9	0.6
4.9	7.7	2.4	0.8	0.2
5.7	4.6	1.0	0.3	0.1
6.6	3.1	0.6	0.1	
7.4	1.6	0.2	0.1	
8.2	0.9	0.1		
9.0	0.5			
9.8	0.3			
Total Per Cent These Directions	10.6	12.0	12.3	12.3

A review of this statistical description of the long term wave climate at Port Washington will be used to define physical model test conditions for the assessment of wave agitation levels in Port Washington's inner harbor under existing conditions as well as with proposed improvement alternatives in place.

A peak over threshold extreme value analysis of the WIS wave data was also undertaken to define extreme wave conditions to be considered in the design of harbor improvement structures. In this analysis, storms with wave heights above a selected threshold were identified and ranked, and the resulting data series was tested for fit against several extreme value distributions. A summary of the results of this analysis for the full year and the three boating seasons is presented in Table 2. Again, these results represent waves from the East through Southeast directions only.

Table 2

Extreme Wave Heights
WIS Station M11
(E through SE directions only)

Return Period (years)	Significant Wave Height (ft) Full Year	Apr. 1 - Nov. 15	May 1 - Oct. 15	Jun. 1 - Sep. 15
2	9.5	6.2	5.0	3.9
5	10.5	7.2	5.7	4.5
10	11.2	7.8	6.4	4.9
20	11.8	8.5	7.0	5.3
50	12.7	9.3	7.7	5.8
100	13.3	10.0	8.4	6.3

Based on these analyses, an offshore wave condition of Hs = 11.8 ft, Tp = 9 s from the ESE (20 year return period) was selected to assess the stability of harbor improvement structures. As noted earlier, the ESE direction is critical with respect to wave agitation in the inner harbor due to the layout and exposure of the existing harbor. Larger waves can occur from more northerly and southerly directions (due to the longer fetches in these sectors), but the existing harbor structures provide substantial protection from these wave directions. In contrast, waves from the ESE propagate directly into Port Washington harbor through the harbor entrance.

These results also indicate the decrease in severity of extreme wave conditions in the boating season versus the full year (which includes winter storms) and as one considers shorter boating seasons (thus dropping off spring and fall storms).

3.3 Harbor Wave Climate

The design of the physical model is such that the wave generator is located in the gap between the North and South harbor breakwaters. The orientation of the wave generator simulates the critical ESE wave direction. The existing conditions within Port Washington harbor, including the existing harbor and marina breakwaters, basin perimeter walls and water depths, are all accurately simulated in the physical model, such that the wave conditions within the harbor are correctly modeled.

3.4 Water Levels

Maximum and minimum water levels recorded by NOAA at Milwaukee, Wisconsin are summarized in Table 3.

Table 3

Extreme Recorded Water Levels
Milwaukee, Wisconsin (1900 - 1990)
(reference LWD)*

Duration	Maximum	Minimum
Instantaneous	+6.11 ft (Mar./87)	-2.69 ft (Jan.23/26)
Daily Mean	+5.41 ft (Oct.4/86)	-1.92 ft (Jan.23/26)
Monthly Mean	+5.05 ft (Oct./86)	-1.42 ft (Feb./64)
Annual Mean	+4.34 ft (1986)	-1.08 ft (1964)

*LWD (low water datum), or chart datum (CD) for Lake Michigan is 576.84 ft IGLD 1955 (International Great Lakes Datum 1955) (576.84 ft IGLD = 0.00 ft LWD)

A review of the monthly mean water levels since 1900 was completed to determine the number of times the monthly mean water level exceeded specified values. This analysis was completed for both the summer and winter seasons; the results are summarized in Table 4.

Table 4

Exceedance of Monthly Mean Water Levels
Milwaukee, Wisconsin
(1900 - 1990)

Monthly Mean Water Level (ft,LWD)	Number of Exceedances		Average Frequency of Exceedance	
	Summer (May 1-Sept.30)	Winter (Oct.1-Apr.30)	Summer (May 1-Sept.30)	Winter (Oct.1-Apr.30)
+2	50	38	1 year in 1.8	1 year in 2.3
+4	5	2	1 year in 17.6	1 year in 44.0
+6	0	0	NA	NA

It is important to note that water levels during storms may be significantly higher than the monthly mean levels, due to short term wind and wave induced setups along the shoreline; the magnitude of this storm "surge" depends on the severity of the storm. The results of a peak over threshold extreme value analyses for storm surge based on the Milwaukee water level data are summarized in Table 5.

Table 5

Extreme Value Analysis for Storm Surge
Milwaukee, Wisconsin
(1906 - 1987)

Return Period (years)	Storm Surge (ft)
2	0.92
5	1.32
10	1.63
20	1.93
50	2.33
100	2.64

The U.S. Army Corps of Engineers (1988) have estimated extreme water levels on each of the Great Lakes based on statistical analyses of recorded water level data. At Port Washington, the estimated extreme water levels (peak instantaneous levels) are summarized in Table 6.

Table 6

Extreme Water Levels
Lake Michigan - Reach G
(from USACOE, 1988)

Return Period (years)	Peak Instantaneous W.L. (ft LWD)
10	+4.7
50	+5.8
100	+6.2

In order to determine an extreme water level appropriate for the design of the rubblemound structures, three scenarios were considered, specifically:

1) A combination of the maximum monthly recorded mean water level of +5.1 ft LWD at Milwaukee and the 20 year storm surge of 1.9 ft (estimated using a peak over threshold analysis) at the same location to obtain a design water level of +7.0 ft LWD).
2) The maximum recorded instantaneous water level of +6.1 ft LWD at Milwaukee.
3) The USACOE (1988) estimated 100 year peak instantaneous water level of +6.2 ft LWD.

Based on these three scenarios, a water level of +6.2 ft LWD was selected as the extreme water level for the structural design of harbor improvement structures and for damage assessment to the perimeter facilities within the slips. Data regarding harbor agitation levels at this extreme water level will be obtained from the physical model test. However, more frequently occurring water levels (+2 to +4 ft LWD) will be selected to meet the defined agitation criteria in terms of inner harbor dockage and operations.

3.5 Combined Occurrence of Waves and Water Levels

Table 7 provides a general indication of the probability of combined occurrence of severe east through southeast wave conditions at extreme water levels.

Table 7

Occurrence of Extreme Environmental Conditions

	Offshore Significant Wave Height (ft) - E through SE Directions [Corresponding Return Period (years)]		
Water Level (ft LWD)	9.5 [2]	10.5 [5]	11.8 [20]
+4	frequent	frequent	probable within project life
+5	probable within project life	probable within project life	possible within project life
>+6	possible within project life	possible within project life	unlikely within project life

3.6 Circulation of Cooling Water

The cooling water discharge represents a significant variable in the development of design alternatives for the slips protection. The advantages and disadvantages of the discharge are clear. In a positive sense, circulation helps de-ice and flush the existing marina and north and west slips. However, it also pushes floating debris from Sauk Creek toward these areas, and creates navigation difficulties at the entrance to the slips.

Several factors make it very difficult to develop a quantitative understanding of how this discharged water flows through the harbor and affects navigation, ice formation and water quality.

1) At present, the discharge varies from negligible to 440,000 gallons per minute dependent upon what capacity the plant is operating at. The plant is currently used for peaking purposes only, so there are frequent periods of negligible discharge. WEPCO staff indicate that future operations scenarios project that the discharge from the plant could range anywhere from 0 gallons per minute (if the plant is closed down) to 550,000 gallons per minute (if it is returned to baseload plant status).
2) The flow is very difficult to simulate numerically. It is turbulent due to its velocity, and three dimensional due to the temperature difference between the discharged water and the lake water.
3) The navigation impacts of the discharge are a function of many variables including flow direction and speed, vessel draft and hull shape.

The discharge will be simulated to scale in the physical model, which should result in an improved understanding of the flows through the harbor. However, this information will still be limited because the water temperature difference cannot be simulated in the model. Field measurements of currents in the harbor at different flow conditions were obtained to improve the current understanding of circulation through the inner harbor, and to calibrate the model. This data will be presented along with the model testing results in the design report.

3.7 Soil Conditions

For the purposes of this study, soil boring logs from three different projects in the vicinity of the north and west slips were used to make inferences as to the potential suitability of the harbor bottom soils for bottom resting coastal structures.

- The Harborside Inn Addition by Geo-Technology Inc. dated April 9, 1992.
- Construction at WEPCO Plant by Milwaukee Testing Laboratory dated February, 1966.
- Construction of Existing Marina by Corps of Engineers date June, 1970.

These boring logs indicate general agreement that the soils to be encountered at depths similar to the north and west slip bottom should be dense sands and gravels, and/or low plasticity stiff clays. They are also consistent with past observations by members of the Harbor Commission, which indicated extreme resistance during pile driving projects in the harbor. This information implies that significant special construction considerations or settlement allowances for proposed coastal structures are not required. However, alignment-specific borings will be necessary for final design of bottom resting or pile driven structures.

3.8 Sedimentation

Sedimentation does not appear to be a significant issue with respect to protecting the inner harbor. Review of the Corps of Engineers condition of channel surveys from July, 1983 to August, 1993 indicate that, within the range of error for this type of survey (approximately ±0.5 ft.), there has been no consistent change in depths in the slips, at the entrance to the inner harbor, or along WEPCO's dock. During a phone conversation, Doug Zande of the Operations and Maintenance Division at the Corps of Engineers Detroit District Office confirmed that no maintenance dredging had been performed by the Corps over that same time period.

This information is consistent with observations related to Sauk Creek, which would be the key source of sedimentation to the inner harbor. The creek has a submerged weir where it discharges into the harbor that, in effect, creates a sediment trap. Observations indicate that the area behind the weir is not full of sediment, as would be expected if the discharge were contributing sand or gravel size particles into the harbor. City staff do not clean this area of sediment nor are they aware that anyone else does. However, it is possible that waves and/or currents in the area remove this material from time to time. The cloudy nature of the discharge when Sauk Creek is flowing with stormwater indicates the presence of silt and clay size particles. The flow of the creek combined with the cooling water discharge likely disperses particles in this size range well into the outer harbor before they come out of suspension.

4.0 CONSTRUCTION CONSIDERATIONS

In order to develop comparative statements of probable construction cost for the proposed design alternatives, different structure types, materials availability and transport, construction methods, and unit costs were investigated.

4.1 Structure Types

Rubblemound breakwaters, rubblemound revetments, and steel sheetpile jetties were the primary structures considered for protecting the slips. Rubblemound structures were considered due to their wave absorbing characteristics and relatively low cost. Steel sheetpile jetties may be attractive at this site because they can be used to separate the navigation channel from the discharge flows, and require less space in an area that is already constrained.

Igloo wave absorbers have been evaluated in detail in past studies of the inner harbor (WES, USACOE, 1976; Nippon Tetrapod Co., Ltd., 1976). They are attractive in that they have similar wave absorption characteristics to high porosity rubblemound revetments, yet require substantially less space.

Bottom resting binwalls were not considered for any of the protection alternatives. While they offer similar space-saving advantages to the sheetpile jetty, they are not as stable in the relatively deep water found at the inner harbor. In addition, they would be less resilient to impact by a coal boat than either a rubblemound structure or a steel sheetpile jetty. Floating structures were also ruled out due to the fact that the width required to attenuate the waves that propagate into the inner harbor would likely exceed the available space.

4.2 Materials Availability and Delivery

Review of our files from similar past projects and conversations with local marine contractors indicates an abundant supply of quarried stone for rubblemound structures in the vicinity of Port Washington. Valders Stone and Marble in Valders, Wisconsin has several hundred thousand tons of residual stone stockpiled from past armor stone and cut stone production. Material from this stockpile was recently processed to produce stone in the 0 to 5 ton range for the breakwaters at the new Harbor Centre Marina in Sheboygan, at a substantial cost savings to the city. The stone in the marina breakwaters at Port Washington is from this source, and appears to be performing well to date. Delivery from Valders would likely be by truck, with a one way haul distance of approximately 60 miles.

Dempsey quarry in Waterloo, Wisconsin has an abundant supply of 1 to 2 ton, and 2 to 5 ton armor stone stockpiled. This material is extremely durable quartzite, and was recently used for the breakwater rehabilitation project at Reefpoint Marina in Racine. This material could be delivered by rail, subject to arranging an off loading point in Port Washington. The one way haul distance is approximately 80 miles if delivered by truck. Halquist Stone Company in Sussex, Wisconsin has also provided armor stone up to 5 tons for past projects in the region. Their representative indicated that they would have to blast new stone specifically for this project. The haul distance is similar to Valders' and would likely be delivered by truck.

Other potential suppliers of quarried stone for the project include: local aggregate producers who might furnish core stone and/or smaller rip rap products with substantially lower hauling costs than the above sources; granite producers in the central portion of the state; and a variety of quarries in the upper peninsula of Michigan. Large hauling distances by rail or barge for the central state and Michigan quarries, respectively could hinder their ability to be cost competitive for this project.

4.3 Construction Methods and Unit Costs

Method of construction is an important consideration in the design of coastal structures. Marine-based construction typically allows for relatively narrow, quantity-minimizing designs. Narrow structures are beneficial in the inner harbor given the space constraints. Also, reducing the quantity of materials also tends to reduce the overall cost of the structure. However, narrow structures may require larger, specially-produced armor stone (rubblemound) or deeper, heavier steel sheets (jetty) to be stable. Marine-based construction is also subject to down time due to wave conditions. These factors can increase the unit costs considerably, and may offset the savings associated with quantity minimization.

