Final Report

Port Stanley
Lakeshore Flooding Look-Up Tables

prepared for

Kettle Creek
Conservation Authority

by

Shoreplan Engineering Limited

December, 1992

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31 December 1992

Kettle Creek Conservation Authority
R.R. # 8
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Attention: Mr. Bryan D. Hall, General Manager

Dear Sir:

re Surge and Run-up Tables for Port Stanley Beach
Our File: 92 - 028

Please find attached five copies of our final report and one reproducible original. Three copies and one original of a site plan at 1:2,000 scale showing the various flood zones is also included as outlined in the Terms of Reference.

We trust you will find this to be a useful tool in predicting floods in the beach area of Port Stanley.

We would like to thank you and your staff for your co-operation during the preparation of this report and your constructive comments on our draft report. Should you have any further questions regarding this report, please do not hesitate to contact the undersigned.

Yours truly

Shoreplan Engineering Limited

M. Sturm, P. Eng.

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1. INTRODUCTION

Shoreplan Engineering Limited was retained by Kettle Creek Conservation Authority to prepare "Lakeshore Flooding Look-Up Tables" for the beach at Port Stanley. The tables and accompanying drawing will be used by the Conservation Authority to help predict the location of potential flood problems during severe storms and at high water levels.

Current water level data from either the Port Stanley gauge or as provided by Environment Canada, and forecast wind speeds from the Ontario Weather Centre of Environment Canada will be the only input needed. Expected instantaneous water levels and flood elevations will be provided by the look-up tables. By incorporating the study mapping into their Geographical Information System (GIS), the Conservation Authority will be able to generate a list of the individual properties expected to be flooded. This will in turn allow the Conservation Authority the opportunity to more efficiently provide warnings of potential flood events.

It must be noted that the purpose of this study is to help improve the Conservation Authority's flood warning capabilities. The results of this study should not used for any planning related purposes. The existing planning regulations and procedures must continue to be used. They are not to be considered to be superseded by this work.

Throughout this report a number of technical terms are used to describe the work done. The Kettle Creek Conservation Authority Shoreline Management Plan final report contains a glossary which explains these terms (Philpott Associates, 1989)

1.1 Field Review of FDRP Mapping

A field survey was carried out to provide a brief check of the accuracy of the spot elevations shown on the FDRP mapping supplied by the Conservation Authority. Overall it was found that the elevations shown were within expected accuracy levels except for the southern end of William Street. The survey found the elevations to be in order of 0.8 m higher than shown on the mapping. A subsequent check with the Conservation Authority indicated that some fill material was placed in that area by the Village of Port Stanley. More detailed surveys should be undertaken to identify the extent of filling carried out and the FDRP mapping should be updated.

2. OVERVIEW OF METHODOLOGY

The look-up tables were prepared by combining the results of separate wind setup, offshore wave generation, nearshore wave refraction and wave runup analyses. The wind setup and offshore wave generation analyses considered a range of potential wind speeds and directions, rather than recorded wind data. This approach was taken because forecast winds rather than recorded winds will be the input for the look-up tables.

The offshore waves were transferred inshore, using the results of an existing wave refraction analysis to provide nearshore wave data. These nearshore data were in turn used to calculate wave runup levels. The predicted wind setup and wave runup levels were added to provide flood level estimates.

3. FORECAST WIND DATA

The wind setup (or storm surge) modelling and the offshore wave generation calculations were based on hypothetical wind conditions. This was required because forecast rather than measured wind data will used to apply the look-up tables. Rather than supplying a wind history or profile, the forecast will provide one wind speed range and direction sector, and possibly some duration information.

The forecasts that the Conservation Authority will be using are the FPCN20 marine forecasts issued by the Ontario Weather Centre of Environment Canada. Figure 3.1 shows a typical example of an FPCN20 forecast printout. The forecasts are issued every 6 hours and apply for a 24 hour period. Winds are given in a 5 knot range with a 45 degree directional resolution. For example, the Lake Erie wind in the forecast shown in Figure 3.1 is for 15 to 20 knots from the southeast (112½°–157½°), increasing to 20 to 25 knots that day.

Nearshore marine forecasts (FPCN21) are also issued by the Ontario Weather Centre but it is recommended that the marine forecasts be used with the look-up tables rather than the nearshore forecasts. The marine forecasts more accurately represent the overwater conditions and the nearshore forecasts are not issued for the entire year.

Based on the review of recorded wind data from land based stations at Windsor and Simcoe and from discussions with staff at the Ontario Weather Centre it was concluded that forecast wind speeds up to 65 to 70 knots are the highest that will likely be forecast and hence the highest that should be considered for the surge and hindcast analyses. The forecast winds are the highest winds that the forecaster expects to occur, excluding gusts. They can be considered to be similar to the wind speeds that would be recorded by Environment Canada if an anemometer were located over the lake.

For winds over Lake Erie it was suggested that winds speeds of 30 to 40 knots can be sustained for 12 hours frequently, and to be sustained for a couple of days is not really unusual. Winds from 40 to 50 knots can be sustained for 12 hours or so. Winds from 50 to 60 knots can be assumed to be sustained for 6 hours and 70 knots for 3 hours. Of course not all storms will have winds of these durations, but the durations are both possible and realistic.

4. WIND SETUP MODELLING

The wind setup, or storm surge analyses were carried out with the one layer free-surface circulation model developed by the Ontario Weather Centre of Environment Canada. This model computes wind setup levels associated with stress on the lake surface. The model does not consider the effects of barometric pressure difference over the surface of Lake Erie. While pressure differences are significant to open ocean surge events they do not contribute significantly to surges on the Great Lakes.

The wind setup level is related to wind speed, the drag coefficient for air on water, the overwater length for which the wind is blowing and the water depth over that length. The Environment Canada model requires input wind speed and direction from the model user, but supplies all other data itself. The model produces output data in 2 formats but for this project only a time series of water levels for a given location (Port Stanley) was used.

A more comprehensive description of the surge model and its use is provided in Sutherland and Murphy (1987). That report discusses the use of the model in general and on Lake Erie in particular. It also contains verification plots showing that the model has been accurately calibrated for use on Lake Erie. Further verification plots were not produced for this study.

4.1 Sensitivity Analyses

A series of model runs were carried out to evaluate the sensitivity of the storm surge model's results to:

- location along shoreline (series A),
- rate of change of wind speed and peak wind speed duration (series B),
- different constant wind directions (series C),
- model startup conditions (series D), and
- changing wind directions (series E).

The location of the Port Stanley beach was scaled from a hydrographic chart as longitude 81°12'30" W and latitude 42°39'35" N. The model was run with arbitrary wind data and results were examined for 6 different latitudes between 42°39'0" and 42°41'30". Latitudes north of 42°41'37" were outside the model boundary.

These different latitudes were considered to see if the model results changed in a shoreline normal direction, meaning that the results were depth sensitive. The results did not change, indicating that the model outputs constant results within a grid square.

Varying the longitude showed that the model results also did not vary within the grid square in the alongshore direction. A grid boundary was found to exist between 81°12'01" and 81°12'02", but this point is located to the east of beach being considered in this study and does not effect the modelling results.

The model's sensitivity to rate of change of wind speed and peak wind speed duration was examined by modelling 5 different arbitrary wind speed profiles. These profile are shown in Figure 4.1. Profile B1 goes from 0 to 48 knots in 12 hours then stops. This gives a wind speed increase of 4 knots per model step (1 hour). Profile B2 also goes from 0 to 48 knots in 4 knot increments but each increment has a duration of 3 model steps, or 3 hours. Profile B3 goes from 0 to 48 knots in 12 hours, like profile B1, but then continues constant at 48 knots rather than stopping. Profile B4 increases from 0 to 48 knots in 24 hours and profile B5 increases from 0 to 48 knots in 48 hours. Each wind speed profile was given a constant wind direction of south.

Wind speed profiles were considered to avoid starting the surge model with the forecast wind speed. This would produce unreliable results at high wind speeds and in any case would not be realistic.

The results of these sensitivity tests are shown in Figure 4.2. It can be seen that the surge levels increase smoothly when the wind speed is increased at a constant rate. When the wind speed is held constant for any duration seiching occurs. The seiching eventually dampens out and the oscillations converge on a constant value. That constant value is approximately equal to the height of the first seiche peak. Examination of profile 2 shows that seiching occurs when the wind speed is increased in steps rather than smoothly. Comparison of the results from wind speed profiles 1 and 3 show that the steady surge level finally reached is higher than the surge that occurs when the wind speed first reaches its peak value. Comparison of the profile 3, 4 and 5 results shows that the faster the wind speeds increase the higher the predicted seiche is.

On the basis of these analyses it was concluded that a steady wind speed increase of 2 knots per hour (profile B4) would be used to model the forecast wind speeds. Different storms will in fact have different wind speed gradients, but such information is not available as part of the wind forecast. The B4 wind profile yields an initial surge value close to the steady state converged level without producing an unrealistic seiche as the B3 profile does. As the ultimate surge results are similar, there is no reason to use a slow wind speed increase rate as in the B5 profile.

The effect of different wind directions on the model results was investigated in the C series of analyses. The results of these test are presented in Figure 4.3. All wind directions were kept constant for the duration of the model run. It can be seen from Figure 4.3 that:

- the highest surges occur when the winds are normal to the shoreline (from 180 degrees),
- the surge results are similar in magnitude for winds from equal directions east or west of the shoreline normal,
- the greater the angle is between the wind direction and the shoreline normal, the lower the surge level is.

The effects of changing wind directions may be seen in Figure 4.4. In these analyses the wind directions were varied about 180 degrees, for a given wind speed profile. This was done to see what effect moving storm fronts would have on the predicted surge levels. The B4 wind speed profile was used here. Profile E1 has the winds constant from 180 degrees. Profile E2 uses a wind direction of 150 degrees as the wind speed builds from 0 to 18 knots (9 hours), swings from 150 degrees to 180 degrees at 2 degrees per hour (ie. hours 10 to 24) then stays constant at 180 degrees. Profile E3 varies from 150 to 210 degrees at a rate of 2 degrees per hour.

