THE DEVELOPMENT OF MANUAL TECHNIQUES FOR THE REAL TIME PREDICTION OF STORM SURGES ON THE GREAT LAKES

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The Great Lakes have been experiencing severe problems of erosion of their shore lines and flooding of low lying areas these past two years. The problems have been the result of short term rises superimposed on abnormally high water levels in 1973 and 1974 and have created an urgent need for forecasting short term changes in the Great Lakes water levels.

A manual technique for forecasting the water level changes has been developed. The statistical approach is used to derive regression relationships. The level changes for Lakes Ontario, Erie, Huron and for Georgian Bay are to be calculated from values of the sea level pressures and air-water temperature differences with lag times of 0 and 6 hours as independent variables. For Lake St. Clair hourly winds at Windsor with lag times of 0 and 1 hour replace the sea level pressure as predictors.

The proportion of variation of the water levels in the various lakes accounted for by this method ranges between 55 and 75%. The comparison of observed and predicted levels has been generally good with the best correlation of peak levels being obtained for Lake St. Clair. A drag coefficient value of 2.46×10^{-3} has also been derived for Lake St. Clair. The standard errors of estimate for all the lakes except Erie range between 0.2 and 0.3 ft. while it is close to 0.6 ft. for Lake Erie.

Based on this report some recommendations have been made for further investigations.

1. INTRODUCTION

Storm surges in Lake Erie have been the subject of a number of investigations in recent years. The devastating effects of such surges range from disruption of electrical power production and transportation to erosion and flooding of low lying areas. The abnormally high water levels for prolonged periods in 1973 and 1974 have compounded the problem and resulted in the other Great Lakes and Lake St. Clair also experiencing similar problems, particularly inundation and erosion. This generated the need for practical methods for forecasting the short term changes in the water levels of the Great Lakes by the Toronto Weather Office. The investigation here is directed towards manual techniques for the real time prediction of the water levels. The statistical approach adopted is based on compilation of data on severe storms on the Great Lakes between the years 1961 and 1973. Regression relationships in terms of sea level pressures and air-water temperature differences have been developed for Lakes Ontario, Erie and Huron and for Georgian Bay, while for Lake St. Clair the sea level pressures are replaced by local winds.

Only the lakes bordering Canada have been investigated. Lake Superior has been omitted from the study because significant storm surges on that lake are not observed.

2. LITERATURE SURVEY

A comprehensive literature search of the various techniques - dynamical approaches including the use of numerical methods, statistical and manual approaches - for forecasting storm surges in shallow waters with particular emphasis on forecast problems in the Great Lakes was undertaken. Because of the large magnitudes of water level set-up due to storm surges, Lake Erie has been the subject of a number of studies in this regard. Dynamical approaches, with the equations of motion being simplified to different degrees, have been adopted by Keulegan (1953), Hunt (1959), Platzman (1963), McClure (1970) and others. Methods of estimating over-water winds which are instrumental in producing the surge have been reported by Richards et al (1966) and Barrientos (1970). While Richardson and Pore (1969, 1972) have adopted a statistical approach to storm surges in Lake Erie, the technique has been used by Hamblin and Budgell (1973) for predicting storm surges in Lake St. Clair. A few of the other more significant and relevant works include Jelesnianski (1967, 1970), Freeman and Murty (1972), Murty and Freeman (1973) and Welander (1961).

3. METHOD OF APPROACH AND ANALYSIS

Based on the survey of literature and discussions with scientists at the Toronto Weather Office, Ontario Hydro, Atmospheric Environment Service and the Marine Sciences Directorate in Ottawa, a statistical approach to the problem of predicting storm surges in the Great Lakes was deemed most suitable at this time.

The choice of the statistical approach as opposed to dynamical or other hybrid techniques was based on two factors:

(a) The need for a practical technique to predict storm surges on an operational basis, and

(b) There are as yet a number of unresolved questions with regard to the dynamical methods and the development of a sufficiently reliable theory would not be possible in the limited time available.

The success of the statistical approach depends, to a large extent, on whether one has accounted for all the important factors influencing the phenomenon. Some degree of physical and dynamic reasoning is employed in the selection of the possible predictors to be used in the statistical models. Such an approach also has the ability to discriminate against inferior assumptions and sometimes makes use of implicit data, hidden correlations not clearly recognized, which serve to improve the predictions.

4. CHOICE OF PARAMETERS

A storm surge results from the action of wind stress and pressure gradient on the water surface. The pressure gradient force plays a significant role in producing the stress. Barometric pressure, therefore, is considered to be the first predictor of importance. Pressure as a predictor is preferable to winds because of the susceptibility of the latter to changes in anemometer height. Past experience has also shown that the use of winds as a predictor in a statistical approach may be faced with the problem of the weather stations being closed (Harris and Angelo, 1963). These problems may be avoided by the use of barometric pressure referred to sea level and at specific grid points as a predictor.

The storm surge for a given lake will be assumed to depend on the sea level pressures at equispaced grid points surrounding that lake. The location and spacing of the grid points are identical to the corresponding ones in the CMC (Canadian Meteorological Centre) weather forecast model, so that the pressures as forecast by the CMC model may be directly used as input for storm surge predictions. Also, an examination of weather conditions at the time of the storms indicates that the magnitude of the surge is greatly influenced by the stability of the atmosphere. The storms are invariably more violent under unstable conditions with the water being warmer than the air above it. Such conditions prevail with the passage of a cold front through the area of interest. Thus the air-water temperature difference, an indicator of stability of the air-water system, is the second parameter to be considered as a predictor. The pressure and temperature taken together indirectly constitute a measure of the general wind conditions. The local winds, however, would also be greatly influenced by the nature of the terrain in the vicinity of the water body. The correlation of the water level with such effects is a hidden one. But with the parameters as obtained from a weather forecast in mind, the pressure and temperature are the two major factors to be included in the statistical model for storm surge forecasting. Such a statistical model is developed for Lakes Ontario, Erie, Huron and for Georgian Bay. The set of grid points used with reference to each of the lakes, for specifying the sea level pressure are (see Figure 1):

Lake	Grid Points
Ontario	4, 5, 7, 8, 10, 11
Huron & Georgian Bay	3, 4, 6, 7, 9, 10
Erie	1, 2, 3, 4, 6, 7

As far as Lake St. Clair is concerned, the independent variables, sea level pressures at the six grid points, are replaced by surface winds at or close to the water level station. Reasons for the choice are explained elsewhere in the report.

5. DATA ACQUISITION

(a) Water Levels

The dependent storms analysed covered the period 1961 through 1971. Analog records of water levels at specified locations on the various lakes were obtained, covering instances of storm surges during this period. Wherever possible an effort was made to have these records available for two days prior to and following the day of maximum surge. These records were then processed to obtain five-minute digitized values.

Storm surges in 1972 (and 1973, for Burlington only) were used as independent cases to test the regression relations derived from the dependent storms. The 1972 hourly water levels were extracted from the data tape supplied by the tides and water levels section of the Marine Sciences Directorate in Ottawa. This tape contains hourly water levels for 1972 for all the Great Lakes water level stations. The 1973 water levels for storms at Burlington were extracted from the data on punched cards, also supplied by the Marine Sciences Directorate.

(b) Sea Level Pressures

For a given water level station, sea level pressures are required at each of the six associated grid points and for times covering the instances of storm surge. The manual extraction of these pressures from weather charts was ruled out because of the excessive amount of time required to process well over 2,000 charts. The alternative was to obtain these pressures by an objective analysis of sea level pressures at three stations surrounding each grid point. The stations selected for each of the eleven grid points are listed in Table 1 and also shown in Figure 1. The proximity of grid points 5 and 10 to the stations at Wilkes Barre and Earlton Airport, respectively eliminated the need for sea level pressures at two other stations. Hence the sea level pressures at Wilkes Barre and Earlton Airport were used as the pressures at grid points 5 and 10.

The sea level pressures for stations in the U. S. were obtained on magnetic tapes from the National Climatic Center in Ashville, North

Carolina. Data selection was by the months in which the storm surges occurred, as this was the most economical means of acquiring the necessary data. From 1961 to 1964 the data - sea level pressure, winds, temperature, etc. - is on an hourly basis, while from 1965 to 1971 they are available on a three-hourly basis.

The sea level pressures for stations in Canada were obtained on magnetic tapes from the Atmospheric Environment Service in Toronto, Ontario. The data, available on an hourly basis, covered the period 1961 to 1972 and included the dry bulb temperature, wind speed and direction in addition to the sea level pressures.

For the storms in 1972, the sea level pressures at the grid points in the U. S. were obtained from surface analysis maps.

(c) Air and Water Temperatures

Air and water temperatures at each of the water level stations are required to compute the air-water temperature difference, which is a measure of the stability of the air in relation to the water.

As the water level station is not normally a first order weather station as well, the air temperatures were obtained from the nearest first order station reporting on an hourly basis. The stations used are listed in Table 2.

The water temperatures for the period 1961 to 1968 were obtained from monthly means published by Richards and Irbe (1969). The monthly mean water temperatures for the period 1969 to 1972 were obtained from J. G. Irbe (Personal Communication). Assuming these means to be applicable on the 15th of the month, linear interpolation was used to obtain the water temperature on the day of maximum surge for each storm. This temperature was then rounded off to the nearest integer and was assumed constant over the period of the storm. For Lake St. Clair, the water temperature as measured at the Detroit River intake at Belle Isle was used. These measurements, available on a daily basis, were made available by the City of Detroit, Detroit Metro Water Department.

(d) Winds

Sea level pressures at grid points 381 kilometers apart are not suitable for use with a lake of the size of Lake St. Clair. The hourly winds at Windsor, about 10 miles from the water level station at Belle River, were used instead as the independent variable for predicting the storm surges at Belle River. The necessary data for the period 1961 to 1972 was provided by the Atmospheric Environment Service.

6. DATA FORMAT

(a) Water Levels

Each water level record consists of station number, date (year, month, day, hour), the system of units used (B for level in feet) and the twelve five-minute water levels for the hour. The format of each record is (I5, 1X, 4I2, 1X, A1, 12I4).

The first record for each station gives the number of dependent storms, followed by the comment "subtract 5 feet to get levels w.r.t. chart datum." The 5 feet was added to keep the levels w.r.t. chart datum positive, simply a matter of convenience. This record is to be decoded according to the format (I4, 19A4). The end of data for each station is indicated by an end of file mark on the tape. Identification of each storm is only by the date of the storm.

(b) Sea Level Pressure

The format of data for the U.S. stations is found in the Tape Reference Manual, Airways Surface Observations, TDF14. This document is issued by the National Climatic Center, Ashville, North Carolina. Hourly observations constituting a record are blocked in groups of six. Thus four such logical records represent 24 hours of observations.

The hourly observations for the Canadian stations are grouped in blocks of ten records each. Each record consists of the station number, the date (year, month, day, hour), sea level pressure, wind direction, wind speed and dry bulb temperature and follows the format (I5, 4I2, I4, I2, I3, I3). The sea level pressure is such that if it is greater than or equal to 1000.0 mb, only the last four digits are recorded. For example, 0247 represents a pressure of 1024.7 mb while 9935 represents a pressure of 993.5 mb.

(c) Air Temperature

The format of records containing the air temperatures in degrees Fahrenheit at the appropriate locations is the same as that described under sea level pressure.

(d) Winds

The wind speed is expressed in miles per hour and the direction code can be obtained from the #1 card format documentation published by the Climatology Division of the Atmospheric Environment Service, Toronto, Canada.

A listing of magnetic tapes on which the data are stored is given in Appendix 7.

7. DATA PROCESSING

The beginning and ending times of each storm were determined by the availability of all the necessary data, a five-day duration being maintained wherever possible. Sea level pressure is the independent variable of primary interest. For a given water level station and for a given grid point, six-hourly sea level pressures at the surrounding stations (3 or 1 as the case may be) were extracted, the times coinciding with the synoptic forecast times of 0000, 0600, 1200 and 1800 hours GMT. These times correspond to 1900, 0100, 0700 and 1300 hours EST. An objective analysis of these station sea level pressures was carried out to arrive at the grid point sea level pressure. A "plane fit" to the three pressures is obtained by solving simultaneously the three equations:

$$P_1 = AX_1 + B\theta_1 + C$$

$$P_2 = AX_2 + B\theta_2 + C$$

$$P_3 = AX_3 + B\theta_3 + C$$

where P_1, P_2 and P_3 are the sea level pressures at the three stations surrounding the grid point, X_1, X_2 and X_3 the radial distances of the stations from the grid point and θ_1, θ_2 and θ_3 the angular orientation of these radial lines from a reference line. If the line through one of the stations, say station 1, is taken as the reference line, then $\theta_1 = 0$ and θ_2 and θ_3 are the angles measured from this line. See Figure 2 for details. C then gives the pressure at the grid point. Sea level pressures are thus calculated at all the grid points for the given water level station.

The other variable of interest is the air-water temperature difference. The water temperature being assumed constant for the period of the storm, it is subtracted from the six-hourly air temperatures (see Table 2 for a list of air temperature stations) to get the six-hourly air-water temperature difference.

The use of six-hourly temperatures and pressures at grid spacings of 380 km was found to be highly inadequate for Lake St. Clair. The air-water temperature difference in fact produced the highest correlation with the water levels, but explained only 3% of the variations of the latter with the pressure accounting for an even lower percentage. As a result of its relatively small size, Lake St. Clair has a short response time, of the order of two hours. It is, therefore, logical to use the local hourly winds (as measured at Windsor Airport) and air-water temperature difference as the independent variables. An "effective" wind is used in place of the actual hourly winds, the "effective" wind being defined by:

$$V_t^2 = 0.25v_{t-2}^2 + 0.5v_{t-1}^2 + 0.25v_t^2$$

where V_t is the "effective" wind at time t hours and v_t is the actual wind at time t hours. In computing the "effective" wind the above choice of actual winds at the specific times was based on the one- to two-hour response time of Lake St. Clair. An examination of the wind and water level records also suggests this apparent correlation. The "effective" wind speed squared along any desired direction can be obtained by taking the components of the actual wind speed squared in that direction. The relevant directions for Lake St. Clair are N-S and NNW-SSE.

As for the water levels, hourly levels were extracted from the five-minute digitized values at each of the six water level stations.

8. PROCEDURE TO SCREEN PREDICTORS AND REGRESSION ANALYSIS

Since water levels are recorded every hour, while the sea level pressure and temperature are available at six-hourly intervals from weather forecasts, the water level data may be divided into six groups:

1. Water levels that occurred at the same time as the pressure.
2. Water levels that occurred one hour after the pressure.
3. Water levels that occurred two hours after the pressure.
4. Water levels that occurred three hours after the pressure.
5. Water levels that occurred four hours after the pressure.
6. Water levels that occurred five hours after the pressure.

The pressures and temperatures at six-hour intervals, each with lag times of 0 and 6 hours, may be screened for each of the six water level groups. The adequacy of the inclusion of only the 0 and 6 hour lag times is based on the report by Richardson and Pore (1972). The inclusion of pressures at lag times greater than six hours does not make any significant contributions toward explaining the variation of the water levels.

The method of screening the predictors is outlined below.

1. $SS = A_1 + B_1X_1$
2. $SS = A_2 + B_2X_1 + C_1X_2$
3. $SS = A_3 + B_3X_1 + C_2X_2 + D_1X_3$

$\vdots$

n. $SS = A_n + B_nX_1 + C_{n-1}X_2 + D_{n-2}X_3 + \ldots + N_1X_n$

where SS is the storm surge, A_1, A_2, A_3, etc. are constants, X_1, X_2, X_3, etc. are the predictors and B_1, B_2 ..., C_1, C_2 ..., etc. are the regression coefficients.

The procedure is to select the single predictor X_1 (sea level pressure at any one of the grid points or air-water temperature difference at 0 or 6 hours lag time) in equation (1) which best explains the variance of the storm surge (i.e. has the highest correlation). The second regression equation contains the first predictor X_1 and the predictor X_2 that contributes most to explaining the residual variance of the storm surge after the first predictor is considered. This process is continued until the reduction in variance attained by additional predictors is not significant or until the desired number of predictors is included.

For Lake St. Clair the predictors to be screened are V_t^2, $(T_A-T_W)_0V_t^2$ and $(T_A-T_W)_{-1}V_t^2$ where V_t is the "effective" wind speed, $(T_A-T_W)_0$ and $(T_A-T_W)_{-1}$ are the air-water temperature differences at 0 and 1 hour lag times. It has been shown (McClure, 1970) that the effect of the air-water temperature difference is to modify the value of the drag coefficient c_d in the expression for the wind stress. The wind stress τ is given by $\tau = c_d\rho V_t^2$, where ρ is the density of air and c_d is expressed as $c_d = A + B(T_A-T_W)$. Hence the above choice of predictors.

The computer program for the multiple regression analysis is listed in Appendix 8. For details see Efroymson (1962).

9. RESULTS

The regression relations obtained from the dependent storms, for the storm surges in Lake St. Clair (Belle River), Lake Ontario (Burlington), Georgian Bay (Collingwood), Lake Huron (Point Edward) and Lake Erie (Port Colborne and Kingsville) are given in Appendices 1 to 6. Also given in these appendices are the storm dates of both the dependent and independent storms and plots of observed and computed water levels for the dependent and independent storms. Table 3 gives the number of dependent and independent storms used at each of the above locations.

A comparison of the observed and computed water levels shows that the statistical approach yields reasonably good results for all the lakes. The maximum discrepancies occur in the predictions for Lake Erie. This is to be expected because of the larger magnitudes of the surge in that lake. In most cases about 60% of the variation in water level is explained by this method (see Table 4). The standard error of estimate is 0.2 to 0.3 feet for lakes St. Clair, Ontario, Huron and Georgian Bay while it is close to 0.6 feet for Lake Erie. (Standard error of estimate is defined by $S.E = \sigma/\sqrt{N}$ where σ^2 is the weighted residual sum of squares (see Efroymson, 1962) and N is the number of degrees of freedom equal to the number of sets of observations minus the number of regression coefficients estimated.) The higher standard error for Lake Erie is a direct result of the greater excursions of the water level in that lake.

Table 4 gives the standard errors of estimate of the dependent and independent storms for all the lakes. The six values given for the dependent storms are the values for water levels measured at 0 through 5 hours after the time of pressure measurement. While the degrees of freedom to be used in evaluating the standard error of estimate for the independent storms should be one less than the number of sets of data, the value actually used in arriving at the figures listed in Table 4 is this value less the maximum number of coefficients to be estimated in any one of the six prediction equations. Hence the standard errors of estimate for the independent storms are in fact better than those listed in Table 4. It should be mentioned here that the standard errors for some of the storms may be a little higher than the overall estimates of Table 4, the latter being a sort of an average value.

Figures 3 to 8 show plots of observed versus predicted peak levels (some minimum levels are also included) at the different locations. For Lake St. Clair the correlation is very good with a correlation coefficient of 0.94 at a significance level of 1%. The correlation coefficients for stations on the other lakes are also in the range 0.93 to 0.97, but with a significance level of 0.1% for Lakes Ontario, Huron and Georgian Bay and even lower for Lake Erie. The high correlation of the peak levels does not necessarily imply a high correlation with respect to their times of occurrence. For Lake St. Clair, however, there is also a fairly good agreement of the times of occurrence of observed and predicted peak levels.

The statistical method of analysis shows that the stability of the atmosphere in relation to the water, of which the air-water temperature difference is a measure, does play a role in influencing the water level changes. The effect is greatest for Lake St. Clair where a little under 5% of the variation is explained by this parameter, while the square of the "effective" wind speed accounts for about 50%.

With the square of the "effective" wind speed being an independent variable, it is possible to derive a value of the drag coefficient for Lake St. Clair.

The displacement S of the free surface from the mean level, in steady state balance with the wind stress, is given by (McClure, 1970, and Hamblin and Budgell, 1973):

$$S = \frac{L}{2} \frac{\rho_\alpha}{\rho_\omega} \frac{c_d}{g} \frac{V^2}{H}$$

where ρ_ω is the density of the water, ρ_α the density of air = 1.2×10^{-3} gm/c.c., L the length of the lake = 46 km, g the acceleration due to gravity, H the depth = 6 m, V the effective wind speed and c_d the drag coefficient.

From the regression analysis the displacement S was also found to be:

$$S = 0.0189 + 0.0007511V^2 - 0.0000446\ (T_A - T_W)_0 V^2 + 0.0000149\ (T_A - T_W)_{-1} V^2$$

(see Appendix 1)

If one neglects the first, third and fourth terms which are small compared to the second, the two expressions for S may be solved for c_d (suitable conversions being made to conform to proper units) giving $c_d = 2.46 \times 10^{-3}$.

The effect of stability (air-water temperature difference) is to slightly modify this value, with it increasing under unstable conditions and decreasing under stable conditions.

10. SOME RELEVANT COMMENTS AND DISCUSSION

A characteristic feature of the Lake St. Clair storm surge not explained by the above method of approach is the gradual and continuous build-up of the water level due to sustained winds. Such a build-up can be observed in the independent storms 8 and 9 for Belle River (see Appendix 1). In both these instances there were sustained winds of over 20 mph for about 18 to 24 hours. The regression relations give the level changes with respect to the calm level. But in cases of sustained winds the build-up is actually a cascading process, with the increase in level at each stage being reduced because of the opposing pressure gradient forces. Some attempts were made to account for this type of increase in water levels by using a six-hour cumulative wind speed squared, but with no apparent success. A 12- to 24-hour cumulative wind may be expected to yield better results. Little success was also achieved by trying to correlate the net force (= wind drag - pressure gradient force) with the increase in water level at each stage. The main source of error, or perhaps the main source of uncertainty, in this case is the estimate of the wind drag. Neglecting consideration of inertial effects also contribute to small errors in the net force estimates.

Among the dependent storms considered for Collingwood there were a few cases where water level increases of about one foot per hour were encountered. Such increases could not be accounted for by the regression relations. It is more than likely that these sharp increases of the water level were caused by the strong winds associated with squall lines.

An examination of the Point Edward (Lake Huron) water level records clearly shows the presence of short period oscillations with periods of about two hours. These oscillations have been recorded by the gauge because of its physical location close to the source of the St. Clair River. The nature of the basin surrounding the gauge perhaps produces these seiche oscillations.

Lake Erie water levels are greatly influenced by the seiches in the lake. The three principal seiches affecting the levels are:

(a) The seiche between Buffalo and Toledo,

(b) The seiche between Buffalo and Long Point, and

(c) The seiche between Toledo and Point Pelee.

At a given location on the lake two identical storms may produce maximum water level changes differing by more than two feet, depending on the part of the cycle the seiche is in, at the time of maximum winds. The seiche effects can be clearly seen in many of the water level records of Lake Erie (see plots in Appendices 5 and 6). The period of the lake-wide seiche has been established to be approximately 14 hours. A regression analysis of the water level data filtered to eliminate oscillations with periods of 12 to 16 hours, did give better correlations with reduced standard errors. However, the reduction in the standard error of estimate may also be the consequence of a general reduction of peak levels due to filtering. An important drawback of the filtering technique is that it would not be possible to arrive at the actual levels from the filtered levels, though it is the former that one is interested in ultimately.

11. RECOMMENDATIONS

Lake St. Clair

A further study of storms with level build-up due to sustained winds needs to be carried out. Such storms could in fact be potentially the most damaging. A dynamical study of such storms may be expected to yield results as good as those obtained from a statistical approach with a number of such storms included.

The response of Lake St. Clair to wind stress may be characterized as "instantaneous." A theoretical study based on lake response to suddenly imposed winds should produce a good deal of insight into the problem.

Lake Ontario at Burlington

Only thirteen dependent storms have been used to derive the regression relationships for the water level at Burlington. The relationships could be independently derived using more dependent storms. On the other hand, the same purpose is also served by checking the relationships derived here with more independent cases.

Among the storms selected here there are none with abrupt increases in water level. The theory that these abrupt changes in water level are produced by squall lines is to be verified by checking the weather maps for the presence of squall lines over the area of concern. If their presence is in fact confirmed, further study of these storms would be most desirable.

Georgian Bay at Collingwood and Lake Huron at Point Edward

Comments made for Lake Ontario on storms with abrupt level changes also apply here. A seiche model may be developed for the short period oscillations at Point Edward.

Lake Erie at Port Colborne and Kingsville

For a successful forecast of Lake Erie water levels, the initial level will have to be properly specified. This would require up-to-the-minute data on the part of the cycle the seiche is in. This can be done by continuous monitoring of the water level at appropriate stations. The technique of filtering the data to eliminate the seiche oscillations needs to be further explored. Resonance effects produced by the storm moving at the same speed as the seiche "wave" also warrant careful consideration.

In general, the regression relationships developed for the different lakes need to be further substantiated with more independent storms. Beginning with the summer of 1974, Toronto Weather Office will be using these relationships to predict storm surges occurring on the Great Lakes, a good test of their validation.

REFERENCES

BARRIENTOS, C.S. (1970) An Objective Method for Forecasting Winds Over Lake Erie and Lake Ontario ESSA Technical Memorandum, WBTM, TDL 34.

EFROYMSON, M.A. (1962) "Multiple Regression Analysis" in Mathematical Methods for Digital Computers By Ralston, A., and Wilf, H.S., Wiley and Sons Vol. 1

FREEMAN, N.G. & MURTY, T.S. (1972) A Study of a Storm Surge on Lake Huron. Proceedings 15th Conference Great Lakes Research p.p. 565-82

HUNT, I.A. (1958, 59) Winds, Wind-Set-ups, and Seiches on Lake Erie, Parts 1, 2. U.S. Corps of Engineers, Lake Survey

HAMBLIN, P.F. & BUDGELL, N.P. (1973) Wind-induced Water Level Changes on the Southeastern Shore of Lake St. Clair C.C.I.W. Paper No. 12

HARRIS, D.L. & ANGELO, A. (1963) A Regression Model for Storm Surge Prediction. Monthly Weather Review Vol. 21 p.p. 701-726

JELESNIANSKI, (1966, 67) Numerical Computations of Storm Surges With Bottom Stress. Monthly Weather Review Vol. 95

JELESNIANSKI, (1970) "Bottom Stress Time-History" in Linearized Equations of Motion for Storm Surges. Monthly Weather Review Vol. 98

KEULEGAN, G.H. (1953) Hydrodynamic Effects of Gales on Lake Erie: Journal of Research, National Bureau of Standards 50 p.p. 99-109

MURTY, T.S. and FREEMAN, N.G. (1973) Storm Surge Models of Lake Huron. 16th Conference on Great Lakes Research

McCLURE, D.J. (1970) Dynamic Forecasting of Lake Erie Water Levels Report No. 70-250-H, Hydro-Electric Power Commission of Ontario. Research Division Report.

PLATZMAN, G.W. (1963) The Dynamical Prediction of Wind Tides on Lake Erie. Meteorological Monographs Vol. 4, No. 26 p.p. 1-44

REFERENCES (Cont'd.)

RICHARDSON, W.S. and PORE, N.A.	(1969 Aug.)	A Lake Erie Storm Surge Forecasting Technique. ESSA Technical Memorandum WBTM, TDL 24
RICHARDSON, W.S. and PORE, N.A.	(1972 Sept.)	Weather Service Program in Lake Erie Storm Surge Forecasting. T.D.L. Report
RICHARDS, T.L. & IRBE, J.G.	(1969)	Estimates of Monthly Evaporation Losses From the Great Lakes 1950 to 1968 Based on the Mass Transfer Technique. Proceedings 12th Conference Great Lakes Research p.p. 469-87
RICHARDS, T.L. DRAGERT, H, & McINTYRE, D.R.	(1966)	Influence of Atmospheric Stability and Over Water Fetch of Winds Over the Lower Great Lakes. Monthly Weather Review Vol. 94
WELANDER, P.	(1961)	Numerical Prediction of Storm Surges. Advances in Geophysics 8-316-379 New York Academic Press 392 p.p.

TABLE 1

List of stations for determining sea level pressures at each of the eleven grid points

Grid Point	Station Name	Station Code
1	Lexington	LEX
	Cincinnati	CVG
	Huntington	HTS
2	Roanoke	ROA
	Beckley	BKW
	Elkins	EKN
3	Fort Wayne	FWA
	Toledo	TOL
	Columbus	CMH
4	Youngstown	YNG
	Erie	ERI
	Bradford	BFD
5	Wilkes Barre	AVP
6	Houghton Lake	HTL
	Oscada	OSC
	Sault Ste. Marie	SSM
7	Wiarton, A.	YVV
	Mount Forest	WMN
	Muskoka, A.	YQA
8	Trenton	YTR
	Ottawa Int. A.	YOW
	Massena (U.S.A.)	MSS
9	White River	YWR
	Sault Ste. Marie	YAM
	Timmins	YTS
10	Earlton, A.	YXR
11	Val d'Or, A.	YVO
	Roberval, A.	YRJ
	Ottawa Int. A.	YOW

TABLE 2

List of first order weather stations used to obtain air temperatures at the water level stations

Station No.	Water Level Stations	Air Temperature Stations	
11965	Belle River	Windsor, A.	(YQG)
13150	Burlington	Toronto Int. A.	(YYZ)
11500	Collingwood	Wiarton	(YVV)
11940	Point Edward	Windsor	(YQG)
12865	Port Colborne	Simcoe	(WMK)
12065	Kingsville	Windsor	(YQG)

TABLE 3

Number of dependent and independent storms
- by location

Location	Number of dependent storms	Number of independent storms
Belle River	24	6
Burlington	13	8
Collingwood	21	6
Point Edward	29	5
Port Colborne	26	9
Kingsville	14	9

TABLE 4

Standard Error of Estimates

Station	Standard Errors of Dependent Storms (ft.)	Proportion Of Variation Explained (%)	Standard Errors of Independent Storms (ft.)
Lake St. Clair at Belle River	0.20074	54.1	0.118
Lake Ontario at Burlington	*0.195	73.9	0.235
	0.201	70.5	
	0.223	67.2	
	0.230	66.5	
	0.227	68.4	
	0.228	64.1	
Georgian Bay at Collingwood	*0.295	56.8	0.257
	0.291	59.3	
	0.284	62.0	
	0.274	62.3	
	0.280	57.8	
	0.283	57.8	
Lake Huron at Point Edward	*0.280	52.1	0.221
	0.272	55.2	
	0.256	58.8	
	0.247	59.7	
	0.269	55.2	
	0.273	52.0	
Lake Erie at Port Colborne	*0.620	61.6	0.495
	0.597	65.0	
	0.567	67.5	
	0.569	67.5	
	0.601	64.1	
	0.628	61.7	
Lake Erie at Kingsville	*0.546	55.4	0.398
	0.525	57.4	
	0.549	56.2	
	0.591	51.9	
	0.545	55.4	
	0.533	56.5	

* The six values of standard errors are for water levels measured at 0, 1, 2, 3, 4 and 5 hours after the time of pressure measurement.

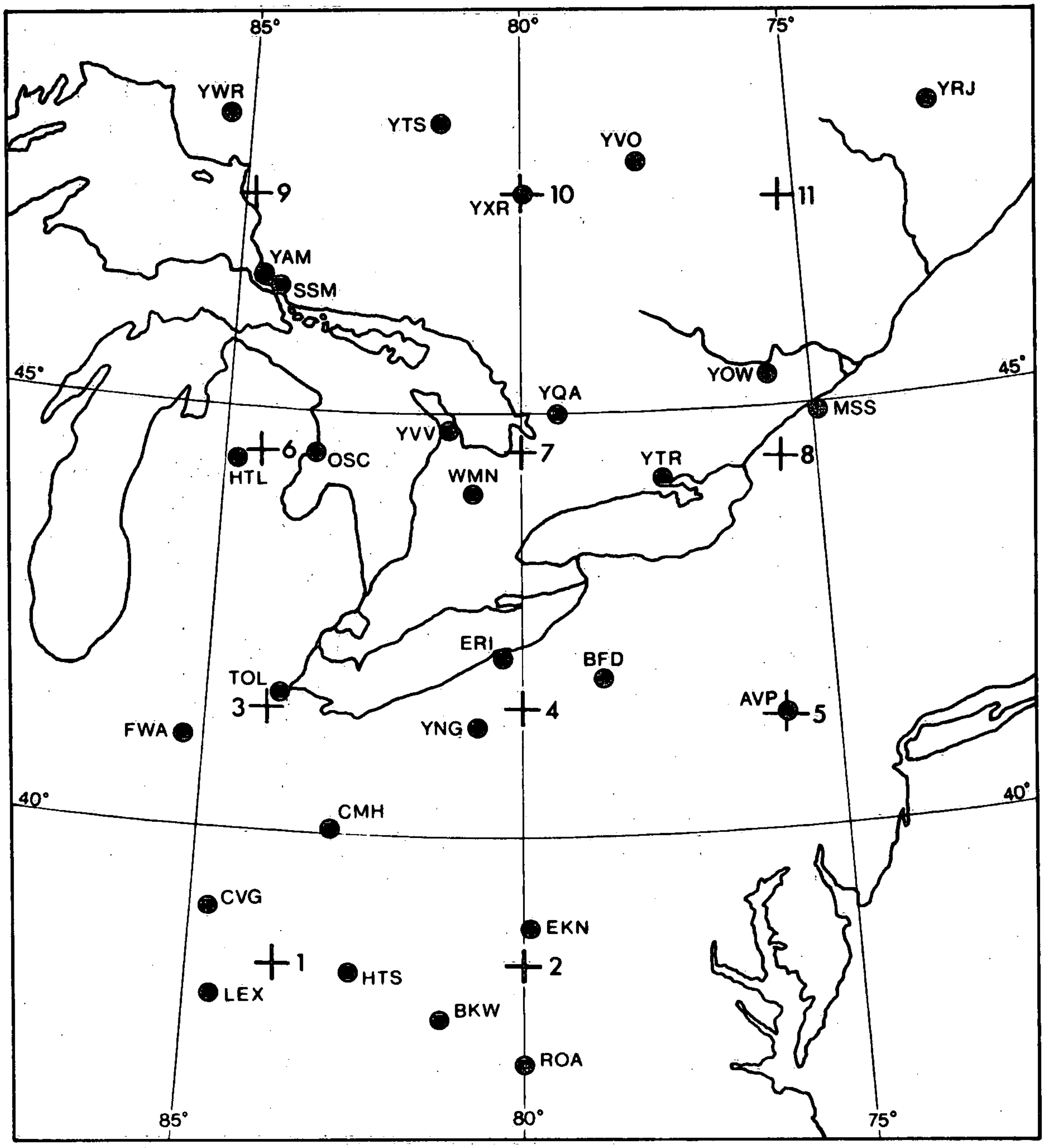
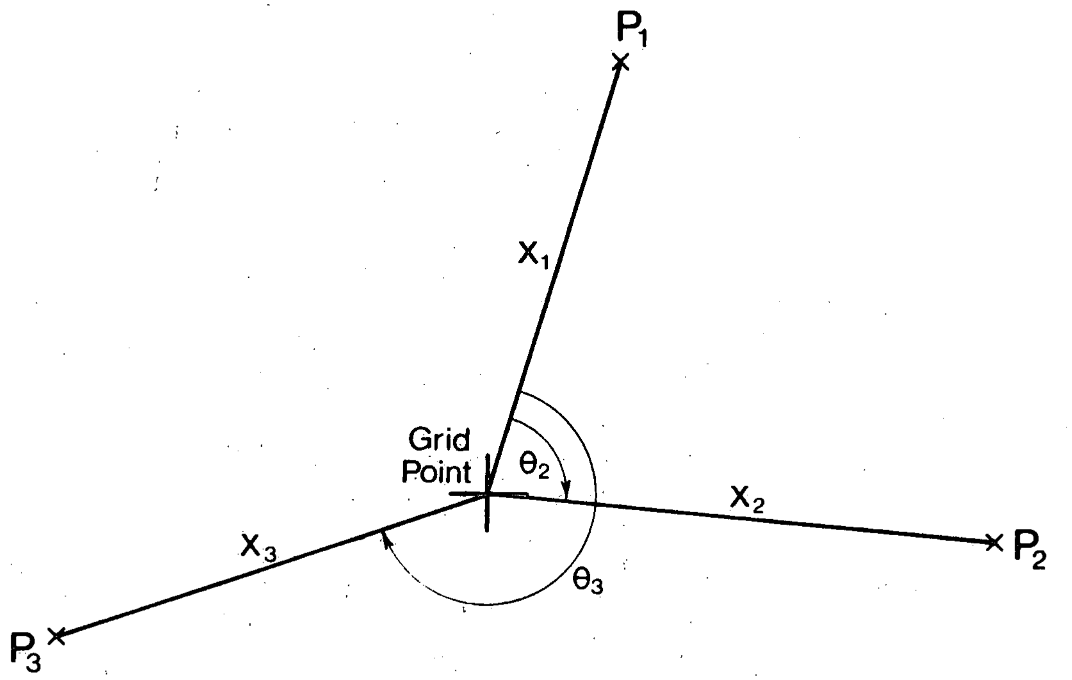


Figure 1. Location of grid points and associated observing stations.



$$P_1 = Ax_1 + C$$
$$P_2 = Ax_2 + B\theta_2 + C$$
$$P_3 = Ax_3 + B\theta_3 + C$$

grid point pressure is given by the value of C

Figure 2. Objective analysis to obtain grid point sea level pressure.