Land-based construction requires wider structures to allow for equipment access. Rubblemound structures built in this manner are often much wider because they are designed to use smaller armor stones in deep, porous layers. The smaller armor stone is more likely to be readily available in the vicinity of the project, and is easier for land-based equipment to handle. Thus, use of smaller stone typically creates a distinct unit cost advantage. Down-time due to wave action is reduced substantially if construction is land-based. A disadvantage of this approach with respect to the inner harbor is that additional space will be consumed by the structures in an area where space is already limited. In addition, equipment access across the existing park, the property on the south side of the west slip, and/or the WEPCO dock would have to be negotiated.

The assumptions presented below have been made for purposes of comparative cost analysis of the alternative designs in the subsequent section of this report.

- Rubblemound breakwater cross sections are of similar crest height, crest width, stone sizes, and layer thicknesses to the east breakwater recently constructed in Sheboygan, given the common location within a federal harbor and the similarities in wave climate. Likely in-place costs for armor stone and core stone are $26/ton and $17/ton, respectively. This translates into costs ranging from $2,000 to $2,600 per lineal foot of breakwater in place, depending on water depth at the structure.
- Rubblemound revetment cross sections are relatively deep and consist of armor stone only, based on the need for high wave absorption. Using an anticipated armor stone unit cost of $26/ton in-place, the revetments should cost on the order of $1,300 per lineal foot.
- Steel sheetpile jetties are 20 feet wide and of similar height to the existing perimeter dockwalls at the park and WEPCO dock. They are defined by a cross-tied double wall of PZ27 sheets with an embedment depth equal to the height above the lake bottom. The jetties are filled with crushed stone, capped with a concrete surface, and have no other special surface treatments. Probable construction cost for these structures is on the order of $3,500 per lineal foot.

The physical model test will be used to determine how wide, how high, and how long the structures should be to provide the desired protection to the slips. It will also be used to determine the size of the individual armor stones, and the thickness of the armor stone layer. Input and feedback with respect to the construction considerations presented in this section will be an important element in this process.

A cost benefit analysis of using igloos will be included in the design report if the physical model testing demonstrates a need for absorptive structures at the ends or sides of the slips. Actual costs from a past similar application of igloos in Milwaukee Harbor were obtained from Mr. Roger Mauer of the Milwaukee Metropolitan Sewerage District. Unit costs for igloos on this project were on the order of $2,000 per lineal foot in 1985 dollars. Adjusted to today's dollars, this would be approximately twice the cost of rubblemound revetments.

5.0 PRELIMINARY DESIGN DEVELOPMENT

Five new alternative protection designs (Alternatives I - IV) were prepared during this study based on the considerations and activities discussed in Sections 2.0 through 4.0 of this report. These alternatives are presented in Appendix B and described briefly below. It is important to note that the thick solid lines shown on the alternative drawings represent the structure crest, and the thick dashed lines represent the toe of structure at the lake bottom. Therefore, much of what is seen in these plan views would be beneath the water surface.

The new alternatives, along with preferred alternatives from past studies, were evaluated with respect to the criteria presented in Section 2.0. The preferred alternatives from past studies are included for reference in Appendix C. Also, the shipping companies who deliver coal to WEPCO were provided the opportunity to review, rank and comment upon the new alternatives in the context of their operations. The results of these evaluations are summarized and discussed in Sections 5.2 and 5.3.

5.1 New Alternative Designs

<u>Alternative I</u>

Alternative I consists of three rubblemound structures. The east breakwater is intended to reduce the wave energy entering the inner harbor area, and provide additional protection to the park. Special treatments could be added to the crest of this structure to provide access from the existing footbridge to the steel sheetpile cell for fishing and pedestrians. The structure is positioned to provide 135 feet in width for coal boat access.

The revetment/breakwater combination along the south edge of the park is proposed to absorb the waves propagating past the east breakwater. It will also define the north limits of the entrance channel to the slips. The west breakwater is intended to provide protection to the west and north slips, define the southern limits of the entrance channel, and deflect the current away from the entrance channel. The entrance itself would be 75 feet wide at navigable water depth. A footbridge and special treatments to the west breakwater crest could be added to provide access for fishing.

<u>Alternative II</u>

An east breakwater extending from WEPCO's dock across the entrance to the inner harbor is the key element of this alternative. Dredging would be required to provide sufficient depth at the new entrance. The deeper water conditions at the new entrance would in turn necessitate improvements to the park revetment to minimize damage to the park.

<u>Alternative III</u>

Alternative III is similar to Alternative I, except a steel sheetpile jetty replaces the park revetment/breakwater. This provides a vertical-walled channel to the slips that is isolated from the cooling water discharge currents. The channel would be approximately 80 feet wide, allowing 135 feet for the coal boat. Some circulation through the slips and marina would be encouraged by leaving a gap between the west end of the west breakwater and the existing sheetpile edge. Again, a footbridge could provide access across this gap for fishing.

A small breakwater would extend from the east end of the jetty to provide a protected entrance. Dredging and improvements to the park revetment would be required as was the case for Alternative II.

<u>Alternative IV</u>

This alternative would use two rubblemound breakwaters to reduce wave energy at the inner harbor entrance. The channel would be seventy five feet wide at navigable water depth. The north breakwater crest could be treated to provide additional park space.

Alternative V

Alternative V would protect the slips area by overlapping an east and west rubblemound breakwater at the immediate entrance to the slips. Similar to the other alternatives, the entrance width would be 75 feet. The discharge would likely be split between the slips area and the outer harbor.

5.2 Alternatives Evaluation

The table in Appendix D presents a qualitative evaluation of the new alternatives, as well as the preferred alternatives from past studies. Each of these alternatives is ranked against the criteria identified during the study. An opinion of probable construction cost for each alternative is also provided in the table. This tabulation was presented and discussed in detail at an open meeting of the Port Washington Harbor Commission on August 30, 1993. Key points of discussion are highlighted below.

- *The criteria differ in importance* . Alternatives must provide adequate wave protection and safe navigation. Damage to landside facilities is both costly and unacceptable. Similarly, an incident leading to boat damage or injury due to currents at the entrance or wave action within the basin will ruin the reputation of the facility, and discourage future use. However, there is likely to be some flexibility with respect to disrupting existing facilities and WEPCO operations, water quality/de-icing circulation, shore fishing opportunities, and trash from Sauk Creek. Furthermore, some of these criteria could change in the future if WEPCO modifies its operations significantly.

- *Different criteria are evaluated with different levels of confidence at this point in the project.* Whether the alternatives will disrupt existing facilities or impact WEPCO operations can be stated conclusively. To the contrary, the complex issues of wave protection, safe navigation in currents, and water quality/de-icing benefits of circulation are very difficult to evaluate at this point. The physical model testing will provide detailed quantitative data with respect to wave protection. It should also improve the qualitative understanding of currents and circulation through the harbor. Navigation through these currents will remain an intuitive issue which may be best addressed by relying upon the experience of local boaters.

- *There is not an obvious "best alternative".* Alternative III, which appears to best satisfy the range of criteria, has a high probable construction cost. Conversely, past Alternative B, and new Alternatives IV and V, which are relatively inexpensive to construct, are questionable in terms of the fundamental criteria of wave protection and navigability.

- *Other options should be considered.* The Harbor Commission believes they have a responsibility to investigate an alternative which would provide protection to the north slip only, given uncertainty with respect to future property ownership around the west slip. Also, it is possible that the physical model study may demonstrate that only the most costly alternatives provide suitable wave protection and safe navigation. This would indicate that another alternative should be considered which closes off the inner harbor and provides access to the slips through the existing marina.

- *Permitting will be required.* Each of the alternatives will require the City to file a joint permit application with the State of Wisconsin Department of Natural Resources (WIDNR) and the USACOE under Section 404 of the U.S. Congress Clean Water Act, which regulates the discharge of dredged and fill material into U.S. waters. As previously discussed, federal harbor de-authorization will likely be required given that portions of the structures under each alternative fall within the federal project limits. In addition, alternatives showing dredging will necessitate application to WIDNR for a Wisconsin Pollutant Discharge Elimination System (WPDES) permit. This could include sampling and testing soils to be dredged to demonstrate that they are not contaminated. Special disposal procedures may be required if they are.

5.3 Shipping Company Rankings

Drawings of Alternatives I - V were forwarded for review and comment to contact persons provided by WEPCO for the two shipping companies who deliver coal to the Port Washington Plant. Specifically, Mr. Stuart Southern of American Steamship Company and Mr. Dick Feldtz of Columbia Transportation Company were contacted. These individuals offered the following comments after reviewing the alternatives.

Mr. Southern ranked the alternatives from best to worst as follows: Alternative V (best); III; I; IV; and II (worst). He added that Alternatives V and III are the most preferable, but they can adjust their unloading operations to make any of the alternatives "do-able" if essential to the project's feasibility.

Mr. Feldtz stated his company's preference for Alternatives IV or V. He indicated that Alternatives I, II and III present difficulties due to constricted access (restricted for Alternative II) to the western end of the WEPCO dock. He seemed somewhat more reluctant to modify their current unloading operations at the Port Washington plant than Mr. Southern did.

6.0 CONCLUSIONS

There are three general categories of wave protection alternatives under consideration for Port Washington's inner harbor.

1) Alternatives which modify the entrance to the west slip.
2) Alternatives which protect the north slip only.
3) Alternatives which close off the north and west slips and require a new entrance to be cut from the existing marina through to the north slip.

The "best" alternative is not obvious. Physical model testing will allow the City to identify which alternatives meet the basic performance criteria. Prioritization and compromise with respect to the project criteria, combined with further analysis of related future downtown development will be required to select the "best" alternative.

7.0 RECOMMENDATIONS

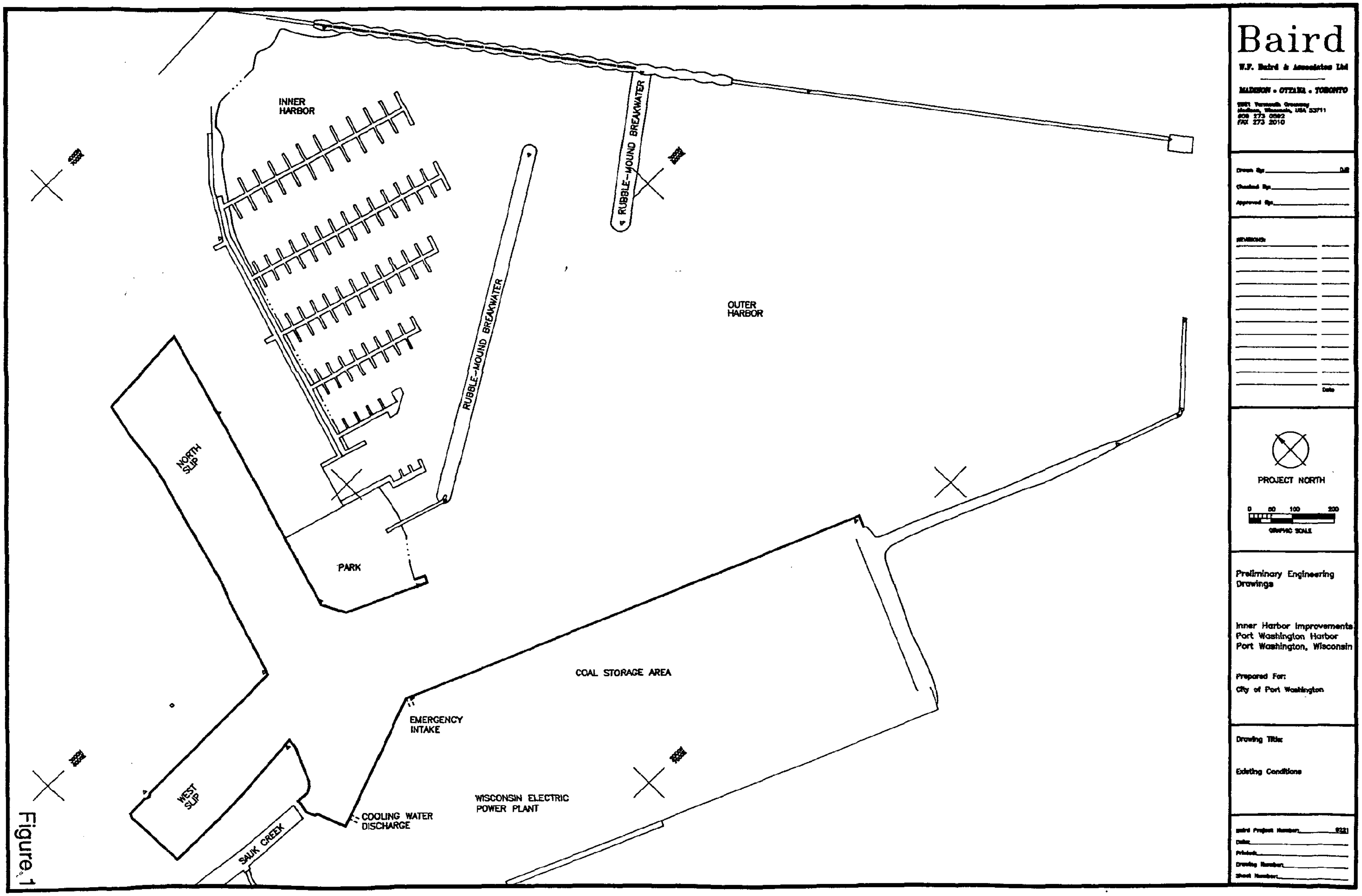
Physical model testing should be performed in an incremental, flexible and interactive manner.

- Alternatives should be constructed one structure at a time, with testing after each structure is in place, to form the basis for cost-benefit analyses. For example, in the case of Alternative I the relative improvement in wave agitation by first adding the west breakwater, then the revetment, then the east breakwater could be assessed.
- Alternatives should be modified in the tank based on observations and intermediate results during testing to better meet the project criteria.