Comparison of the E1 and E2 results and the E3 and 150 degree series C results (Figure 4.3) shows that varying wind directions prior to the peak of the wind speed profile does not significantly effect the predicted surge levels. This in turn means that using constant wind directions in this study, as is necessary with forecast winds, will not introduce significant errors if the forecast winds accurately represent the actual wind conditions at the peak of the storm.

Finally, the effects of different model start-up procedures were examined. Sutherland and Murphy (1987) suggest that historic winds need to be modelled in order to "capture the state of the lake up to forecast time". This is necessary to account for any seiching action existing at the start of the model run. In order to see if this would effect the model results for the type of application used in this study three different start-up conditions were considered. Figure 4.5 shows these results.

Profile D1 models the B4 wind speed profile for south winds starting at hour 25. Profile D2 considers a 10 knot south wind for the 30 hour period prior to the 10 knot wind speed in profile D1. Profile D3 is likewise with a 20 knot wind. From Figure 4.5 it can be seen that the peak surge levels predicted are not dependant upon the model start-up when the winds are gradually built up to the peak wind speed, as done here.

To summarise the storm surge modelling sensitivity analyses, it was found that:

- predicted surge levels are constant within a model grid square and therefore not dependant upon specific location on the Port Stanley Beach,
- the highest predicted surge level occurs after the peak wind speed is first reached, if it has a duration of more than 1 hour, and is related to seiching,
- faster wind speed increases produces higher seiche levels but the ultimate surge level will stabilize at a constant value if the wind speed is kept constant for a sufficient duration,
- the constant surge level is similar to the first seiche peak level,
- wind speeds increasing at a rate of 2 knots per hour can be used to represent the forecast winds,
- storm surge levels are dependant upon wind direction but are not sensitive to the differences between constant and changing wind directions, and
- wind conditions prior to the start of the modelled winds do not effect the model results for the way the model will be used in this study.

4.2 Wind Setup Results

As noted during the sensitivity analyses, the setup levels predicted by the storm surge model are dependant upon the wind direction. The forecast wind directions apply over 45 degree sectors, but, as can be seen from Figure 4.3 a 45 degree difference in wind direction will have a significant effect on the predicted surge results. Because the look-up tables are going to be used for flood warnings it was concluded that the "worst-case" or conservative setup levels should be considered. The wind directions used for the surge modelling were therefore based on the directions that gave the highest surge levels for the direction sectors considered. The directions used were:

East	105 degrees
Southeast	150 degrees
South	180 degrees
Southwest	210 degrees

Winds from west through northeast cause setdown rather than setup at Port Stanley and were therefore not considered.

In order to keep the results conservative the upper wind speed of the forecast wind speed range was used for calculating the wind setup levels. Table 1 shows the results of the wind setup analysis. The setup levels are in centimetres.

Table 4.1 Wind Setup Levels

Speed (knots)	Wind Direction			
	East	Southeast	South	Southwest
10	2	3	3	2
15	4	6	7	4
20	7	10	11	7
25	10	15	17	10
30	13	20	23	15
35	16	27	31	20
40	19	34	41	27
45	21	43	52	35
50	23	52	65	45
55	24	63	79	56
60	26	74	94	67
65	27	86	110	80
70	28	99	128	93

wind setup levels are in centimetres above static lake level

5. WAVE CONDITIONS

The wave runup calculations used to define the flood areas require nearshore wave height and period as input. The nearshore wave conditions are calculated by first estimating offshore wave conditions and transferring them inshore considering the effects of refraction and wave energy loss.

Offshore wave conditions were calculated using the SMB hindcast equations presented in the Shore Protection Manual (CERC, 1984). These are parametric equations that yield estimates of significant wave height and significant wave period given an overwater wind speed, wind duration, average water depth and overwater fetch length. The winds are assumed to be representative of those that would be measured at a height of 10 metres above the water surface.

The hindcast wave heights are proportional to the fetch length, which is the overwater distance (in the direction of the wind) over which the winds generate waves. Because actual wind directions vary about the recorded or forecast directions average fetch lengths are used for wave hindcasting. For this study the average fetch lengths calculated during the preparation of the Kettle Creek Conservation Authority Shoreline Management Plan were utilized (Philpott Associates, 1989). The longest fetch length in each direction sector was selected. Table 5.1 shows the fetch lengths and water depths used for the offshore hindcast.

Table 5.1 Hindcast Fetch Lengths and Water Depths

Direction	Fetch Length	Depth
East	121 Km	15 m
Southeast	117 Km	20 m
South	128 Km	22 m
Southwest	150 Km	20 m

With a sufficient wind duration the waves become fetch limited, meaning that they have reached their maximum possible height and period values for the given wind speed and overwater fetch length. If the wind blows for a shorter duration the resulting wave heights and periods will have lower values for the same overwater fetch length.

The wind duration required to produce the fetch limited wave conditions for each direction sector were calculated and compared to the potential wind durations discussed in Section 3 of the report. It all cases it was found that the fetch limited wave conditions could be achieved. Reduced wave conditions due to duration limited winds were therefore not considered. Figures 5.1 and 5.2 show the hindcast wave heights and periods, respectively.

Nearshore wave conditions were calculated by applying wave height transfer coefficients to the hindcast wave heights. Wave periods are not effected by wave refraction and energy loss. The transfer coefficients were derived through a spectral wave transformation analysis carried out during preparation of the Shoreline Management Plan. A detailed description of the refraction analysis is provided in Philpott Associates (1989). Figure 5.3 shows the nearshore wave heights.

As can be seen from Figures 5.2 and 5.3 the nearshore wave heights and periods for waves from the southeast, south and southwest are very similar. This is due to the similarity in maximum fetch lengths and water depths within these sectors. Because these values are similar average values of nearshore wave height and wave period were selected to describe waves coming from the southeast through southwest. This in turn halves the number of entries that would have been required for the look–up tables.

6. Water Levels

For the purpose of this study the wind setup levels and wave conditions can be assumed to be independent of changes in the static lake water levels. The runup elevations, however, are dependant upon water levels and an initial water level must be specified as part of the runup calculations.

MNR (1989) calculated the 100 year instantaneous water level for Port Stanley to be 175.5 m GSC and the 100 year static water level for Lake Erie to be 175.0 m GSC. Considering the magnitude of potential surges at Port Stanley for the range of wind speeds considered in this study it was concluded that instantaneous water levels up to 176.0 m GSC should be considered for the runup analysis. This is considerably higher than the MNR 100 year instantaneous level and would only occur with a severe storm during extreme static lake levels. The MNR (1989) study used combined probability theories to derive their instantaneous water level return periods. In this study the wind setup levels are simply being added to the static water level and will therefore produce instantaneous water levels higher than those predicted for the 100 year return period event.

The 100 year water level has to be considered because even frequently occurring storms at high static lake levels will cause flooding. Runup calculations for extreme storms at extreme water levels were therefore included for completeness rather than because there is a reasonable statistical probability of their occurrence.

7. Wave Runup and Lakeshore Flooding

Wave runup levels were computed for each nearshore wave condition and for a number of initial water levels. A range of initial water levels was selected to consider all relevant combinations of static lake levels and wind setup levels. Initial water levels below 174.50 m GSC were not considered because uprushing waves at those levels would not cause flooding along the shoreline.

The recent MNR reports on acceptable practices for wave runup calculations recommended that an approximate upper limit of the "acceptable" runup procedures be used for the management of flood hazard shorelines on the Great Lakes (Atria, 1991a, 1991b). The upper limit was calculated to produce an outer boundary to the scatter of the runup results for a number of shoreline types and slopes. This was needed because of the wide range of results produced by the different wave runup procedures considered in those studies. That in turn was a direct result of the inexact nature of wave runup calculations.

The Hunt (1959) runup procedure is accepted as producing reasonable results on sand beaches. To ensure that runup levels were not underestimated for this study it was decided that we would average the results from the Hunt procedure with the upper limit boundary proposed by Atria. It was felt that the upper limit boundary itself was more conservative than warranted at this site because it was developed to provide an outer limit boundary for runup on structures as well as on beaches. However, because the actual runup levels are not well predicted by any existing procedures it was concluded that using the Hunt (1959) procedure alone could lead to under prediction of the runup levels. The two methods were therefore averaged to produce a slightly more conservative estimate of the runup levels.

Profiles were defined at 50 meter intervals, giving a total of 37 profiles along the beach. Offsets from an arbitrary baseline and above water elevations were taken from the 1:2,000 scale FDRP mapping provided by the Conservation Authority. During preparation of the Shoreline Management Plan cross–shore sediment transport modelling was used to evaluate beach profile shape changes in response to wave conditions (Philpott Associates, 1989). It was found that beach slope was in the order of 1:10 at the water level and slightly flatter below water. An average profile extending from 1 metre above the water level to the wave breaking depth was therefor superimposed on each of the profiles scaled off the FDRP mapping.

Runup levels were computed using an average slope procedure to match predicted runup with the actual beach profile. This is necessary as the runup equations use one value of slope. The average slope procedure computes the runup elevation for an initial slope, computes the average slope from the wave breaking point to the point on the profile equal in elevation to the calculated runup elevation, recalculates a new runup elevation using that average slope, recalculates a new slope using the new runup elevation, etc. until the predicted slope and runup elevation converge to a specific point on the profile.

Because each profile has a fixed shape above the water line, the average slopes computed, and hence the runup elevations predicted, are dependant upon the instantaneous water level. A maximum instantaneous water level of 176.0 m GSC was considered, as discussed in Section 6. A 0.25 m increment of water levels was selected, giving addition instantaneous water levels of 175.75 m, 175.50 m, 175.25 m, etc. A minimum instantaneous water level of 174.50 m GSC was considered, as wave runup from lower water levels does not cause flooding.

Separate runup calculations were performed for each of the 26 nearshore wave conditions at each of the 37 beach profiles for the 7 initial water levels considered. This resulted in more than 6700 runup elevations, far more than could be easily considered within look–up tables. The beach was therefore divided into 4 alongshore sections which display similar runup characteristics. This allows the runup results to be displayed in a total of only 8 look-up tables. The runup results are presented in Section 8 of the report, which describes the use of the runup tables. The locations of the 4 alongshore sections are shown on the accompanying drawing and on Figure 7.1.