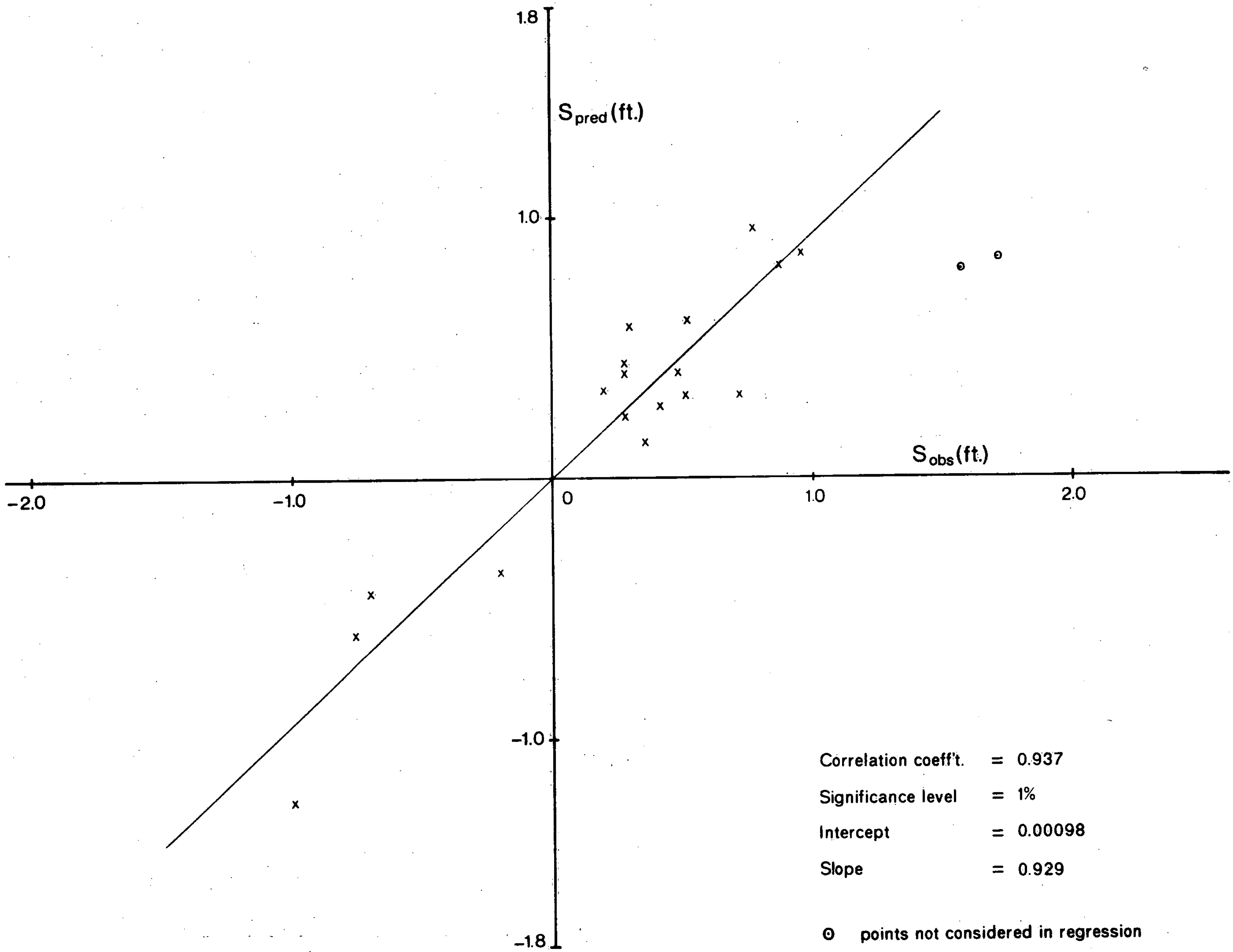


Figure 3. Observed vs. Predicted Max./Min. Levels
Lake St. Clair at Belle River

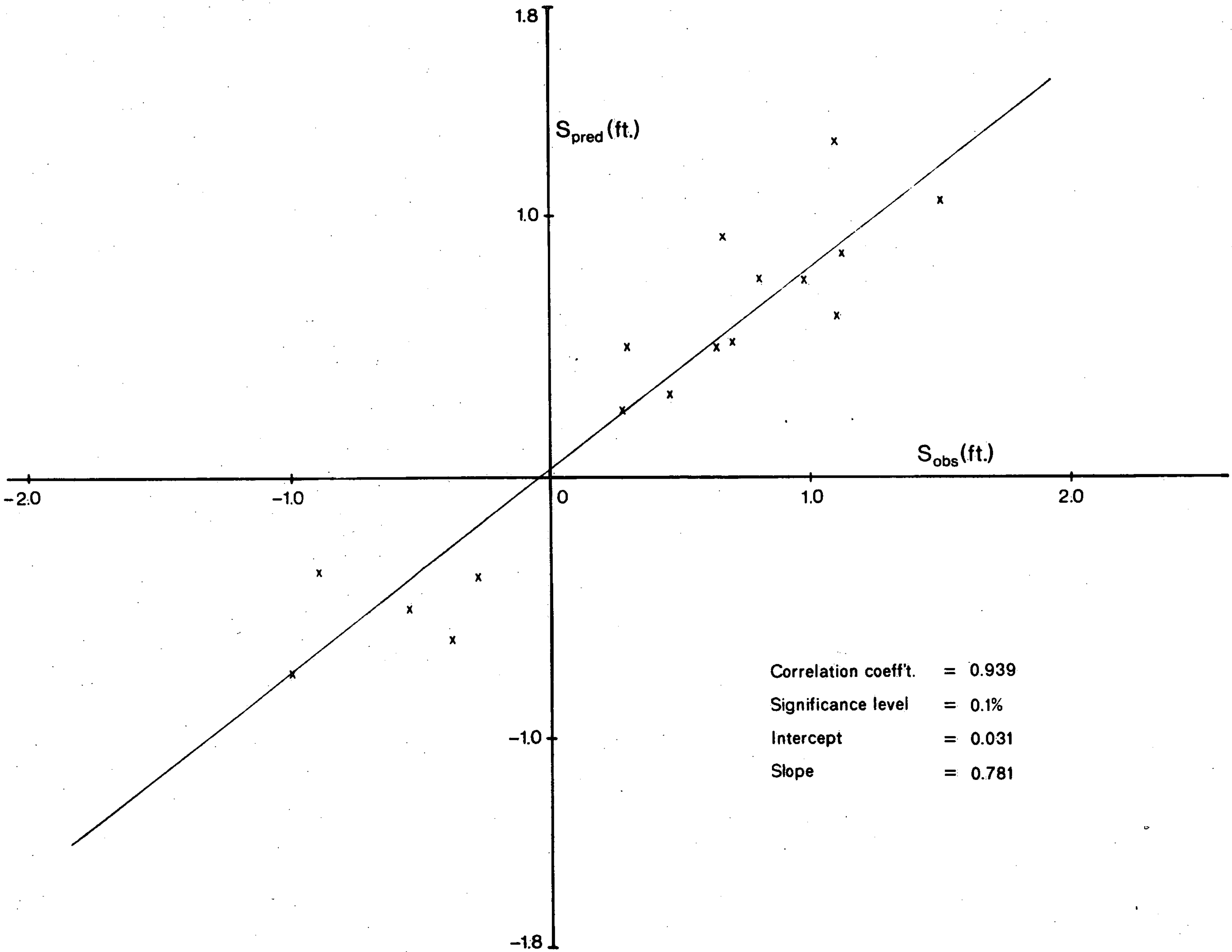


Figure 4. Observed vs. Predicted Max./Min. Levels
Lake Ontario at Burlington

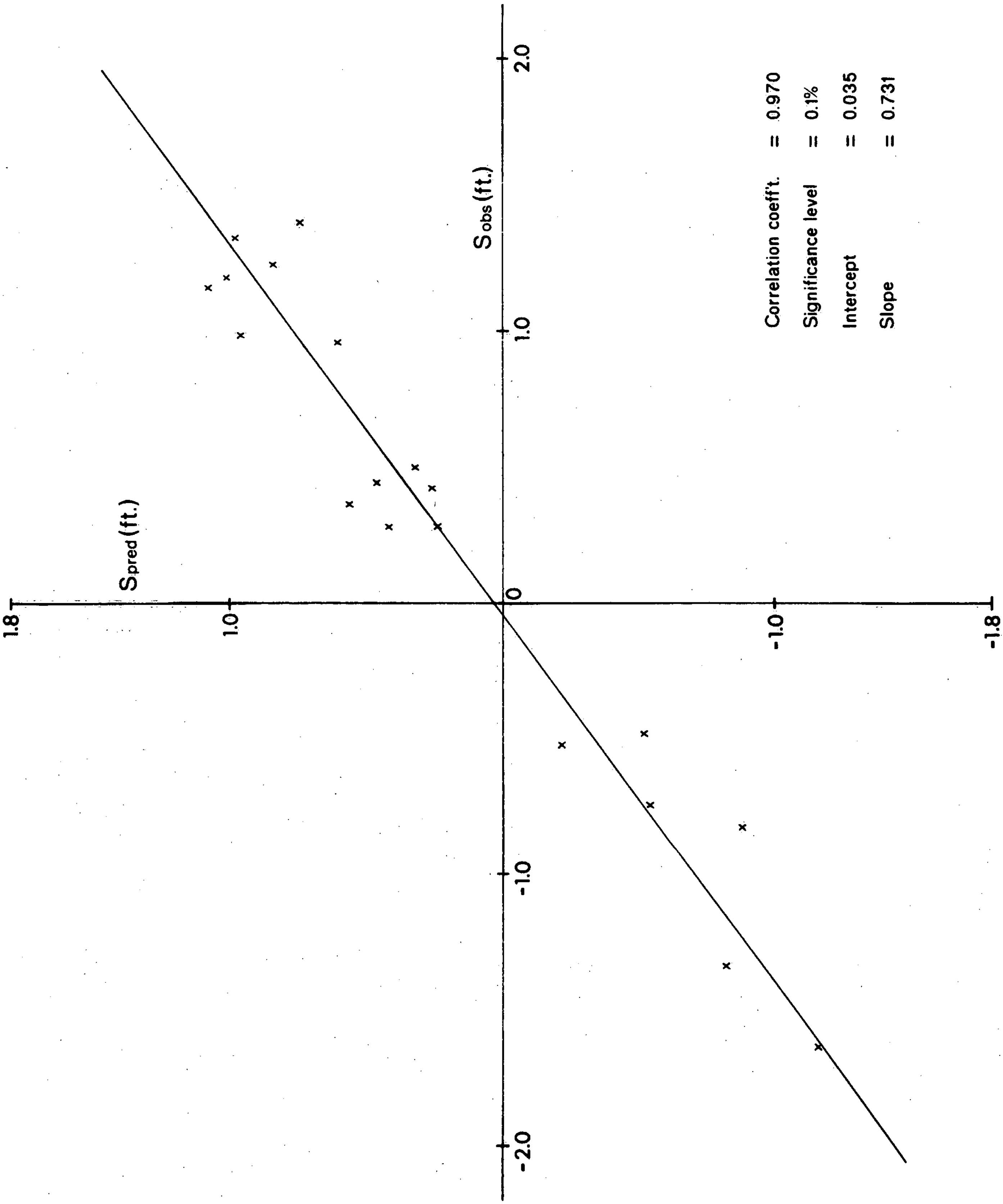


Figure 5. Observed vs. Predicted Max./Min. Levels
Georgian Bay at Collingwood

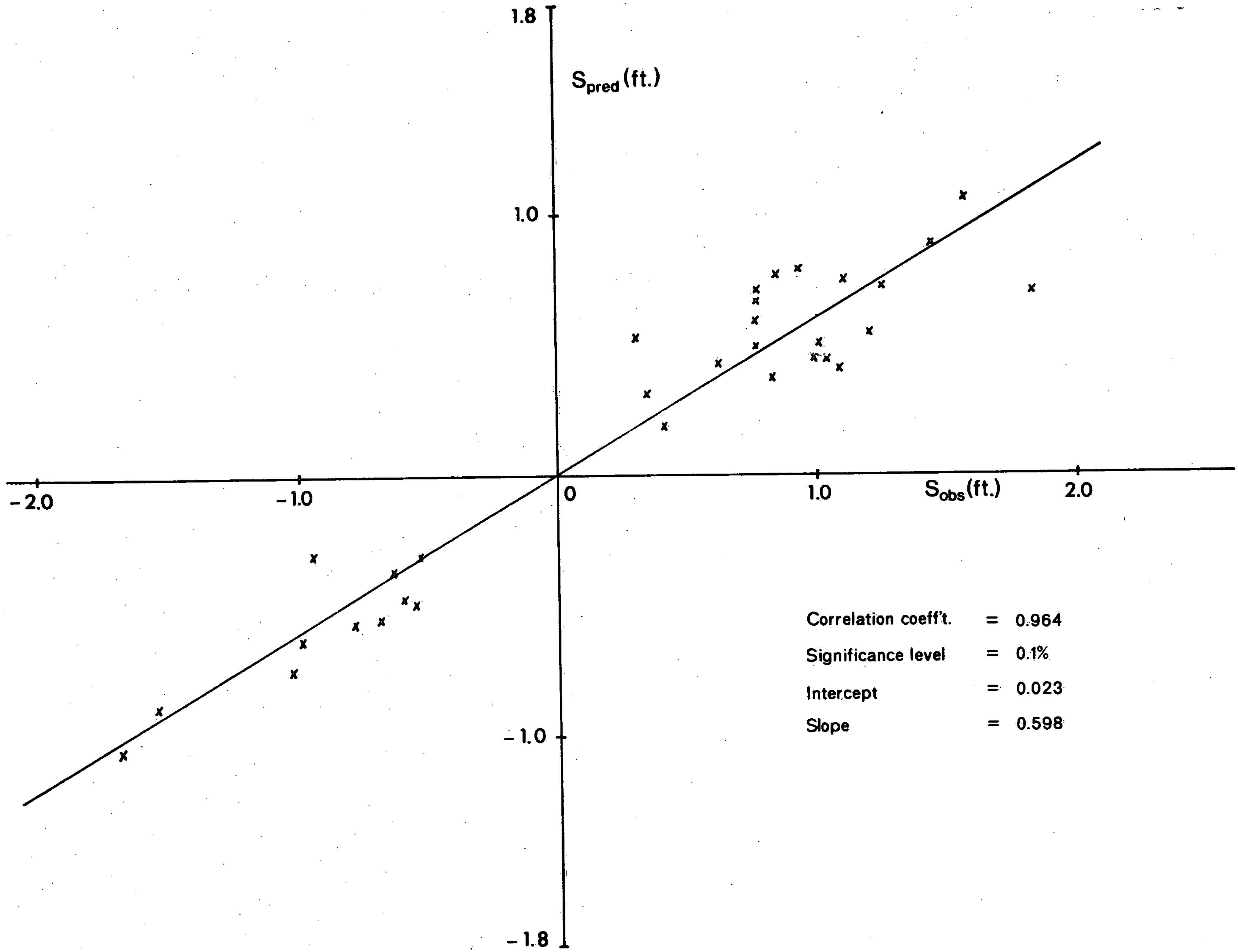


Figure 6. Observed vs. Predicted Max./Min. Levels
Lake Huron at Point Edward

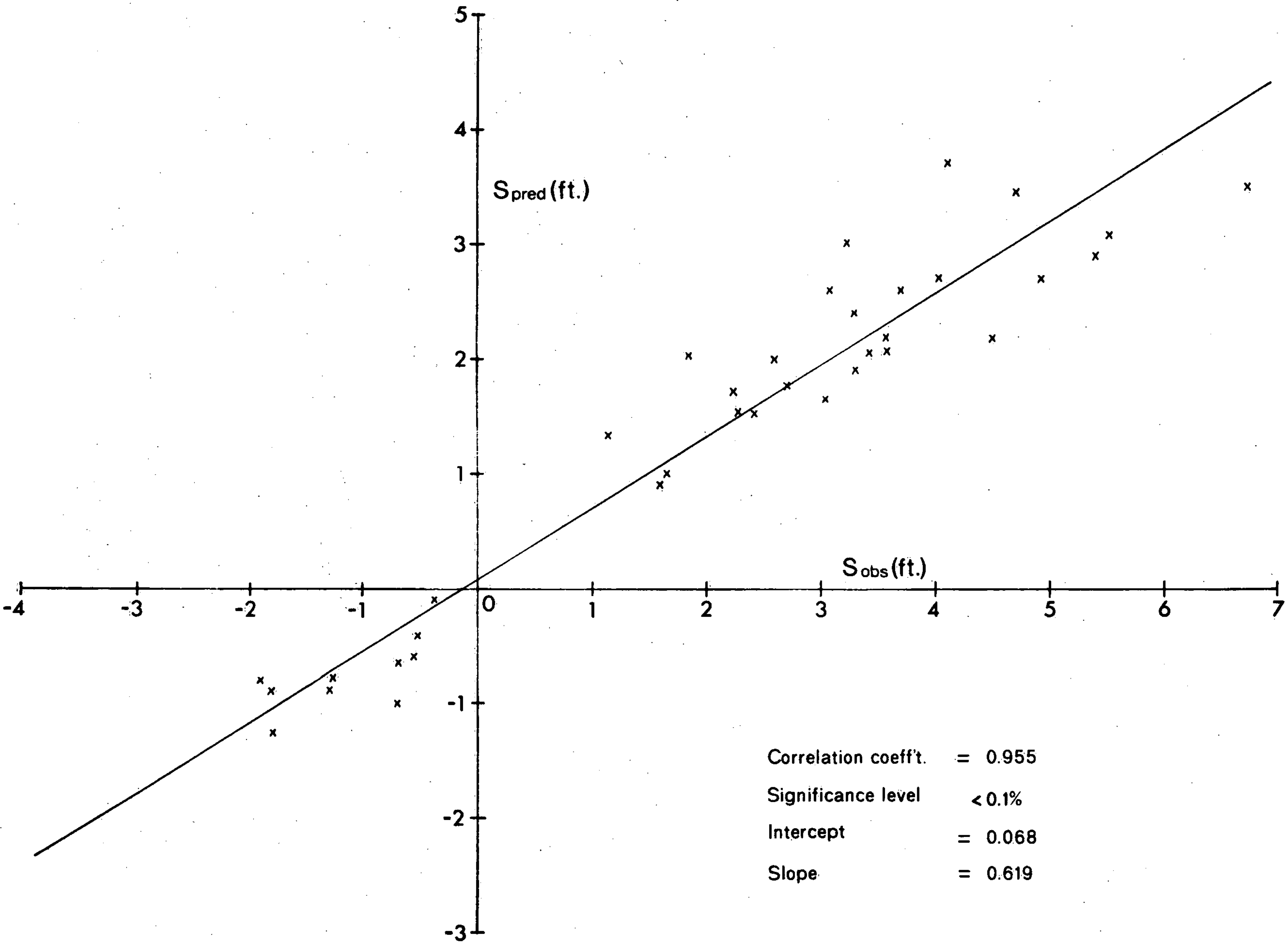


Figure 7. Observed vs. Predicted Max./Min. Levels
Lake Erie at Port Colborne

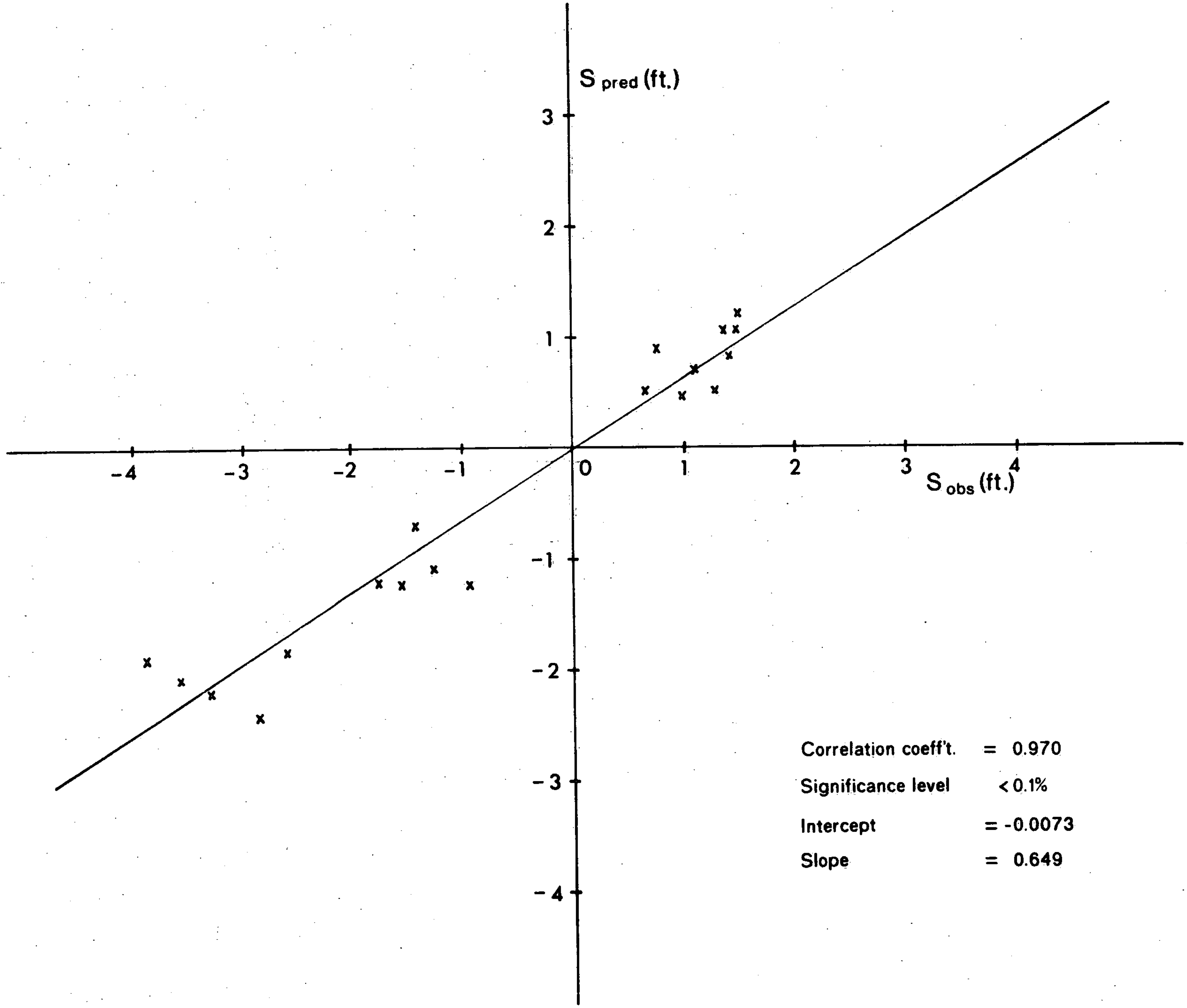


Figure 8. Observed vs. Predicted Max./Min. Levels.
Lake Erie at Kingsville

APPENDIX 1

The convention adopted in the plots following is:

-x-x-x-x- observed water levels

——————— computed water levels

STORM SURGE PREDICTION EQUATIONS

for Lake St. Clair at Belle River

$$S = 0.0189 + .0007511\, V^2 - 0.0000446(T_A - T_W)_0 V^2 + 0.0000149(T_A - T_W)_{-1} V^2$$

where

S = Surge in feet from mean water level

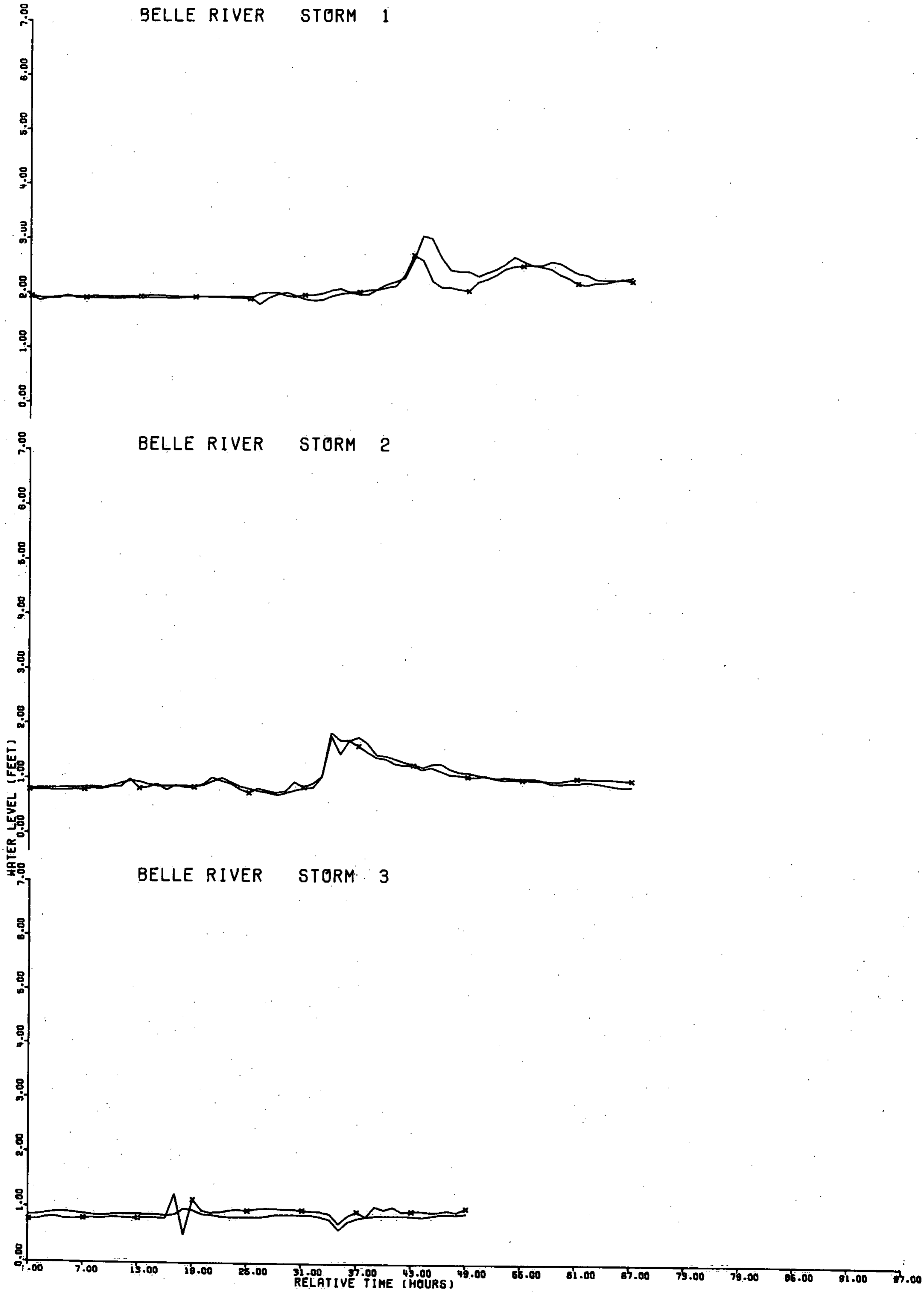
V^2 = Component of effective wind speed in the north-south direction

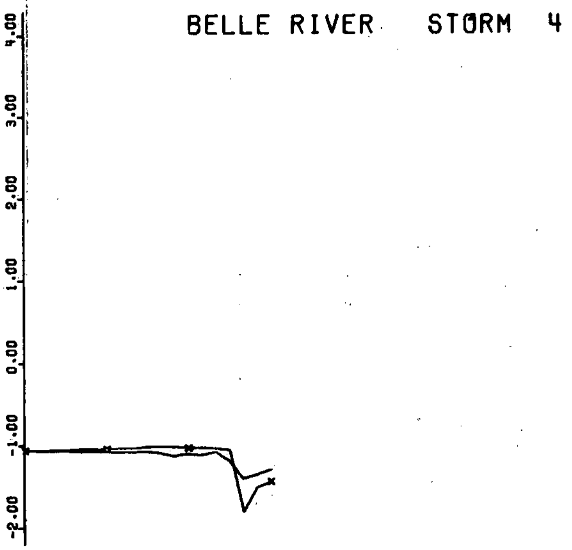
$(T_A - T_W)_{0\&-1}$ = Air-water temperature difference at 0 and 1 hour lag times

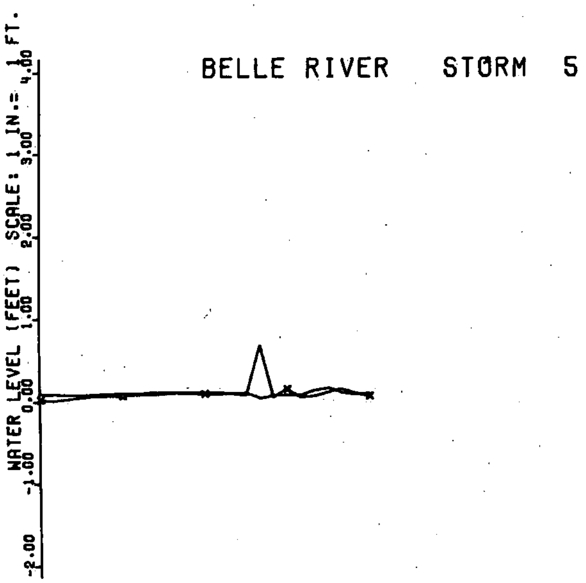
Lake St. Clair (Belle River) Storm Dates

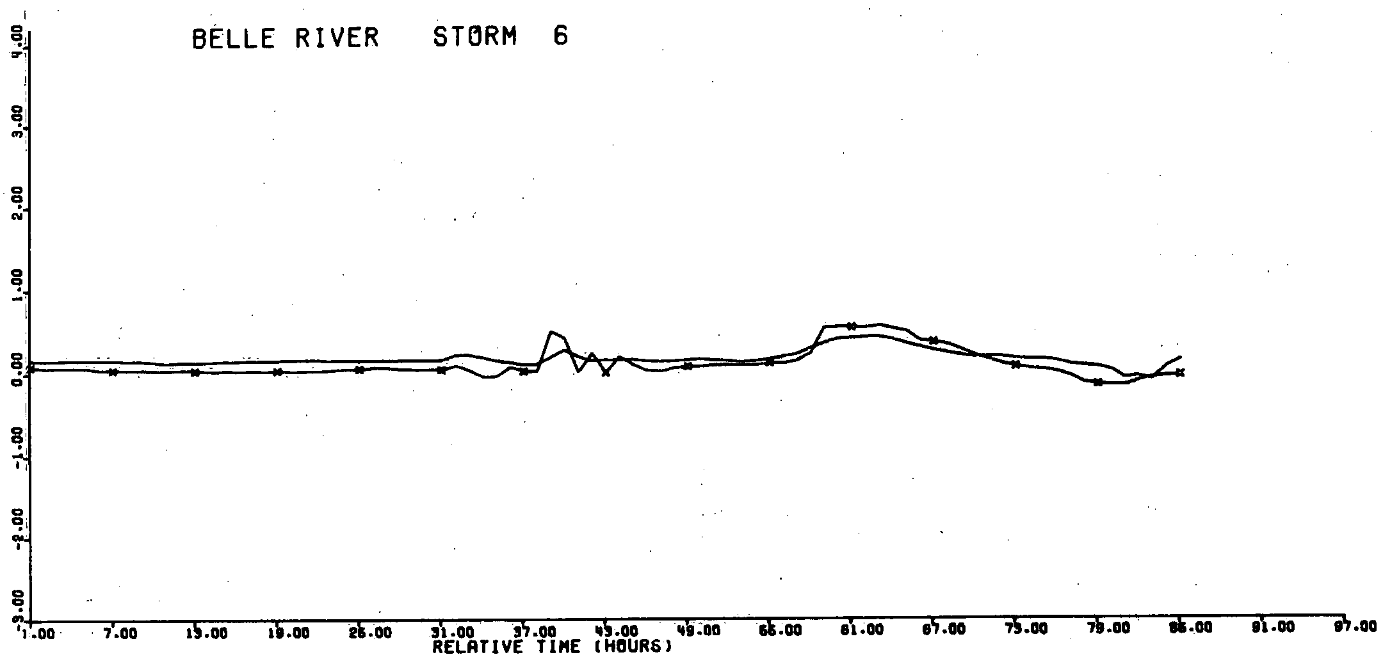
Sl. No.	Dependent Storms yr/mo/day/hr (EST)		Sl. No.	Independent Storms yr/mo/day/hr (EST)	
	Start	End		Start	End
1	61/06/12/13	61/06/15/07	1	72/04/05/19	72/04/09/12
2	63/05/09/07	63/05/09/01	2	72/05/29/07	72/06/01/12
3	63/06/09/07	63/06/11/07	3	72/07/19/19	72/06/24/18
4	64/03/04/13	64/03/05/07	4	72/10/14/07	72/10/17/18
5	64/06/19/07	64/06/20/07	5	72/12/16/07	72/12/18/18
6	64/07/10/07	64/07/13/19	6	72/12/25/19	72/12/28/18
7	65/11/15/13	65/11/18/07			
8	65/12/23/19	65/12/27/01			
9	66/11/01/13	66/11/04/13			
10	67/04/21/07	67/04/23/19			
11	67/06/16/07	67/06/17/01			
12	67/07/13/07	67/07/14/01			
13	67/09/08/13	67/09/11/13			
14	68/08/16/07	68/08/17/01			
15	70/03/25/13	70/03/27/01			
16	70/12/03/07	70/12/03/19			
17	71/03/19/07	71/03/21/01			
18	71/04/08/19	71/04/09/13			
19	71/04/22/19	71/04/25/13			
20	71/05/01/19	71/05/04/07			
21	71/06/05/19	71/06/08/13			
22	71/06/12/13	71/06/13/07			
23	71/06/28/07	71/06/30/01			
24	71/08/21/13	71/08/24/07			