- Members of the Port Washington Harbor Commission and other interested parties should be invited to participate in a modeling workshop, so that their observations, experiences and insights may be considered and added to the testing program.
- Modeling should be conducted at a scale that allows quantitative analysis of both wave agitation and structure cross sections, as well as qualitative assessment of circulation and currents.

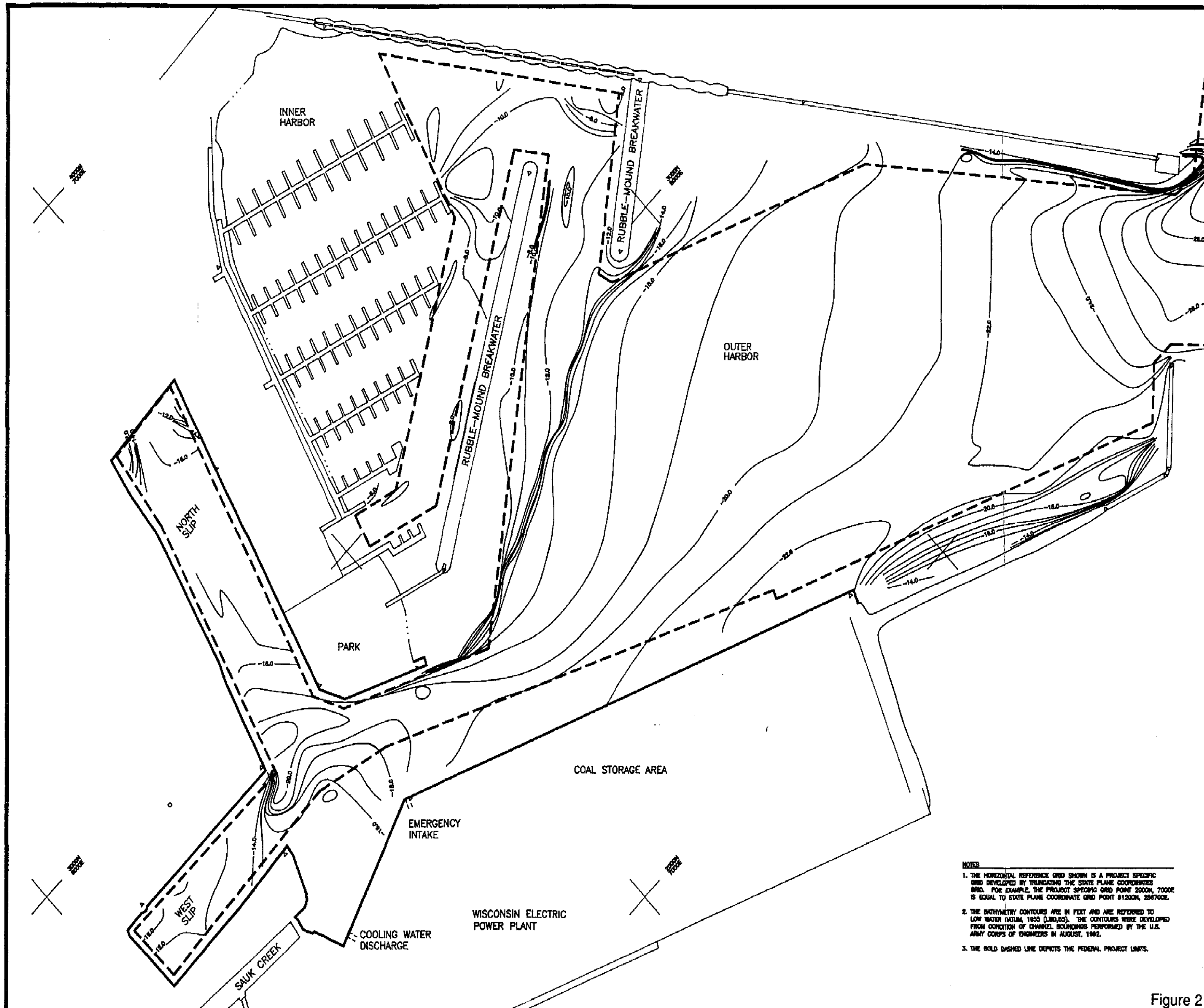
As preliminary engineering of wave protection alternatives proceeds, the City should begin to establish a downtown waterfront development strategy. Those wave protection alternatives which meet the performance criteria set forth in this study should be carried forward until this strategy is better defined.

Figures



INNER HARBOR
OUTER HARBOR
RUBBLE-MOUND BREAKWATER
RUBBLE-MOUND BREAKWATER
NORTH SLIP
PARK
COAL STORAGE AREA
EMERGENCY INTAKE
WISCONSIN ELECTRIC POWER PLANT
COOLING WATER DISCHARGE
WEST SLIP
SAUK CREEK
Baird
W.F. Baird & Associates Ltd
MADISON • OTTAWA • TORONTO
608 273 0592
FAX 273 2010
Drawn By
Checked By
Approved By
REVISIONS
Date
PROJECT NORTH
0 50 100 200
GRAPHIC SCALE
Preliminary Engineering Drawings
Inner Harbor Improvements
Port Washington Harbor
Port Washington, Wisconsin
Prepared For:
City of Port Washington
Drawing Title:
Existing Conditions
Baird Project Number
Date
Printed
Drawing Number
Sheet Number

Figure 1



NOTES

1. THE HORIZONTAL REFERENCE GRID SHOWN IS A PROJECT SPECIFIC GRID DEVELOPED BY TRUNCATING THE STATE PLANE COORDINATES GRID. FOR EXAMPLE, THE PROJECT SPECIFIC GRID POINT 2000N, 7000E IS EQUAL TO STATE PLANE COORDINATE GRID POINT 81200N, 256700E.
2. THE BATHYMETRY CONTOURS ARE IN FEET AND ARE REFERRED TO LOW WATER DATUM, 1955 (LWD,55). THE CONTOURS WERE DEVELOPED FROM CONDITION OF CHANNEL SOUNDINGS PERFORMED BY THE U.S. ARMY CORPS OF ENGINEERS IN AUGUST, 1992.
3. THE BOLD DASHED LINE DEPICTS THE FEDERAL PROJECT LIMITS.

Figure 2

Baird
W.F. Baird & Associates Ltd
MADISON • OTTAWA • TORONTO
2981 Yarmouth Greenway
Madison, Wisconsin, USA 53711
608 273 0592
FAX 273 2010

Drawn By: DJR
Checked By: DDS
Approved By: DJR

REVISIONS: Date

PROJECT NORTH

0 50 100 200
GRAPHIC SCALE

Preliminary Engineering Drawings

Inner Harbor Improvements
Port Washington Harbor
Port Washington, Wisconsin

Prepared For:
City of Port Washington

Drawing Title:
Existing Conditions

Baird Project Number: 8221
Date: June, 1993
Printed:
Drawing Number:
Sheet Number:

Appendix A - Wave Climate Statistical Summary

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) = 0.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	
0.00-0.24	280	181	8	7	.	.	.	.	.	.	476
0.25-0.49	63	585	53	52	8	.	.	.	.	.	761
0.50-0.74	.	489	511	81	39	2	.	.	.	.	1122
0.75-0.99	.	17	398	149	22	10	.	.	.	.	596
1.00-1.24	.	.	306	402	36	12	.	.	.	.	756
1.25-1.49	.	.	36	348	40	7	1	.	.	.	432
1.50-1.74	.	.	2	333	142	9	2	.	.	.	488
1.75-1.99	.	.	.	25	222	4	1	.	.	.	252
2.00-2.24	.	.	.	6	241	14	3	.	.	.	264
2.25-2.49	.	.	.	.	95	11	.	.	.	.	106
2.50-2.74	.	.	.	.	55	58	.	1	.	.	114
2.75-2.99	.	.	.	.	1	38	6	2	.	.	47
3.00-3.24	.	.	.	.	.	71	6	.	.	.	77
3.25-3.49	.	.	.	.	.	16	5	.	.	.	21
3.50+	.	.	.	.	.	8	34	12	1	.	55
TOTAL	343	1272	1314	1403	901	260	58	15	1	0	

MEAN HS(M) = 1.1 LARGEST HS(M)= 5.8 MEAN TP(SEC)= 4.4 NO. OF CASES= 5229.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) = 22.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	
0.00-0.24	379	177	14	3	.	.	.	.	.	.	573
0.25-0.49	83	833	79	55	3	.	.	.	.	.	1053
0.50-0.74	.	528	852	95	34	2	.	.	.	.	1511
0.75-0.99	.	8	498	243	20	2	.	.	.	.	771
1.00-1.24	.	.	281	463	29	8	.	.	.	.	781
1.25-1.49	.	.	12	272	90	4	1	.	.	.	379
1.50-1.74	.	.	.	183	144	3	.	.	.	.	330
1.75-1.99	.	.	.	16	120	4	3	.	.	.	143
2.00-2.24	.	.	.	1	149	11	.	.	.	.	161
2.25-2.49	.	.	.	.	47	23	.	.	.	.	70
2.50-2.74	.	.	.	.	13	71	.	.	.	.	84
2.75-2.99	.	.	.	.	.	38	1	.	.	.	39
3.00-3.24	.	.	.	.	.	32	2	.	.	.	34
3.25-3.49	.	.	.	.	.	9	8	.	.	.	17
3.50+	.	.	.	.	.	5	38	2	1	.	46
TOTAL	462	1546	1736	1331	649	212	53	2	1	0	

MEAN HS(M) = 0.9 LARGEST HS(M)= 5.9 MEAN TP(SEC)= 4.2 NO. OF CASES= 5623.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) = 45.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	
0.00-0.24	491	283	16	13	1	.	.	.	.	.	804
0.25-0.49	100	1096	90	77	3	.	.	.	.	.	1366
0.50-0.74	.	535	761	114	26	2	.	.	.	.	1438
0.75-0.99	.	4	365	199	16	4	.	.	.	.	588
1.00-1.24	.	.	204	382	25	6	.	.	.	.	617
1.25-1.49	.	.	11	180	91	4	.	.	.	.	286
1.50-1.74	.	.	.	168	152	1	2	.	.	.	323
1.75-1.99	.	.	.	13	113	3	1	.	.	.	130
2.00-2.24	.	.	.	.	154	10	.	.	.	.	164
2.25-2.49	.	.	.	.	78	24	.	.	.	.	102
2.50-2.74	.	.	.	.	14	79	2	.	.	.	95
2.75-2.99	.	.	.	.	2	50	.	.	.	.	52
3.00-3.24	.	.	.	.	.	35	.	.	.	.	35
3.25-3.49	.	.	.	.	.	20	3	.	.	.	23
3.50+	.	.	.	.	.	5	28	2	.	.	35
TOTAL	591	1918	1447	1146	675	243	36	2	0	0	

MEAN HS(M) = 0.8 LARGEST HS(M)= 6.1 MEAN TP(SEC)= 4.1 NO. OF CASES= 5686.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) = 67.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	
0.00-0.24	290	126	12	5	.	.	.	.	.	.	433
0.25-0.49	62	551	71	42	4	.	.	.	.	.	730
0.50-0.74	.	260	353	44	19	1	.	.	.	.	677
0.75-0.99	.	3	154	108	8	1	.	.	.	.	274
1.00-1.24	.	.	59	165	12	1	.	.	.	.	237
1.25-1.49	.	.	2	67	60	.	.	.	.	.	129
1.50-1.74	.	.	.	52	86	2	.	.	.	.	140
1.75-1.99	.	.	.	2	58	3	.	.	.	.	63
2.00-2.24	.	.	.	.	71	9	.	.	.	.	80
2.25-2.49	.	.	.	.	35	8	.	.	.	.	43
2.50-2.74	.	.	.	.	7	32	.	.	.	.	39
2.75-2.99	.	.	.	.	.	14	.	.	.	.	14
3.00-3.24	.	.	.	.	.	12	.	.	.	.	12
3.25-3.49	.	.	.	.	.	3	1	.	.	.	4
3.50+	.	.	.	.	.	.	4	.	.	.	4
TOTAL	352	940	651	485	360	86	5	0	0	0	

MEAN HS(M) = 0.8 LARGEST HS(M)= 3.6 MEAN TP(SEC)= 4.0 NO. OF CASES= 2711.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) = 90.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	TOTAL
0.00-0.24	336	132	17	6	.	.	.	.	.	.	491
0.25-0.49	79	512	53	59	5	.	.	.	.	.	708
0.50-0.74	.	210	313	35	13	.	.	.	.	.	571
0.75-0.99	.	.	125	108	2	3	.	.	.	.	238
1.00-1.24	.	.	57	171	18	2	.	.	.	.	248
1.25-1.49	.	.	2	69	60	1	.	.	.	.	132
1.50-1.74	.	.	.	40	75	4	1	.	.	.	120
1.75-1.99	.	.	.	2	44	6	1	.	.	.	53
2.00-2.24	.	.	.	.	57	14	.	.	.	.	71
2.25-2.49	.	.	.	.	28	7	.	.	.	.	35
2.50-2.74	.	.	.	.	1	21	.	.	.	.	22
2.75-2.99	.	.	.	.	.	6	.	.	.	.	6
3.00-3.24	.	.	.	.	.	6	.	.	.	.	6
3.25-3.49	.	.	.	.	.	1	1	.	.	.	2
3.50+	.	.	.	.	.	.	1	.	.	.	1
TOTAL	415	854	567	490	303	71	4	0	0	0	