The runup elevations within each alongshore section were classified by flood zones. The characteristics of these zones were used in part to identify the boundaries of the 4 alongshore sections. Runup elevations for any given instantaneous water level and forecast wind condition are therefore presented as flood zones. Each zone has an average flood depth associated with it but actual wave runup levels within the shoreline sections can vary somewhat from the average flood depth. Table 7.1 shows the average flood elevations associated with each flood zone.

Table 7.1 Average Flood Zone Elevations

Shoreline Flood Zone Number	Average Flood Elevation (m GSC)
A1	176.25
A2	176.5
A3	176.75
A4	177.0
A5	177.25
A6	177.5
B1	176.25
B2	176.5
B3	176.75
C1	176.0
C2	176.2
C3	176.4
D1	176.0
D2	176.1
D3	176.2
D4	176.3

It must be noted that both wave runup and the resulting flooding are continuous in both the alongshore and cross-shore directions. By defining the flooded areas as zones with average flood elevations there will be discontinuities in the predicted flood elevations, along the flood zone boundaries, that do not occur in real life. The flood risk associated with properties near the flood zone boundaries should therefore be assessed, in part, on the flood elevations predicted for adjacent flood zones.

The flood zones within shoreline sections A and B were based entirely on the calculated wave runup elevations. Locating the shoreline section A flood zone on the accompanying drawing proved to be difficult due to the steep beach slopes and lack of contours on the FDRP mapping. As only a few structures are located within shoreline section A the Conservation Authority should survey the actual land elevations around those structures. The flood risk for the individual structures could then be based on the flood elevations provided by the look-up tables rather than relying on the flood zones shown on the accompanying drawing.

The flood zones in shoreline sections C and D were based on both wave runup elevation and the computed offset from the baseline required to give an elevation convergence on the actual profile during the runup calculations, as discussed above. This approach was required for shoreline sections C and D because the backshore area is so flat. Once the uprushing wave passes over the crest of the beach the water will flood over an extensive area. Because the backshore portion of the beach profile is assumed to have a constant elevation, the predicted runup elevation is the same for the different wave conditions. The runup solution, however, produces a progressively larger value of offset to reconcile the flat elevation with the greater volume of water passing over the beach crest with higher wave heights.

The northern limits of flood zones C1 and C2 were established from the offsets associated with the average beach slopes used in the wave runup calculations. While the beach elevations within zones C1 and C2 are roughly the same, flooding associated with "C1 events" is not expected to extend much further than 50 metres from the beach crest. The average flood elevation is in fact equal to the average elevation of the beach within flood zones C1 and C2, as determined from the FDRP mapping. It is therefore expected that water will wash over the beach surface within flood zone C1 but ponding will also occur in the low lying areas of zone C2 that are accessible to flowing water.

Shoreline section D is so flat and low in elevation that it was assumed that when waves overtop the beach crest the entire area will be flooded. This is because the land elevation in zone D is, on average, lower than the elevation of the crest of the beach. The four flood zones D1, D2, D3 and D4 therefore occupy the same horizontal area but have different average flood depths. Because the land elevation is lower than the beach crest some wave action will occur within the flooded area. Waves which overtop the beach crest will propagate through the flooded area in the form of bores rather than sinusoidal waves. It is not possible to accurately calculate wave heights within this area because of the shallow water depths associated with such a flat area and the presence of so many structures,but the average flood depths contain an approximate allowance for the bores which will occur.

Shoreline sections C and D are also vulnerable to flooding from waves which enter the harbour area, run along the west harbour pier, and overtop the pier as they reflect off it. Flooding from the harbour, however, is not expected to occur at any combination of water levels and wave activity that would not also cause flooding from runup over the beach. Any flooding from the harbour is therefore already accounted for with the shoreline flood zones and does not need to be considered separately.

The Conservation Authority should monitor actual flood events to determine the areas flooded and the average flood elevations. That information should then be compared to the predicted flood zones to establish confidence levels for the look-up tables. It is difficult to access the error levels associated with the tables due to the uncertainty of the error of the various computational components and, more importantly, because the entire flood prediction process is based on forecast winds. If the forecast winds are not realised then the predicted flood elevations will not be accurate. If, however, the wind conditions are accurately forecast and the winds are sustained long enough that fetch limited waves are generated, as assumed for this study, then the predicted nearshore wave conditions are expected to be reasonably accurate. Given accurate nearshore wave conditions the uprush levels are expected to plus or minus about 0.25 metres, or 1 shoreline flooding zone. Monitoring of the instantaneous water levels will be needed to assess the accuracy of the storm surge model.

8. Use of the Look-Up Tables

A total of 8 lakeshore flooding look-up tables were prepared to identify potential flood areas on Port Stanley Beach. There are two tables for each of the four alongshore sections A, B, C and D; one table for east wind forecasts and one table for southeast through southwest wind forecasts. The look-up tables provide flood zone numbers which identify flood prone areas on the accompanying drawing. Forecast wind speeds and instantaneous water levels are required to enter the look-up tables. Instantaneous water levels are estimated by adding wind setup levels to the existing static lake levels. The wind set-up levels are produced from a ninth look-up table. The current static lake level is calculated from either recently recorded water levels or through water level gauge readings.

The steps required to use the look-up tables are listed below. A more detailed description of each step follows.

1. Obtain wind speed and direction forecast from Environment Canada

2. Estimate static lake level.

3. Enter the wind setup look-up table with the forecast wind speed and wind direction to obtain the wind setup level.

4. Add the wind setup level to the static lake level to get the predicted instantaneous water level.

5. Select the four lakeshore flooding look-up tables (one for each of the four alongshore sections) that correspond to the forecast wind direction.

6. Enter each look-up table with the forecast wind speed and instantaneous water level to obtain the flood zone number for that particular shoreline section.

7. Refer the flood number to the accompanying drawing to identify the flooded areas and average flood water surface elevation.

The following paragraphs provide a more detailed description of use of the look-up tables, including a sample analysis. The look-up tables are located in Appendix A.

Step 1 Wind Forecast

The FPCN20 forecast can be obtained through a computer hook-up with the Ontario Weather Centre. Details of that hook-up are left to the Conservation Authority. An example of the FPCN20 forecast was given in Figure 3.1

Environment Canada also issues three types of high wind warnings:

- storm warnings are issued year round when winds are forecast to exceed 55 knots,
- gale warnings are issued year round when winds are forecast to exceed 34 knots, and
- small craft warnings are issued during the boating season when winds are forecast to exceed 20 knots.

These warnings will be automatically received by the Conservation Authority once they make the computer link to the Ontario Weather Centre.

As long as the Lake Erie static water level is below a certain threshold value the wind forecasts will not have to be checked on a daily basis. It will be sufficient to wait until high wind warnings are issued by Environment Canada to see if any of the shoreline is at risk of flooding. When the Lake Erie static water level is above the threshold value, however, wind speeds below those that trigger Environment Canada warnings could cause flooding. When the static lake level is higher than the threshold value the Conservation Authority should monitor the forecasts daily. The threshold value will vary with the time of year because small craft warnings, which are given when winds are forecast to exceed 20 knots, are only issued during the boating season. Using the flood values in the look-up tables the threshold static water level was computed to be 175.25 m above International Great Lakes Datum(IGLD) during the boating season when small craft warnings are issued and 174.80 m IGLD during the rest of the year when only gale and storm warnings are issued.

For the sample analysis assume that a storm warning has been issued and south winds from 50 to 55 knots have been forecast.

Step 2 Static Lake Level

The static lake level can be estimated from daily water levels recorded on the lake. There is at present an Environment Canada automatic water level data logger located at Port Stanley that can be accessed via computer. There are also water level gauges at Port Colborne and Kingsville which have voice recordings that can be accessed through a telephone. The Port Colborne phone number is (416) 835-2501. The Kingsville number is (519) 733-4417. These recordings, however, only give the present water level and the maximum and minimum recorded levels over the past 12 hours. During stormy conditions it will not likely be possible to estimate the static lake level from that information.

In order to estimate the static lake level you need the Port Stanley daily mean, minimum and maximum water level for a recent day on which there has been no significant storm activity. If the daily mean is within 0.03 metres of the average of the daily minimum and daily maximum then the daily mean can be taken as the static lake level. If the difference exceeds 3 centimetres then a similar calculation should be performed with the previous day's data. Any day within the previous week should provide reasonably accurate results.

The Conservation Authority has a computer hook-up with Environment Canada's automatic water level data logger at Port Stanley. Approximately 1 week's worth of data can be obtained from the data logger, but only the recorded water levels are available. The daily minimum, mean and maximum water levels are not specifically provided. A simple computer program could be written to calculate these values, or they can be obtained by contacting Environment Canada staff in Burlington at (416) 336-4844.

The recorded water level values are given as metres above the Lake Erie chart datum, which is 173.5 m above the 1985 International Great Lakes Datum (IGLD). This datum, however, is 0.03 m higher than Geodetic Survey Canada (GSC) datum so the calculated mean water level should be added to 173.47 m to give the static lake elevation in m GSC. All flood elevations in this study are based on GSC datum.

For the example analysis assume that the daily minimum, mean and maximum water levels were 1.14, 1.21 and 1.32 m above chart datum, respectively. The average of the minimum and maximum water levels is 1.23 m, which is within 3 centimetres of the daily mean. The static lake level is therefore calculated as 173.47 + 1.21 = 174.68 m GSC.

Step 3 Obtain Wind Setup Level

The wind setup level is obtained from the wind setup look-up table in Appendix A. Entering the table with a 50 to 55 knot forecast wind speed and a south forecast wind direction gives a setup level of 0.79 m for the example analysis.

Step 4 Calculate Instantaneous Water Level

The instantaneous water level is calculated as the sum of the static lake level and the wind setup analysis.

For the example analysis the instantaneous water level = 174.68 + 0.79 = 175.47 m GSC.