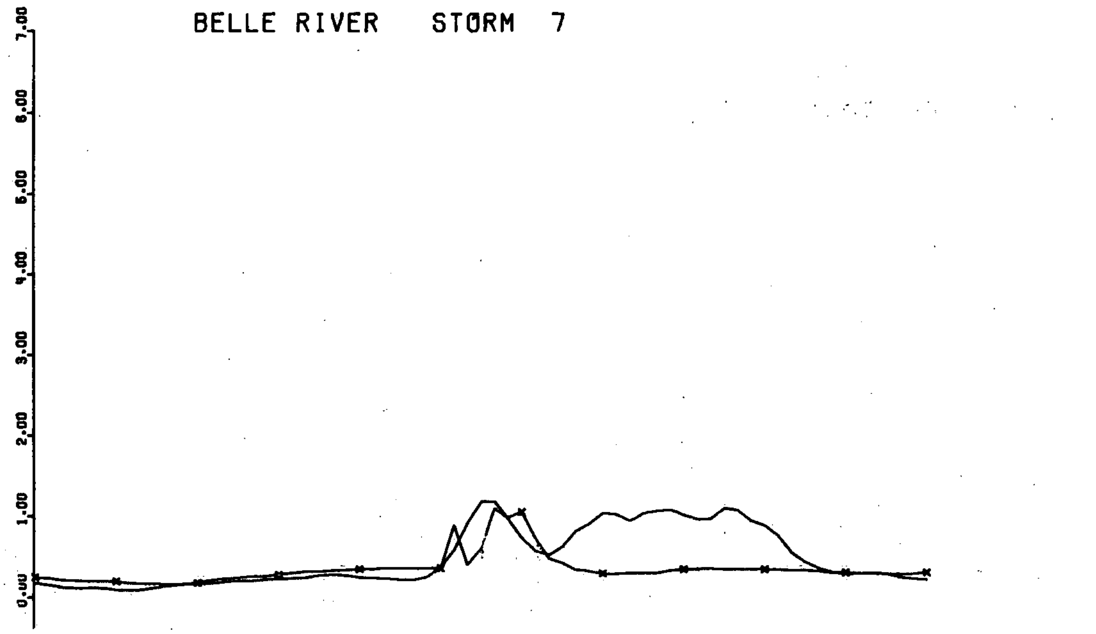
DEPENDENT STORMS

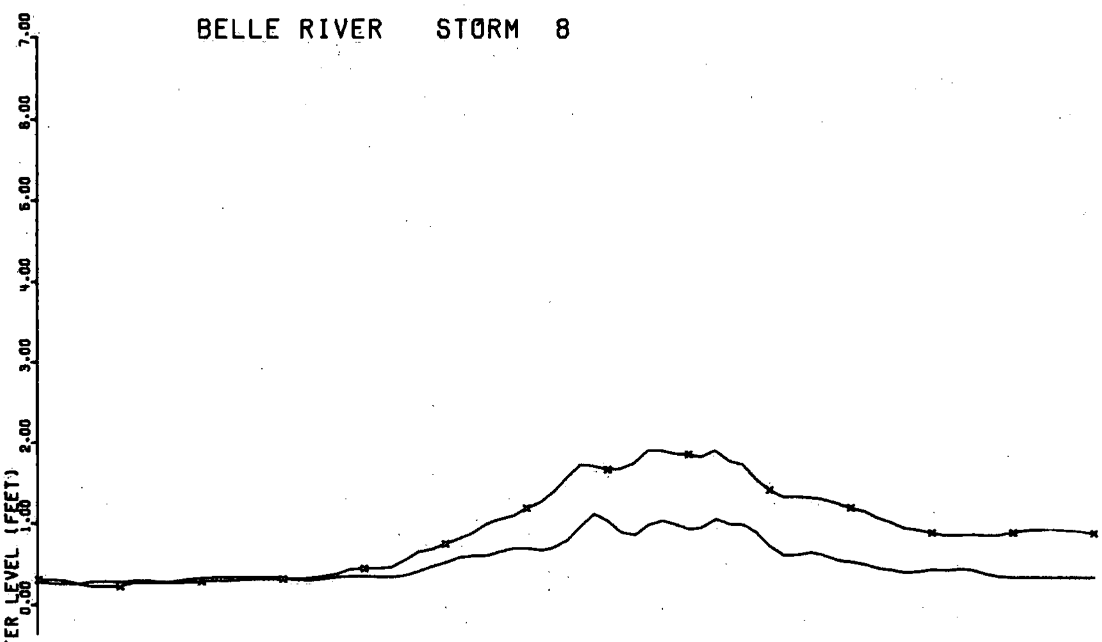

BELLE RIVER STORM 1
BELLE RIVER STORM 2
BELLE RIVER STORM 3
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00

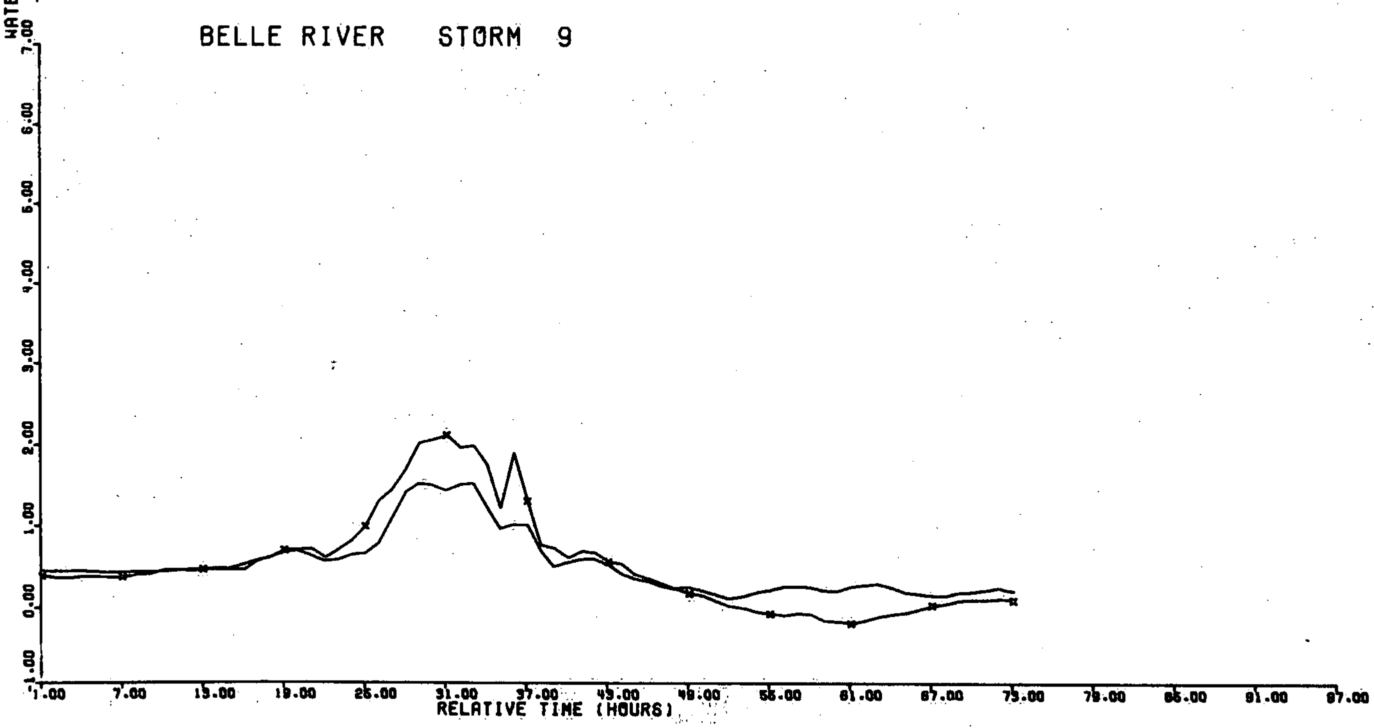

BELLE RIVER STORM 4
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00

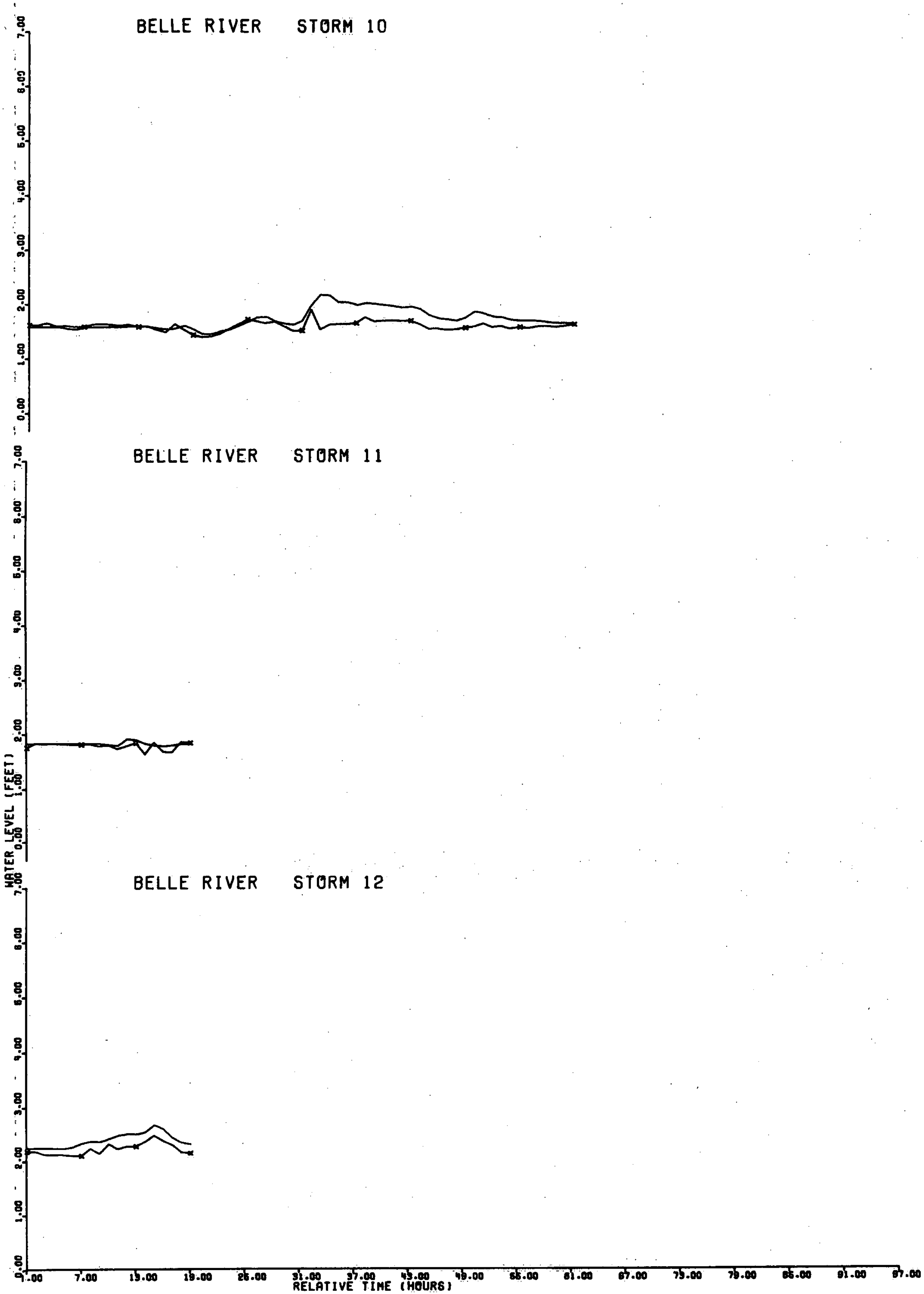

BELLE RIVER STORM 5
WATER LEVEL (FEET) SCALE: 1 IN.= 1 FT.
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00


BELLE RIVER STORM 6
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
1.00 7.00 13.00 19.00 25.00 31.00 37.00 43.00 49.00 55.00 61.00 67.00 73.00 79.00 85.00 91.00 97.00
RELATIVE TIME (HOURS)

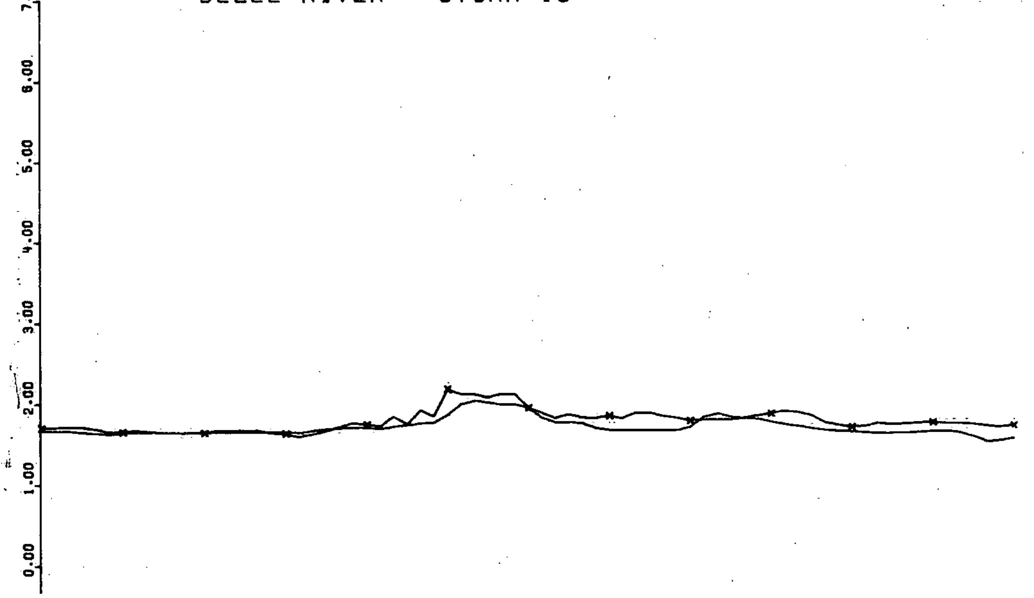

BELLE RIVER STORM 7


BELLE RIVER STORM 8
WATER LEVEL (FEET)

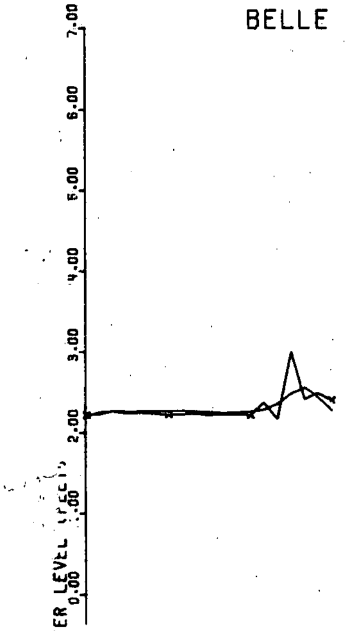

BELLE RIVER STORM 9
RELATIVE TIME (HOURS)


BELLE RIVER STORM 10
BELLE RIVER STORM 11
BELLE RIVER STORM 12
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00

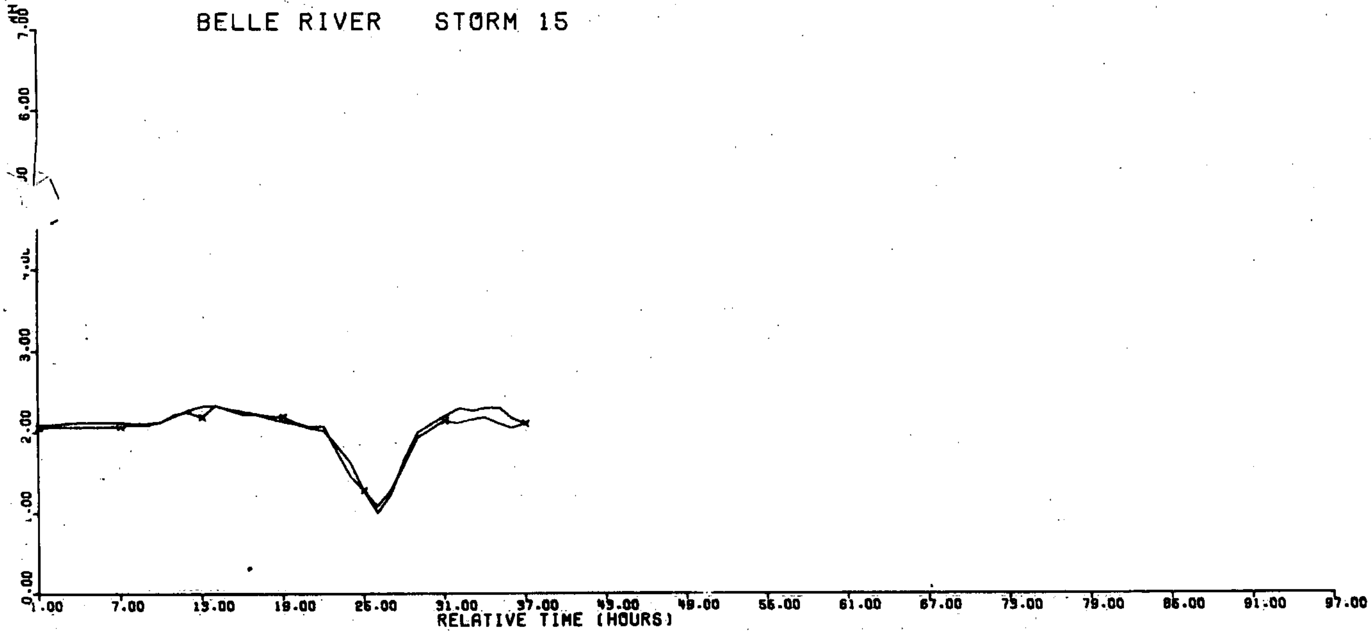
BELLE RIVER STORM 13

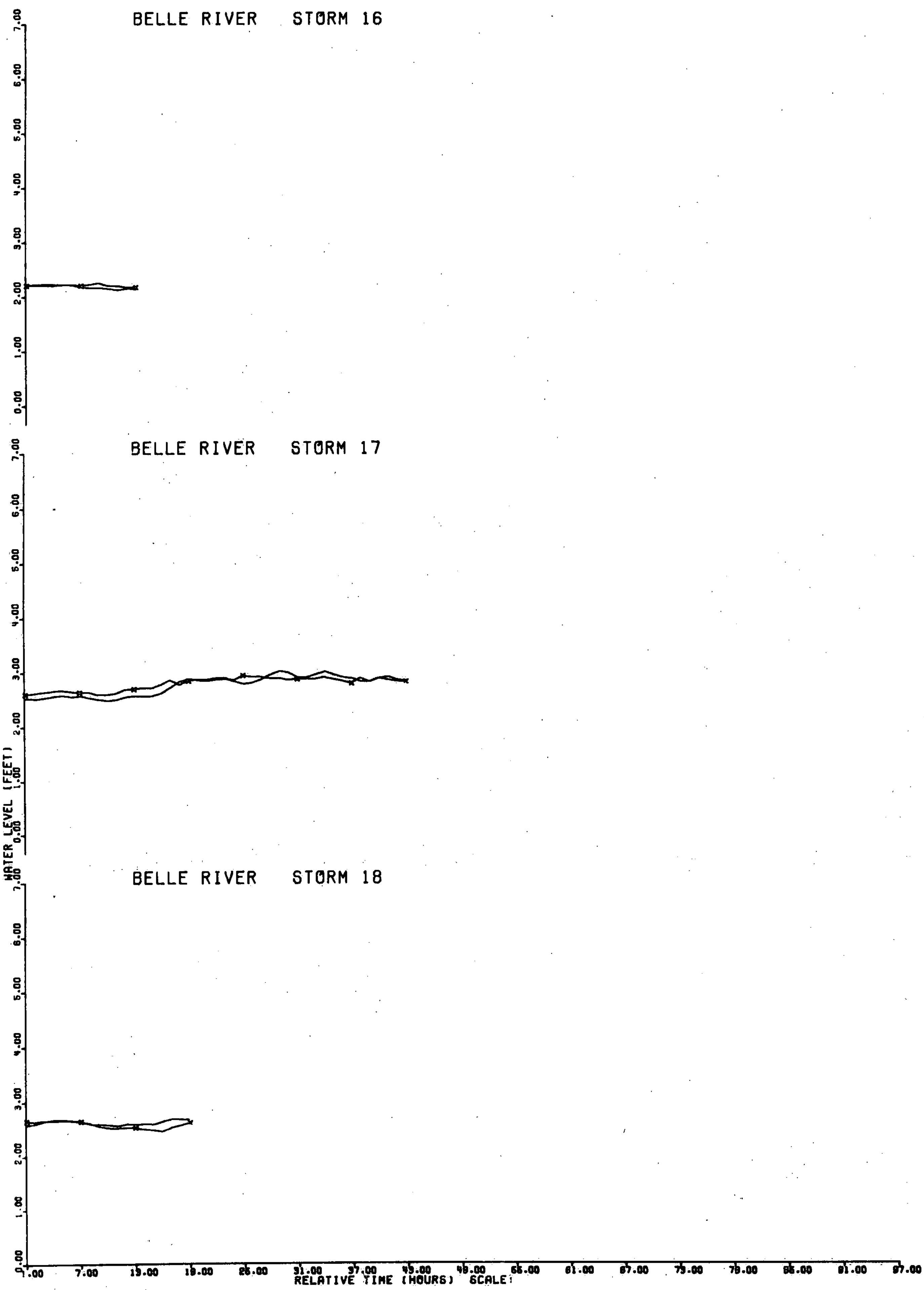


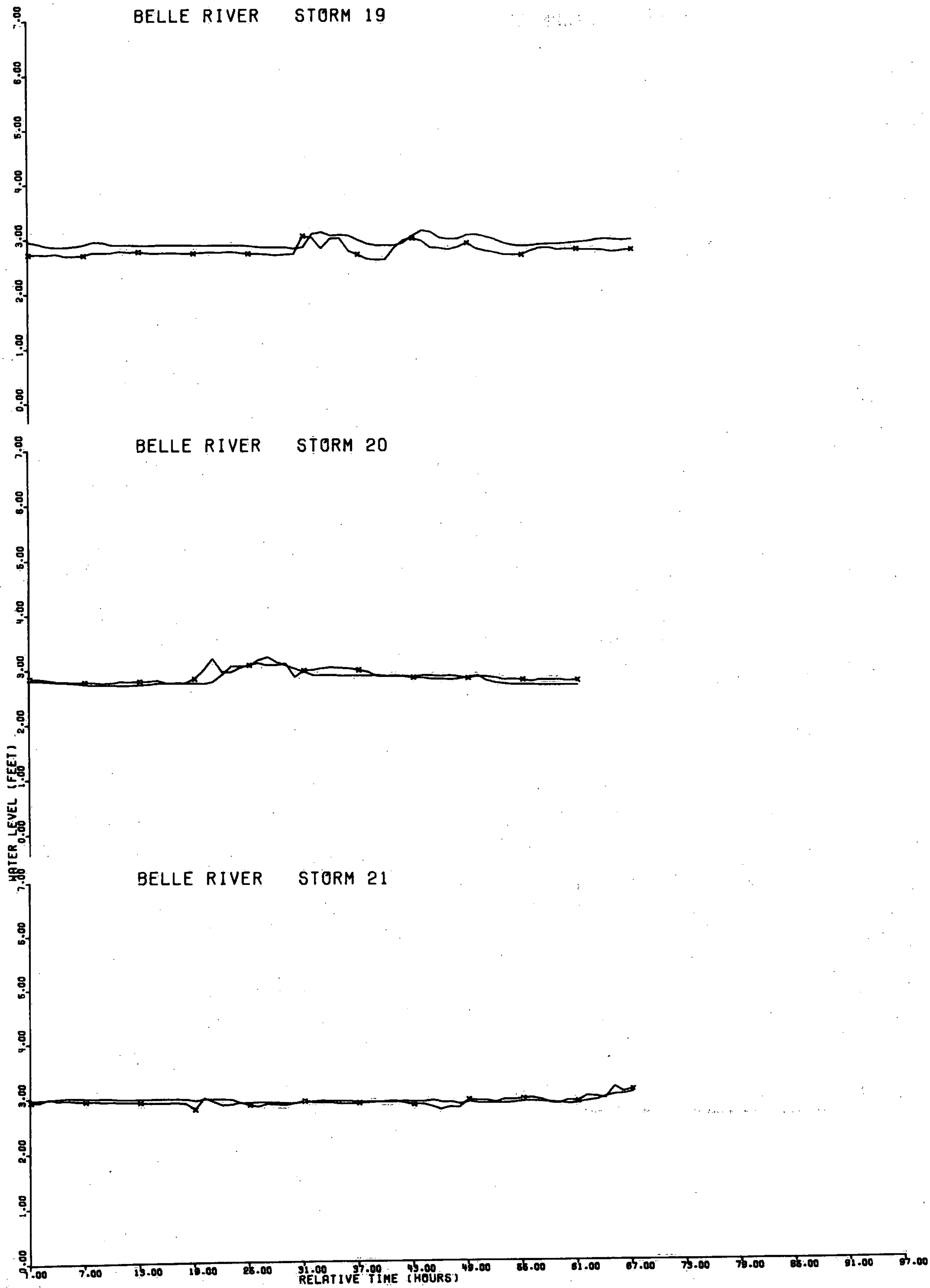
BELLE RIVER STORM 14

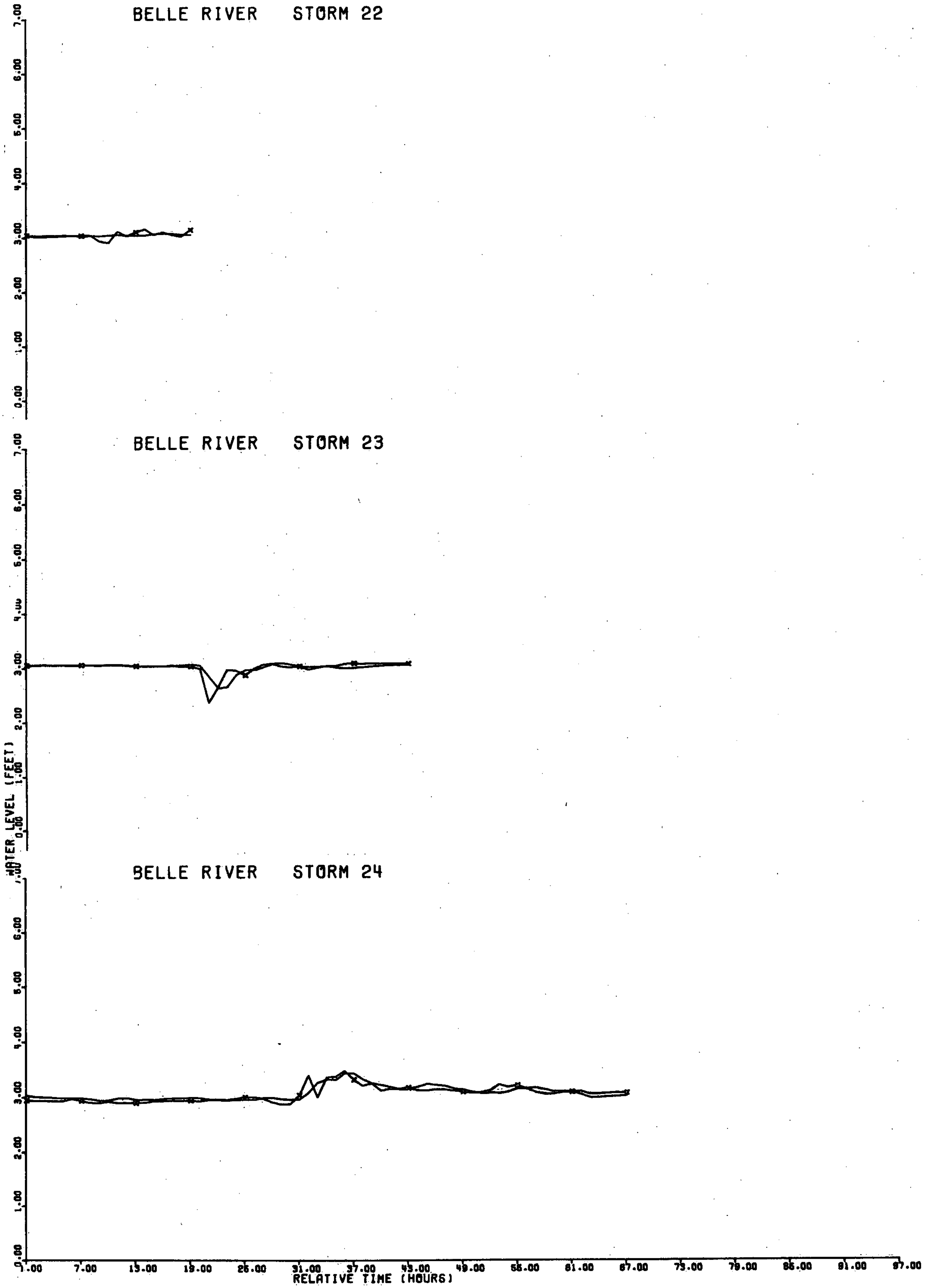


BELLE RIVER STORM 15

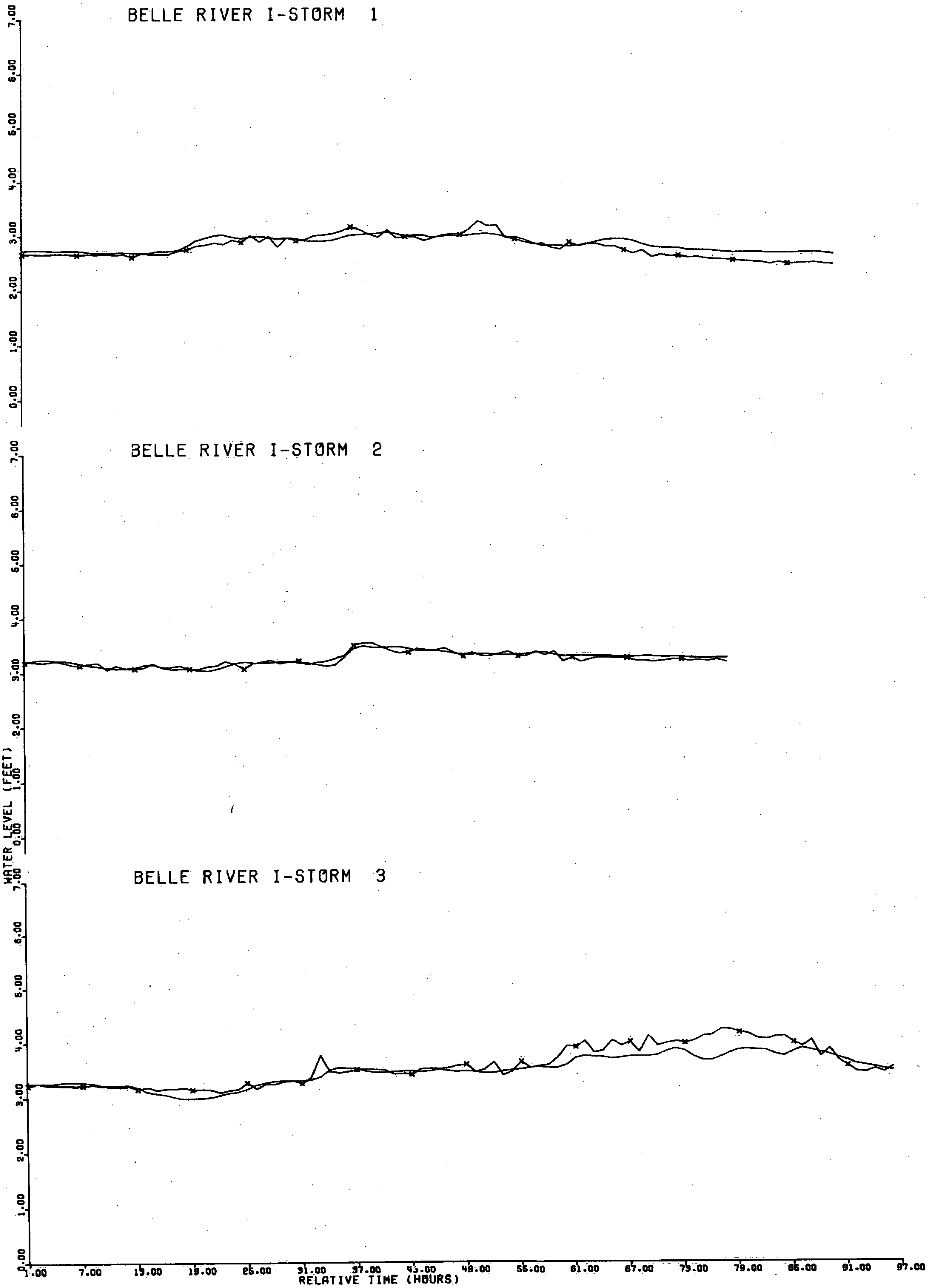


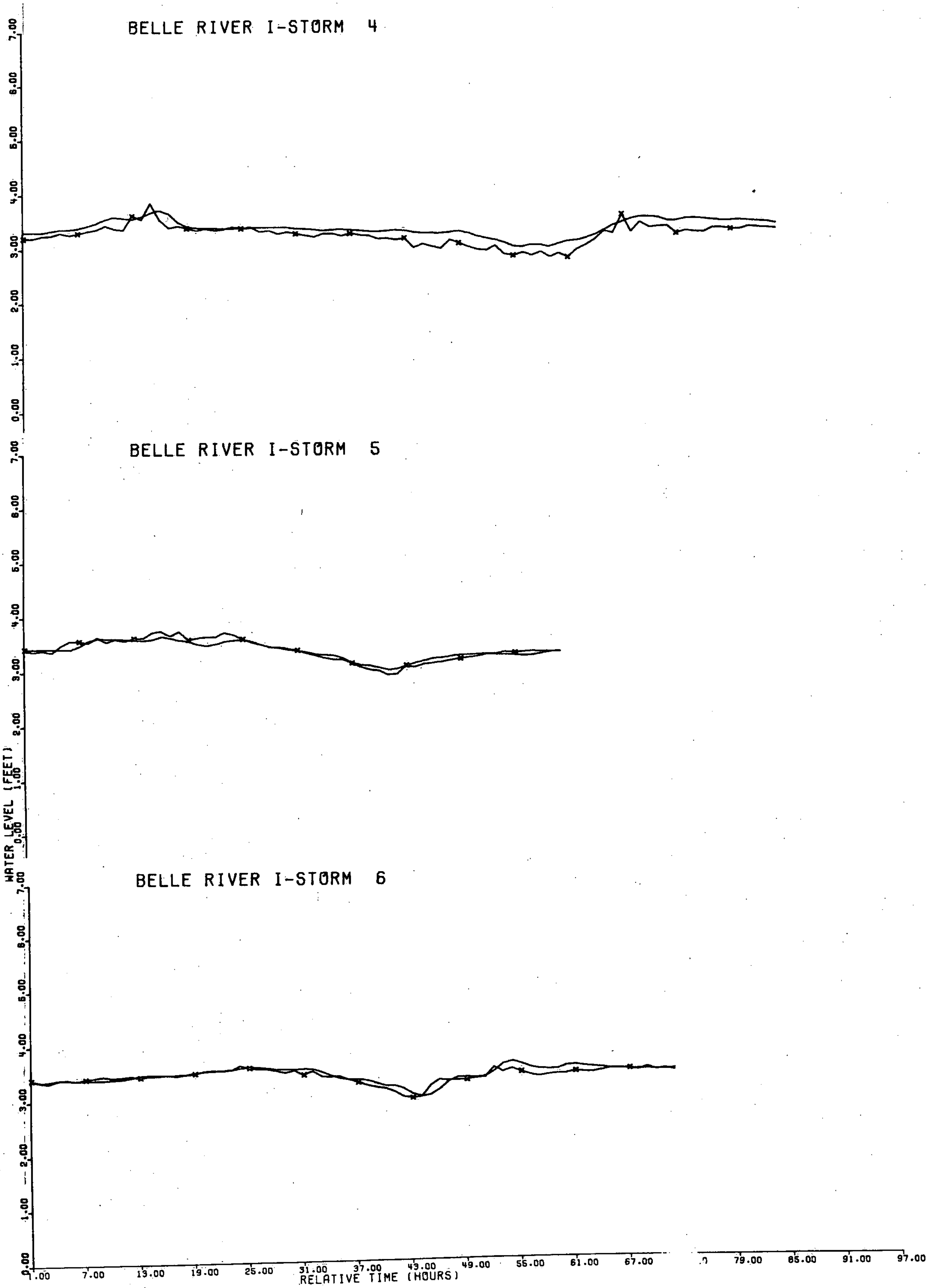

BELLE RIVER STORM 16
BELLE RIVER STORM 17
BELLE RIVER STORM 18
WATER LEVEL (FEET)
0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00
1.00 7.00 13.00 19.00 25.00 31.00 37.00 43.00 49.00 55.00 61.00 67.00 73.00 79.00 85.00 91.00 97.00
RELATIVE TIME (HOURS) SCALE:


BELLE RIVER STORM 19
BELLE RIVER STORM 20
BELLE RIVER STORM 21
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)


BELLE RIVER STORM 22
BELLE RIVER STORM 23
BELLE RIVER STORM 24
WATER LEVEL (FEET)
0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00
1.00 7.00 13.00 19.00 25.00 31.00 37.00 43.00 49.00 55.00 61.00 67.00 73.00 79.00 85.00 91.00 97.00
RELATIVE TIME (HOURS)

INDEPENDENT STORMS


BELLE RIVER I-STORM 1
BELLE RIVER I-STORM 2
BELLE RIVER I-STORM 3
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00


BELLE RIVER I-STORM 4
BELLE RIVER I-STORM 5
BELLE RIVER I-STORM 6
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)

APPENDIX 2

The convention adopted in the plots following is:

-x-x-x-x- observed water levels

———— computed water levels

Lake Ontario (Burlington) Storm Dates

Sl. No.	Dependent Storms yr/mo/day/hr (EST)		Sl. No.	Independent Storms yr/mo/day/hr (EST)	
	Start	End		Start	End
1	62/01/05/01	62/01/08/18	1	72/01/24/01	72/01/28/00
2	62/02/22/07	62/02/25/12	2	72/02/01/01	72/02/06/00
3	62/06/18/01	62/06/20/18	3	72/08/11/01	72/08/16/00
4	63/03/15/19	63/03/18/00	4	72/11/12/01	72/11/15/00
5	63/03/18/07	63/03/21/18	5	73/02/01/04	73/02/03/21
6	63/09/11/01	63/09/14/00	6	73/02/10/04	73/02/13/21
7	64/03/24/07	64/03/28/18	7	73/03/04/04	73/03/07/21
8	65/11/25/19	65/11/28/12	8	73/03/15/04	73/03/18/21
9	67/01/25/19	67/01/29/00			
10	67/02/14/13	67/02/17/12			
11	68/12/26/19	68/12/30/00			
12	70/03/24/19	70/03/27/12			
13	70/04/01/13	70/04/04/00			

STORM SURGE PREDICTION EQUATIONS

for Lake Ontario at Burlington

$$S_0 = 11.803400 - 0.00995P_{(4,-6)} - 0.02037P_{(5,-6)} + 0.05294P_{(7,-6)} - 0.02037P_{(10,-6)} + 0.01408P_{(11,-6)} - 0.03538P_{(4,0)} + 0.00756P_{(10,0)} + 0.004150(T_A-T_W)_0$$

$$S_1 = 10.139650 - 0.01696P_{(5,-6)} + 0.03510P_{(7,-6)} - 0.00001P_{(11,-6)} + 0.004130(T_A-T_W)_{-6} - 0.03987P_{(4,0)} + 0.01187P_{(8,0)}$$

$$S_2 = 10.804910 - 0.01204P_{(5,-6)} + 0.03639P_{(7,-6)} - 0.01635P_{(8,-6)} - 0.00986P_{(10,-6)} + 0.01133P_{(11,-6)} + 0.001650(T_A-T_W)_{-6} - 0.05144P_{(4,0)} + 0.01405P_{(7,0)} + 0.01742P_{(8,0)} + 0.003480(T_A-T_W)_0$$

$$S_3 = 12.164860 - 0.00720P_{(5,-6)} + 0.03001P_{(7,-6)} - 0.01319P_{(8,-6)} - 0.01062P_{(10,-6)} - 0.05993P_{(4,0)} + 0.03762P_{(7,0)} - 0.01566P_{(10,0)} + 0.02714P_{(11,0)} + 0.004480(T_A-T_W)_0$$

$$S_4 = 10.085550 + 0.02541P_{(4,-6)} - 0.01007P_{(5,-6)} - 0.00451P_{(10,-6)} - 0.07463P_{(4,0)} + 0.05827P_{(7,0)} - 0.01404P_{(8,0)} - 0.01518P_{(10,0)} + 0.02495P_{(11,0)} + 0.002650(T_A-T_W)_0$$

$$S_5 = 09.678000 + 0.02094P_{(4,-6)} - 0.01157P_{(5,-6)} - 0.00121P_{(10,-6)} + 0.003610(T_A-T_W)_{-6} - 0.07317P_{(4,0)} + 0.05705P_{(7,0)} - 0.01571P_{(10,0)} + 0.01428P_{(11,0)}$$

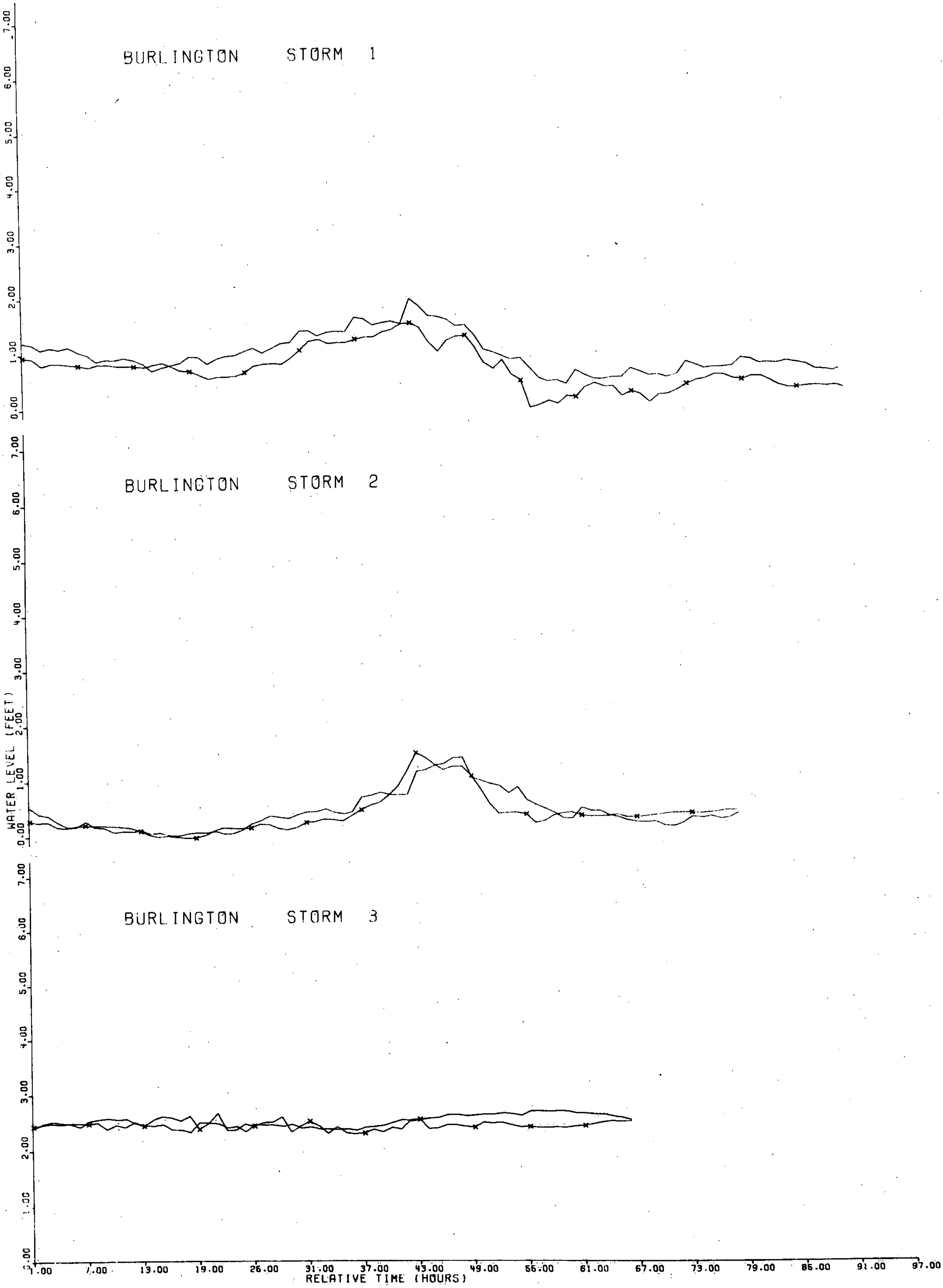
where

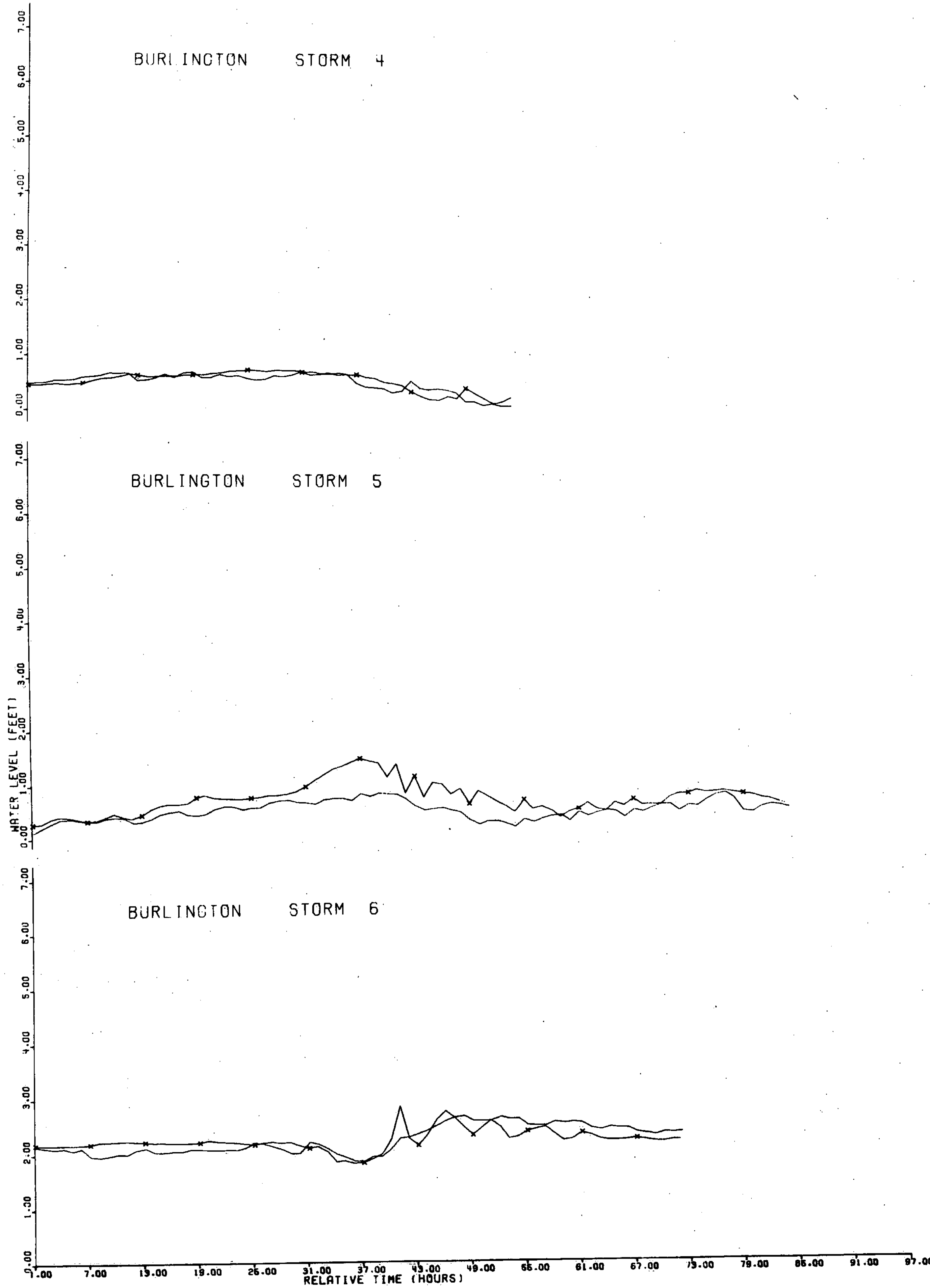
S = Surge in feet, with the subscript representing the number of hours after the time of the pressure forecast

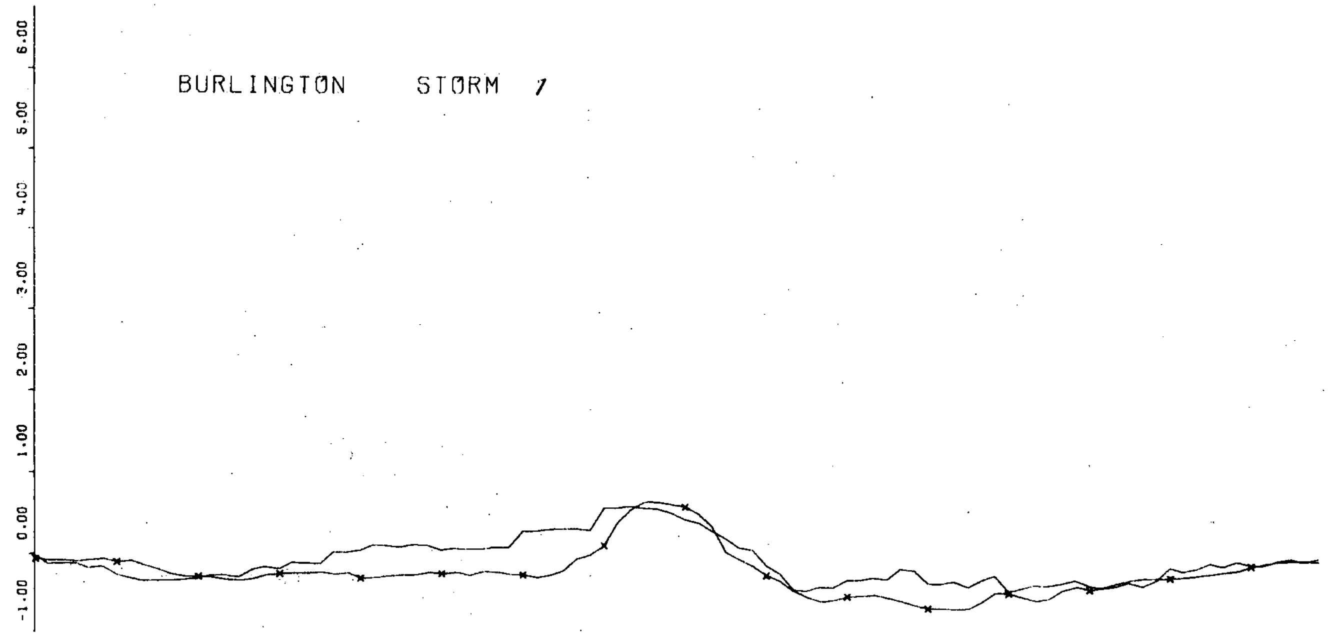
$P_{(N,T)}$ = Pressure in millibar at grid point number N (see Figure 1) and lag time T hours

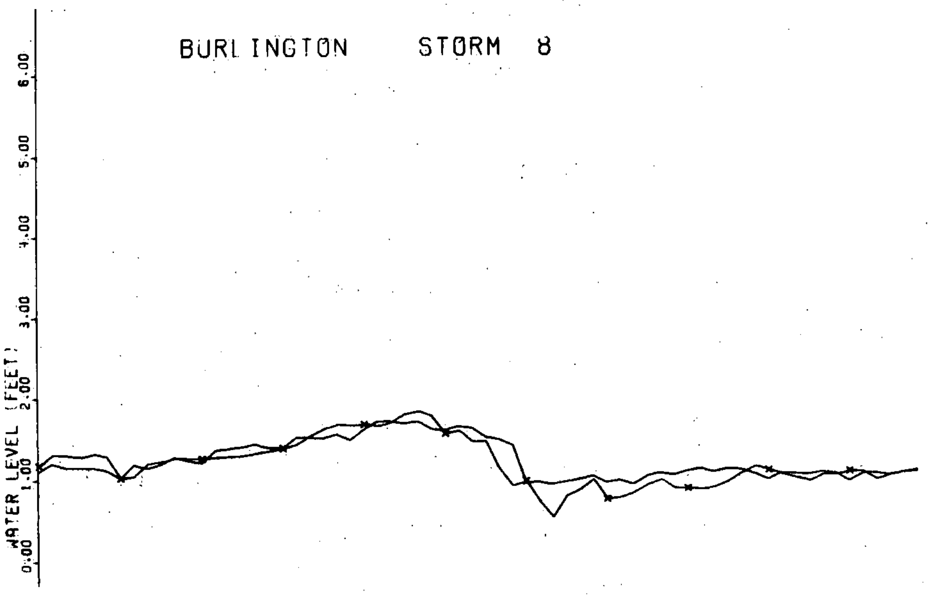
$(T_A-T_W)_T$ = Air-water temperature difference at the water level station at a lag time of T hours

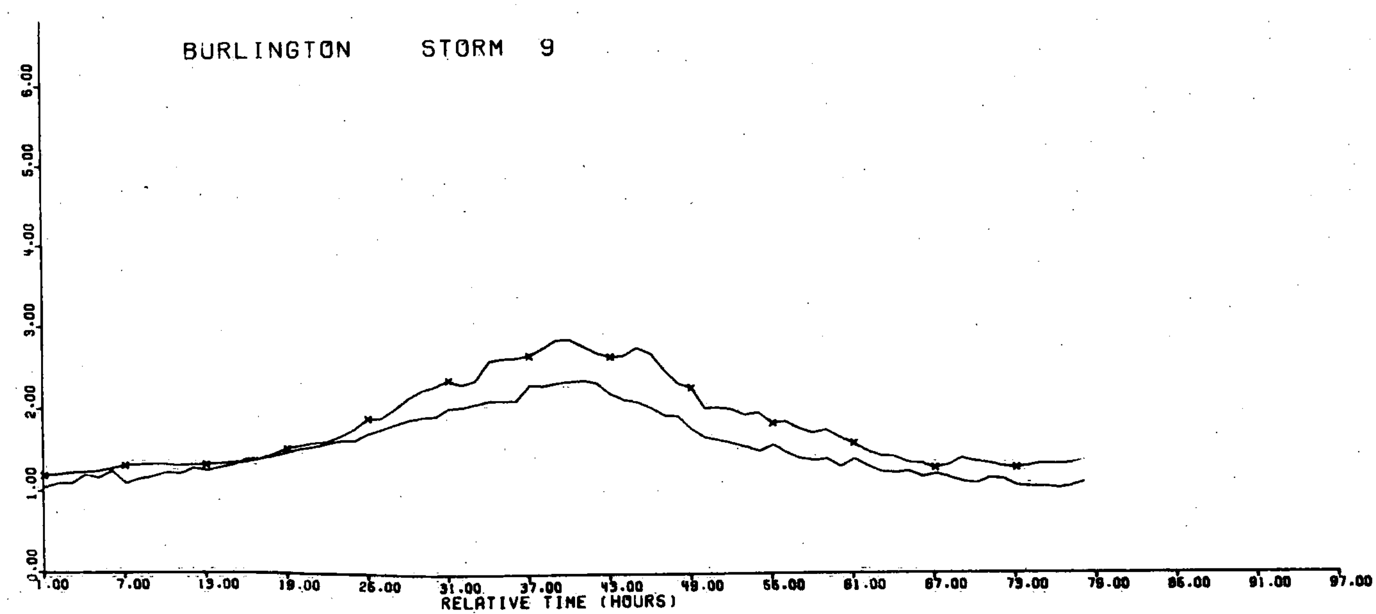
DEPENDENT STORMS

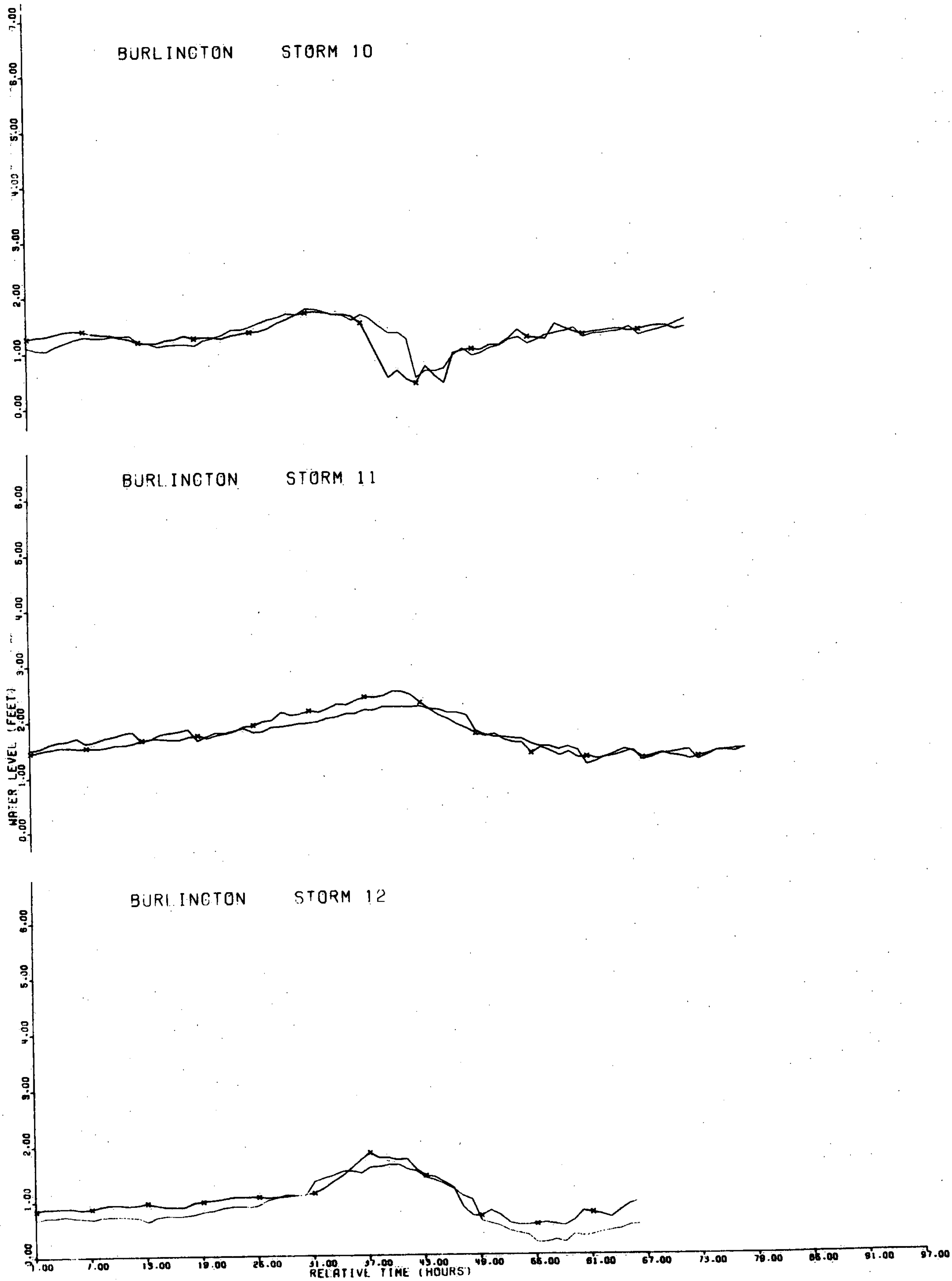

BURLINGTON STORM 1
BURLINGTON STORM 2
BURLINGTON STORM 3
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
WATER LEVEL (FEET)
1.00
7.00
13.00
19.00
26.00
31.00
37.00
43.00
49.00
56.00
61.00
67.00
73.00
79.00
86.00
91.00
97.00
RELATIVE TIME (HOURS)

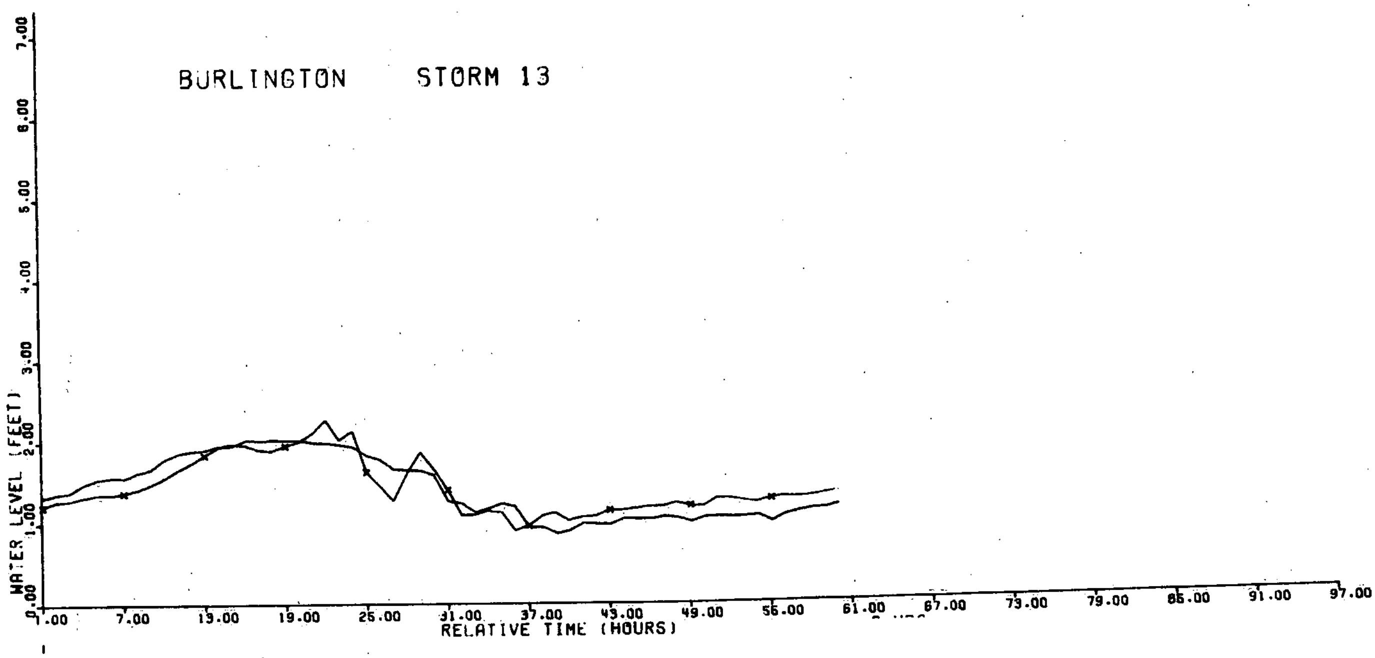

BURLINGTON STORM 4
BURLINGTON STORM 5
BURLINGTON STORM 6
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)


BURLINGTON STORM 7
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

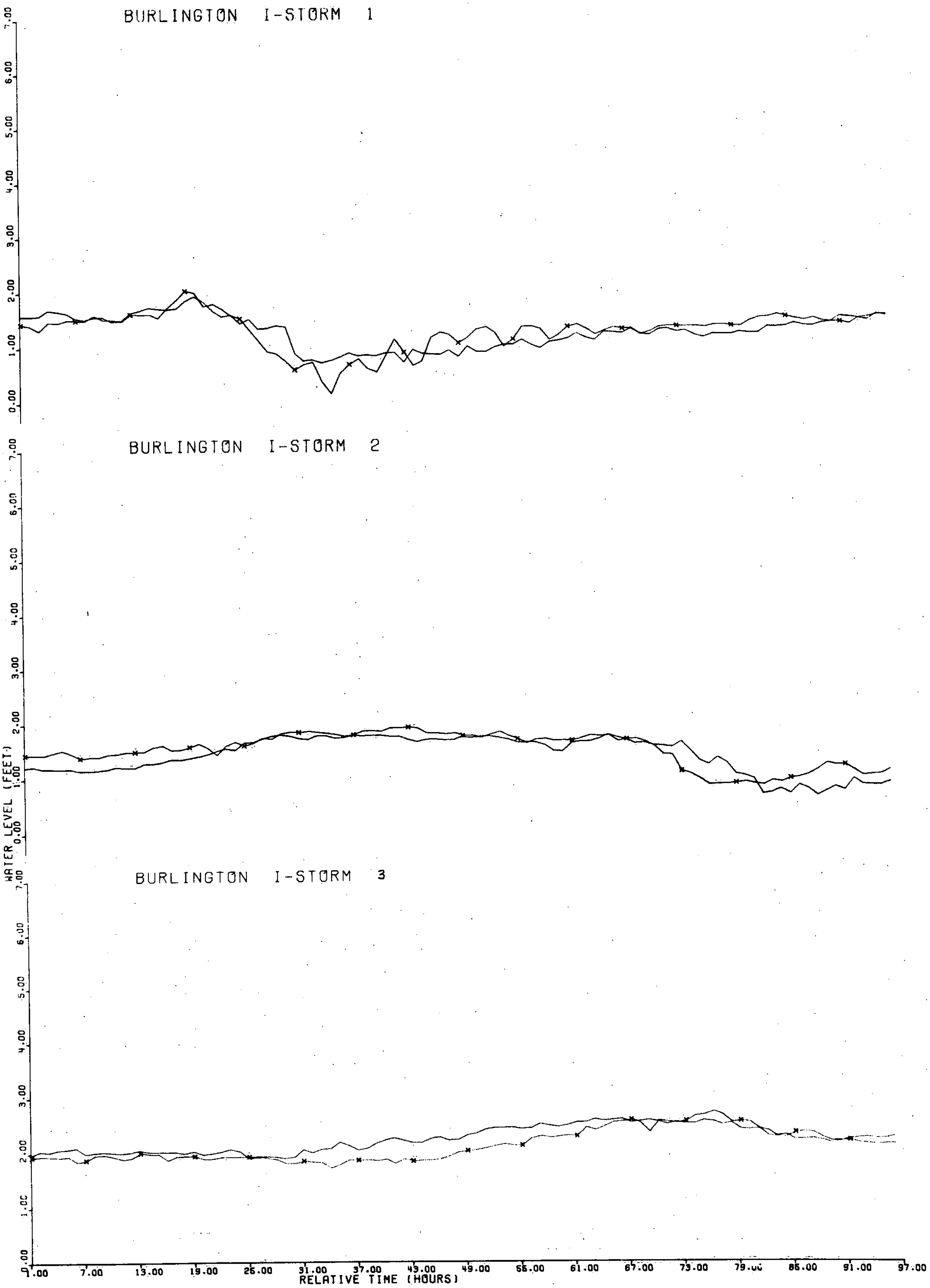

BURLINGTON STORM 8
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00


BURLINGTON STORM 9
0.00
1.00
2.00
3.00
4.00
5.00
6.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)


BURLINGTON STORM 10
BURLINGTON STORM 11
BURLINGTON STORM 12
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00


BURLINGTON STORM 13
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)