MEAN HS(M) = 0.7 LARGEST HS(M)= 3.5 MEAN TP(SEC)= 3.9 NO. OF CASES= 2545.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =112.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	TOTAL
0.00-0.24	333	134	13	4	1	.	.	.	.	.	485
0.25-0.49	102	545	56	48	4	.	.	.	.	.	755
0.50-0.74	.	328	290	25	8	.	.	.	.	.	651
0.75-0.99	.	3	137	89	2	1	.	.	.	.	232
1.00-1.24	.	.	66	141	23	.	.	.	.	.	230
1.25-1.49	.	.	5	64	82	1	.	.	.	.	152
1.50-1.74	.	.	.	42	62	1	.	.	.	.	105
1.75-1.99	.	.	.	.	31	4	1	.	.	.	36
2.00-2.24	.	.	.	.	36	16	.	1	.	.	53
2.25-2.49	.	.	.	.	12	9	.	.	.	.	21
2.50-2.74	.	.	.	.	2	11	.	.	.	.	13
2.75-2.99	.	.	.	.	.	9	.	.	.	.	9
3.00-3.24	.	.	.	.	.	8	1	.	.	.	9
3.25-3.49	.	.	.	.	.	2	1	.	.	.	3
3.50+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	435	1010	567	413	263	62	3	1	0	0	

MEAN HS(M) = 0.7 LARGEST HS(M)= 3.3 MEAN TP(SEC)= 3.7 NO. OF CASES= 2591.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =135.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	TOTAL
0.00-0.24	467	205	17	12	.	.	.	.	.	.	701
0.25-0.49	156	887	103	50	2	.	.	.	.	.	1198
0.50-0.74	.	632	674	65	19	1	.	.	.	.	1391
0.75-0.99	.	14	241	208	6	1	.	.	.	.	470
1.00-1.24	.	.	172	285	50	.	.	.	.	.	507
1.25-1.49	.	.	9	112	90	1	.	.	.	.	212
1.50-1.74	.	.	.	63	89	5	1	.	.	.	158
1.75-1.99	.	.	.	4	41	21	.	.	.	.	66
2.00-2.24	.	.	.	.	34	23	.	.	.	.	57
2.25-2.49	.	.	.	.	11	14	2	.	.	.	27
2.50-2.74	.	.	.	.	2	14	1	.	.	.	17
2.75-2.99	.	.	.	.	.	6	2	.	.	.	8
3.00-3.24	.	.	.	.	.	6	2	.	.	.	8
3.25-3.49	.	.	.	.	.	1	4	.	.	.	5
3.50+	.	.	.	.	.	.	9	.	.	.	9
TOTAL	623	1738	1216	799	344	93	21	0	0	0	

MEAN HS(M) = 0.7 LARGEST HS(M)= 3.8 MEAN TP(SEC)= 3.8 NO. OF CASES= 4538.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =157.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	TOTAL
0.00-0.24	478	587	73	31	5	.	.	.	.	.	1174
0.25-0.49	146	2004	486	210	27	.	.	.	.	.	2873
0.50-0.74	.	836	1722	526	115	2	.	.	.	.	3201
0.75-0.99	.	52	495	642	100	7	.	.	.	.	1296
1.00-1.24	.	.	315	496	204	23	.	.	.	.	1038
1.25-1.49	.	.	20	194	170	6	1	.	.	.	391
1.50-1.74	.	.	1	122	180	25	1	.	.	.	329
1.75-1.99	.	.	.	14	91	39	.	.	.	.	144
2.00-2.24	.	.	.	.	71	47	1	.	.	.	119
2.25-2.49	.	.	.	.	21	22	5	.	.	.	48
2.50-2.74	.	.	.	.	3	34	5	.	.	.	42
2.75-2.99	.	.	.	.	2	12	3	.	.	.	17
3.00-3.24	.	.	.	.	.	12	2	.	.	.	14
3.25-3.49	.	.	.	.	.	1	5	.	.	.	6
3.50+	.	.	.	.	.	.	7	.	.	.	7
TOTAL	624	3479	3112	2235	989	230	30	0	0	0	

MEAN HS(M) = 0.7 LARGEST HS(M)= 3.8 MEAN TP(SEC)= 4.0 NO. OF CASES= 10025.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =180.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	
0.00-0.24	681	709	95	31	6	.	.	.	.	.	1522
0.25-0.49	195	2150	598	168	33	1	.	.	.	.	3145
0.50-0.74	.	1758	1603	499	82	4	.	.	.	.	3946
0.75-0.99	.	241	1124	799	136	31	.	.	.	.	2331
1.00-1.24	.	.	784	791	389	45	3	.	.	.	2012
1.25-1.49	.	.	120	432	385	19	2	.	.	.	958
1.50-1.74	.	.	19	394	358	41	2	.	.	.	814
1.75-1.99	.	.	.	44	241	51	3	.	.	.	339
2.00-2.24	.	.	.	4	253	96	5	.	.	.	358
2.25-2.49	.	.	.	.	68	86	4	.	.	.	158
2.50-2.74	.	.	.	.	19	136	3	.	.	.	158
2.75-2.99	.	.	.	.	1	65	5	.	.	.	71
3.00-3.24	.	.	.	.	.	48	4	.	.	.	52
3.25-3.49	.	.	.	.	.	9	18	.	.	.	27
3.50+	.	.	.	.	.	2	48	1	.	.	51
TOTAL	876	4858	4343	3162	1971	634	97	1	0	0	

MEAN HS(M) = 0.8 LARGEST HS(M)= 4.9 MEAN TP(SEC)= 4.2 NO. OF CASES= 14928.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =202.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	
0.00-0.24	474	270	34	19	3	.	.	.	.	.	800
0.25-0.49	175	1338	86	89	18	.	.	.	.	.	1706
0.50-0.74	.	2175	312	26	37	7	.	.	.	.	2557
0.75-0.99	.	183	827	42	7	.	.	.	.	.	1059
1.00-1.24	.	.	591	60	11	2	.	.	.	.	664
1.25-1.49	.	.	276	56	33	1	1	.	.	.	367
1.50-1.74	.	.	59	165	55	.	.	.	.	.	279
1.75-1.99	.	.	1	36	36	5	.	.	.	.	78
2.00-2.24	.	.	.	20	47	11	.	.	.	.	78
2.25-2.49	.	.	.	2	16	10	.	.	.	.	28
2.50-2.74	.	.	.	1	5	16	.	.	.	.	22
2.75-2.99	.	.	.	.	.	5	1	.	.	.	6
3.00-3.24	.	.	.	.	1	11	4	.	.	.	16
3.25-3.49	.	.	.	.	.	3	2	.	.	.	5
3.50+	.	.	.	.	.	.	10	.	.	.	10
TOTAL	649	3966	2186	516	269	71	18	0	0	0	

MEAN HS(M) = 0.7 LARGEST HS(M)= 4.8 MEAN TP(SEC)= 3.5 NO. OF CASES= 7198.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =225.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	
0.00-0.24	510	224	29	13	3	.	.	.	.	.	779
0.25-0.49	159	952	69	112	32	3	.	.	.	.	1327
0.50-0.74	.	2023	207	17	35	5	.	.	.	.	2287
0.75-0.99	.	177	602	9	11	4	.	.	.	.	803
1.00-1.24	.	.	462	2	1	.	.	.	.	.	465
1.25-1.49	.	.	222	2	.	.	.	.	.	.	224
1.50-1.74	.	.	32	124	.	.	.	.	.	.	156
1.75-1.99	.	.	1	42	.	.	1	.	.	.	44
2.00-2.24	.	.	.	28	1	.	.	.	.	.	29
2.25-2.49	.	.	.	3	2	.	.	.	.	.	5
2.50-2.74	.	.	.	.	3	.	.	.	.	.	3
2.75-2.99	.	.	.	.	1	.	.	.	.	.	1
3.00-3.24	.	.	.	.	3	.	.	.	.	.	3
3.25-3.49	.	.	.	.	1	.	.	.	.	.	1
3.50+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	669	3376	1624	352	93	12	1	0	0	0	

MEAN HS(M) = 0.6 LARGEST HS(M)= 3.4 MEAN TP(SEC)= 3.3 NO. OF CASES= 5741.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =247.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	
0.00-0.24	440	175	26	27	5	1	.	.	.	.	674
0.25-0.49	190	852	57	120	54	3	.	.	.	.	1276
0.50-0.74	.	1480	55	45	70	18	1	.	.	.	1669
0.75-0.99	.	189	330	16	11	7	.	.	.	.	553
1.00-1.24	.	.	238	5	5	4	2	.	.	.	254
1.25-1.49	.	.	90	.	1	.	.	.	.	.	91
1.50-1.74	.	.	32	24	.	.	1	.	.	.	57
1.75-1.99	.	.	.	9	.	.	.	.	.	.	9
2.00-2.24	.	.	.	12	.	.	.	.	.	.	12
2.25-2.49	.	.	.	1	2	.	.	.	.	.	3
2.50-2.74	.	.	.	.	2	.	.	.	.	.	2
2.75-2.99	.	.	.	.	1	.	.	.	.	.	1
3.00-3.24	.	.	.	.	.	.	.	.	.	.	0
3.25-3.49	.	.	.	.	2	.	.	.	.	.	2
3.50+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	630	2696	828	259	153	33	4	0	0	0	

MEAN HS(M) = 0.6 LARGEST HS(M)= 3.4 MEAN TP(SEC)= 3.3 NO. OF CASES= 4319.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =270.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS) <3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	TOTAL
0.00-0.24	480	163	28	21	6	.	.	.	.	.	698
0.25-0.49	263	1067	105	144	77	2	.	.	.	.	1658
0.50-0.74	.	1781	59	77	143	20	.	.	.	.	2080
0.75-0.99	.	325	381	14	44	33	1	.	.	.	798
1.00-1.24	.	.	255	6	11	6	4	.	.	.	282
1.25-1.49	.	.	96	.	1	2	.	.	.	.	99
1.50-1.74	.	.	41	18	.	1	1	.	.	.	61
1.75-1.99	.	.	.	12	.	.	.	.	.	.	12
2.00-2.24	.	.	.	1	.	.	.	.	.	.	1
2.25-2.49	.	.	.	.	.	.	.	.	.	.	0
2.50-2.74	.	.	.	.	.	.	.	.	.	.	0
2.75-2.99	.	.	.	.	.	.	.	.	.	.	0
3.00-3.24	.	.	.	.	.	.	.	.	.	.	0
3.25-3.49	.	.	.	.	.	.	.	.	.	.	0
3.50+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	743	3336	965	293	282	64	6	0	0	0	

MEAN HS(M) = 0.6 LARGEST HS(M)= 2.2 MEAN TP(SEC)= 3.3 NO. OF CASES= 5333.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =292.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS) <3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	TOTAL
0.00-0.24	362	151	8	16	2	.	.	.	.	.	539
0.25-0.49	192	1128	74	114	48	1	.	.	.	.	1557
0.50-0.74	.	2378	142	72	161	21	.	.	.	.	2774
0.75-0.99	.	297	731	38	73	51	.	.	.	.	1190
1.00-1.24	.	.	507	13	17	47	14	.	.	.	598
1.25-1.49	.	.	222	.	.	8	6	.	.	.	236
1.50-1.74	.	.	44	45	.	5	2	.	.	.	96
1.75-1.99	.	.	.	14	.	.	4	.	.	.	18
2.00-2.24	.	.	.	8	.	.	2	1	.	.	11
2.25-2.49	.	.	.	.	.	.	2	3	.	.	5
2.50-2.74	.	.	.	.	.	.	.	.	.	.	0
2.75-2.99	.	.	.	.	.	.	.	.	.	.	0
3.00-3.24	.	.	.	.	.	.	.	.	.	.	0
3.25-3.49	.	.	.	.	.	.	.	.	.	.	0
3.50+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	554	3954	1728	320	301	133	30	4	0	0	

MEAN HS(M) = 0.7 LARGEST HS(M)= 2.4 MEAN TP(SEC)= 3.5 NO. OF CASES= 6585.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =315.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS) <3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	TOTAL
0.00-0.24	262	126	11	10	.	.	.	.	.	.	409
0.25-0.49	60	684	70	87	37	.	.	.	.	.	938
0.50-0.74	.	2164	309	91	89	10	.	.	.	.	2663
0.75-0.99	.	142	903	87	96	43	1	.	.	.	1272
1.00-1.24	.	.	753	80	38	65	6	.	.	.	942
1.25-1.49	.	.	390	29	16	29	11	.	.	.	475
1.50-1.74	.	.	54	166	18	17	14	.	.	.	269
1.75-1.99	.	.	1	24	8	4	16	1	.	.	54
2.00-2.24	.	.	.	9	10	5	18	.	.	.	42
2.25-2.49	.	.	.	2	.	.	5	2	.	.	9
2.50-2.74	.	.	.	.	.	.	.	4	.	.	4
2.75-2.99	.	.	.	.	.	.	1	1	1	.	3
3.00-3.24	.	.	.	.	.	.	2	1	.	.	3
3.25-3.49	.	.	.	.	.	1	.	1	.	.	2
3.50+	.	.	.	.	.	.	.	.	1	.	1
TOTAL	322	3116	2491	585	312	174	74	10	2	0	

MEAN HS(M) = 0.8 LARGEST HS(M)= 3.5 MEAN TP(SEC)= 3.8 NO. OF CASES= 6648.