Steps 5, 6 Look–Up flood Zone Numbers

The runup calculations were carried out with 0.25 m increments of instantaneous water level. Because the runup results are reported as flood zones rather than actual elevations it is not possible to interpolate between the given results to obtain a precise runup estimation for the actual instantaneous water level used. Some judgement will be required in selecting the appropriate look–up table columns. We suggest that the instantaneous water level be rounded down to the nearest value on the look–up table if it is within 10 centimetres of the value in the tables, otherwise they should be rounded up.

For our example analysis flood zone numbers for shoreline sections A, B, C, and D are obtained from the southeast to southwest look–up tables because a south wind was forecast. With an instantaneous water level of 175.47 m. the 175.5 m water level column of the look–up tables should be used. With a 50 – 55 knot forecast wind speed the following flood zones will be identified :

shoreline section A – flood zone A4
shoreline section B – flood zone B2
shoreline section C – flood zone C2
shoreline section D – flood zone D3

Step 7 Identify Flood Risk Areas

The specific areas of shoreline associated with the flood zones are shown on the accompanying drawing. Because flooding occurs from the lake, all flood zones lakeward of the flood zone identified in the look–up tables will also be flooded. These areas should be expected to be flooded to approximately the same average flood elevations as specified from the look–up tables.

For the example analysis in can be seen that zones A1, A2, A2, and A4, B1 and B2, C1 and C2, and D will be flooded. The average flood elevation in shoreline section A will be 177.0 m GSC. The average flood elevation in shoreline section B will be 176.5 m GSC. The average flood elevation in shoreline sections C and D will be 176.2 m GSC.

9. CONCLUSIONS

A series of look–up tables and an accompanying drawing were prepared to help the Conservation Authority identify the location of expected flood areas during storms at high lake levels. The look–up tables are based on calculated wind setup and wave runup levels associated with specific combinations of static Lake Erie water levels, wind speeds and wind directions. Measured water levels and forecast wind speeds and directions are used as input for the look–up tables.

The flood prone portion of Port Stanley beach was divided into four alongshore sections classified as having similar wave runup characteristics. Flood zones with average flood depths have been defined for each alongshore section. Wave runup and flooding are continuous in both the alongshore and cross–shore directions, but the flood elevations have been defined with a number of discrete zones. This will cause a discontinuity of the flood elevations along the edges of the flood zones that does not occur in real life. The flood risk associated with properties near the flood zone boundaries should therefore be assessed, in part, on the flood levels predicted for adjacent flood zones.

The flood zones within shoreline sections A and B have been defined from 0.25 m contour intervals interpolated from the FDRP mapping. Locating the section A flood zones on the mapping proved to be difficult due to steep slopes and a lack of contour information in that area. The flood risk for the individual structures should be based on the flood elevations provided by the look–up tables rather than relying on the flood zones shown on the accompanying drawing.

The flood zones within shoreline section D occupy the same horizontal area but have different average flood depths associated with them. These flood depths include approximate allowances for potential wave activity. It is not possible to accurately predict wave heights within this area because of the actual topography and the presence of structures.

10. RECOMMENDATIONS

1. The Conservation Authority should establish computer links with the Environment Canada water level data logger at Port Stanley and the Ontario Weather Centre FPCN20 marine forecasts.

2. The Conservation Authority should undertake surveys to determine the elevation of the properties around the structures in shoreline section A and to determine the extent of filling that has taken place at the foot of William Street. The FDRP mapping should be updated for the William Street area.

3. When the Lake Erie static water level is below about elevation 175.25 m IGLD during the boating season and below about elevation 174.80 m IGLD during the rest of the year, the Conservation Authority can rely upon Environment Canada weather warnings to identify potential flood causing storms. When static lake levels are above these values the Conservation Authority should monitor the Ontario Weather Centre forecasts daily.

4. The Conservation Authority should monitor flood events to establish both the areas flooded and the extent of flooding which occurred. This information should be compared to the predicted flood zones to establish confidence levels for the look-up tables.

FIGURE 3.1

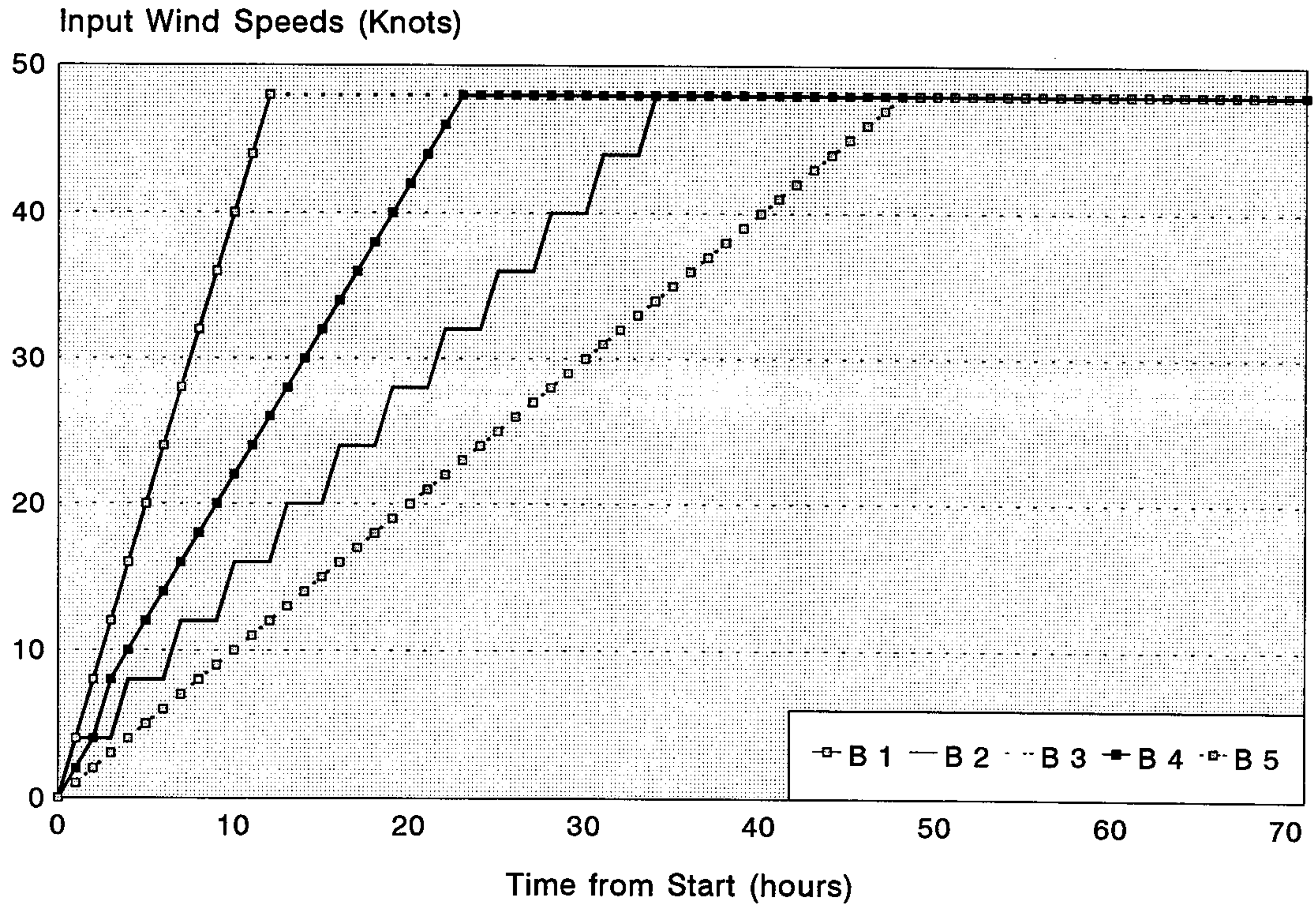
```
FPCN20 CYYZ 090900
MARINE FORECASTS FOR THE GREAT LAKES ISSUED BY ENVIRONMENT CANADA
AT 4.00 AM EST MONDAY 09 NOVEMBER 1992 FOR THE PERIOD ENDING AT
4.00 AM EST TUESDAY.
THE NEXT SCHEDULED FORECAST WILL BE ISSUED AT 10.00 AM TODAY.

WAVE HEIGHTS ARE FOR OFFSHORE AND ARE MEASURED FROM TROUGH TO CREST

LAKE SUPERIOR.
WINDS SOUTHEAST 20 TO 25 KNOTS VEERING TO SOUTH TONIGHT. PERIODS OF
SNOW CHANGING TO RAIN OR DRIZZLE TODAY. RAIN OR DRIZZLE TONIGHT.
WAVES 1 TO 2 METRES.

LAKE HURON
GEORGIAN BAY.
WINDS SOUTH TO SOUTHEAST 20 TO 25 KNOTS. OCCASIONAL RAIN MIXED WITH
WET SNOW THIS MORNING. FAIR TONIGHT. WAVES 1 TO 2 METRES.

LAKE ST CLAIR
LAKE ERIE.
WINDS SOUTHEAST 15 TO 20 KNOTS INCREASING TO SOUTH 20 TO 25 TODAY.
PATCHY LIGHT RAIN THIS MORNING MIXED WITH SNOW AT FIRST OVER
EASTERN ERIE. FAIR TONIGHT. WAVES BUILDING TO 1 TO 2 METRES TODAY.

LAKE ONTARIO
ST LAWRENCE RIVER-KINGSTON TO GANANOQUE.
WINDS SOUTHEAST 10 KNOTS INCREASING TO 15 TO 20 THIS AFTERNOON AND
SOUTH 20 TO 25 TONIGHT. PERIODS OF SNOW CHANGING TO RAIN TODAY.
FAIR TONIGHT. WAVES ON THE LAKE 1 METRE OR LESS BUILDING TO
1 TO 2 METRES TONIGHT.

SYNOPSIS.
AT 4 AM NORTH TO SOUTH RIDGE AVERAGE PRESSURE 1032 MB THROUGH EAST
LAKE ONTARIO MOVING TO LIE ALONG ATLANTIC SEABOARD BY 4 AM TUESDAY.
AT 4 AM WARM FRONT GREEN BAY TO CLEVELAND MOVING TO LIE THUNDER BAY
TO KINGSTON BY 4 AM TUESDAY.

MAFOR 0909.
SUPERIOR..12337 12336 14435 WAVES 1 TO 2 METRES
HURON/GEORGIAN..12337 12336 14430 WAVES 1 TO 2 METRES
ST.CLAIR/ERIE..12327 12320 14430 WAVES BUILDING TO 1 TO 2 METRES
 TODAY
ONTARIO/ST LAWRENCE RIVER-KINGSTON TO GANANOQUE..13317 12326 13430
 WAVES ON THE LAKE 1 METRE OR LESS BUILDING TO 1 TO 2 METRES TONIGHT

END/JRP
```