INDEPENDENT STORMS


BURLINGTON I-STORM 1
BURLINGTON I-STORM 2
BURLINGTON I-STORM 3
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
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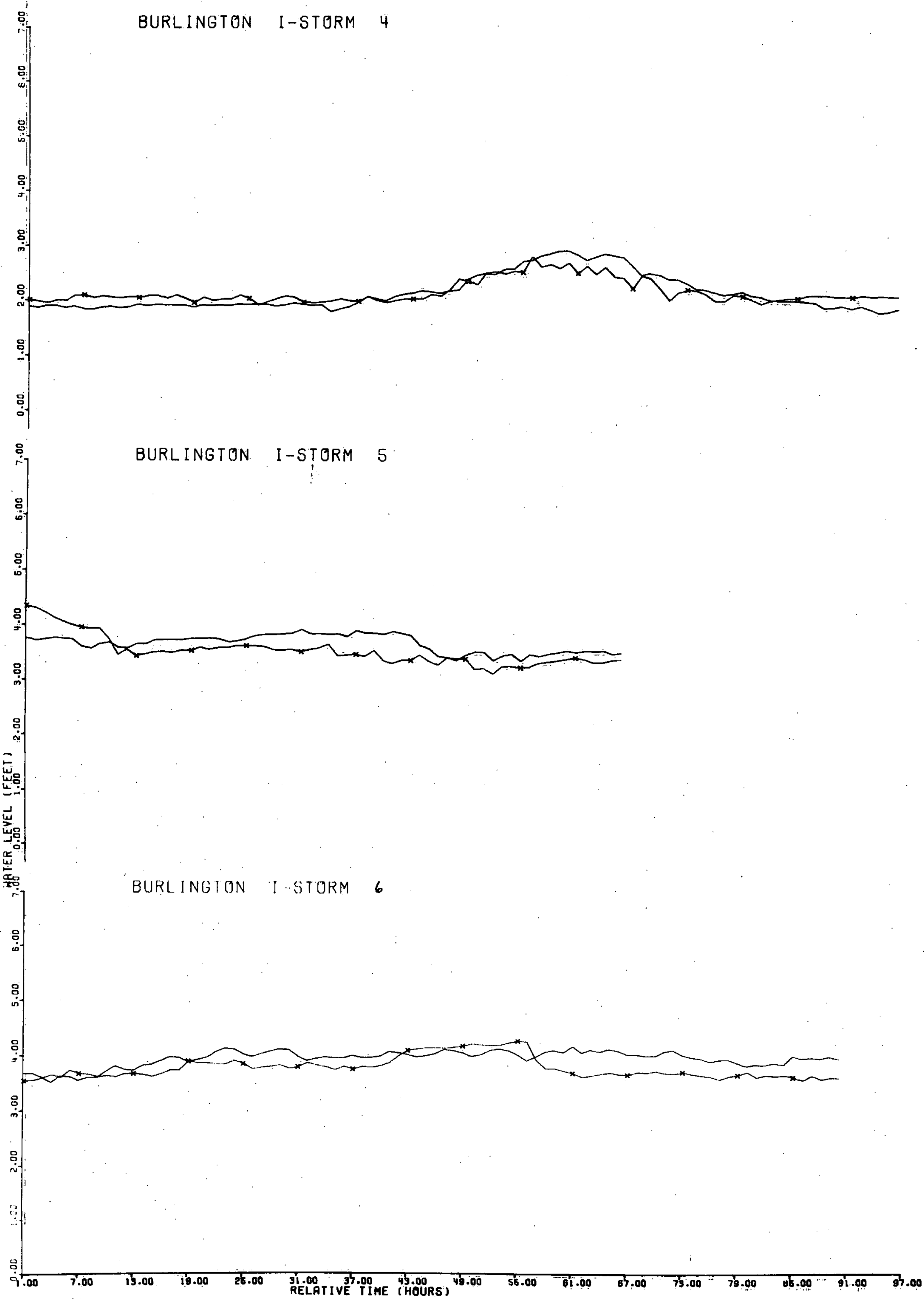
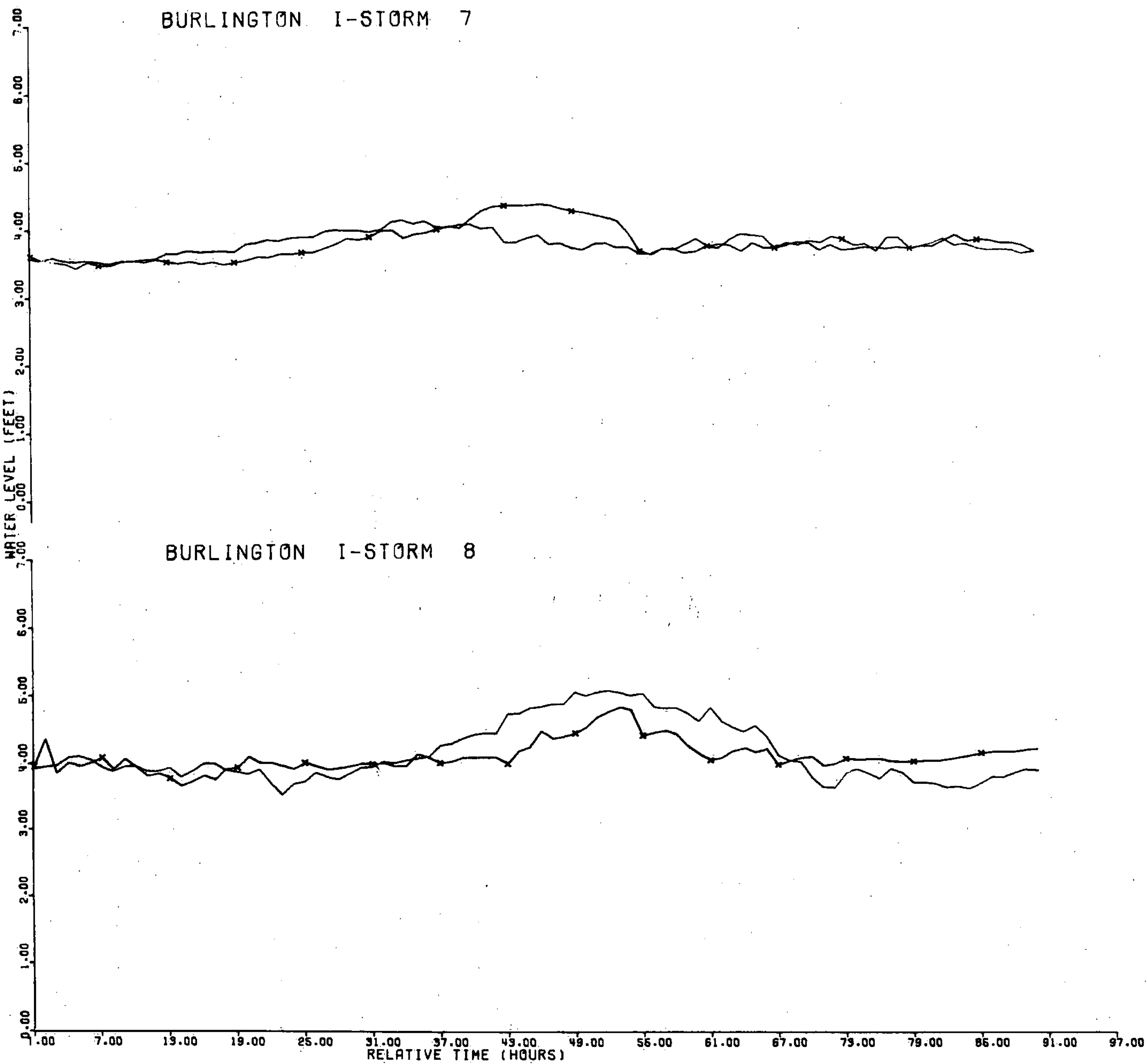
85.00
91.00
97.00


BURLINGTON I-STORM 4
BURLINGTON I-STORM 5
BURLINGTON I-STORM 6
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00


BURLINGTON I-STORM 7
BURLINGTON I-STORM 8
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
56.00
61.00
67.00
73.00
79.00
86.00
91.00
97.00
RELATIVE TIME (HOURS)

APPENDIX 3

The convention adopted in the plots following is:

-x-x-x-x- observed water levels

——————— computed water levels

Georgian Bay (Collingwood) Storm Dates

Sl. No.	Dependent Storms yr/mo/day/hr (EST)		Sl. No.	Independent Storms yr/mo/day/hr (EST)	
	Start	End		Start	End
1	61/03/05/13	61/03/08/12	1	72/01/05/01	72/01/09/18
2	63/11/21/19	63/11/24/18	2	72/01/23/01	72/01/27/18
3	65/10/29/19	65/11/01/00	3	72/02/03/01	72/02/06/18
4	65/11/02/07	65/11/06/00	4	72/09/15/01	72/09/18/18
5	65/11/25/07	65/11/28/06	5	72/10/06/01	72/10/09/18
6	66/05/26/01	66/05/29/18	6	72/12/05/01	72/12/08/18
7	66/07/16/07	66/07/19/18			
8	66/09/28/13	66/09/30/18			
9	66/12/27/01	66/12/30/12			
10	67/01/15/19	67/01/18/18			
11	67/10/24/19	67/10/27/18			
12	67/12/20/07	67/12/23/12			
13	68/06/10/07	68/06/13/00			
14	68/07/20/19	68/07/23/00			
15	69/04/16/13	69/04/19/18			
16	69/06/25/07	69/06/28/18			
17	70/08/26/19	70/08/29/18			
18	70/12/02/13	70/12/07/18			
19	71/05/17/01	71/05/20/06			
20	71/11/01/13	71/11/04/06			
21	71/12/23/01	71/12/26/00			

STORM SURGE PREDICTION EQUATIONS

for Georgian Bay at Collingwood

$$S_0 = 10.903050 + 0.01097P_{(4,-6)} - 0.03517P_{(10,-6)} - 0.02183P_{(3,0)} + 0.04691P_{(6,0)} - 0.01164P_{(10,0)} - 0.004680(T_A-T_W)_0$$

$$S_1 = 9.890630 + 0.01580P_{(4,-6)} - 0.02338P_{(9,-6)} - 0.01110P_{(10,-6)} \; 0.003700(T_A-T_W)_{-6} - 0.02271P_{(3,0)} + 0.06267P_{(6,0)} - 0.02559P_{(7,0)} + 0.01548P_{(9,0)} - 0.02093P_{(10,0)} - 0.001740(T_A-T_W)_0$$

$$S_2 = 8.069170 - 0.01213P_{(5,-6)} + 0.03338P_{(7,-6)} - 0.01754P_{(9-6)} - 0.01323P_{(10,-6)} - 0.01314P_{(3,0)} + 0.05873P_{(6,0)} - 0.03047P_{(7,0)} + 0.02644P_{(9,0)} - 0.04000P_{(10,0)} - 0.004320(T_A-T_W)_0$$

$$S_3 = 8.389940 + 0.02566P_{(7,-6)} - 0.02229P_{(9,-6)} - 0.00598P_{(10,-6)} - 0.0117P_{(3,0)} + 0.05529P_{(6,0)} - 0.03541P_{(7,0)} + 0.02561P_{(9,0)} - 0.03940P_{(10,0)} - 0.005040(T_A-T_W)_0$$

$$S_4 = 9.677820 - 0.01089P_{(3,-6)} + 0.03688P_{(7,-6)} - 0.01901P_{(10,-6)} + 0.06540P_{(6,0)} - 0.05273P_{(7,0)} - 0.02922P_{(10,0)} - 0.003790(T_A-T_W)_0$$

$$S_5 = 9.393110 - 0.02087P_{(3,-6)} + 0.04418P_{(7,-6)} - 0.02025P_{(9,-6)} - 0.01028P_{(10,-6)} + 0.01087P_{(3,0)} + 0.05780P_{(6,0)} - 0.05666P_{(7,0)} + 0.01208P_{(9,0)} - 0.02615P_{(10,0)} - 0.004380(T_A-T_W)_0$$

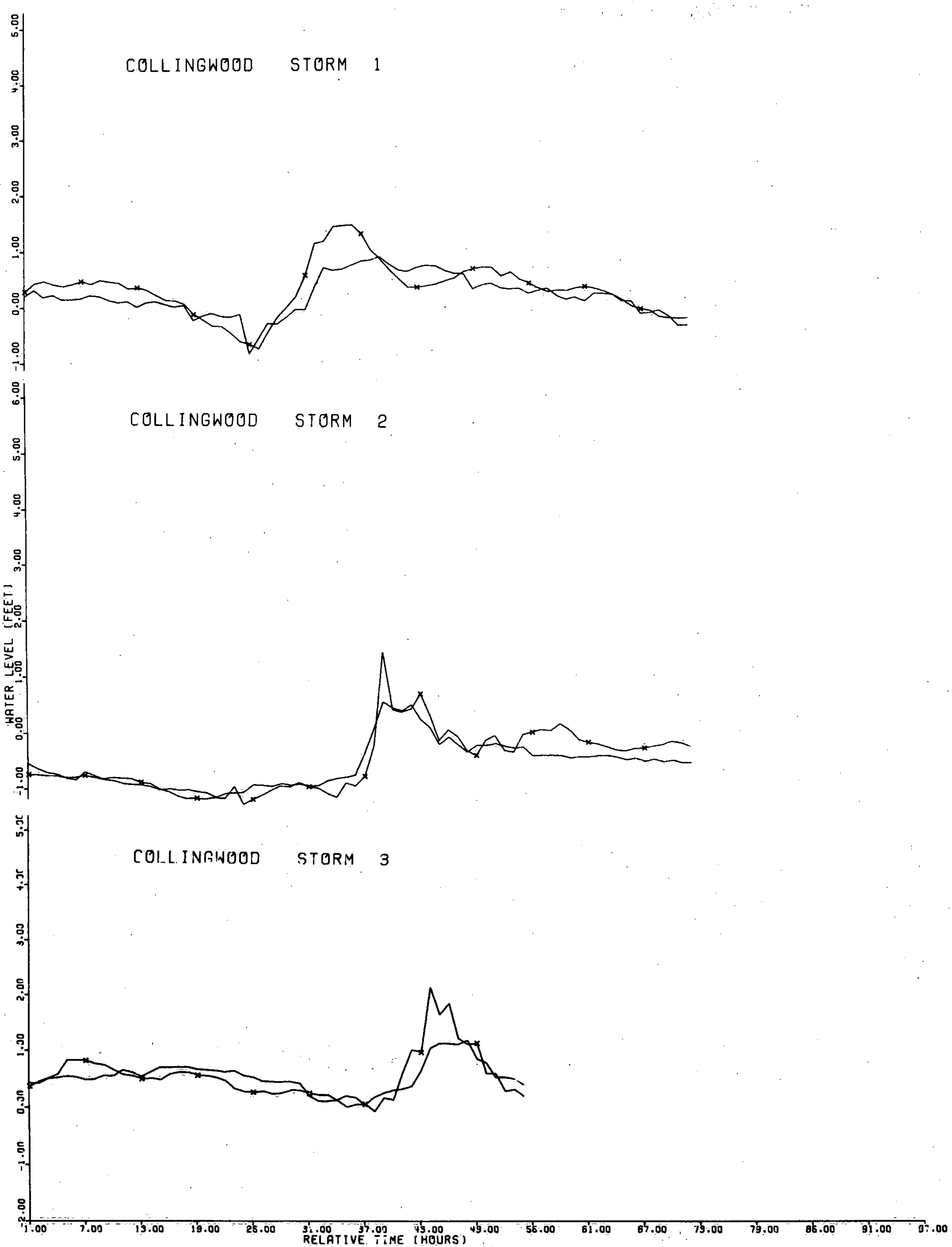
where

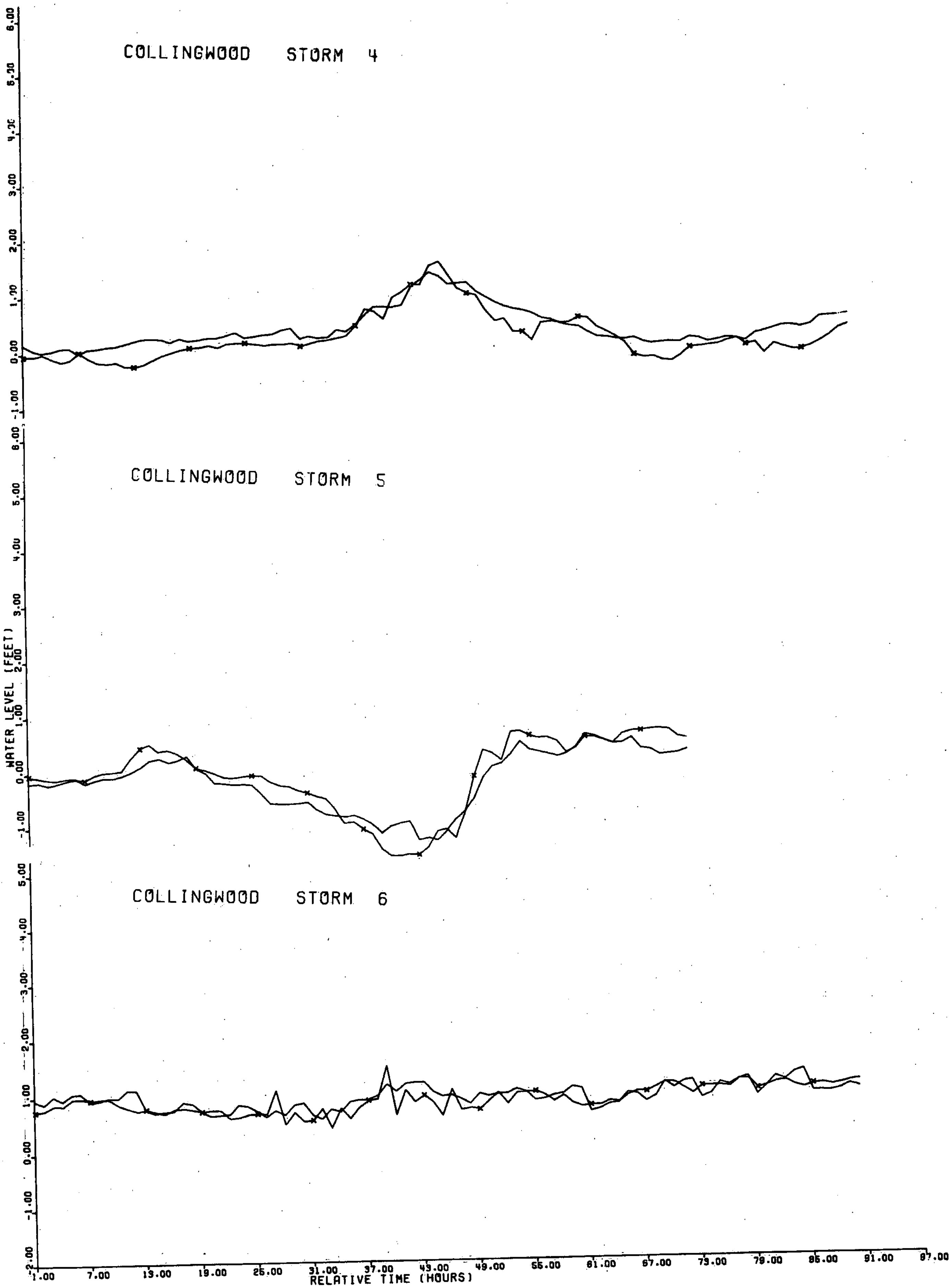
S = Surge in feet, with the subscript representing the number of hours after the time of the pressure forecast

$P_{(N,T)}$ = Pressure in millibar at grid point number N (see Figure 1) and lag time T hours

$(T_A-T_W)_T$ = Air-water temperature difference at the water level station at a lag time of T hours

DEPENDENT STORMS


COLLINGWOOD STORM 1
COLLINGWOOD STORM 2
COLLINGWOOD STORM 3
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00


COLLINGWOOD STORM 4
COLLINGWOOD STORM 5
COLLINGWOOD STORM 6
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
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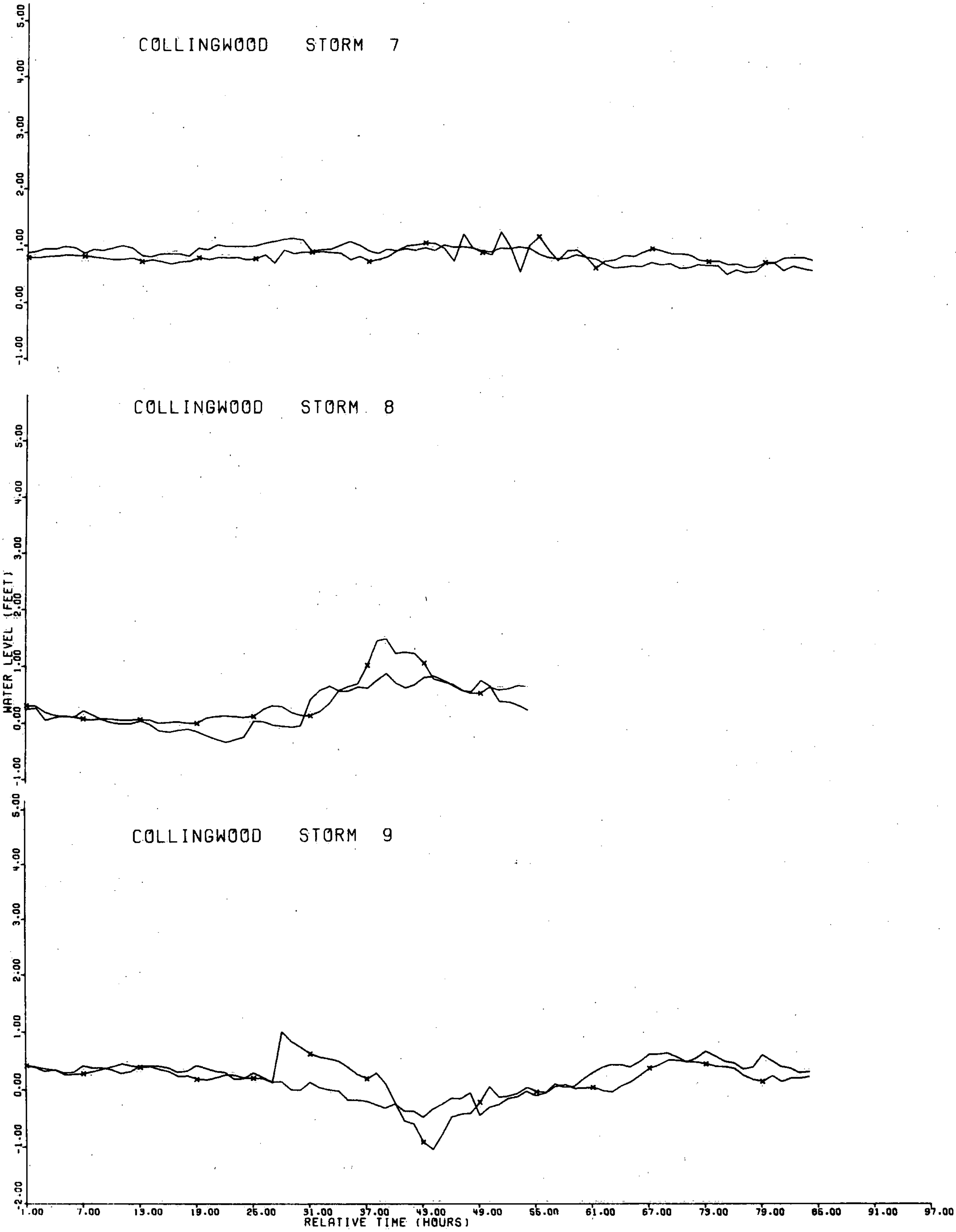
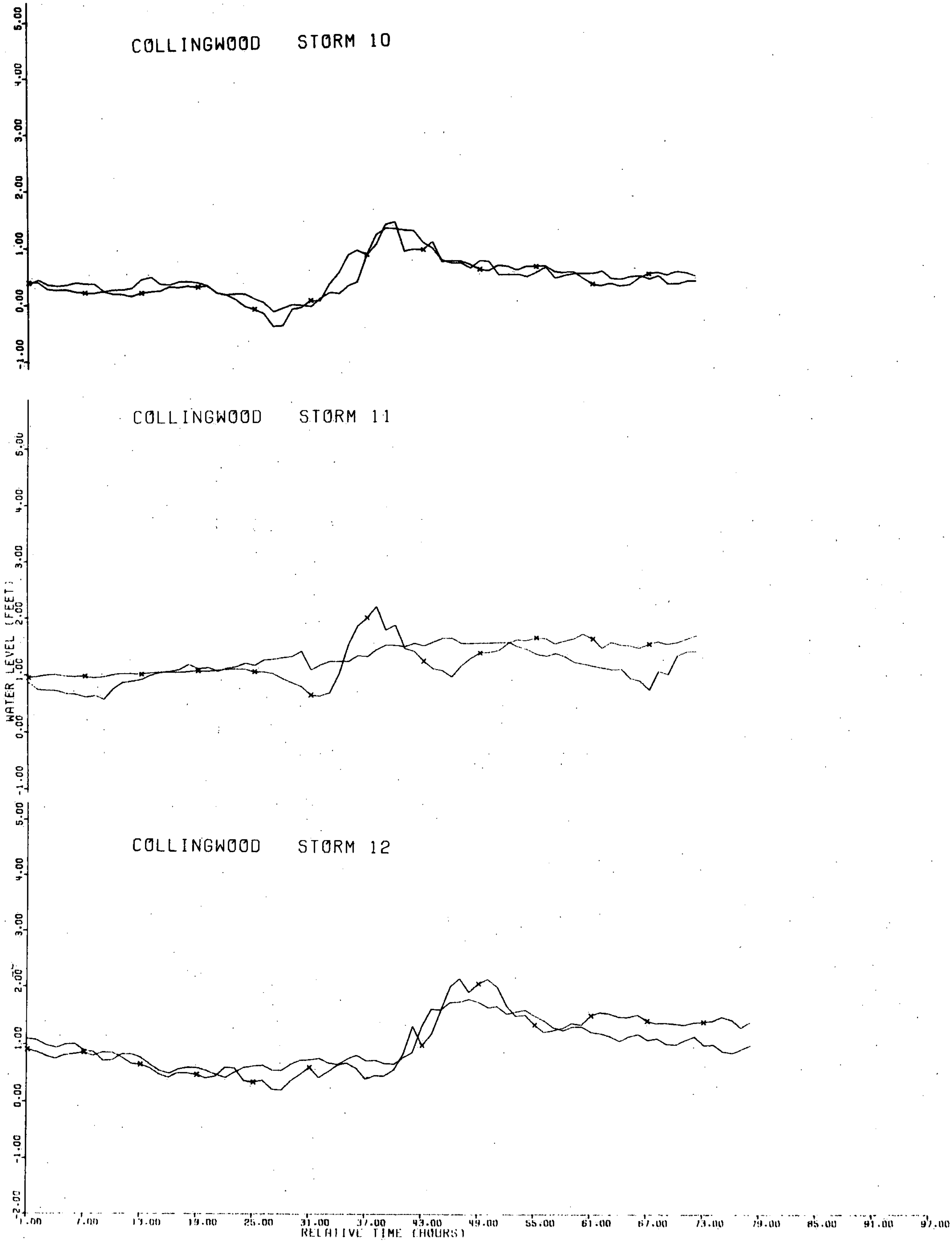
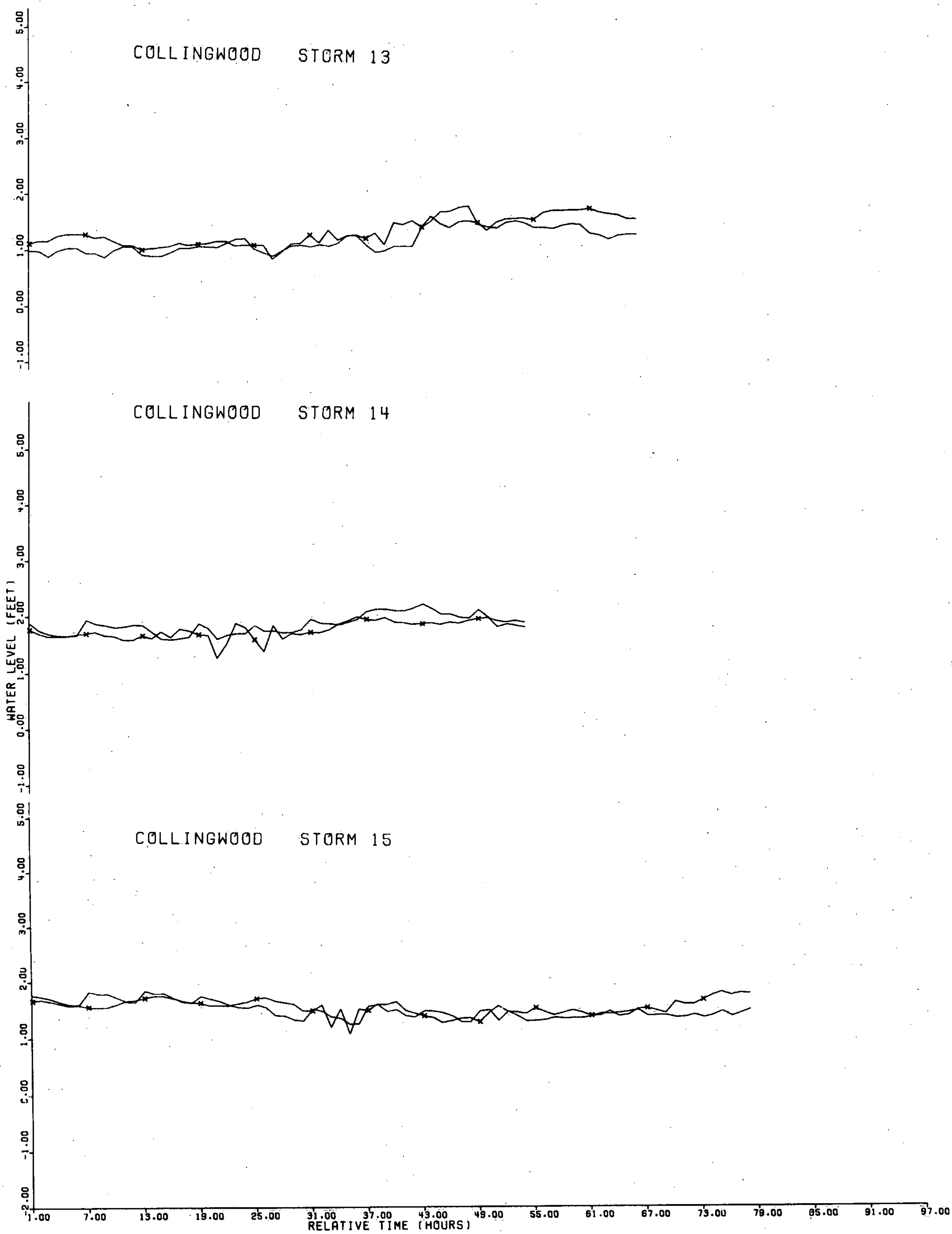
85.00
91.00
97.00



COLLINGWOOD STORM 7
COLLINGWOOD STORM 8
COLLINGWOOD STORM 9
WATER LEVEL (FEET)
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)


COLLINGWOOD STORM 10
COLLINGWOOD STORM 11
COLLINGWOOD STORM 12
WATER LEVEL (FEET)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)


COLLINGWOOD STORM 13
COLLINGWOOD STORM 14
COLLINGWOOD STORM 15
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
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67.00
73.00
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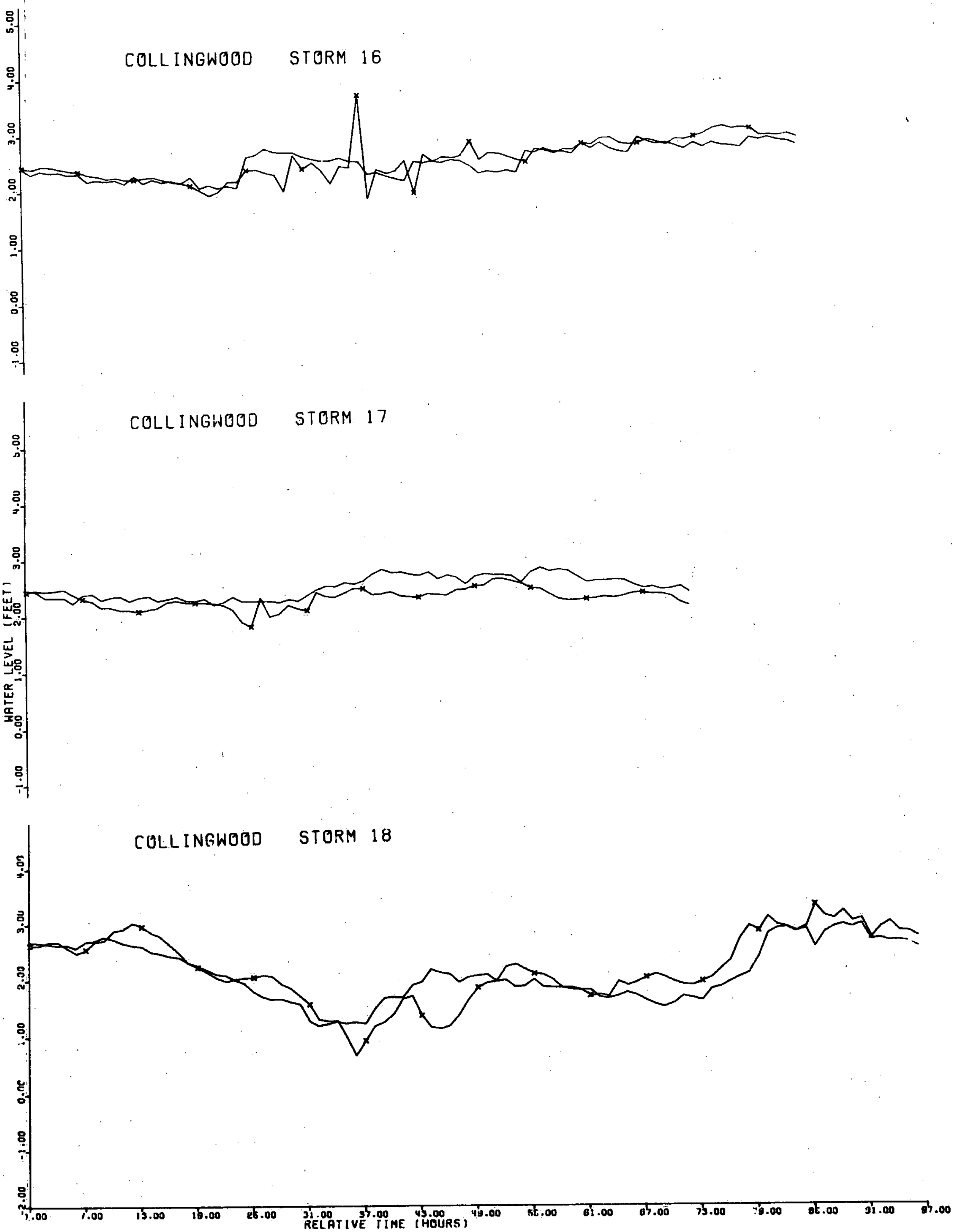
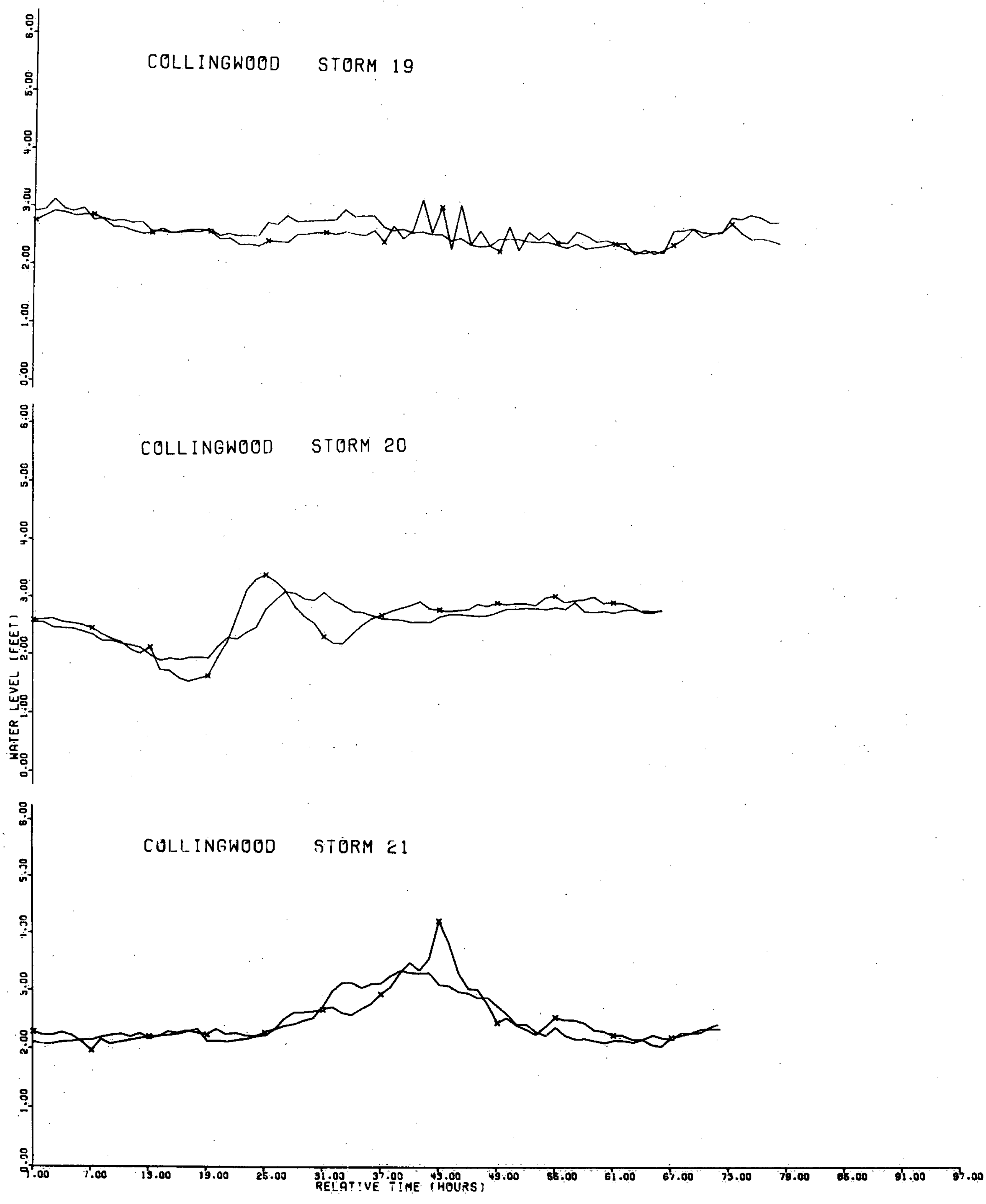
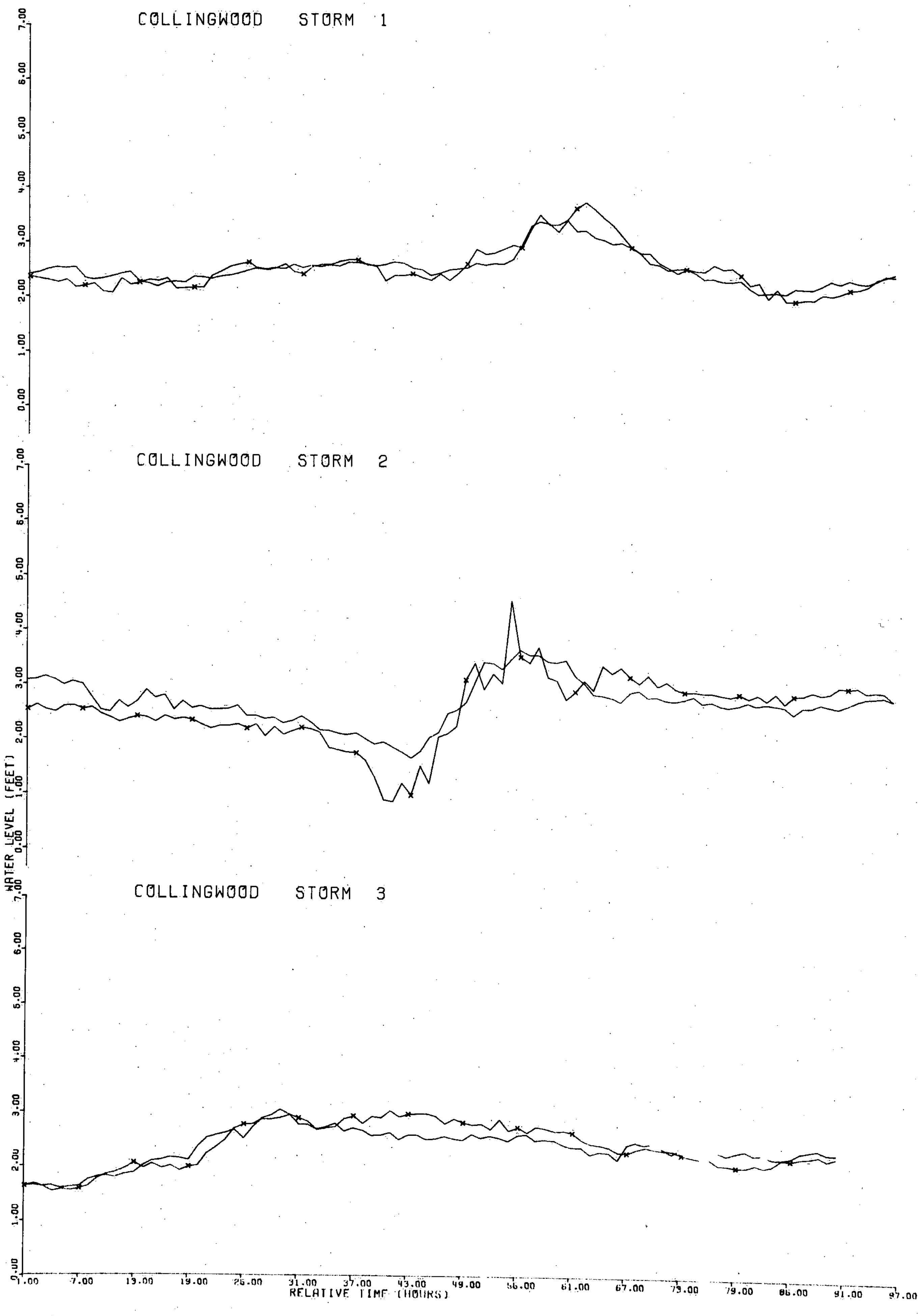
85.00
91.00
97.00