STATION M11 43.27N 87.68W AZIMUTH(DEGREES) =337.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

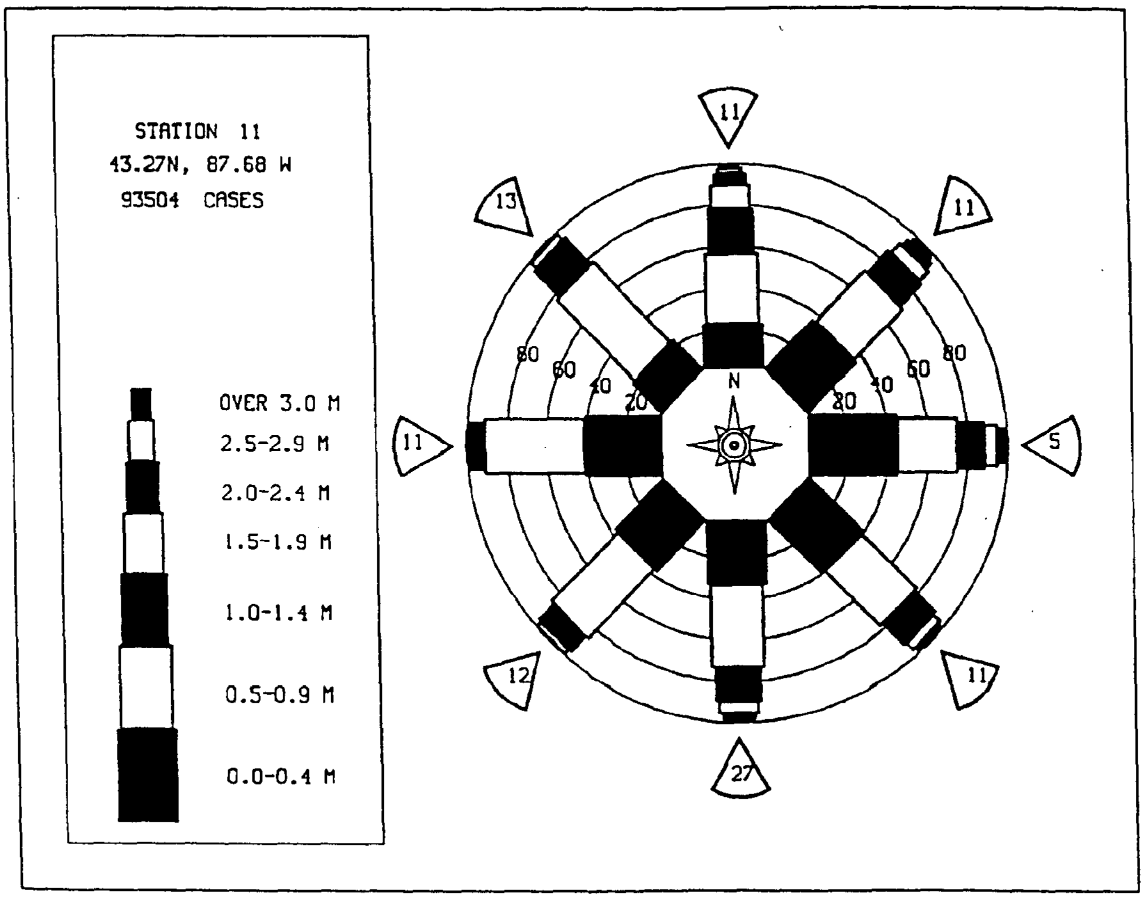
HEIGHT(METRES)	PEAK PERIOD(SECONDS) <3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	TOTAL
0.00-0.24	172	106	5	2	.	.	.	.	.	.	285
0.25-0.49	39	419	41	42	11	.	.	.	.	.	552
0.50-0.74	.	788	286	69	62	6	.	.	.	.	1211
0.75-0.99	.	33	434	81	58	23	.	.	.	.	629
1.00-1.24	.	.	268	185	35	39	2	.	.	.	529
1.25-1.49	.	.	109	157	19	11	3	.	.	.	299
1.50-1.74	.	.	14	168	55	10	5	.	.	.	252
1.75-1.99	.	.	1	24	63	6	2	.	.	.	96
2.00-2.24	.	.	.	5	72	4	2	.	.	.	83
2.25-2.49	.	.	.	.	27	1	1	.	.	.	29
2.50-2.74	.	.	.	.	23	14	1	.	.	.	38
2.75-2.99	.	.	.	.	1	14	.	.	.	.	15
3.00-3.24	.	.	.	.	.	13	1	2	.	.	16
3.25-3.49	.	.	.	.	.	1	1	.	.	.	2
3.50+	.	.	.	.	.	7	2	.	.	.	9
TOTAL	211	1346	1158	733	426	149	20	2	0	0	

MEAN HS(M) = 0.9 LARGEST HS(M)= 3.7 MEAN TP(SEC)= 4.1 NO. OF CASES= 3804.

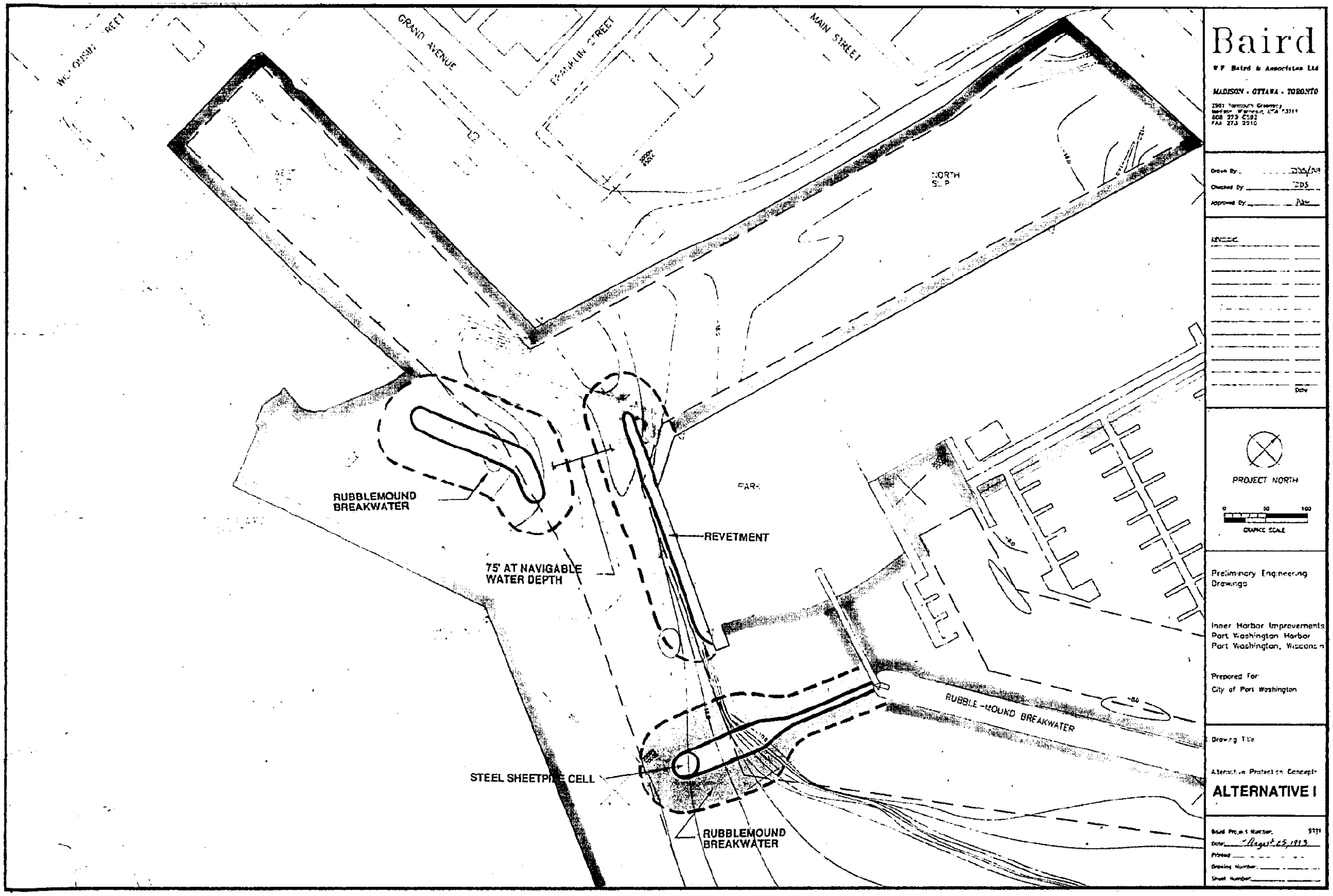
STATION M11 43.27N 87.68W FOR ALL DIRECTIONS
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD FOR ALL DIRECTIONS

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	
0.00-0.24	644	375	41	22	3	.	.	.	.	.	1085
0.25-0.49	207	1561	210	147	37	1	.	.	.	.	2163
0.50-0.74	.	1837	845	188	95	10	.	.	.	.	2975
0.75-0.99	.	169	775	284	62	22	.	.	.	.	1312
1.00-1.24	.	.	532	365	91	26	3	.	.	.	1017
1.25-1.49	.	.	162	198	114	9	2	.	.	.	485
1.50-1.74	.	.	30	211	142	12	3	.	.	.	398
1.75-1.99	.	.	.	28	107	15	3	.	.	.	153
2.00-2.24	.	.	.	9	120	26	3	.	.	.	158
2.25-2.49	.	.	.	.	44	22	2	.	.	.	68
2.50-2.74	.	.	.	.	15	49	1	.	.	.	65
2.75-2.99	.	.	.	.	.	26	2	.	.	.	28
3.00-3.24	.	.	.	.	.	25	2	.	.	.	27
3.25-3.49	.	.	.	.	.	6	5	.	.	.	11
3.50+	.	.	.	.	.	2	18	1	.	.	21
TOTAL	851	3942	2595	1452	830	251	44	1	0	0	

MEAN HS(M)= 0.8 LARGEST HS(M)= 6.1 MEAN TP(SEC)= 3.8 TOTAL CASES= 93504.