PORT STANLEY FLOOD TABLES	Project 92-028 December 29 1992
Example of FPCN20 Marine Forecast Issued by Environment Canada	**SHOREPLAN ENGINEERING**

KCCA LAKESHORE FLOODING LOOK-UP TABLES

Surge Model Sensitivity Analyses - Series B

Wind Speed Profiles Used



All wind directions are from south

Figure 4.1

KCCA LAKESHORE FLOODING LOOK-UP TABLES

Surge Model Sensitivity Analyses - Series B

Effect of Wind Speed Gradient and Peak Speed Duration

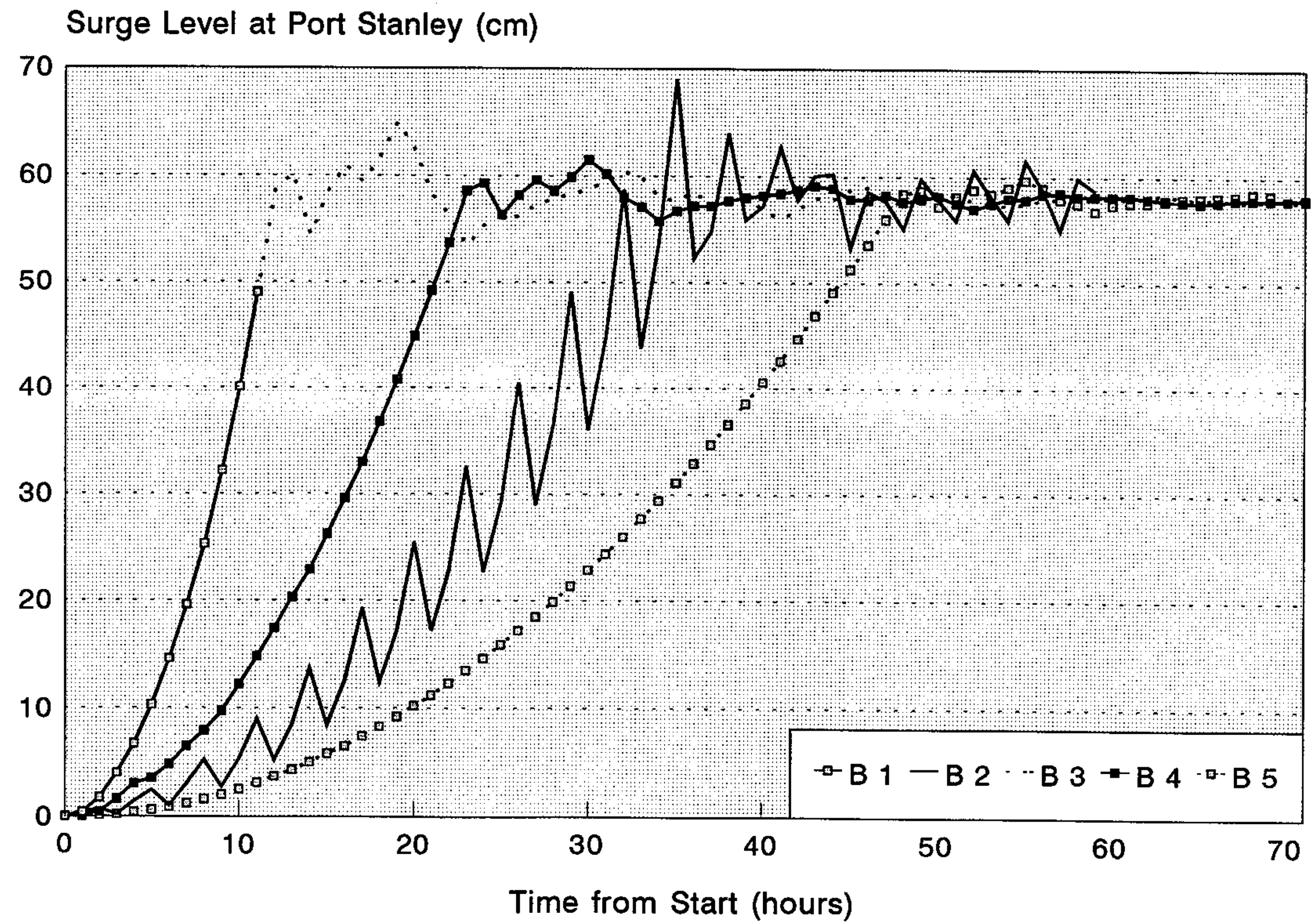
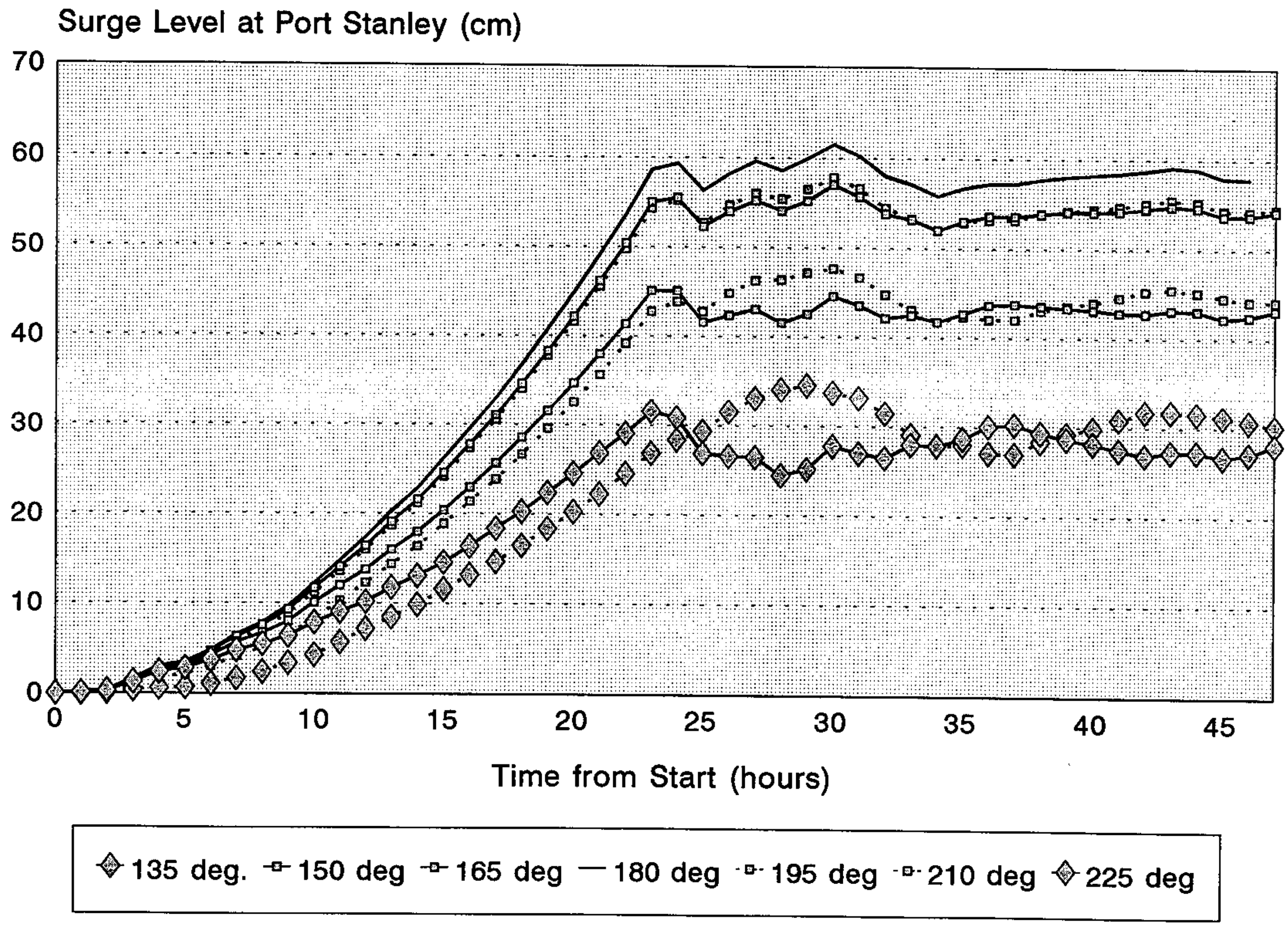


Figure 4.2

KCCA LAKESHORE FLOODING LOOK-UP TABLES

Surge Model Sensitivity Analyses - Series C
Effect of Different Constant Wind Directions