COLLINGWOOD STORM 16
COLLINGWOOD STORM 17
COLLINGWOOD STORM 18
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)


COLLINGWOOD STORM 19
COLLINGWOOD STORM 20
COLLINGWOOD STORM 21
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)

INDEPENDENT STORMS


COLLINGWOOD STORM 1
COLLINGWOOD STORM 2
COLLINGWOOD STORM 3
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
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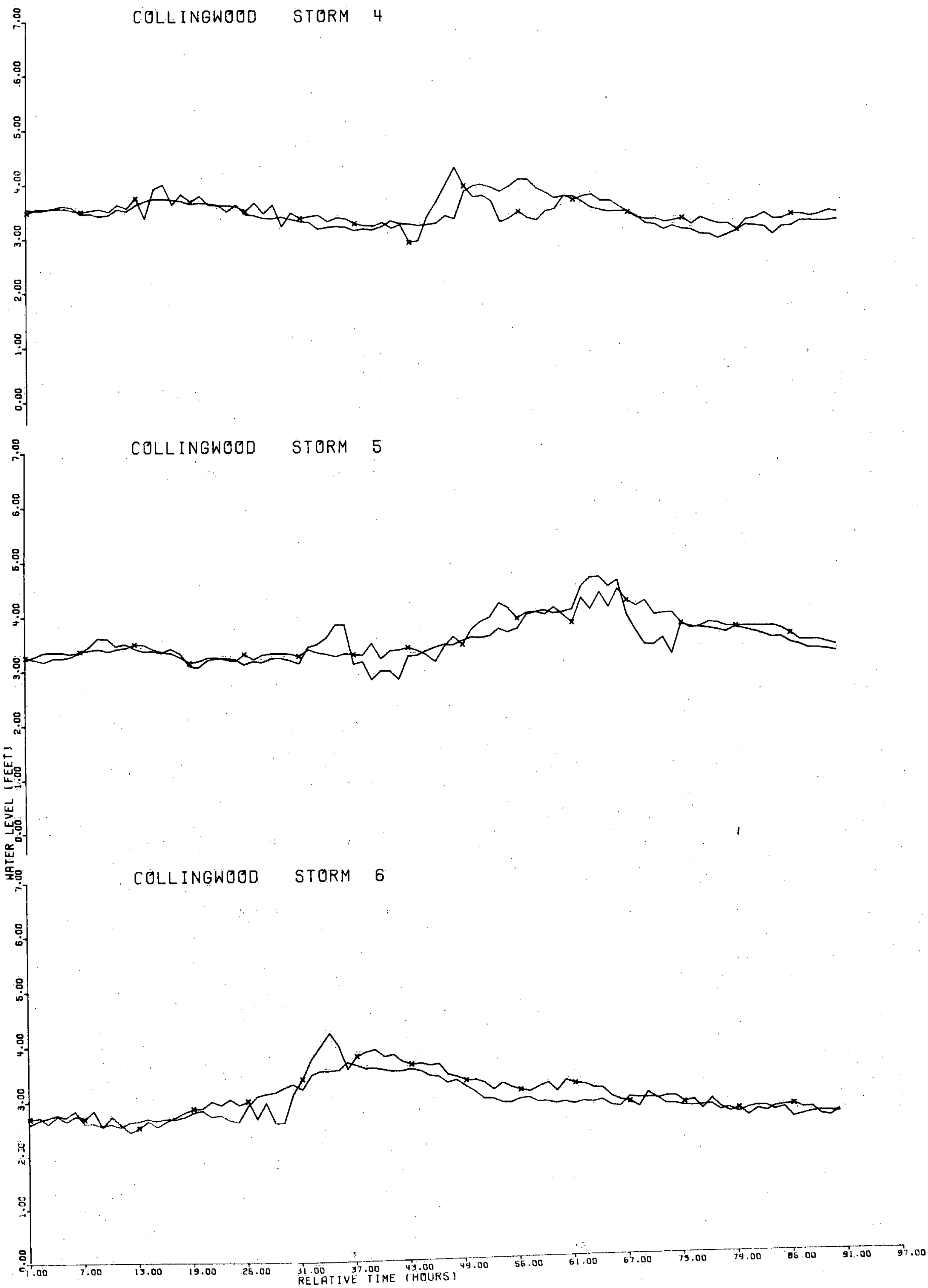
85.00
91.00
97.00



COLLINGWOOD STORM 4
COLLINGWOOD STORM 5
COLLINGWOOD STORM 6
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
56.00
61.00
67.00
73.00
79.00
86.00
91.00
97.00
RELATIVE TIME (HOURS)

APPENDIX 4

The convention adopted in the plots following is:

-x-x-x-x- observed water levels

———— computed water levels

Lake Huron (Pt. Edward) Storm Dates

Sl. No.	Dependent Storms yr/mo/day/hr (EST)		Sl. No.	Independent Storms yr/mo/day/hr (EST)	
	Start	End		Start	End
1	62/05/12/07	62/05/15/12	1	72/01/05/01	72/01/09/18
2	62/09/12/01	62/09/15/06	2	72/01/23/01	72/01/27/18
3	63/01/20/01	63/01/22/18	3	72/09/15/01	72/09/18/18
4	63/03/19/01	63/03/22/06	4	72/10/06/01	72/10/09/18
5	63/06/09/07	63/06/12/12	5	72/12/05/01	72/12/08/18
6	63/12/17/07	63/12/20/06			
7	63/12/23/13	63/12/26/00			
8	64/06/08/13	64/06/11/18			
9	64/11/26/01	64/11/30/18			
10	65/01/25/13	65/01/29/12			
11	65/10/02/01	65/10/05/12			
12	65/12/23/07	65/12/27/00			
13	66/11/26/07	66/11/30/18			
14	67/02/14/13	67/02/17/18			
15	67/06/14/19	67/06/17/18			
16	67/11/13/07	67/11/16/12			
17	67/12/20/13	67/12/23/18			
18	68/06/10/01	68/06/14/00			
19	68/07/20/13	68/07/23/12			
20	68/08/06/07	68/08/08/12			
21	68/11/17/19	68/11/23/12			
22	68/12/22/07	68/12/25/06			
23	69/07/04/01	69/07/06/06			
24	70/04/01/01	70/04/04/00			
25	70/09/25/19	70/09/30/06			
26	70/11/19/19	70/11/25/06			
27	70/12/03/01	70/12/06/06			
28	71/02/04/01	71/02/06/18			
29	71/12/14/13	71/12/19/06			

STORM SURGE PREDICTION EQUATIONS

for Lake Huron at Point Edward

$$S_0 = -1.430540 + 0.03077P_{(4,-6)} + 0.02204P_{(6,-6)} - 0.03520P(7,-6) + 0.01249P_{(9,-6)} - 0.01475P_{(10,-6)} - 0.003980(T_A - T_W)_{-6} - 0.01209P_{(3,0)} - 0.01862P_{(4,0)} + 0.05119P_{(6,0)} - 0.05316P_{(7,0)} - 0.00852P_{(9,0)} + 0.02726P_{(10,0)} + 0.005760(T_A - T_W)_0$$

$$S_1 = 1.257540 + 0.2845P_{(4,-6)} + 0.01744P_{(6,-6)} - 0.01809P_{(7,-6)} - 0.01309P_{(10,-6)} - 0.004300(T_A - T_W)_{-6} - 0.01147P_{(3,0)} - 0.02834P_{(4,0)} + 0.05619P_{(6,0)} - 0.05304P_{(7,0)} + 0.00367P_{(9,0)} + 0.01708P_{(10,0)} + 0.002960(T_A - T_W)_0$$

$$S_2 = 0.443800 + 0.01896P_{(4,-6)} + 0.00802P_{(7,-6)} + 0.01378P_{(9,-6)} - 0.03248P_{(10,-6)} - 0.01230P_{(3,0)} - 0.01635P_{(4,0)} + 0.05887P_{(6,0)} - 0.06762P_{(7,0)} + 0.00234P_{(9,0)} + 0.02639P_{(10,0)}$$

$$S_3 = 0.707210 + 0.02807P_{(4,-6)} + 0.01948P_{(6,-6)} - 0.01056P_{(7,-6)} - 0.02278P_{(10,-6)} - 0.01086P_{(3,0)} - 0.02269P_{(4,0)} + 0.04735P_{(6,0)} - 0.05864P_{(7,0)} + 0.00936P_{(9,0)} + 0.02059P_{(10,0)}$$

$$S_4 = 0.443770 + 0.02266P_{(4,-6)} + 0.01983P_{(6,-6)} - 0.02215P_{(10,-6)} - 0.001590(T_A-T_W)_{-6} - 0.01137P_{(3,0)} - 0.01649P_{(4,0)} + 0.04404P_{(6,0)} - 0.06681P_{(7,0)} + 0.01515P_{(9,0)} + 0.01472P_{(10,0)}$$

$$S_5 = 1.399820 + 0.01944P_{(4,-6)} + 0.02927P_{(6,-6)} - 0.00820P_{(7,-6)} - 0.01697P_{(9,-6)} - 0.01128P_{(10,-6)} - 0.001240(T_A - T_W)_{-6} - 0.01635P_{(3,0)} + 0.03489P_{(6,0)} - 0.07130P_{(7,0)} + 0.02699P_{(9,0)} + 0.01214P_{(10,0)}$$

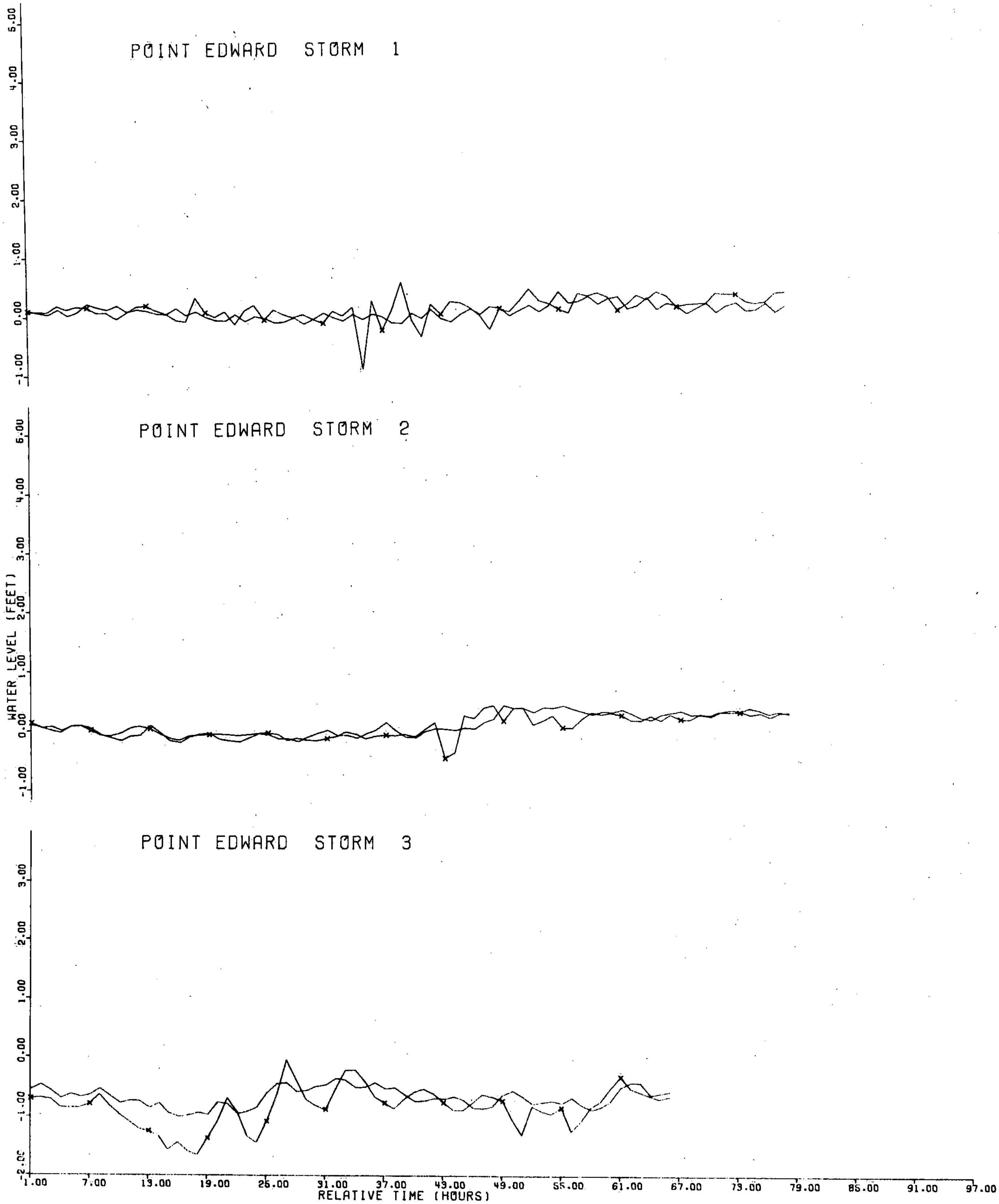
where

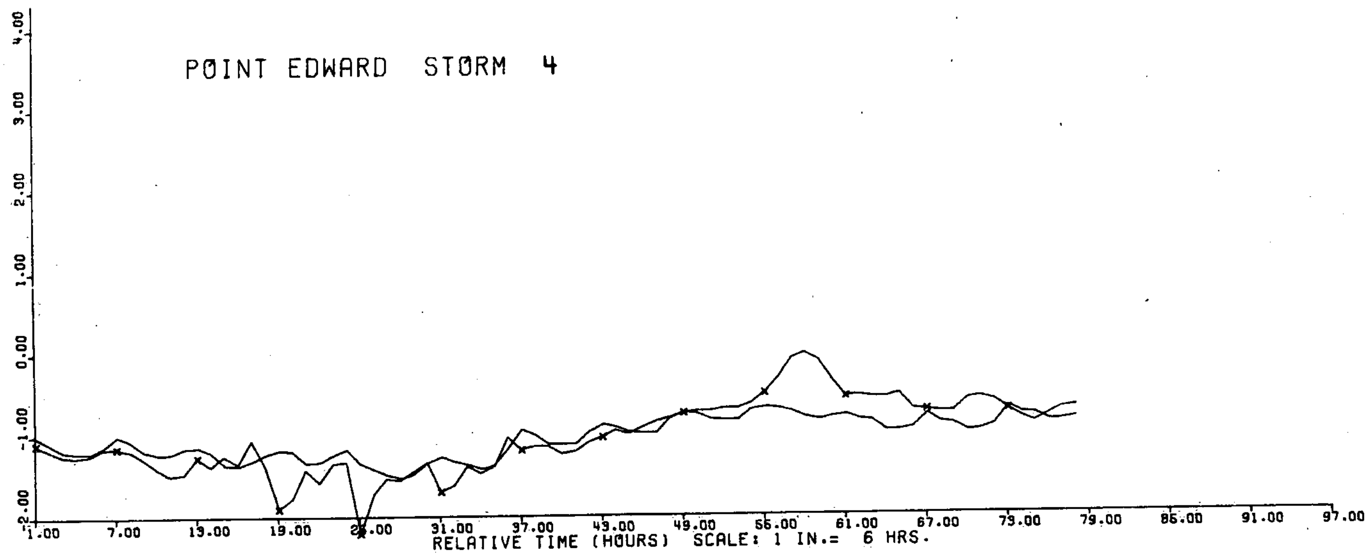
S = Surge in feet, with the subscript representing the number of hours after the time of the pressure forecast

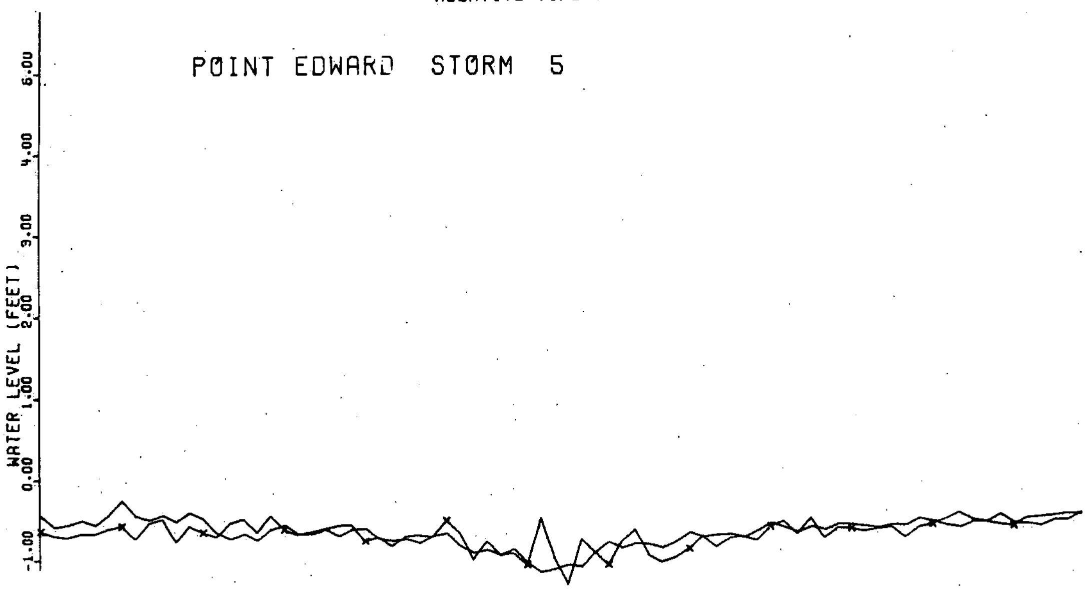
$P_{(N,T)}$ = Pressure in millibar at grid point number N (see Figure 1) and lag time T hours

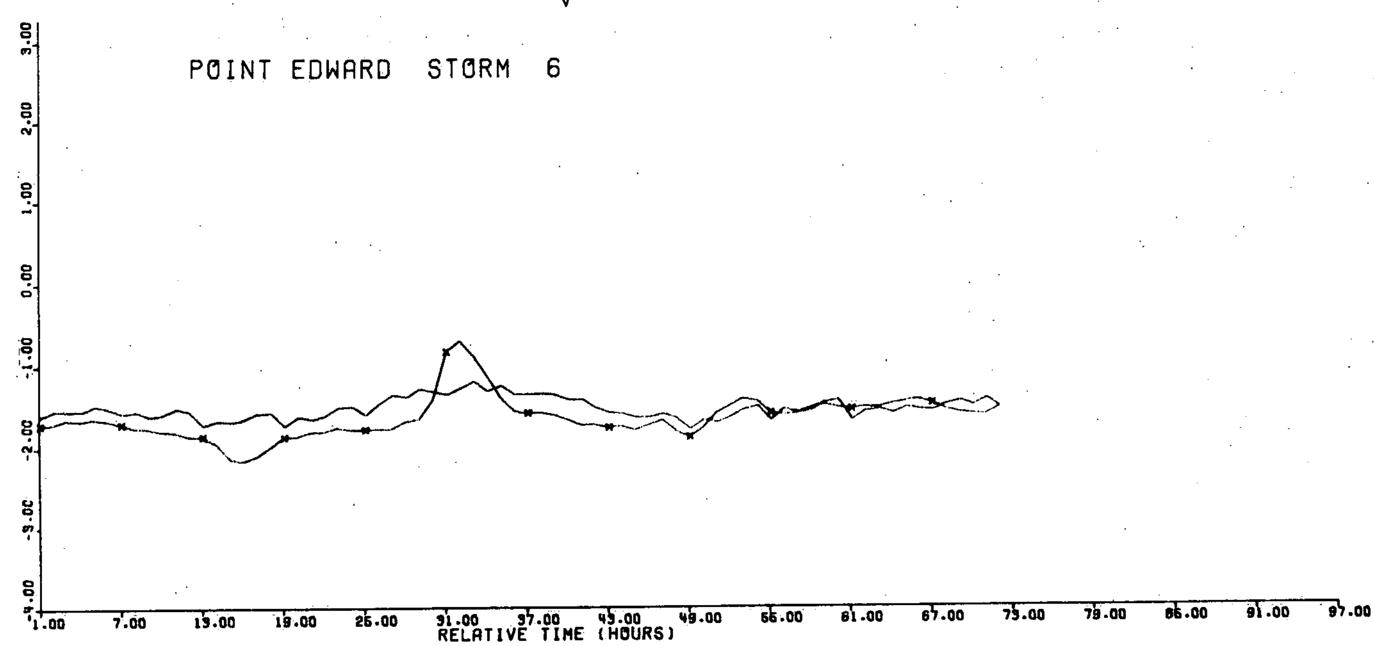
$(T_A-T_W)_T$ = Air-water temperature difference at the water level station at a lag time of T hours

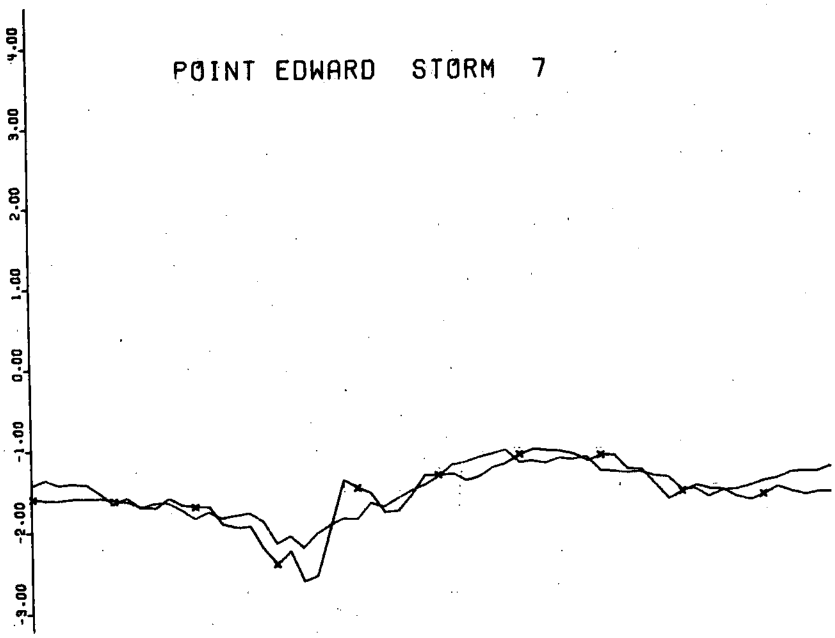
DEPENDENT STORMS

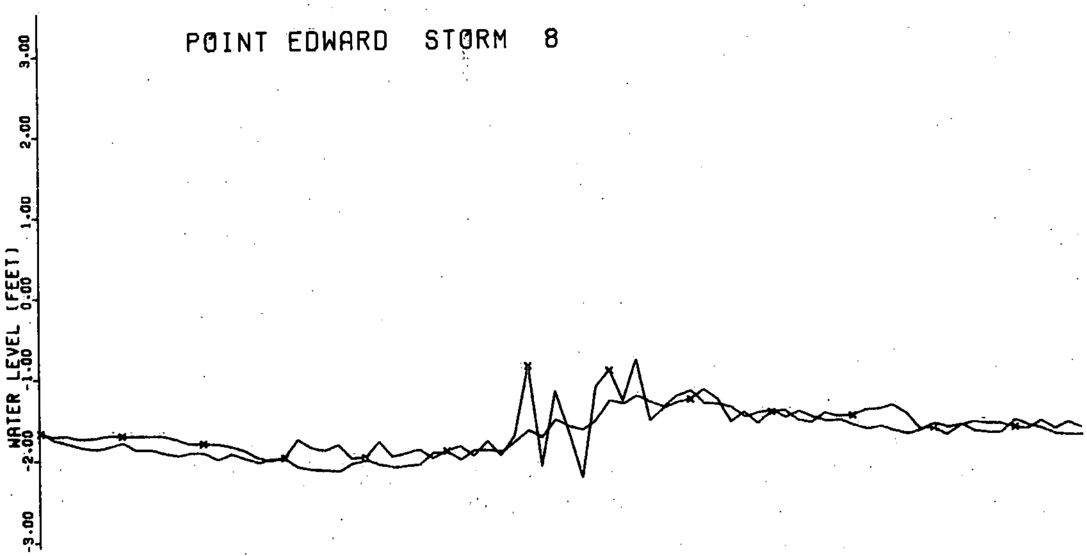

POINT EDWARD STORM 1
POINT EDWARD STORM 2
POINT EDWARD STORM 3
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00

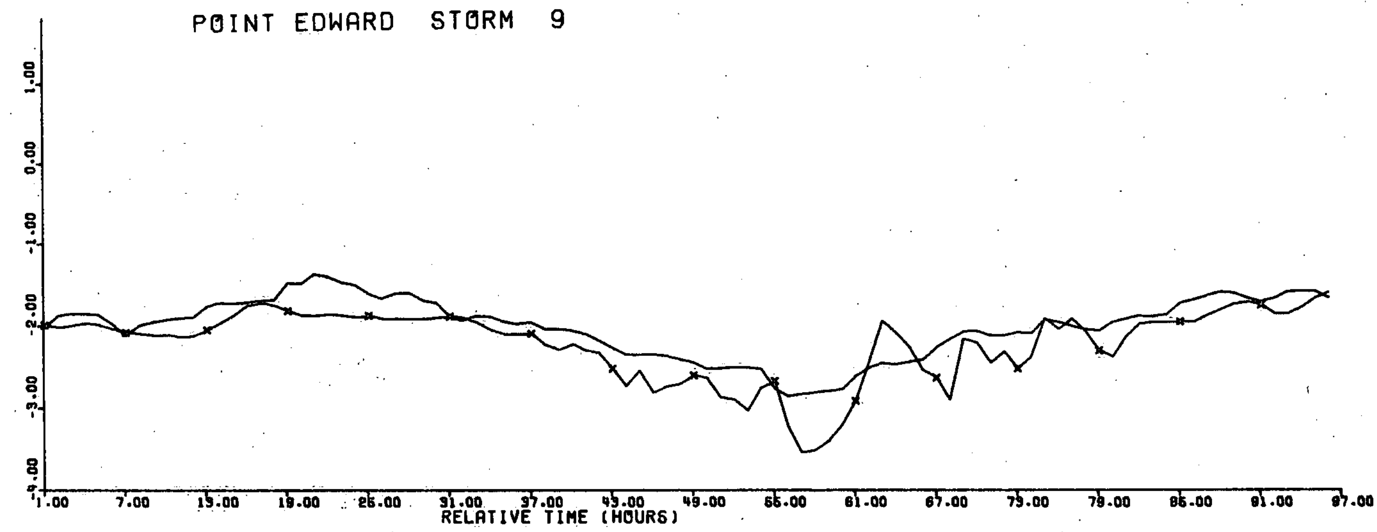

POINT EDWARD STORM 4
RELATIVE TIME (HOURS) SCALE: 1 IN.= 6 HRS.