Appendix B - New Alternatives



WISCONSIN STREET
GRAND AVENUE
FRANKLIN STREET
MAIN STREET
NORTH SLIP
PARK
RUBBLEMOUND BREAKWATER
75' AT NAVIGABLE WATER DEPTH
REVETMENT
RUBBLE-MOUND BREAKWATER
STEEL SHEETPILE CELL
RUBBLEMOUND BREAKWATER
Baird
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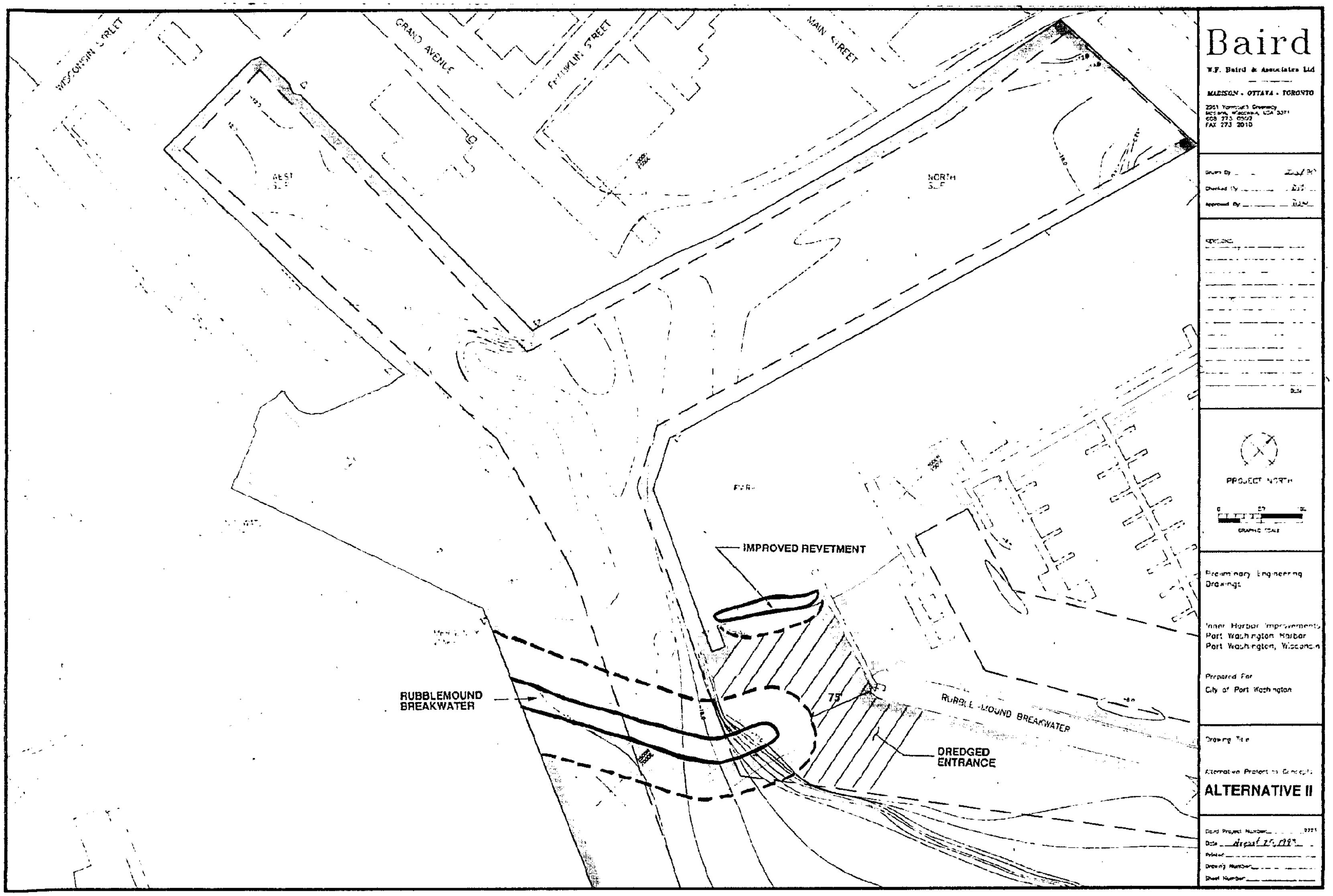
PROJECT NORTH
GRAPHIC SCALE
Preliminary Engineering Drawings
Inner Harbor Improvements
Port Washington Harbor
Port Washington, Wisconsin
Prepared For
City of Port Washington
Drawing Title
Alternative Protection Concepts
ALTERNATIVE I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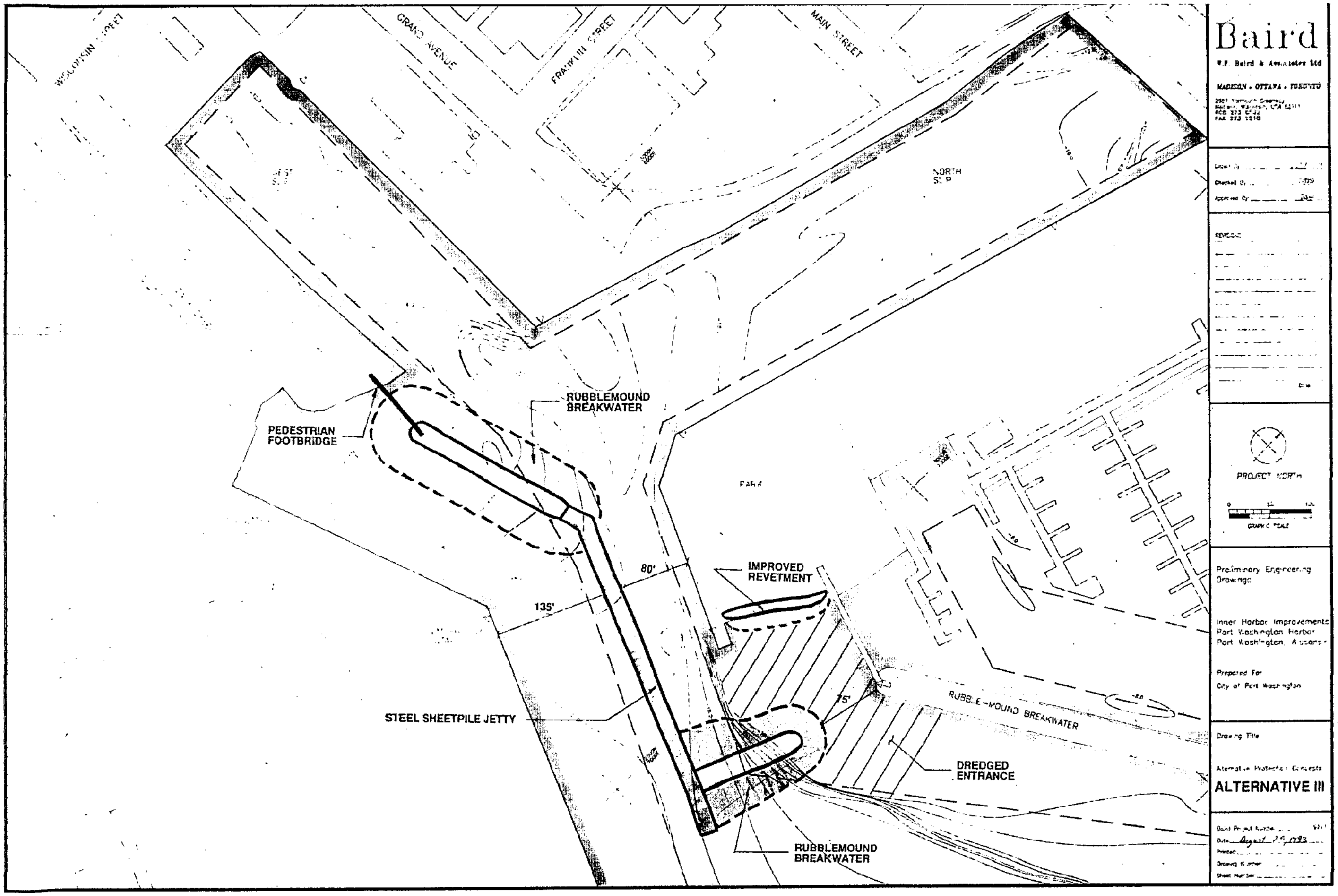
PROJECT NORTH
GRAPHIC SCALE
Preliminary Engineering Drawings
Inner Harbor Improvements
Port Washington Harbor
Port Washington, Wisconsin
Prepared For
City of Port Washington
Drawing Title
Alternative Protection Concepts
ALTERNATIVE II
WISCONSIN STREET
GRAND AVENUE
FRANKLIN STREET
MAIN STREET
NORTH SLIP
WEST SLIP
IMPROVED REVETMENT
RUBBLEMOUND BREAKWATER
RUBBLE-MOUND BREAKWATER
DREDGED ENTRANCE
75'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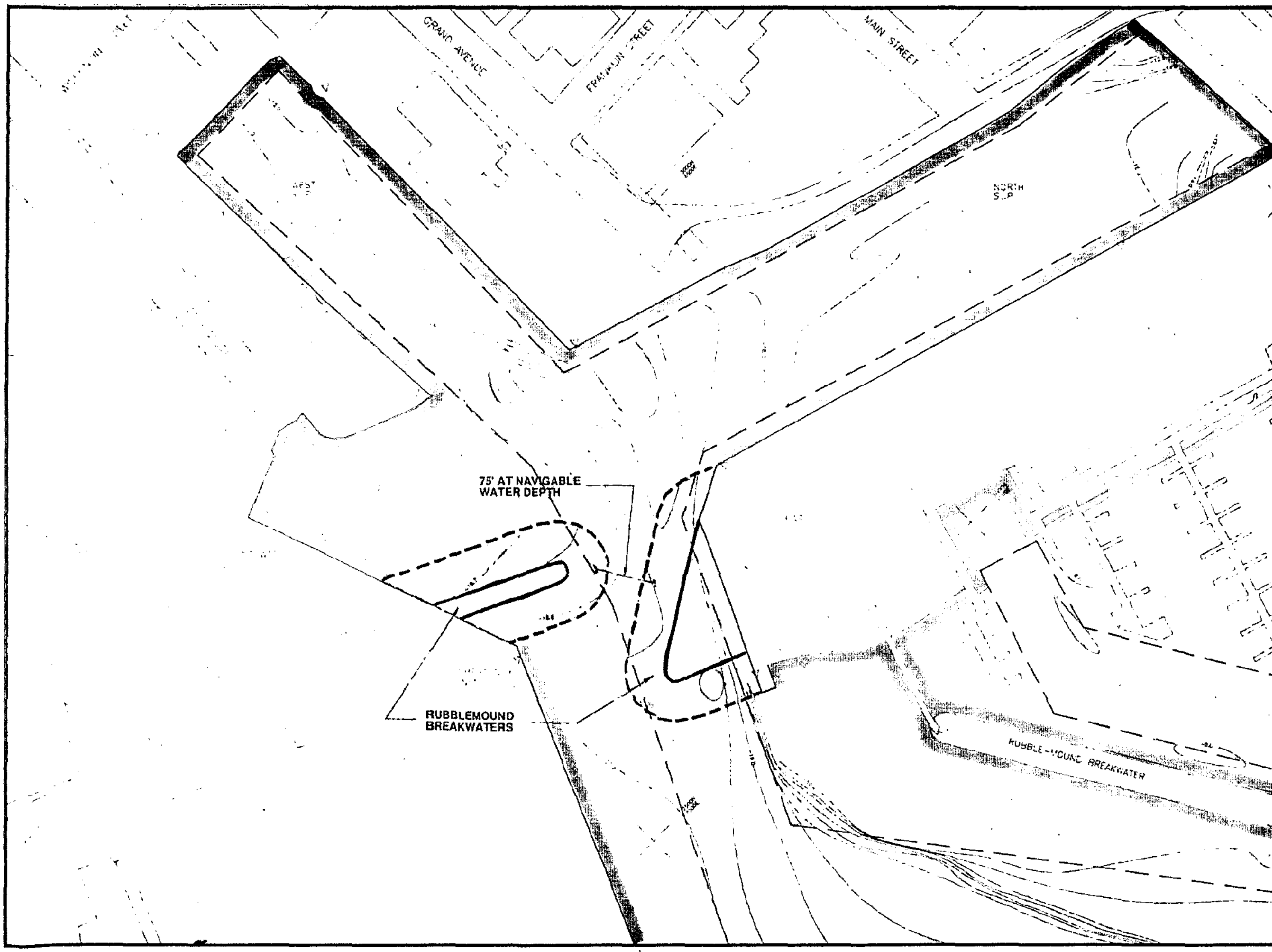
Preliminary Engineering Drawings
Inner Harbor Improvements
Port Washington Harbor
Port Washington, Wisconsin
Prepared For
City of Port Washington
Drawing Title
Alternative Protection Concepts
ALTERNATIVE III
WISCONSIN STREET
GRAND AVENUE
FRANKLIN STREET
MAIN STREET
NORTH SLIP
PARK
PEDESTRIAN FOOTBRIDGE
RUBBLEMOUND BREAKWATER
80'
135'
IMPROVED REVETMENT
75'
RUBBLE-MOUND BREAKWATER
STEEL SHEETPILE JETTY
DREDGED ENTRANCE
RUBBLEMOUND BREAKWATER



Baird

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Drawn By
Checked By
Approved By

Preliminary Engineering Drawings

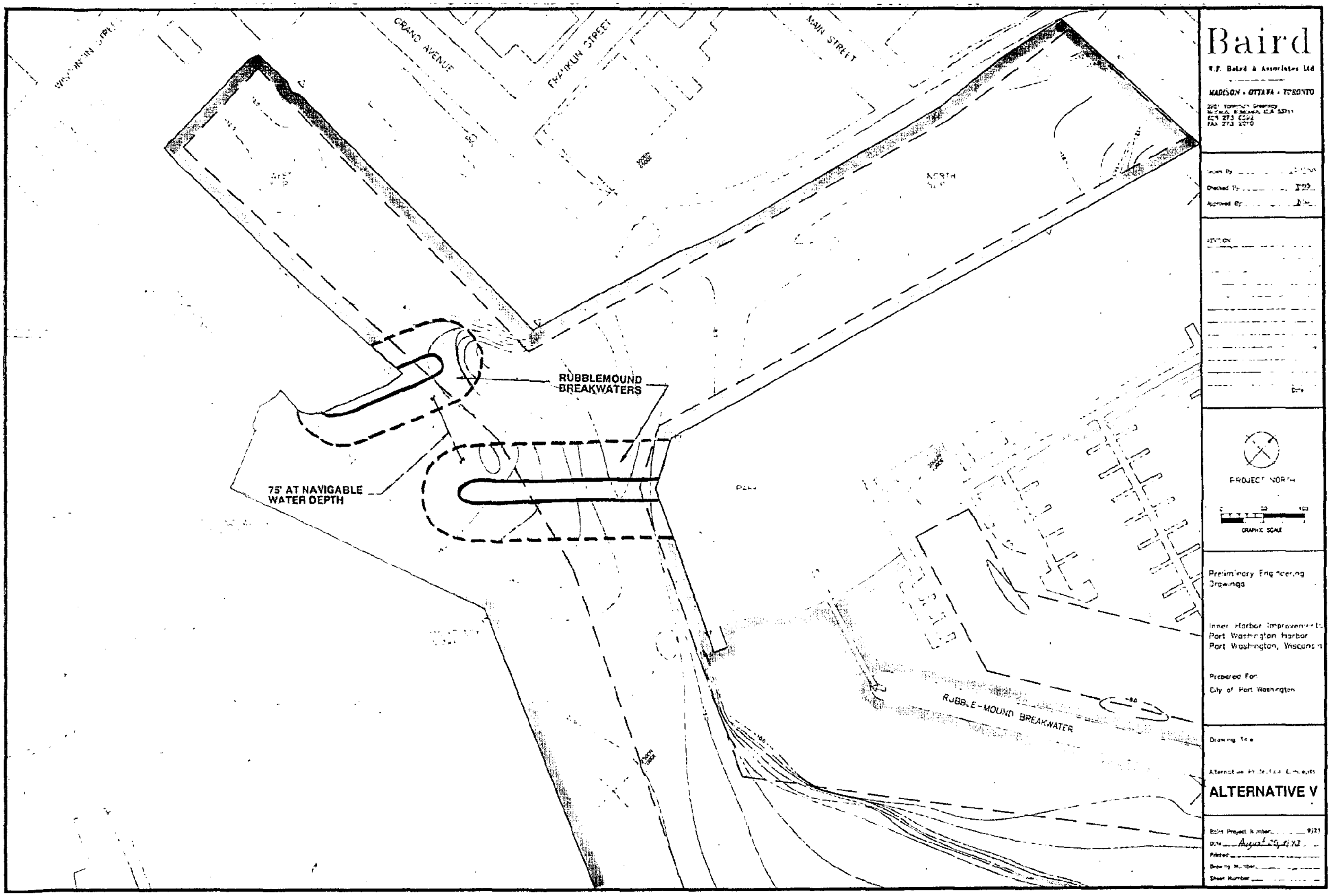
Inner Harbor Improvements

Prepared For:

Drawing Title

ALTERNATIVE IV

Baird Project Number
Date
Printed
Drawing Number
Sheet Number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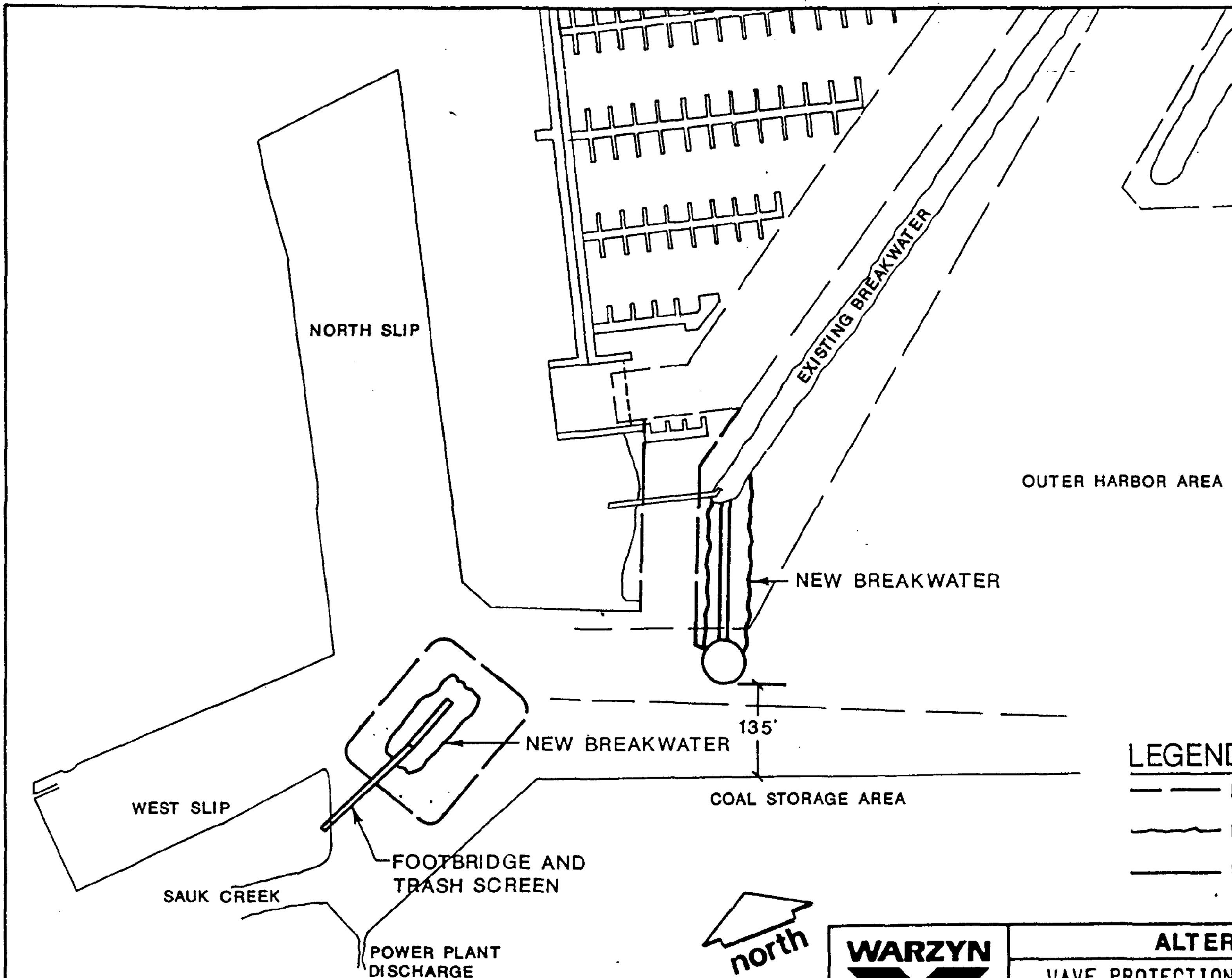
Preliminary Engineering Drawings
Inner Harbor Improvements
Port Washington Harbor
Port Washington, Wisconsin
Prepared For
City of Port Washington
Drawing Title
ALTERNATIVE V
PROJECT NORTH
GRAPHIC SCALE
RUBBLEMOUND BREAKWATERS
75' AT NAVIGABLE WATER DEPTH
RUBBLE-MOUND BREAKWATER
GRAND AVENUE
FRANKLIN STREET
MAIN STREET
NORTH
Baird Project Number
Date
Plotted
Drawing Number
Sheet Number

Appendix C -
Past Alternatives



LEGEND

- PROJECT DREDGING DEPTH LINE
- BREAKWATER WATER LINE
- BREAKWATER CREST LINE

(ORIGINAL SEA GRANT OPTION B)

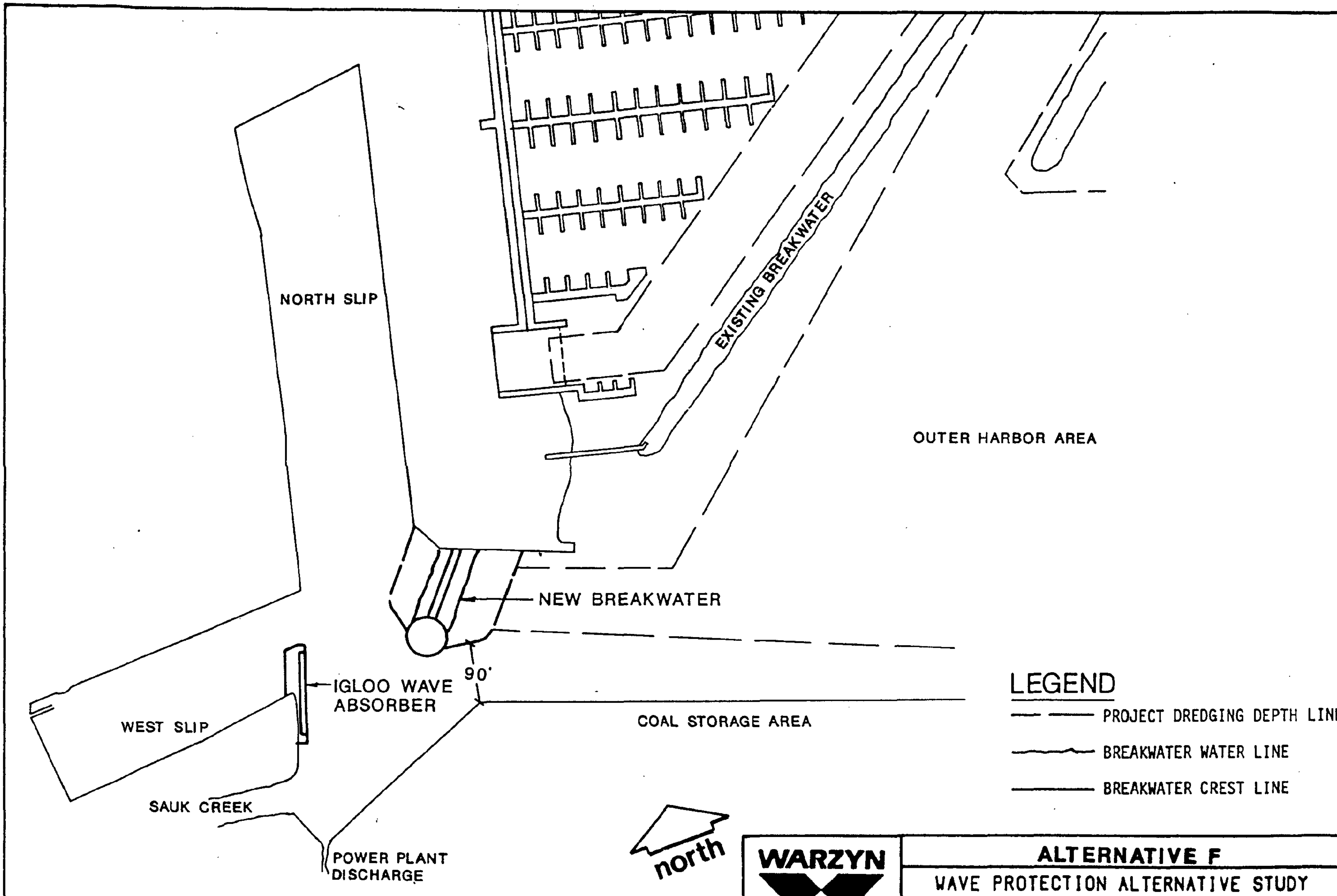
SCALE 1" = 200'

WARZYN

ALTERNATIVE B

WAVE PROTECTION ALTERNATIVE STUDY
PORT WASHINGTON INNER HARBOR
PORT WASHINGTON, WISCONSIN

DWN ALH	CHK'D GRC	APP'D [signature]	DATE 6·23·01	25193-A2



(ORIGINAL SEA GRANT OPTION F)

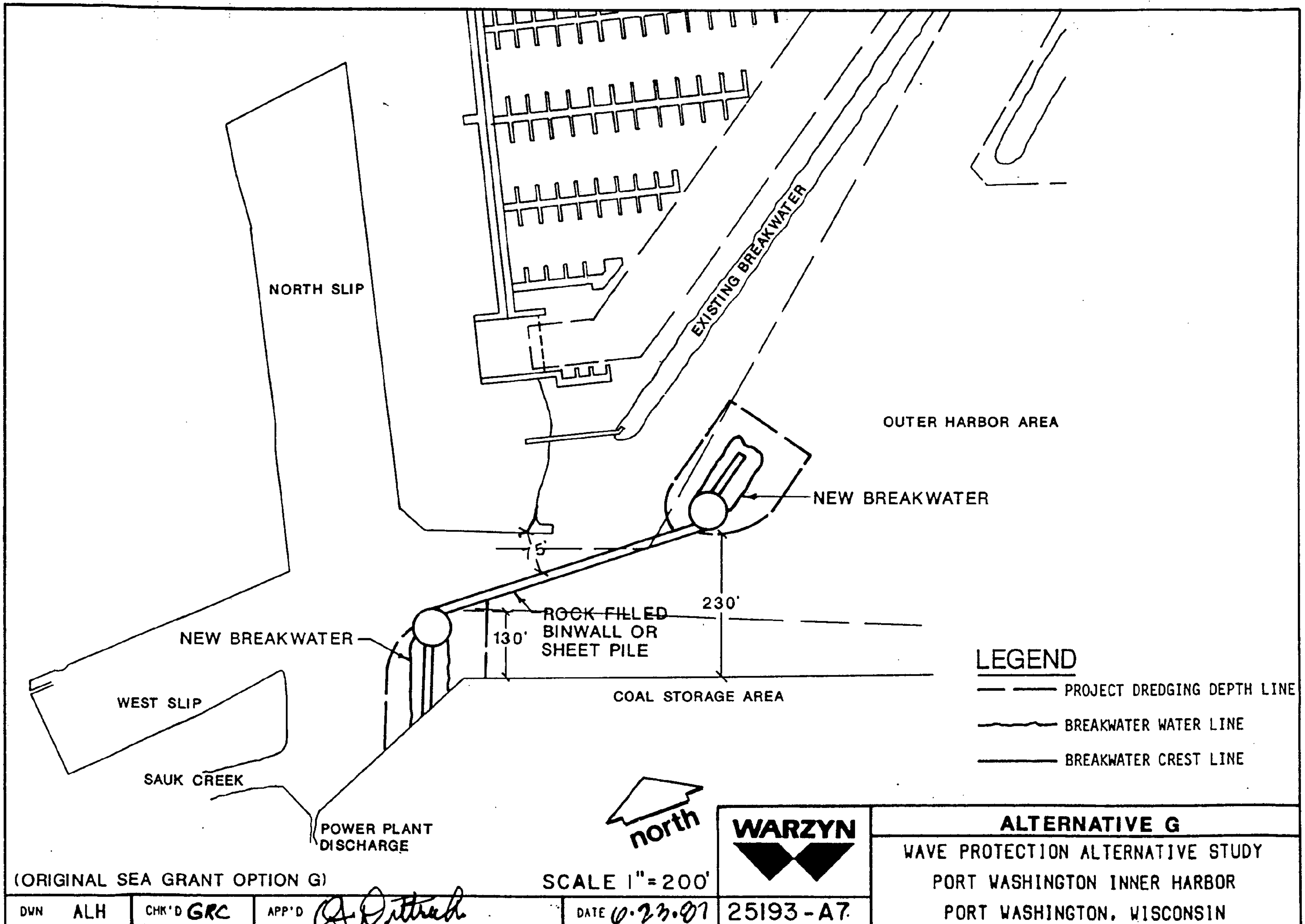
SCALE 1" = 200'