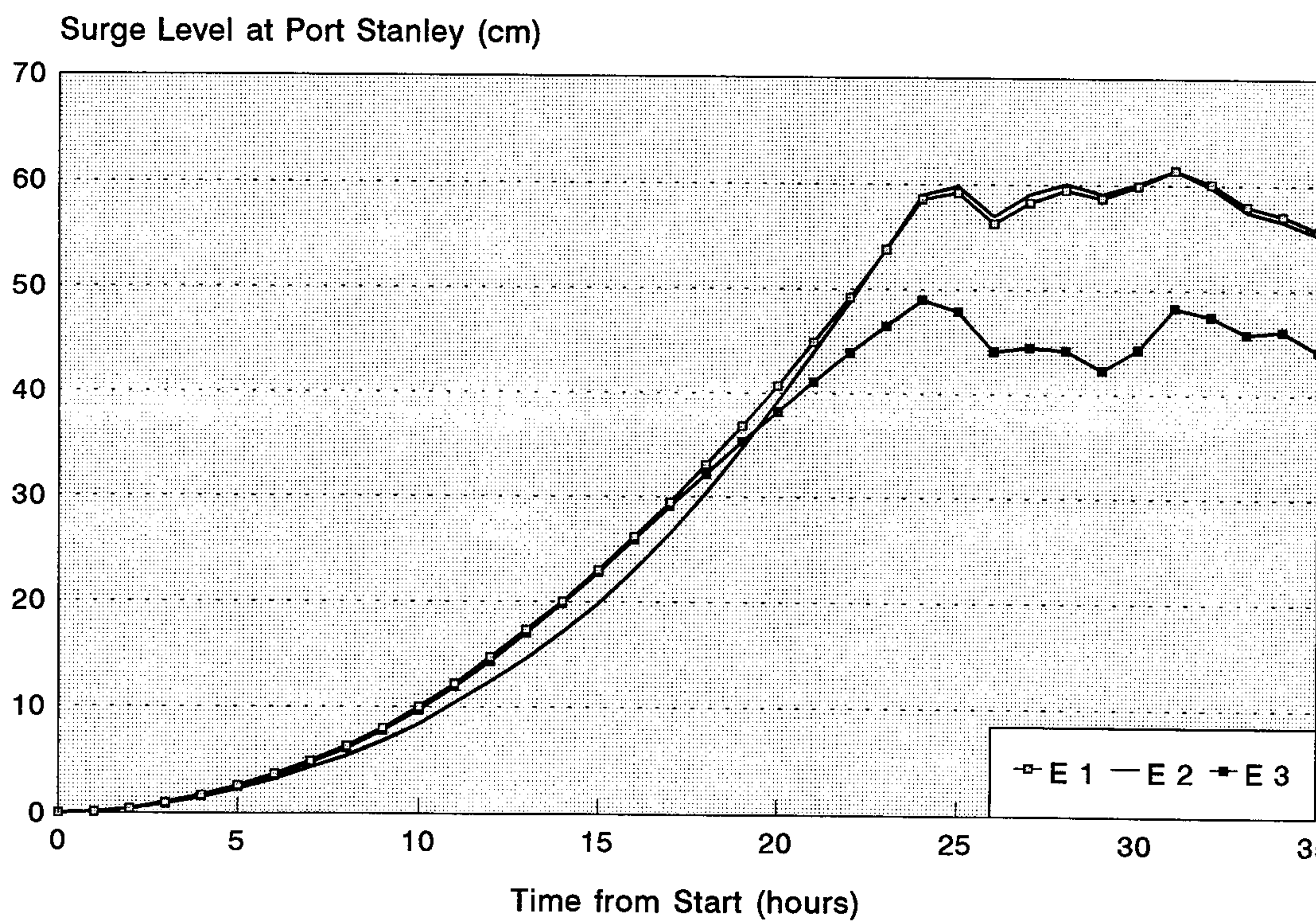


Wind speed profile B4 used

Figure 4.3

KCCA LAKESHORE FLOODING LOOK-UP TABLES

Surge Model Sensitivity Analyses - Series E
Effect of Shifting Wind Directions

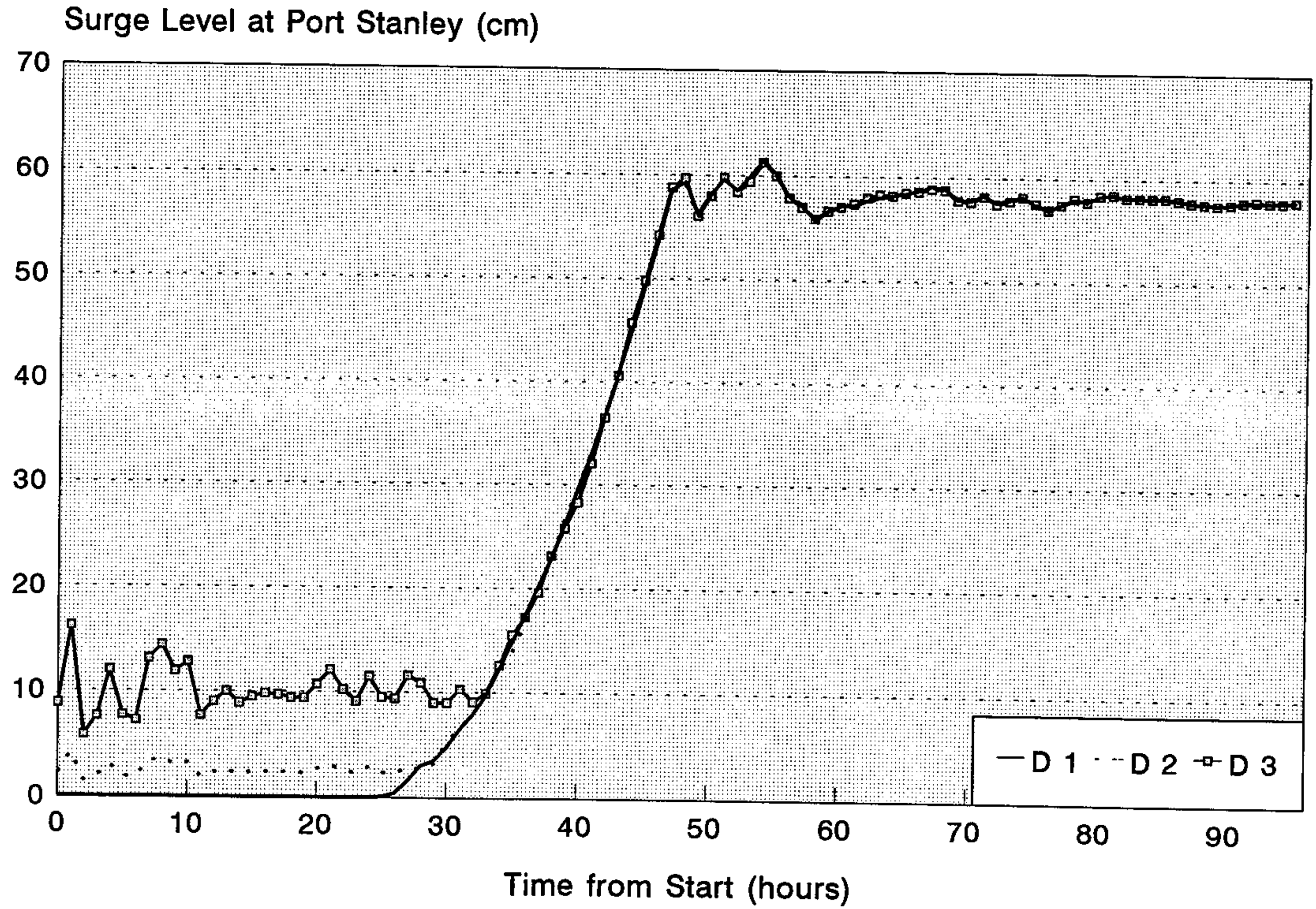


Wind speed profile B4 used

Figure 4.4

KCCA LAKESHORE FLOODING LOOK-UP TABLES

Surge Model Sensitivity Analyses - Series D
Effect of Different Model Start-up Procedures