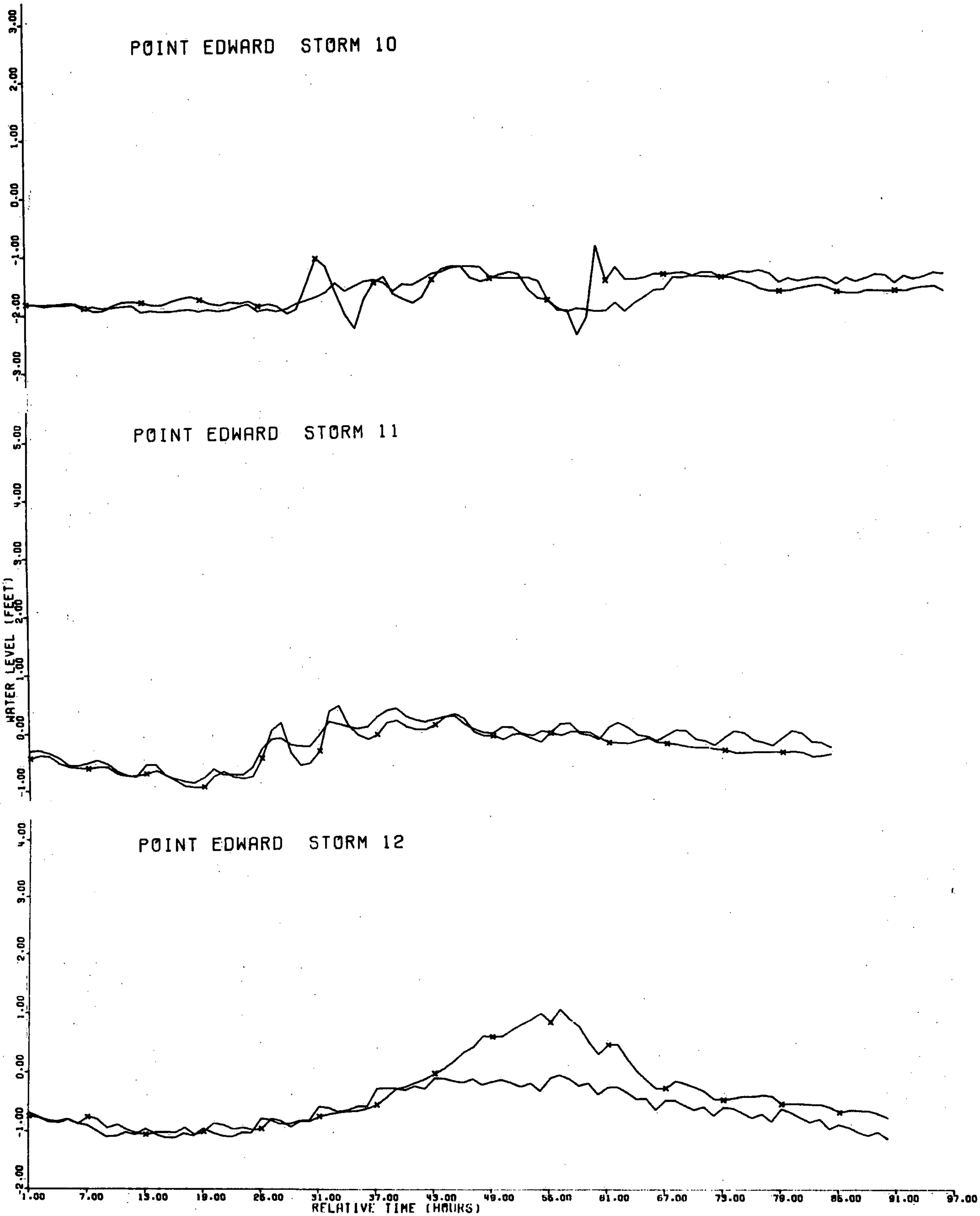

POINT EDWARD STORM 5
WATER LEVEL (FEET)

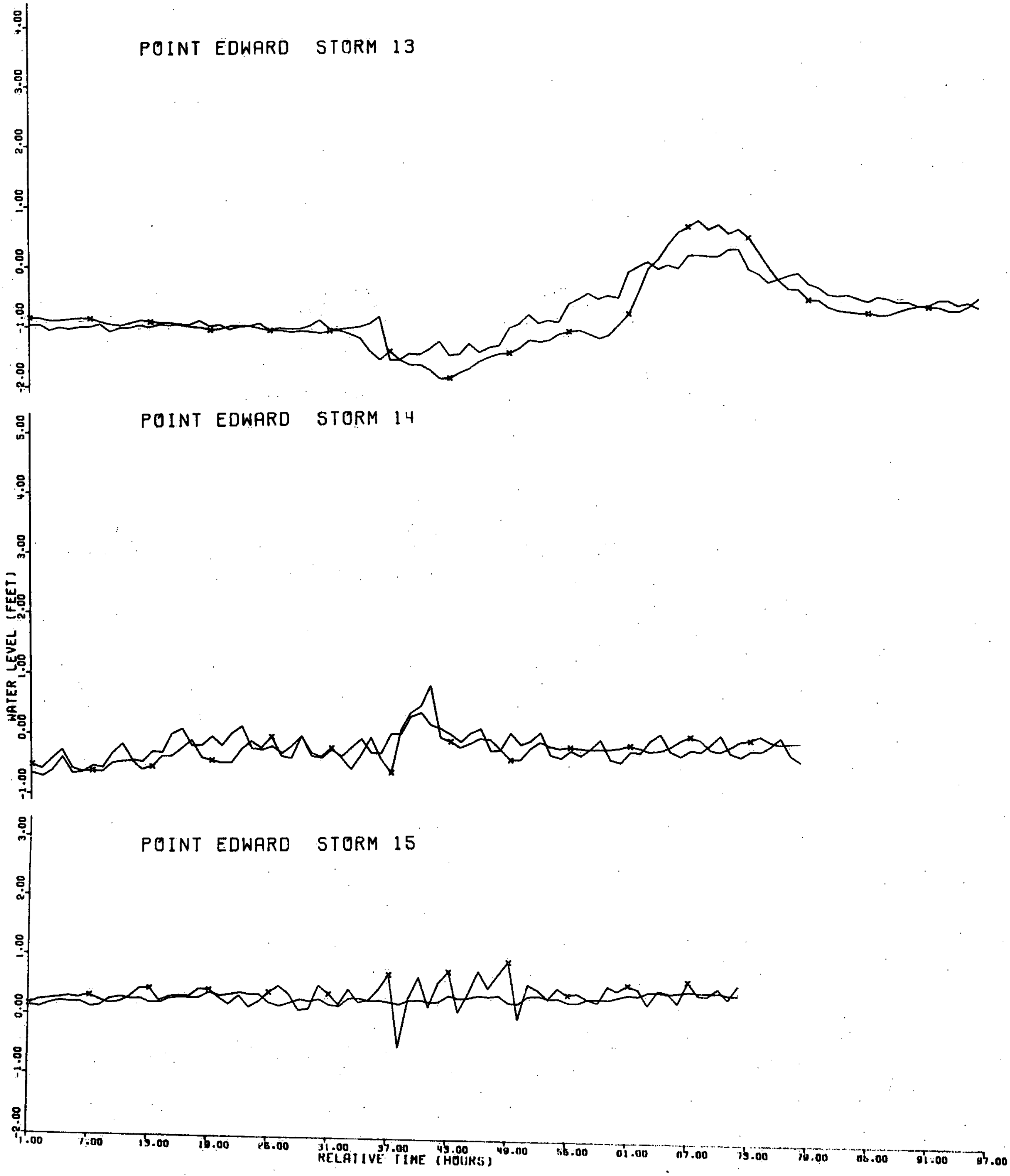

POINT EDWARD STORM 6
RELATIVE TIME (HOURS)


POINT EDWARD STORM 7
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00

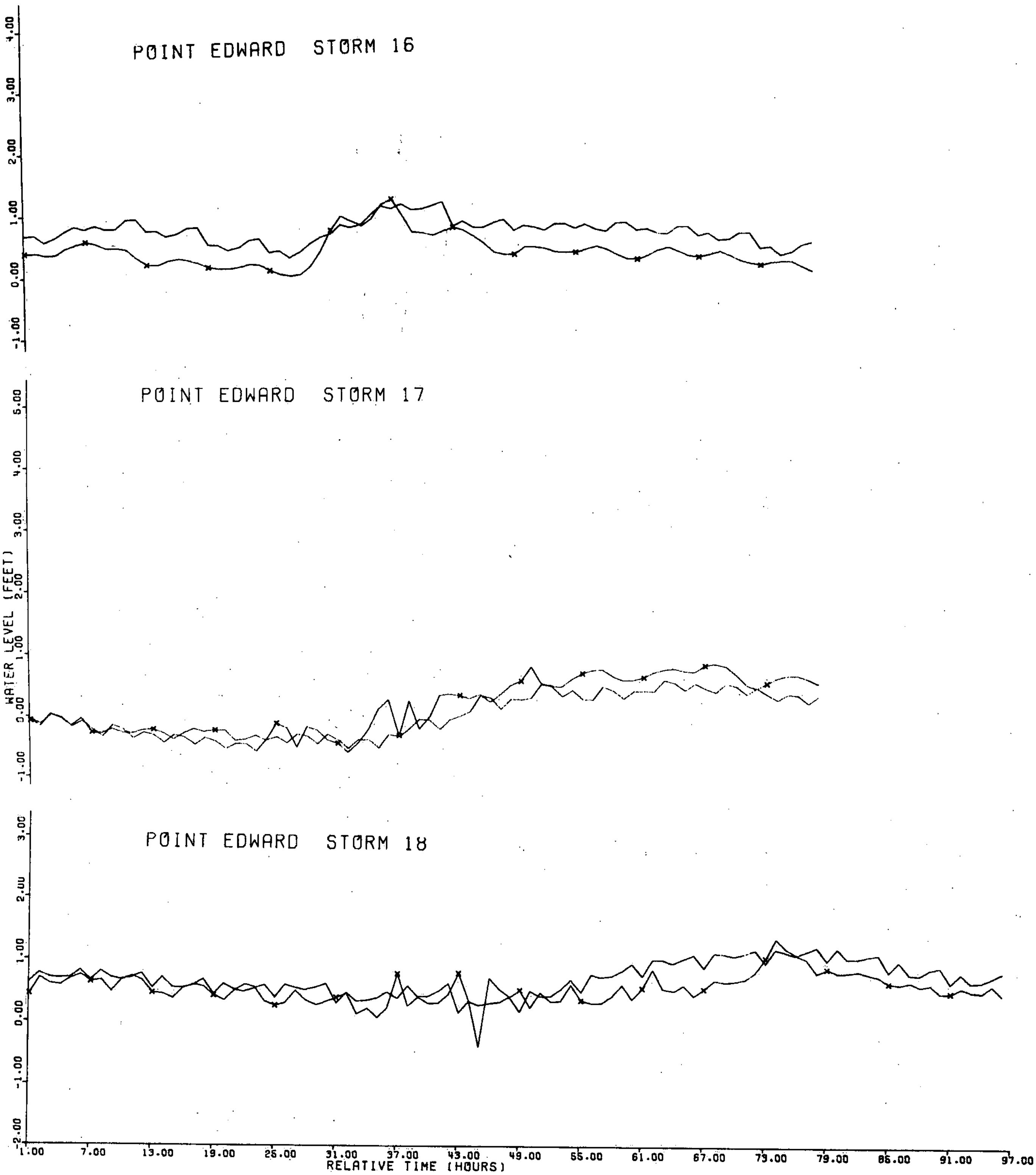

POINT EDWARD STORM 8
WATER LEVEL (FEET)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00


POINT EDWARD STORM 9
1.00
0.00
-1.00
-2.00
-3.00
-4.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)


POINT EDWARD STORM 10
POINT EDWARD STORM 11
POINT EDWARD STORM 12
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00



POINT EDWARD STORM 13
POINT EDWARD STORM 14
POINT EDWARD STORM 15
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)


POINT EDWARD STORM 16
POINT EDWARD STORM 17
POINT EDWARD STORM 18
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
-2.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
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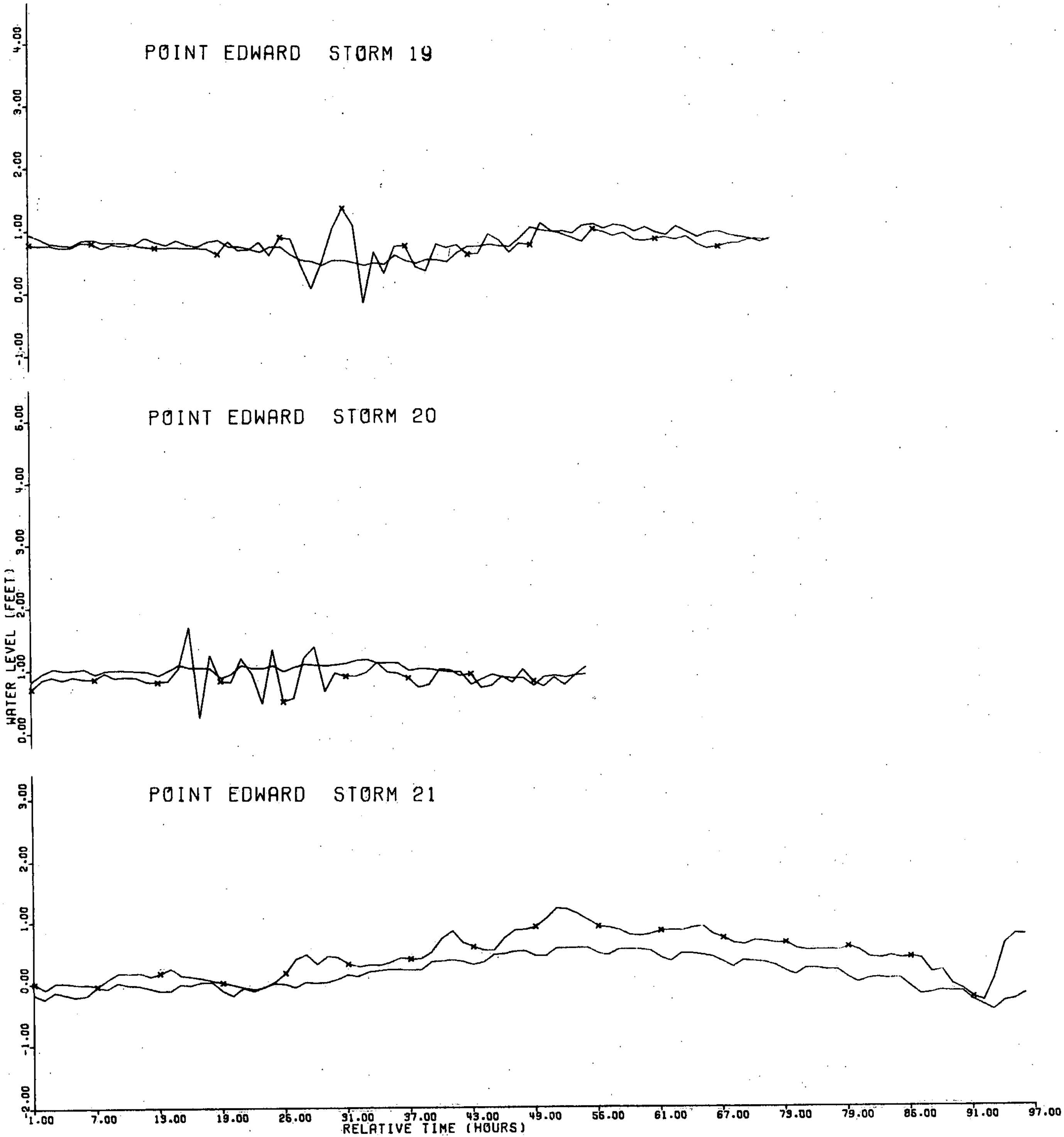
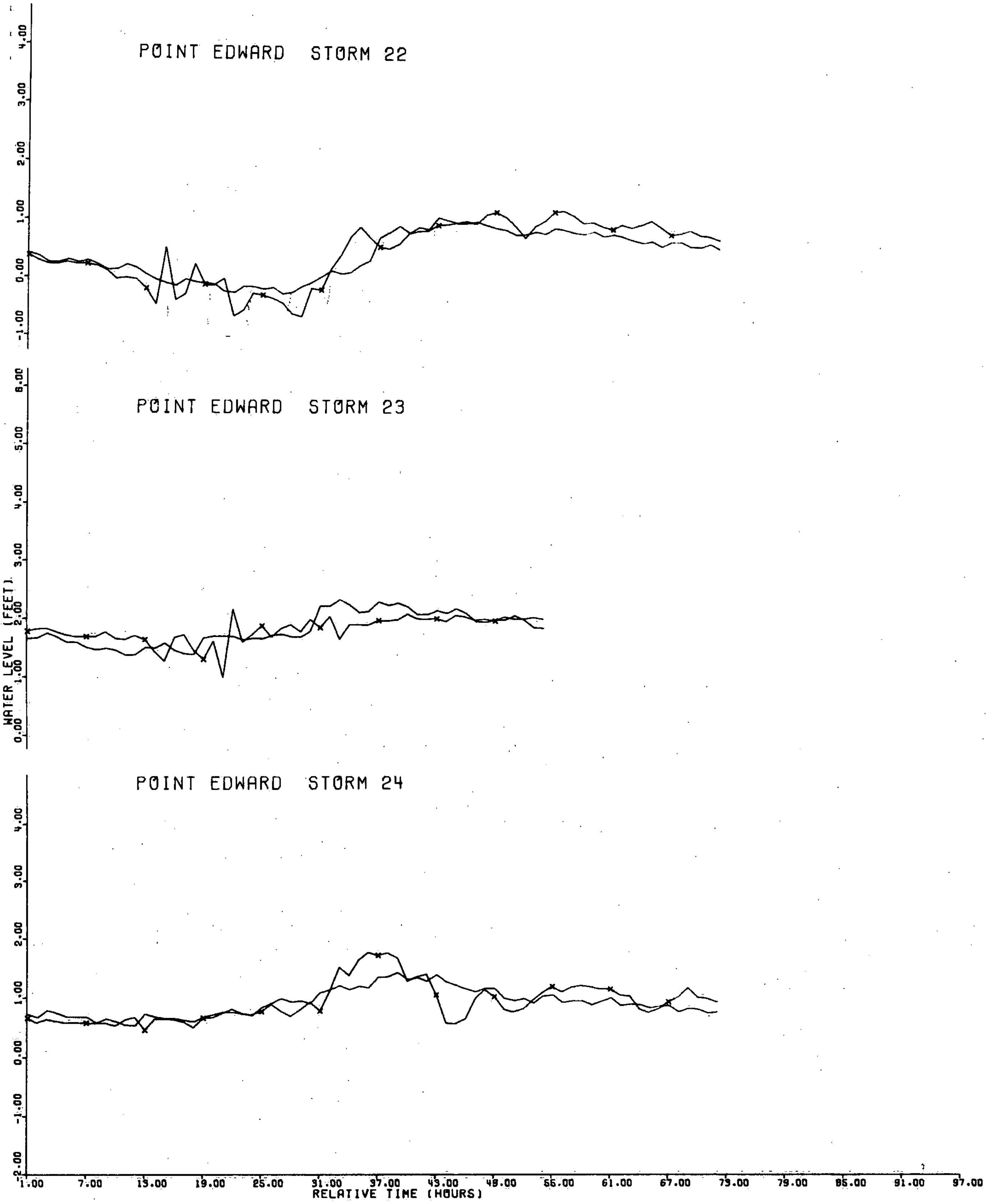
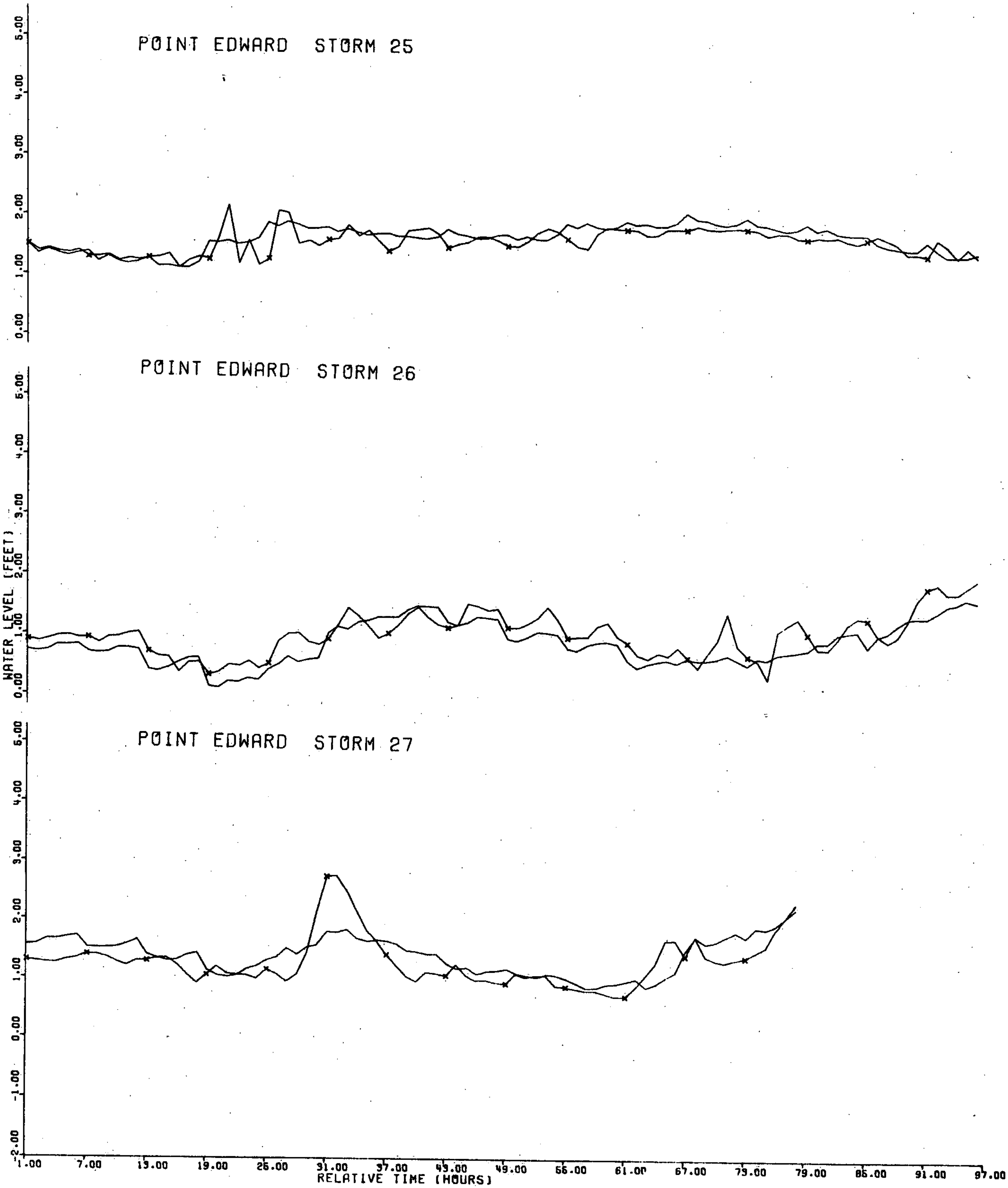
67.00
73.00
79.00
85.00
91.00
97.00



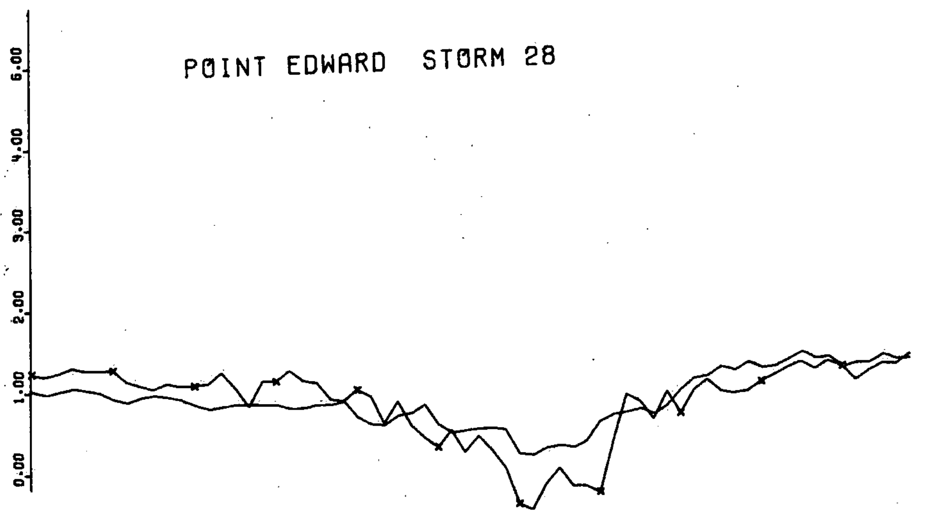
POINT EDWARD STORM 19
POINT EDWARD STORM 20
POINT EDWARD STORM 21
WATER LEVEL (FEET)
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
-2.00
1.00
7.00
13.00
19.00
26.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)

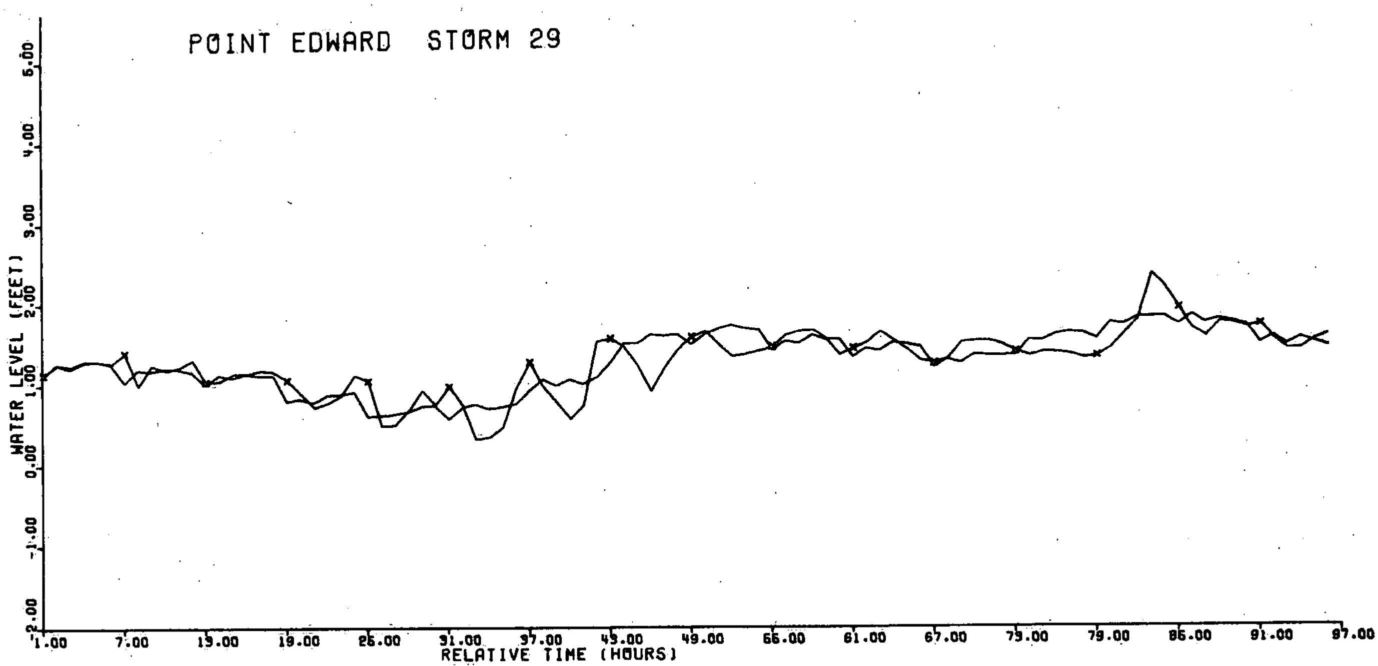


POINT EDWARD STORM 22
POINT EDWARD STORM 23
POINT EDWARD STORM 24
WATER LEVEL (FEET)
1.00 7.00 13.00 19.00 25.00 31.00 37.00 43.00 49.00 55.00 61.00 67.00 73.00 79.00 85.00 91.00 97.00
RELATIVE TIME (HOURS)

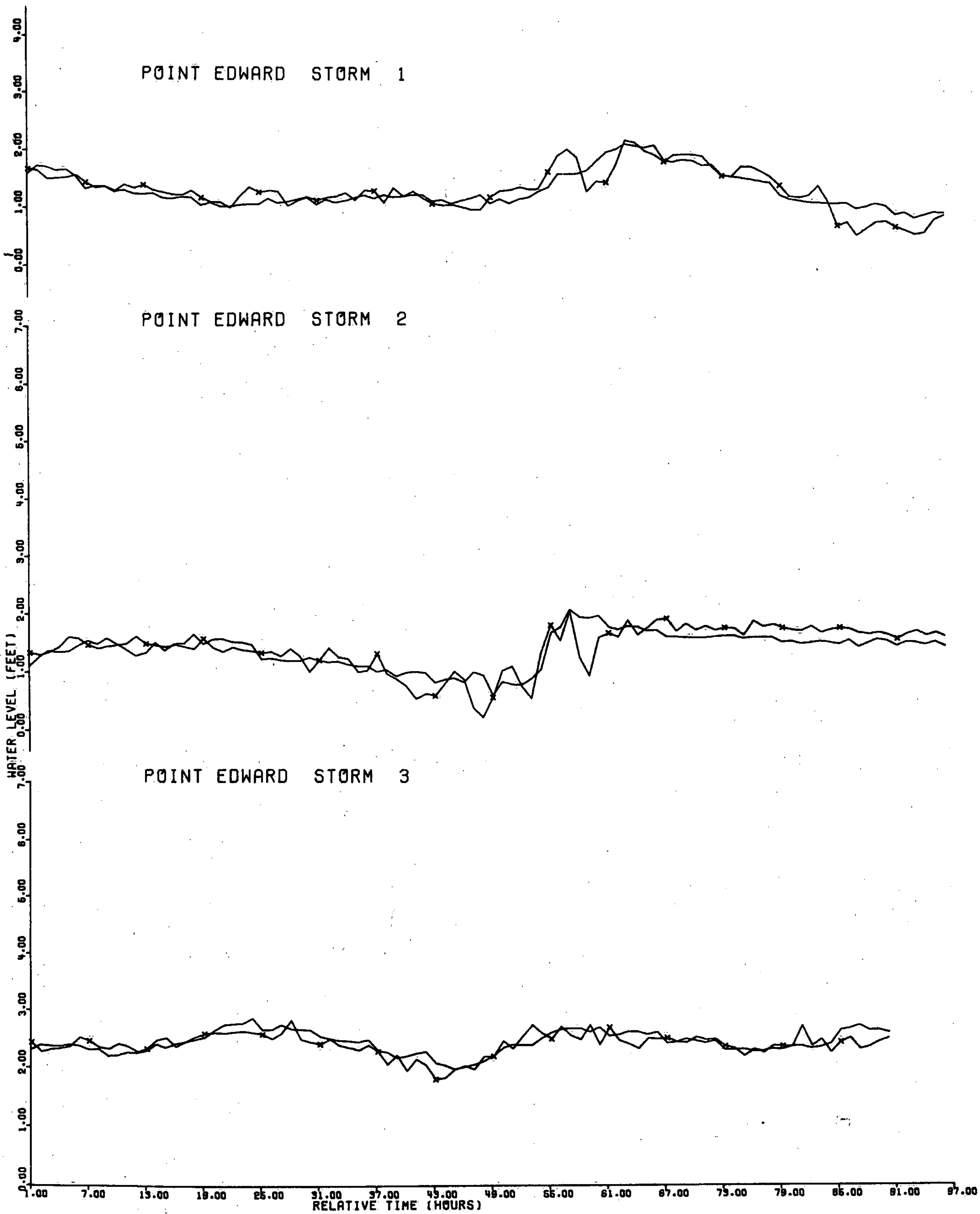


POINT EDWARD STORM 25
POINT EDWARD STORM 26
POINT EDWARD STORM 27
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)

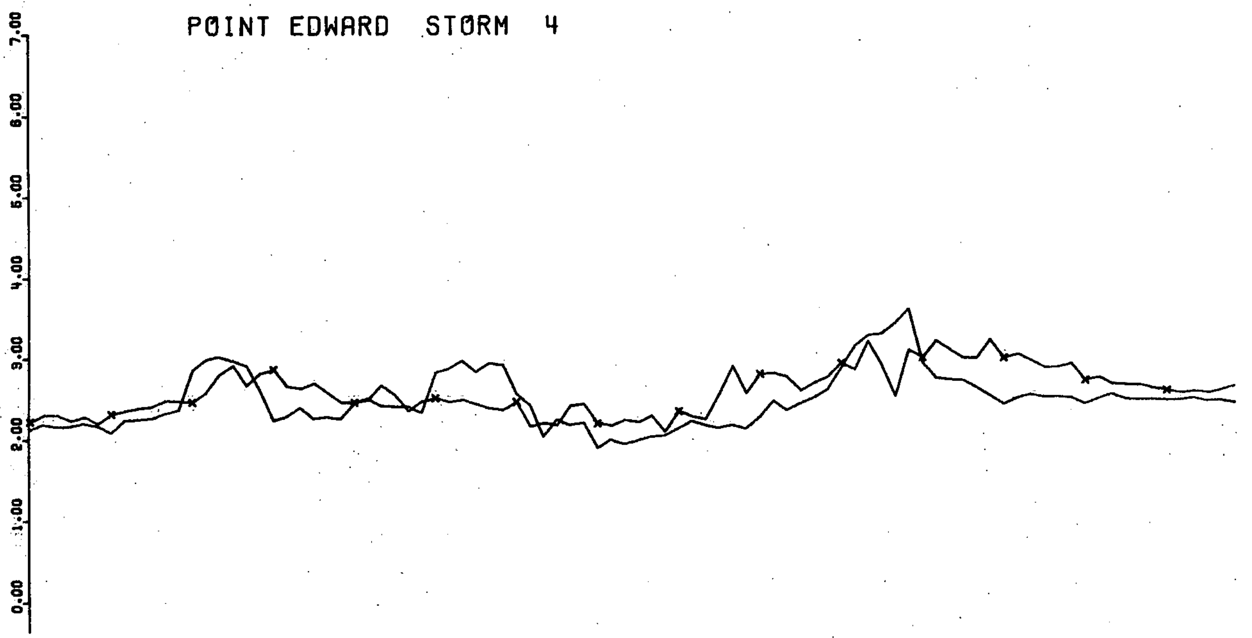

POINT EDWARD STORM 28
6.00
4.00
3.00
2.00
1.00
0.00

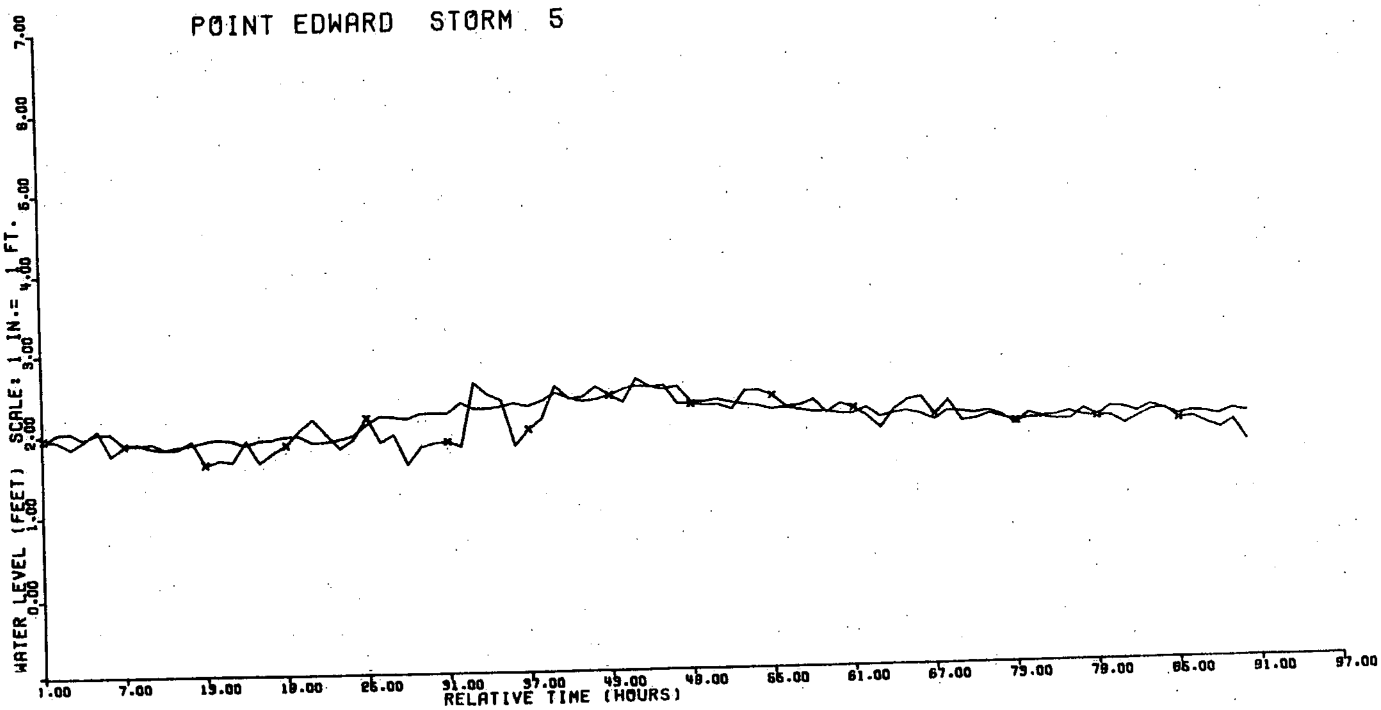

POINT EDWARD STORM 29
WATER LEVEL (FEET)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)

INDEPENDENT STORMS



POINT EDWARD STORM 1
POINT EDWARD STORM 2
POINT EDWARD STORM 3
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00


POINT EDWARD STORM 4
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00


POINT EDWARD STORM 5
WATER LEVEL (FEET) SCALE: 1 IN.= 1 FT.
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)

APPENDIX 5

The convention adopted in the plots following is:

-x-x-x-x- observed water levels

———— computed water levels

Lake Erie (Port Colborne) Storm Dates

Sl. No.	Dependent Storms yr/mo/day/hr (EST)		Sl. No.	Independent Storms yr/mo/day/hr (EST)	
	Start	End		Start	End
1	61/04/15/01	61/04/19/12	1	72/01/05/04	72/01/10/03
2	61/04/24/13	61/04/28/12	2	72/01/23/04	72/01/28/03
3	61/08/05/01	61/08/07/18	3	72/02/02/04	72/02/07/03
4	61/12/03/13	61/12/08/00	4	72/03/12/04	72/03/16/03
5	62/01/05/13	62/01/10/00	5	72/04/15/04	72/04/20/03
6	62/02/12/13	62/02/15/18	6	72/10/14/04	72/10/19/03
7	63/01/19/07	63/01/22/06	7	72/10/21/04	72/10/26/03
8	63/06/09/07	63/06/12/18	8	72/11/30/04	72/12/06/03
9	63/09/10/13	63/09/13/18	9	72/12/10/04	72/12/18/03
10	63/12/08/07	63/12/11/18			
11	64/03/24/07	64/03/28/18			
12	64/11/19/19	64/11/23/18			
13	65/01/25/13	65/01/29/18			
14	65/11/26/01	65/11/29/18			
15	66/10/14/13	66/10/17/06			
16	67/02/14/13	67/02/17/12			
17	67/10/26/19	67/10/29/18			
18	68/02/01/19	68/02/04/12			
19	68/06/24/07	68/06/27/06			
20	68/12/27/07	68/12/31/00			
21	69/05/08/19	69/05/12/18			
22	70/03/25/01	70/03/28/06			
23	70/04/18/01	70/04/22/18			
24	70/09/03/13	70/09/07/12			
25	71/01/25/01	71/01/28/00			
26	71/12/09/19	71/12/15/00			