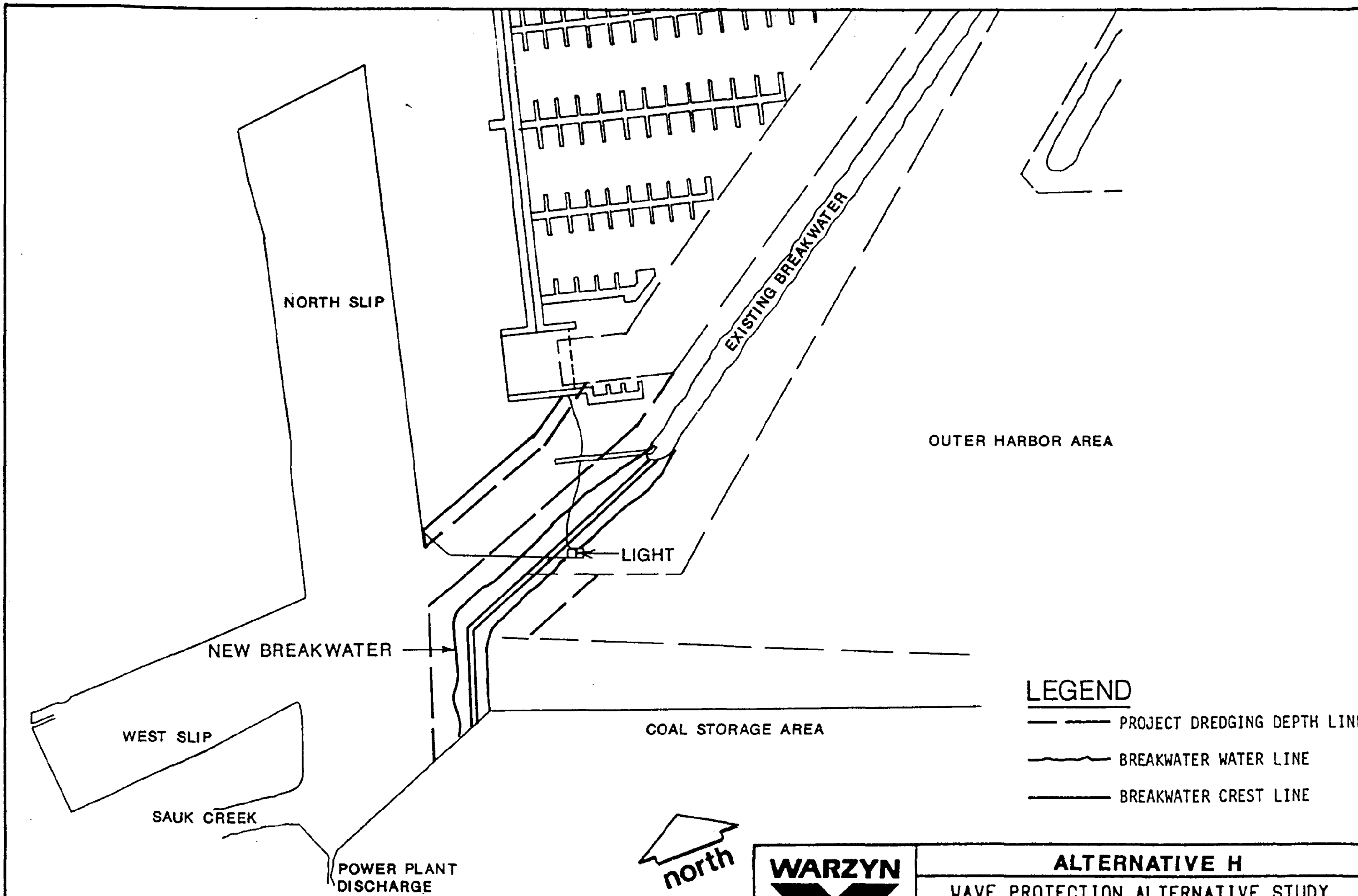
WARZYN

ALTERNATIVE F

WAVE PROTECTION ALTERNATIVE STUDY
PORT WASHINGTON INNER HARBOR
PORT WASHINGTON, WISCONSIN

DWN ALH	CHK'D GRC	APP'D [signature]	DATE 6·23·01	25193-A6

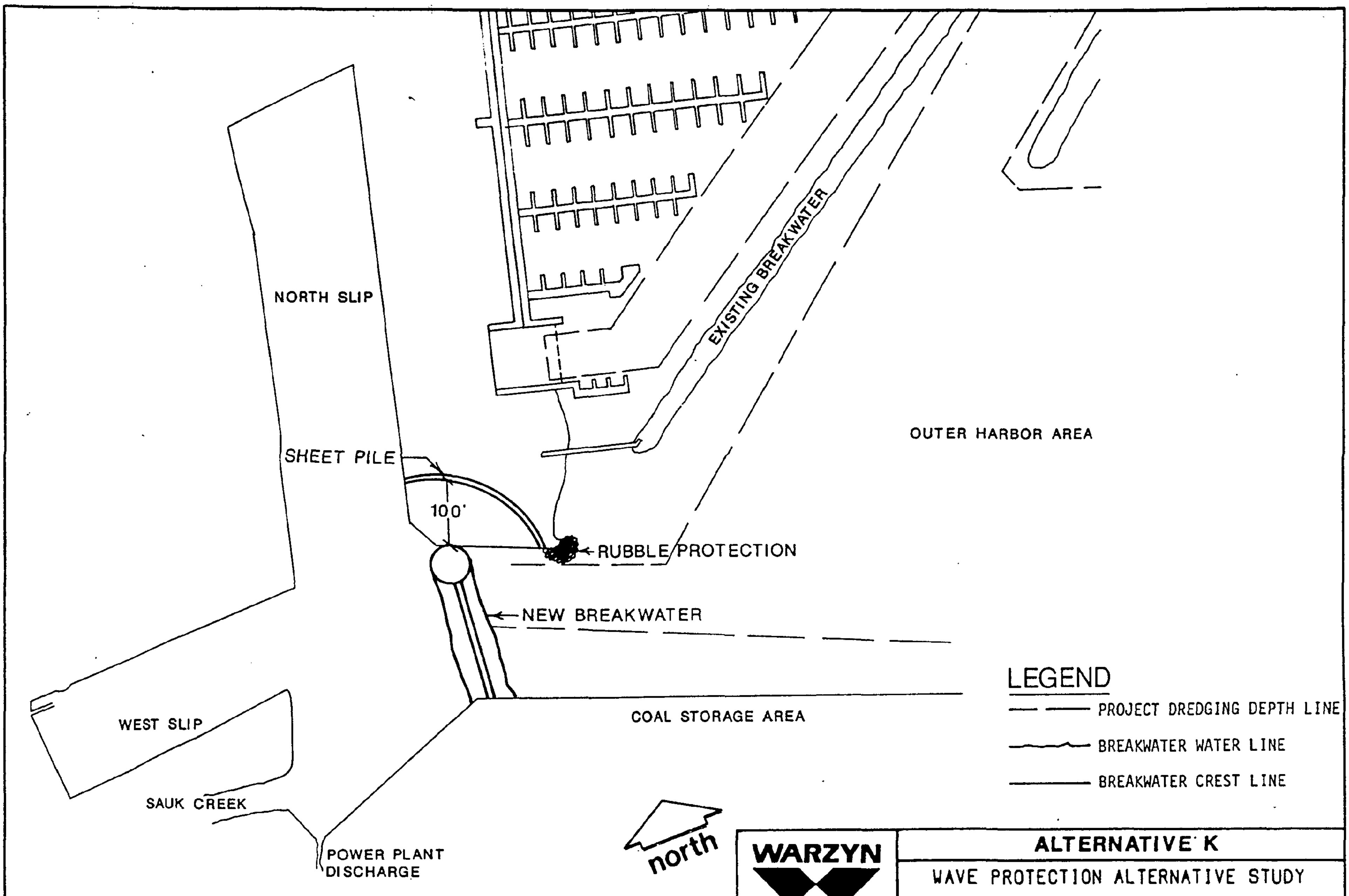

NORTH SLIP
EXISTING BREAKWATER
OUTER HARBOR AREA
NEW BREAKWATER
75'
ROCK FILLED
BINWALL OR
SHEET PILE
230'
130'
NEW BREAKWATER
WEST SLIP
COAL STORAGE AREA
LEGEND
PROJECT DREDGING DEPTH LINE
BREAKWATER WATER LINE
BREAKWATER CREST LINE
SAUK CREEK
POWER PLANT
DISCHARGE
north
(ORIGINAL SEA GRANT OPTION G)
SCALE 1"=200'
WARZYN
ALTERNATIVE G
WAVE PROTECTION ALTERNATIVE STUDY
PORT WASHINGTON INNER HARBOR
PORT WASHINGTON, WISCONSIN
DWN ALH
CHK'D GRC
APP'D
DATE 6·23·87
25193-A7



(ORIGINAL SEA GRANT EXPANSION PROPOSAL 1)

SCALE 1"=200'

DWN ALH	CHK'D GRC	APP'D [signature]	DATE 6·23·87	WARZYN 25193-A8	**ALTERNATIVE H** WAVE PROTECTION ALTERNATIVE STUDY PORT WASHINGTON INNER HARBOR PORT WASHINGTON, WISCONSIN



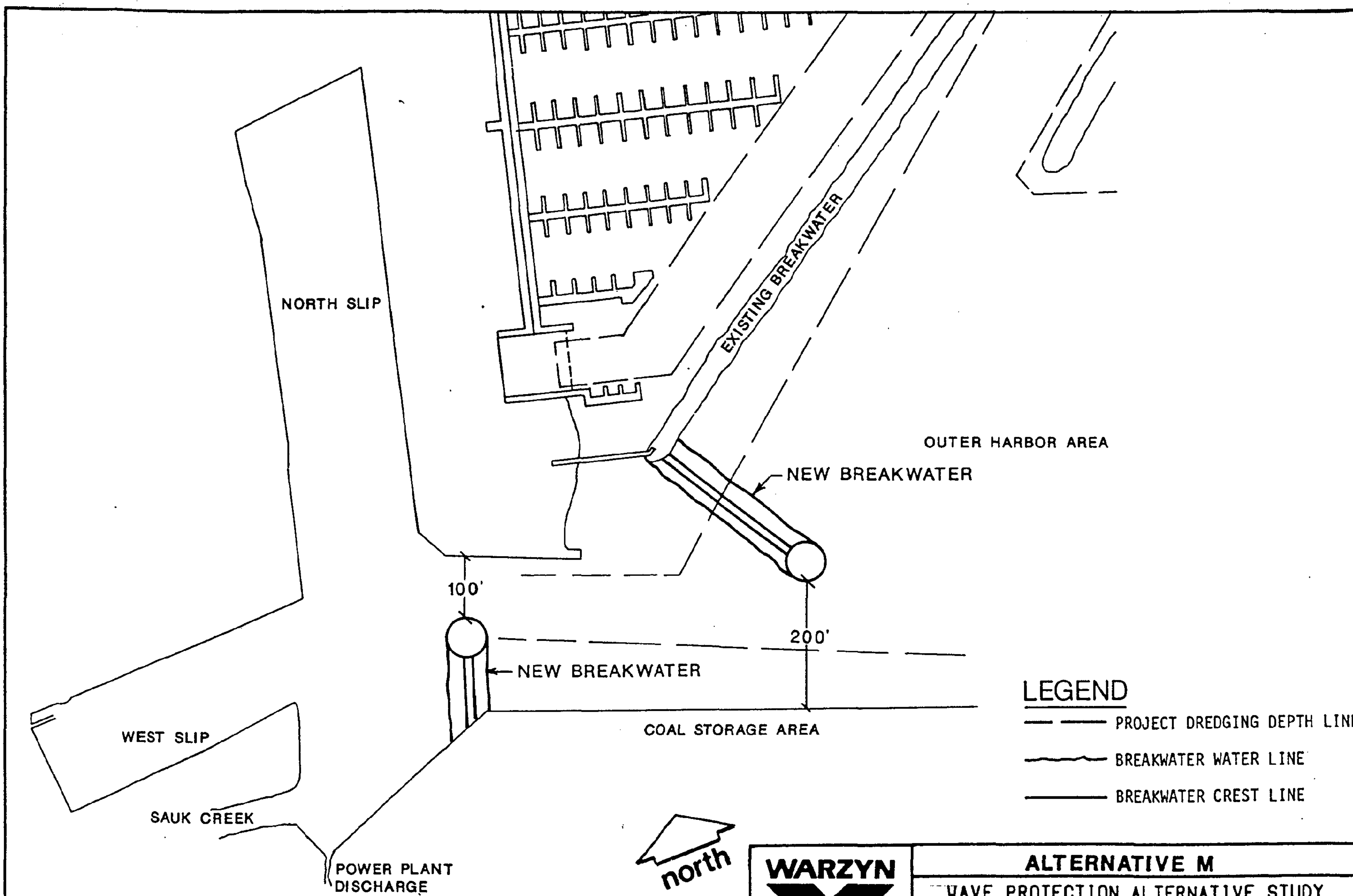
SCALE 1" = 200'

WARZYN

ALTERNATIVE K

WAVE PROTECTION ALTERNATIVE STUDY
PORT WASHINGTON INNER HARBOR
PORT WASHINGTON, WISCONSIN

DWN ALH	CHK'D GRC	APP'D [signature]	DATE 6-23-87	25193-A11



SCALE 1"=200'

WARZYN

ALTERNATIVE M

WAVE PROTECTION ALTERNATIVE STUDY
PORT WASHINGTON INNER HARBOR
PORT WASHINGTON, WISCONSIN

DWN ALH	CHK'D GRC	APP'D [signature]	DATE 6.23.87	25193 - A13

Appendix D -
Alternatives Evaluation

PORT WASHINGTON INNER HARBOR IMPROVEMENTS - ALTERNATIVES REVIEW

Alternative	Probable Construction Cost (see note)	Wave Protection	Safe Navigation	Coal Dock Operations Interference?	Entrance/ Coal Boat Conflicts?	Water Quality /De-icing Circulation?	Creek Trash in Marina and Slips?	Park and Existing Facilities Disruption?	Improved Shore Fishing Opportunities?	WEPCO Attachment Required?
Past Studies:										
B * (3)	$1,400,000	(?)	(?)	***no***	yes	***yes***	yes	***no***	***yes***	***no***
F * (2)	$2,000,000	(?)	(-)	***no***	yes	***yes***	yes	***no***	minor	***no***
G (1)	$3,100,000	***(+)***	(?)	***no***	***no***	***yes***	yes	***no***	no	yes
H (4)	$3,200,000	***(+)***	(?)	***no***	***no***	***yes***	yes	yes	no	yes
K *	$1,900,000	(?)	(?)	yes	minor	***yes***	yes	yes	no	yes
M *	$1,900,000	(?)	***(+)***	***no***	minor	***yes***	yes	***no***	minor	yes
This Project:										
I	$2,250,000	(?)	***(+)***	***no***	yes	***yes***	yes	***no***	***yes***	***no***
II	$1,500,000	***(+)***	(?)	yes	***no***	***yes***	yes	***no***	no	yes
III	$3,100,000	***(+)***	***(+)***	***no***	***no***	***yes***	***no***	***no***	***yes***	***no***
IV	$1,600,000	(?)	(?)	***no***	yes	***yes***	yes	***no***	minor	yes
V	$1,400,000	(?)	(-)	***no***	***no***	***yes***	yes	***no***	***yes***	***no***

Notes:

Bold italicized items represent a "positive" situation.

* denotes alternative recommended for hydraulic model study by Warzyn Engineering, 1987.

(#) denotes City's preference after past studies.

Costs for past studies prepared by Warzyn Engineering, 1987 have been adjusted to 1993 dollars assuming 4% inflation per year.

Costs for Alternatives I - IV include a 25% contingency.

Prepared for discussion at the 8/30/93 Harbor Commission Meeting