All wind directions from South

Figure 4.5

KCCA LAKESHORE FLOODING LOOK-UP TABLES

Hindcast Offshore Wave Heights

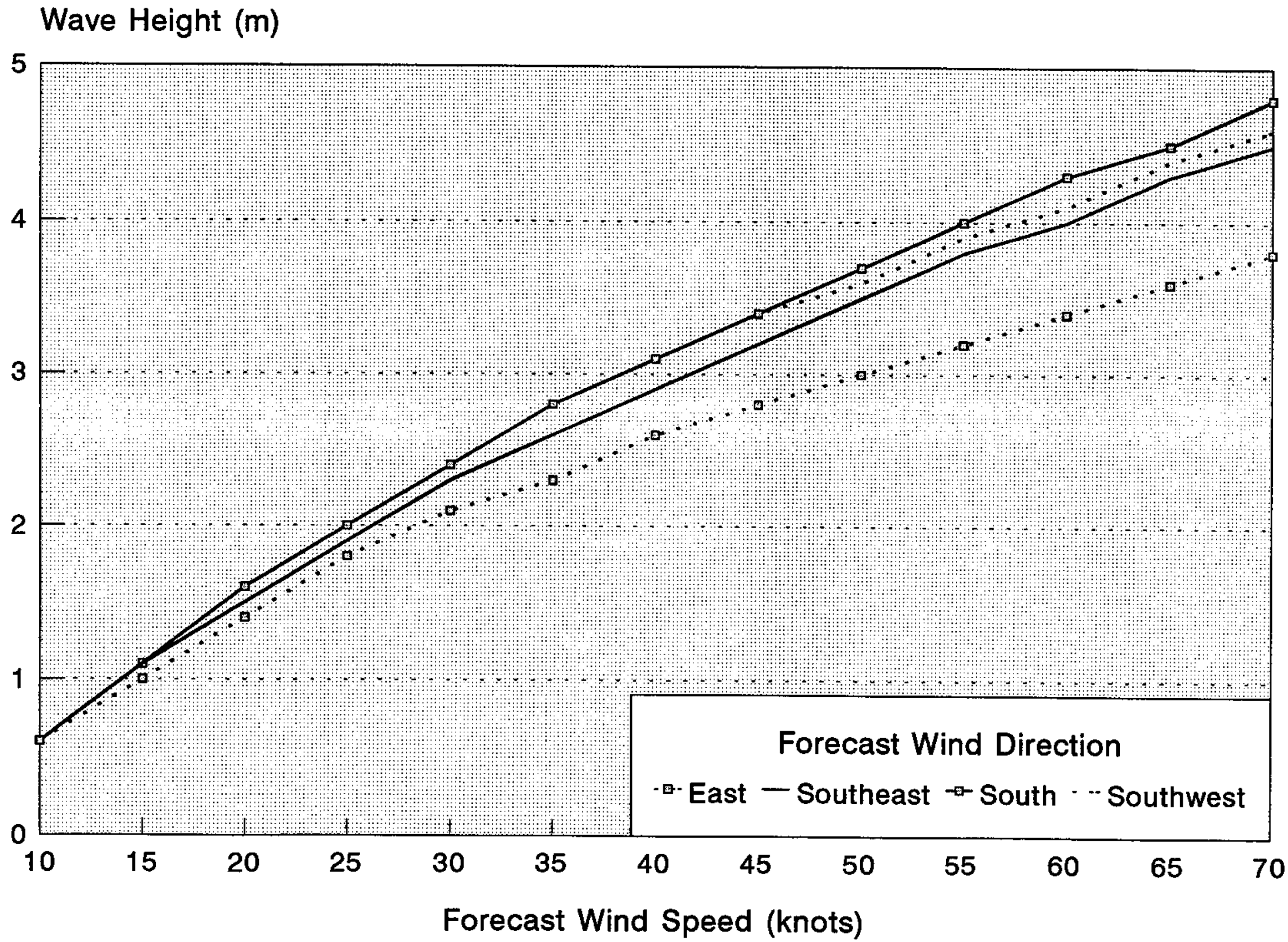


Figure 5.1

KCCA LAKESHORE FLOODING LOOK-UP TABLES

Hindcast Offshore Wave Periods

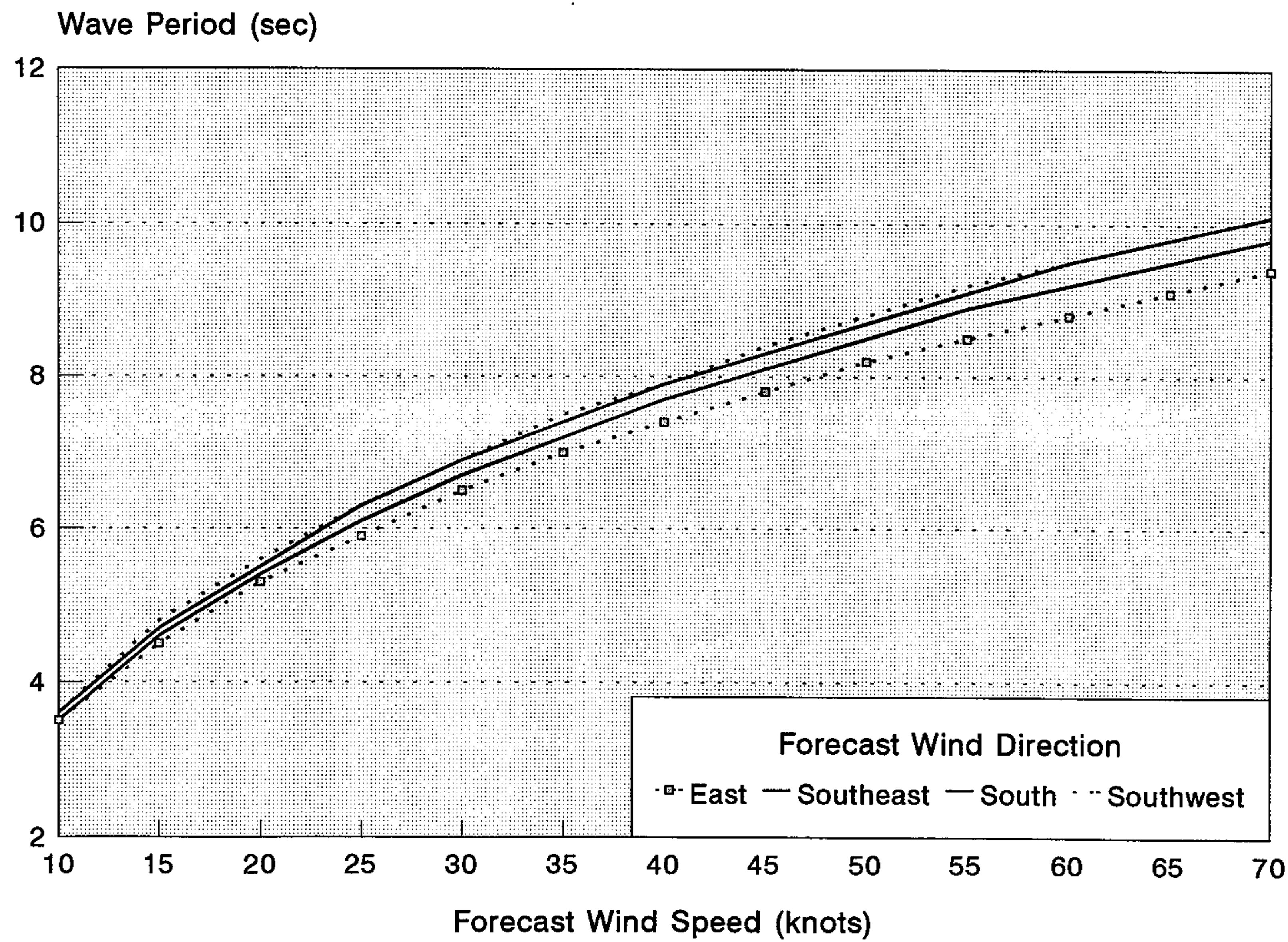


Figure 5.2

KCCA LAKESHORE FLOODING LOOK-UP TABLES
Nearshore Wave Heights

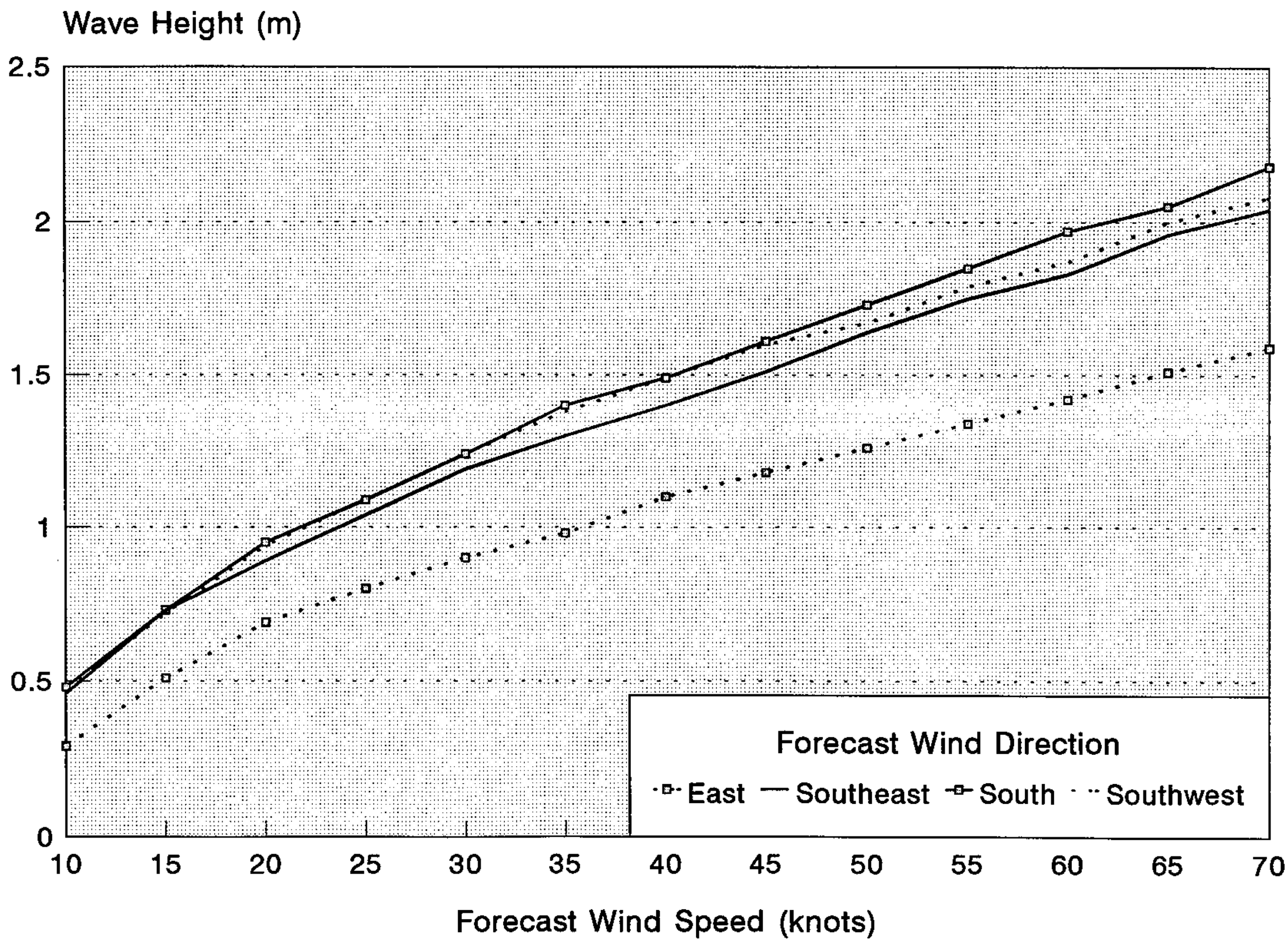


Figure 5.3

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APPENDIX A

LOOK-UP TABLES

KETTLE CREEK CONSERVATION AUTHORITY

WIND SETUP LOOK-UP TABLE

Wind Speed (Knots)	Wind Direction			
	East	Southeast	South	Southwest
5 - 10	0.02	0.03	0.03	0.02
10 - 15	0.04	0.06	0.07	0.04
15 - 20	0.07	0.10	0.11	0.07
20 - 25	0.10	0.15	0.17	0.10
25 - 30	0.13	0.20	0.23	0.15
30 - 35	0.16	0.27	0.31	0.20
35 - 40	0.19	0.34	0.41	0.27
40 - 45	0.21	0.43	0.52	0.35
45 - 50	0.23	0.52	0.65	0.45
50 - 55	0.24	0.63	0.79	0.56
55 - 60	0.26	0.74	0.94	0.67
60 - 65	0.27	0.86	1.10	0.80
65 - 70	0.28	0.99	1.28	0.93

WIND SETUP LEVELS ARE IN METRES ABOVE THE STATIC LAKE LEVEL

KETTLE CREEK CONSERVATION AUTHORITY
SHORELINE FLOODING LOOK-UP TABLES

SHORELINE SECTION A

EAST WINDS

Wind Speed (Knots)	Instantaneous Water Level (m GSC)						
	174.50	174.75	175.00	175.25	175.50	175.75	176.00
5 - 10	–	–	–	–	–	A1	A2
10 - 15	–	–	–	–	–	A1	A2
15 - 20	–	–	–	–	A1	A2	A3
20 - 25	–	–	–	–	A1	A2	A4
25 - 30	–	–	–	–	A2	A3	A4
30 - 35	–	–	–	A1	A2	A3	A4
35 - 40	–	–	–	A1	A3	A4	A4
40 - 45	–	–	–	A2	A3	A4	A4
45 - 50	–	–	–	A2	A3	A4	A5
50 - 55	–	–	A1	A2	A4	A4	A5
55 - 60	–	–	A1	A2	A4	A4	A5
60 - 65	–	–	A1	A3	A4	A5	A5
65 - 70	–	A1	A2	A3	A4	A5	A5

Note: A dash (–) indicates that wave uprush does not overwash the crest of the beach and therefore does not cause flooding.

Instantaneous water levels 175.75 and 176.00 have a lesser probability of occurrence than the 100 year return period.

KETTLE CREEK CONSERVATION AUTHORITY
SHORELINE FLOODING LOOK-UP TABLES

SHORELINE SECTION A

SOUTHEAST to SOUTHWEST WINDS

Wind Speed (Knots)	Instantaneous Water Level (m GSC)						
	174.50	174.75	175.00	175.25	175.50	175.75	176.00
5 - 10	-	-	-	-	-	A1	A2
10 - 15	-	-	-	-	A1	A2	A3
15 - 20	-	-	-	-	A1	A2	A3
20 - 25	-	-	-	-	A2	A3	A4
25 - 30	-	-	-	A1	A2	A3	A4
30 - 35	-	-	-	A1	A3	A4	A4
35 - 40	-	-	-	A2	A3	A4	A4
40 - 45	-	-	A1	A2	A3	A4	A5
45 - 50	-	-	A1	A3	A4	A5	A5
50 - 55	-	A1	A2	A3	A4	A5	A6
55 - 60	-	A1	A2	A3	A4	A5	A6
60 - 65	-	A1	A2	A4	A4	A5	A6
65 - 70	A1	A2	A3	A4	A5	A5	A6

Note: A dash (-) indicates that wave uprush does not overwash the crest of the beach and therefore does not cause flooding.

Instantaneous water levels 175.75 and 176.00 have a lesser probability of occurrence than the 100 year return period.

SHORELINE SECTION B

EAST WINDS

Wind Speed (Knots)	Instantaneous Water Level (m GSC)						
	174.50	174.75	175.00	175.25	175.50	175.75	176.00
5 - 10	–	–	–	–	–	–	B1
10 - 15	–	–	–	–	–	B1	B2
15 - 20	–	–	–	–	B1	B2	B2
20 - 25	–	–	–	–	B1	B2	B2
25 - 30	–	–	–	–	B2	B2	B2
30 - 35	–	–	–	B1	B2	B2	B2
35 - 40	–	–	–	B1	B2	B2	B2
40 - 45	–	–	–	B1	B2	B2	B2
45 - 50	–	–	–	B2	B2	B2	B2
50 - 55	–	–	–	B2	B2	B2	B2
55 - 60	–	–	B1	B2	B2	B2	B2
60 - 65	–	–	B1	B2	B2	B2	B3
65 - 70	–	–	B1	B2	B2	B2	B3

Note: A dash (–) indicates that wave uprush does not overwash the crest of the beach and therefore does not cause flooding.

Instantaneous water levels 175.75 and 176.00 have a lesser probability of occurrence than the 100 year return period.

KETTLE CREEK CONSERVATION AUTHORITY
SHORELINE FLOODING LOOK-UP TABLES

SHORELINE SECTION B

SOUTHEAST to SOUTHWEST WINDS

Wind Speed (Knots)	Instantaneous Water Level (m GSC)						
	174.50	174.75	175.00	175.25	175.50	175.75	176.00
5 - 10	-	-	-	-	-	B1	B2
10 - 15	-	-	-	-	B1	B1	B2
15 - 20	-	-	-	-	B1	B2	B2
20 - 25	-	-	-	-	B2	B2	B2
25 - 30	-	-	-	B1	B2	B2	B2
30 - 35	-	-	-	B1	B2	B2	B2
35 - 40	-	-	-	B2	B2	B2	B2
40 - 45	-	-	B1	B2	B2	B2	B2
45 - 50	-	-	B1	B2	B2	B2	B3
50 - 55	-	-	B2	B2	B2	B2	B3
55 - 60	-	B1	B2	B2	B2	B2	B3
60 - 65	-	B1	B2	B2	B2	B2	B3
65 - 70	-	B2	B2	B2	B2	B3	B3

Note: A dash (-) indicates that wave uprush does not overwash the crest of the beach and therefore does not cause flooding.

Instantaneous water levels 175.75 and 176.00 have a lesser probability of occurrence than the 100 year return period.

KETTLE CREEK CONSERVATION AUTHORITY
SHORELINE FLOODING LOOK-UP TABLES

SHORELINE SECTION C

EAST WINDS

Wind Speed	Instantaneous Water Level (m GSC)						
(Knots)	174.50	174.75	175.00	175.25	175.50	175.75	176.00
5 - 10	–	–	–	–	–	C1	C3
10 - 15	–	–	–	–	C1	C1	C3
15 - 20	–	–	–	–	C1	C1	C3
20 - 25	–	–	–	–	C1	C2	C3
25 - 30	–	–	–	C1	C1	C2	C3
30 - 35	–	–	–	C1	C1	C2	C3
35 - 40	–	–	–	C1	C1	C3	C3
40 - 45	–	–	–	C1	C2	C3	C3
45 - 50	–	–	–	C1	C2	C3	C3
50 - 55	–	–	C1	C1	C2	C3	C3
55 - 60	–	–	C1	C1	C2	C3	C3
60 - 65	–	–	C1	C2	C2	C3	C3
65 - 70	–	–	C1	C2	C3	C3	C3

Note: A dash (–) indicates that wave uprush does not overwash the crest of the beach and therefore does not cause flooding.

Instantaneous water levels 175.75 and 176.00 have a lesser probability of occurrence than the 100 year return period.

KETTLE CREEK CONSERVATION AUTHORITY
SHORELINE FLOODING LOOK-UP TABLES

SHORELINE SECTION C

SOUTHEAST to SOUTHWEST WINDS

Wind Speed (Knots)	Instantaneous Water Level (m GSC)						
	174.50	174.75	175.00	175.25	175.50	175.75	176.00
5 - 10	-	-	-	-	-	C1	C3
10 - 15	-	-	-	-	-	C1	C3
15 - 20	-	-	-	-	C1	C1	C3
20 - 25	-	-	-	-	C1	C1	C3
25 - 30	-	-	-	-	C1	C1	C3
30 - 35	-	-	-	C1	C1	C2	C3
35 - 40	-	-	-	C1	C1	C2	C3
40 - 45	-	-	C1	C1	C1	C2	C3
45 - 50	-	-	C1	C1	C1	C2	C3
50 - 55	-	-	C1	C1	C2	C3	C4
55 - 60	-	-	C1	C1	C2	C3	C4
60 - 65	-	-	C1	C1	C2	C3	C4
65 - 70	-	-	C1	C1	C2	C3	C4

Note: A dash (-) indicates that wave uprush does not overwash the crest of the beach and therefore does not cause flooding.

Instantaneous water levels 175.75 and 176.00 have a lesser probability of occurrence than the 100 year return period.

KETTLE CREEK CONSERVATION AUTHORITY
SHORELINE FLOODING LOOK-UP TABLES

SHORELINE SECTION D

EAST WINDS

Wind Speed (Knots)	Instantaneous Water Level (m GSC)						
	174.50	174.75	175.00	175.25	175.50	175.75	176.00
5 - 10	-	-	-	-	-	D1	D4
10 - 15	-	-	-	-	D1	D1	D4
15 - 20	-	-	-	-	D1	D2	D4
20 - 25	-	-	-	-	D1	D2	D4
25 - 30	-	-	-	D1	D1	D2	D4
30 - 35	-	-	-	D1	D2	D2	D4
35 - 40	-	-	-	D1	D2	D2	D4
40 - 45	-	-	-	D2	D2	D3	D4
45 - 50	-	-	-	D2	D2	D3	D4
50 - 55	-	-	D1	D2	D2	D3	D4
55 - 60	-	-	D1	D2	D2	D3	D4
60 - 65	-	-	D1	D2	D2	D3	D4
65 - 70	-	-	D1	D2	D2	D3	D4

Note: A dash (-) indicates that wave uprush does not overwash the crest of the beach and therefore does not cause flooding.

Instantaneous water levels 175.75 and 176.00 have a lesser probability of occurrence than the 100 year return period.

KETTLE CREEK CONSERVATION AUTHORITY
SHORELINE FLOODING LOOK-UP TABLES

SHORELINE SECTION D

SOUTHEAST to SOUTHWEST WINDS

Wind Speed (Knots)	Instantaneous Water Level (m GSC)						
	174.50	174.75	175.00	175.25	175.50	175.75	176.00
5 - 10	-	-	-	-	D1	D1	D4
10 - 15	-	-	-	-	D1	D1	D4
15 - 20	-	-	-	-	D1	D2	D4
20 - 25	-	-	-	D1	D2	D2	D4
25 - 30	-	-	-	D1	D2	D2	D4
30 - 35	-	-	-	D2	D2	D3	D4
35 - 40	-	-	-	D2	D2	D3	D4
40 - 45	-	-	D1	D2	D2	D3	D4
45 - 50	-	-	D1	D2	D2	D3	D4
50 - 55	-	-	D1	D2	D3	D3	D4
55 - 60	-	-	D1	D2	D3	D4	D4
60 - 65	-	-	D1	D2	D3	D4	D4
65 - 70	-	-	D1	D2	D3	D4	D4

Note: A dash (-) indicates that wave uprush does not overwash the crest of the beach and therefore does not cause flooding.

Instantaneous water levels 175.75 and 176.00 have a lesser probability of occurrence than the 100 year return period.