STORM SURGE PREDICTION EQUATIONS

for Lake Erie at Port Colborne

$$S_0 = 9.408580 - 0.04541P_{(1,-6)} + 0.04436P_{(2,-6)} + 0.10715P_{(3,-6)} - 0.19730P_{(4,-6)} - 0.08530P_{(6,-6)} + 0.11814P_{(7,-6)} + 0.06895P_{(1,0)} - 0.08614P_{(3,0)} + 0.15633P_{(4,0)} + 0.06645P_{(6,0)} - 0.15647P_{(7,0)} - 0.012770(T_A - T_W)_0$$

$$S_1 = 4.772560 + 0.02176P_{(2,-6)} + 0.05259P_{(3,-6)} - 0.18012P_{(4,-6)} - 0.08540P_{(6,-6)} + 0.15582P_{(7,-6)} + 0.009360(T_A - T_W) + 0.05271P_{(1,0)} - 0.05225P_{(3,0)} + 0.14780P_{(4,0)} + 0.07043P_{(6,0)} - 0.18799P_{(7,0)} - 0.021230(T_A - T_W)_0$$

$$S_2 = 2.805560 + 0.02716P_{(3,-6)} - 0.13865P_{(4,-6)} - 0.06757P_{(6,-6)} + 0.15575P_{(7,-6)} + 0.013960(T_A - T_W)_{-6} + 0.04003P_{(1,0)} + 0.02283P_{(2,0)} + 0.09439P_{(4,0)} + 0.04903P_{(6,0)} - 0.18566P_{(7,0)} - 0.023530(T_A - T_W)_0$$

$$S_3 = 2.972070 - 0.02682P_{(2,-6)} - 0.07063P_{(4,-6)} - 0.04007P_{(6,-6)} + 0.12997P_{(7,-6)} + 0.016890(T_A - T_W)_{-6} + 0.02355P_{(1,0)} + 0.04485P_{(2,0)} + 0.07561P_{(3,0)} + 0.00536P_{(4,0)} - 0.14462P_{(7,0)} - 0.023080(T_A - T_W)_0$$

$$S_4 = 0.751780 + 0.02516P_{(1,-6)} - 0.04391P_{(2,-6)} - 0.04971P_{(3,-6)} - 0.03233P_{(6,-6)} + 0.11057P_{(7,-6)} + 0.011510(T_A - T_W)_{-6} + 0.02154P_{(1,0)} + 0.05460P_{(2,0)} + 0.10284P_{(3,0)} - 0.06430P_{(4,0)} - 0.12508P_{(7,0)} - 0.001842(T_A - T_W)_0$$

$$S_5 = 3.459240 + 0.00911P_{(1,-6)} - 0.04955P_{(2,-6)} - 0.07901P_{(3,-6)} + 0.07572P_{(4,-6)} + 0.00836P_{(6,-6)} + 0.04780P_{(7,-6)} + 0.011560(T_A - T_W)_{-6} + 0.03466P_{(1,0)} + 0.05364P_{(2,0)} + 0.14898P_{(3,0)} - 0.14690P_{(4,0)} - 0.05458P_{(6,0)} - 0.05150P_{(7,0)} - 0.016890(T_A - T_W)_0$$

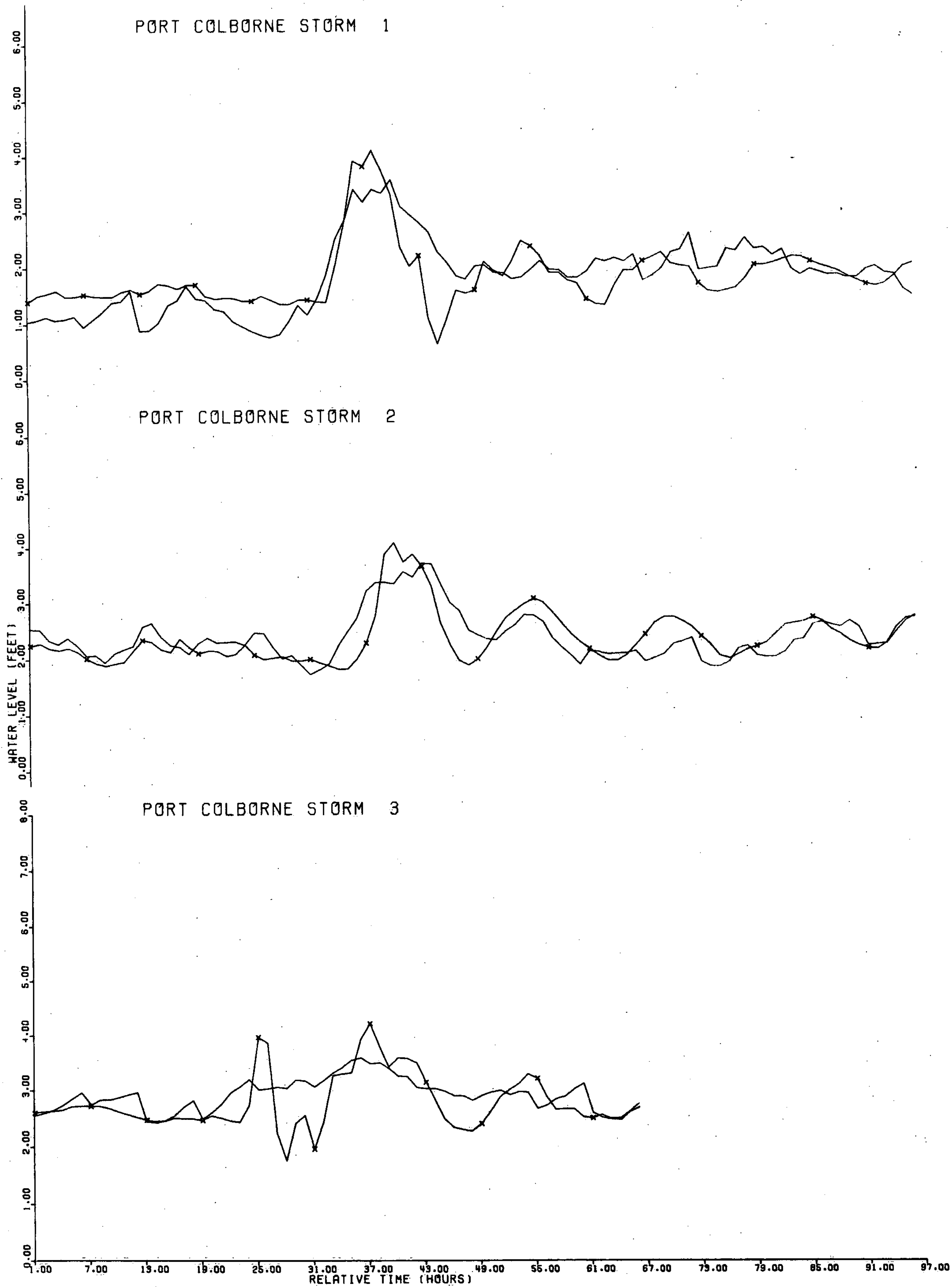
where

S = Surge in feet, with the subscript representing the number of hours after the time of the pressure forecast

$P_{(N,T)}$ = Pressure in millibar at grid point number N (see Figure 1) and lag time T hours

$(T_A - T_W)_T$ = Air-water temperature difference at the water level station at a lag time of T hours

DEPENDENT STORMS


PORT COLBORNE STORM 1
PORT COLBORNE STORM 2
PORT COLBORNE STORM 3
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
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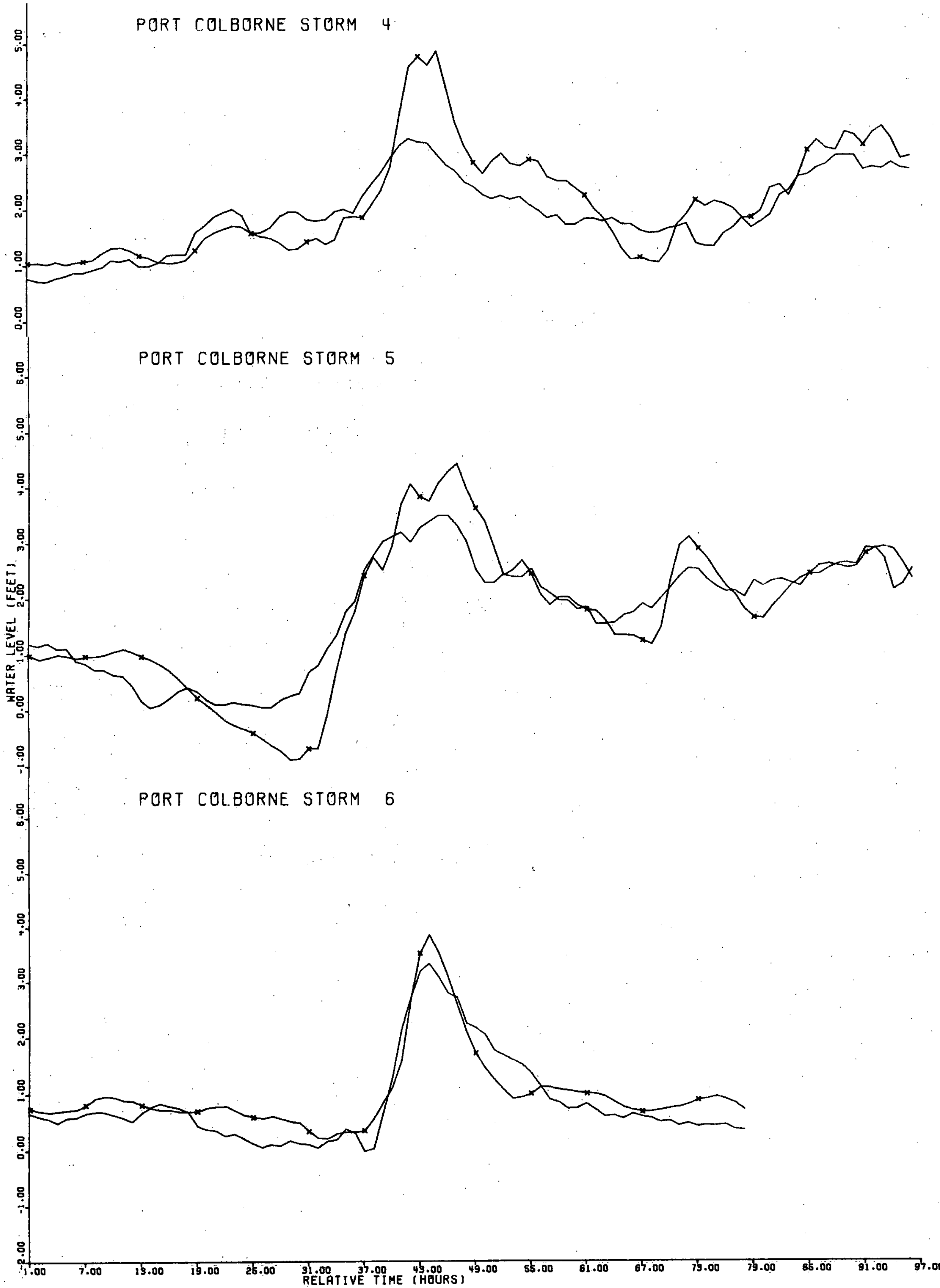
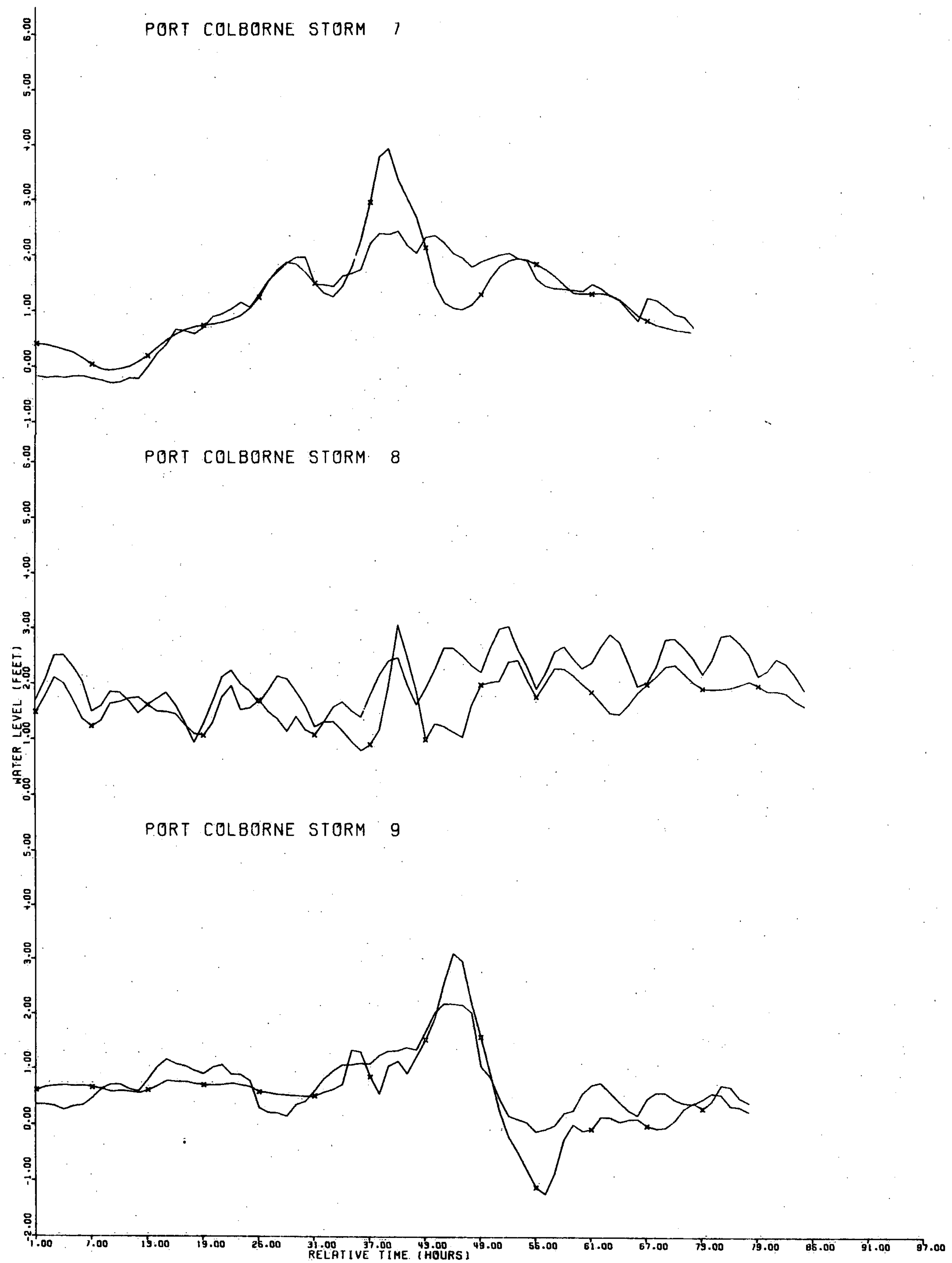
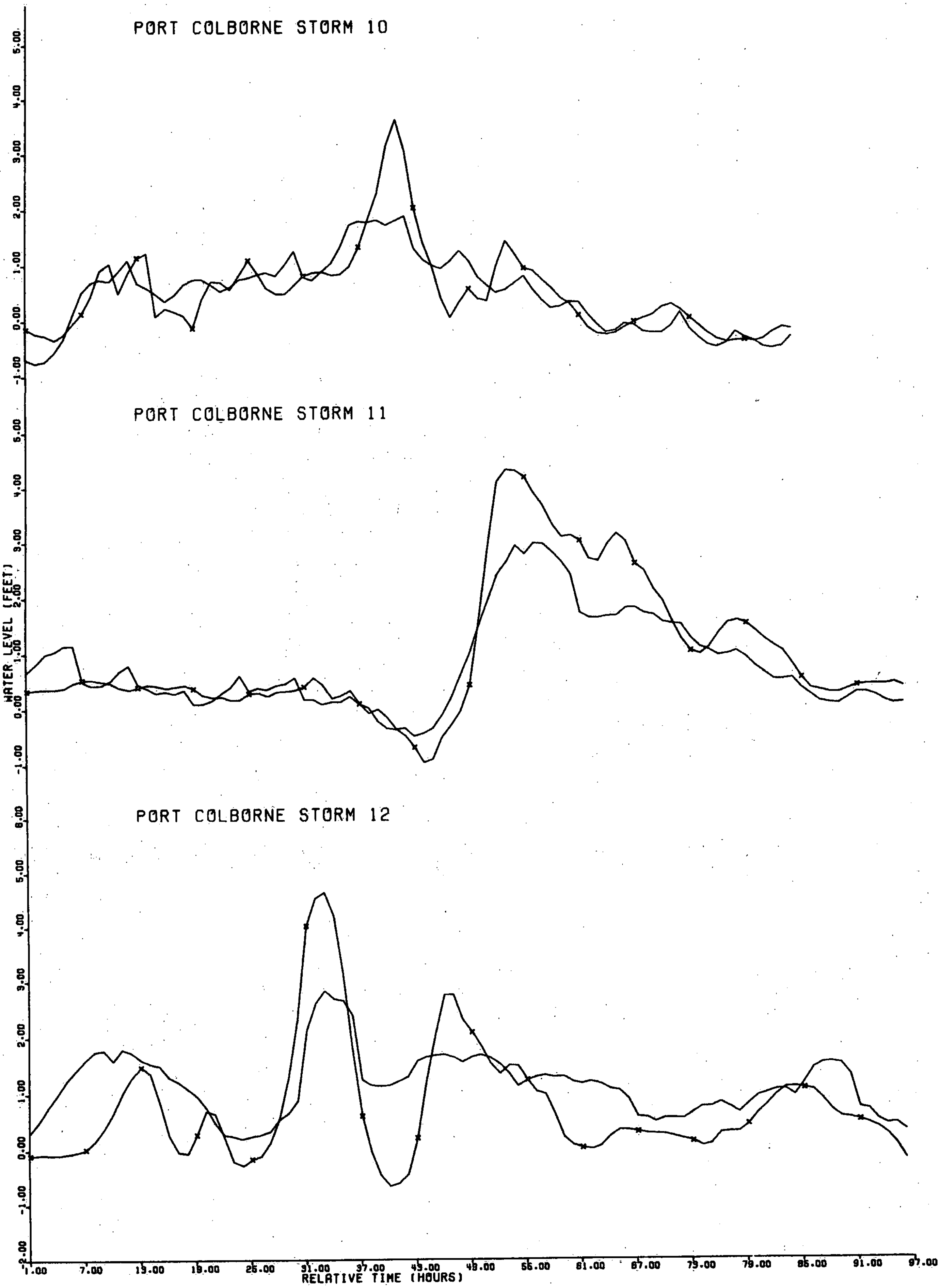
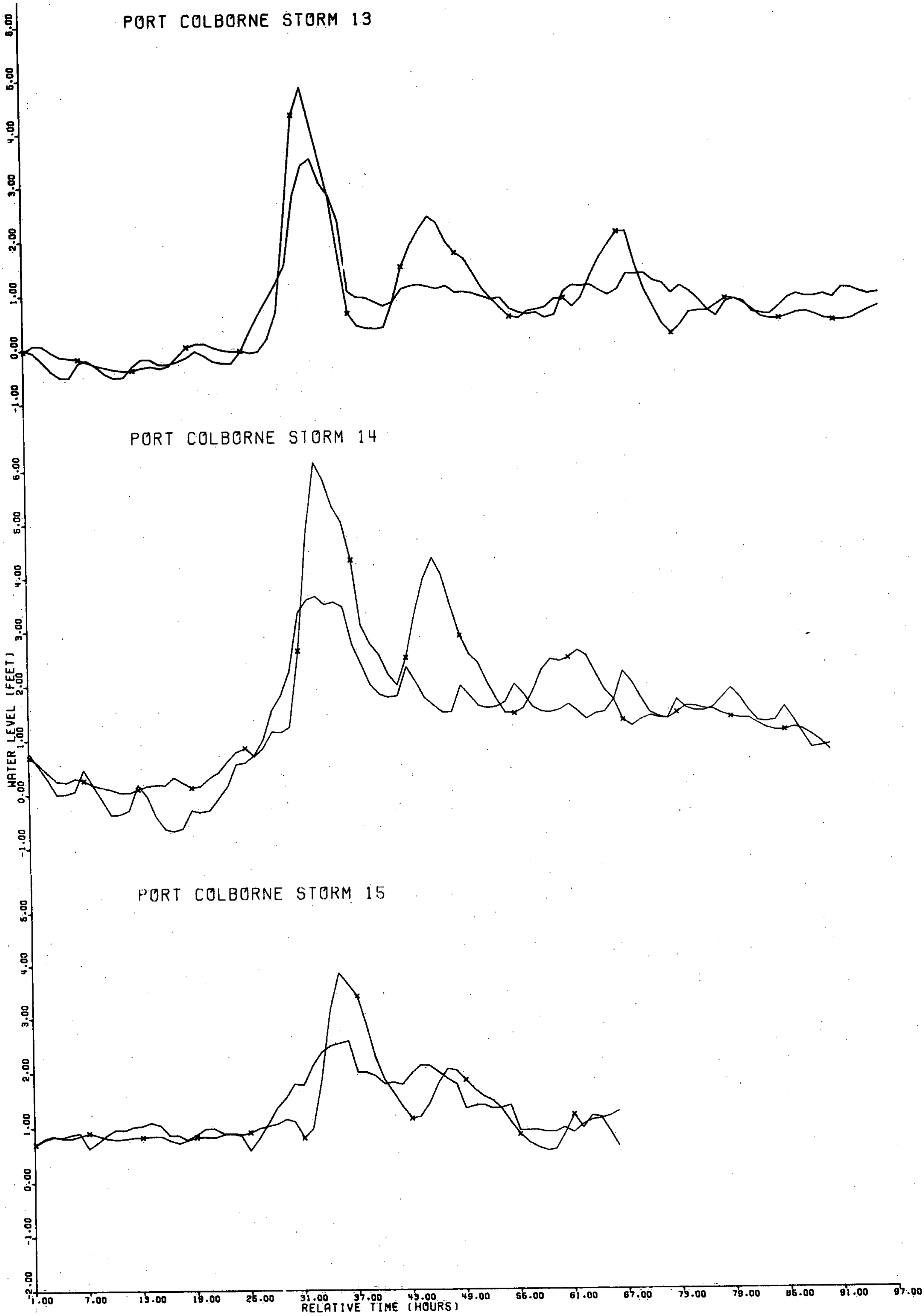
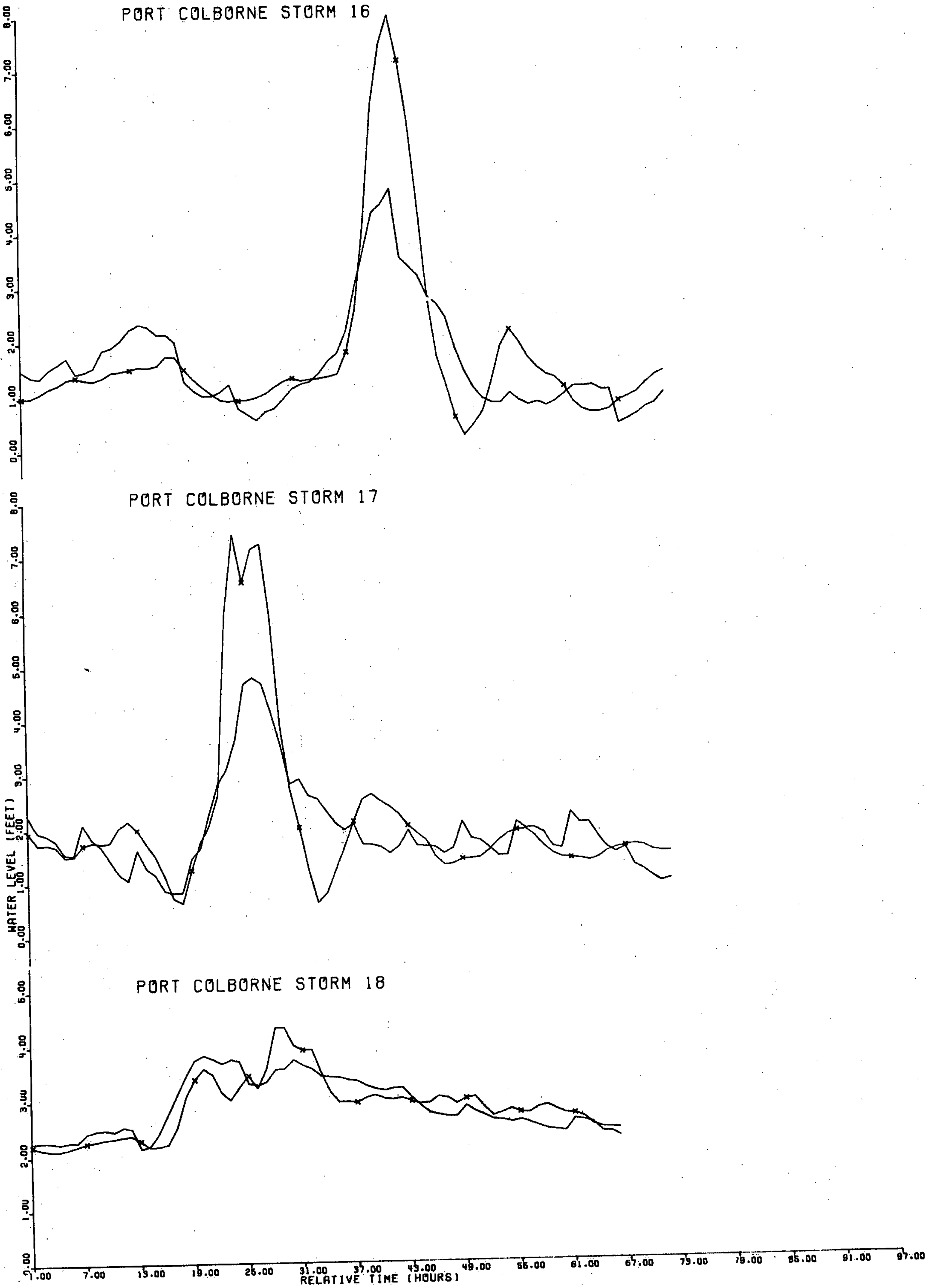
61.00
67.00
73.00
79.00
85.00
91.00
97.00


PORT COLBORNE STORM 4
PORT COLBORNE STORM 5
PORT COLBORNE STORM 6
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00

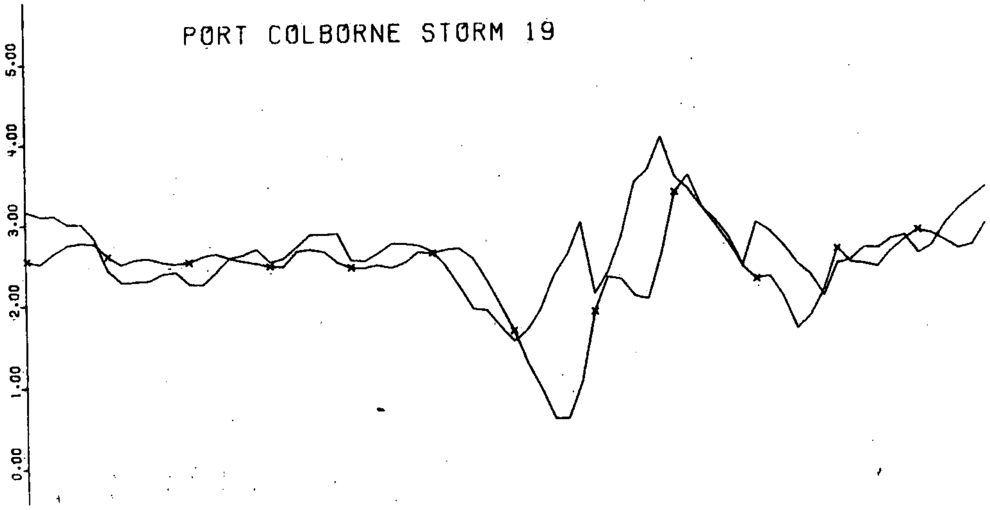

PORT COLBORNE STORM 7
PORT COLBORNE STORM 8
PORT COLBORNE STORM 9
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

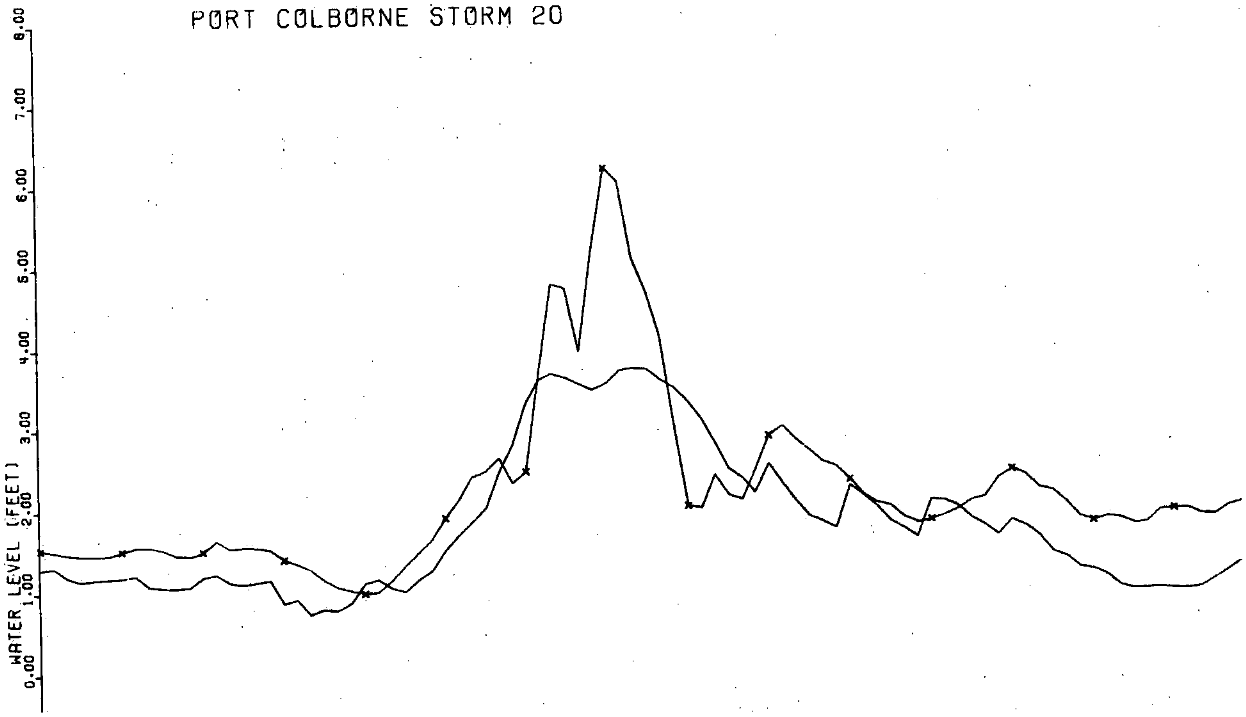

PORT COLBORNE STORM 10
PORT COLBORNE STORM 11
PORT COLBORNE STORM 12
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)

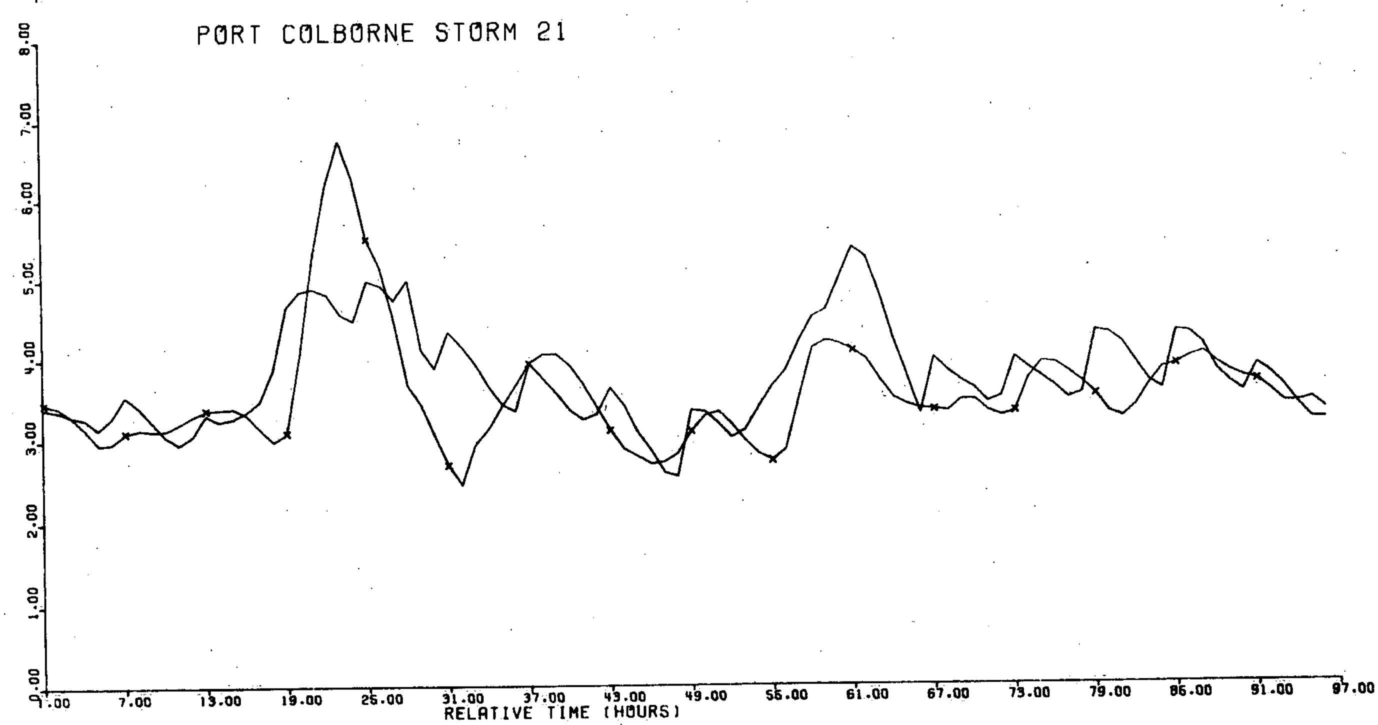

PORT COLBORNE STORM 13
PORT COLBORNE STORM 14
PORT COLBORNE STORM 15
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
1.00 7.00 13.00 19.00 25.00 31.00 37.00 43.00 49.00 55.00 61.00 67.00 73.00 79.00 85.00 91.00 97.00

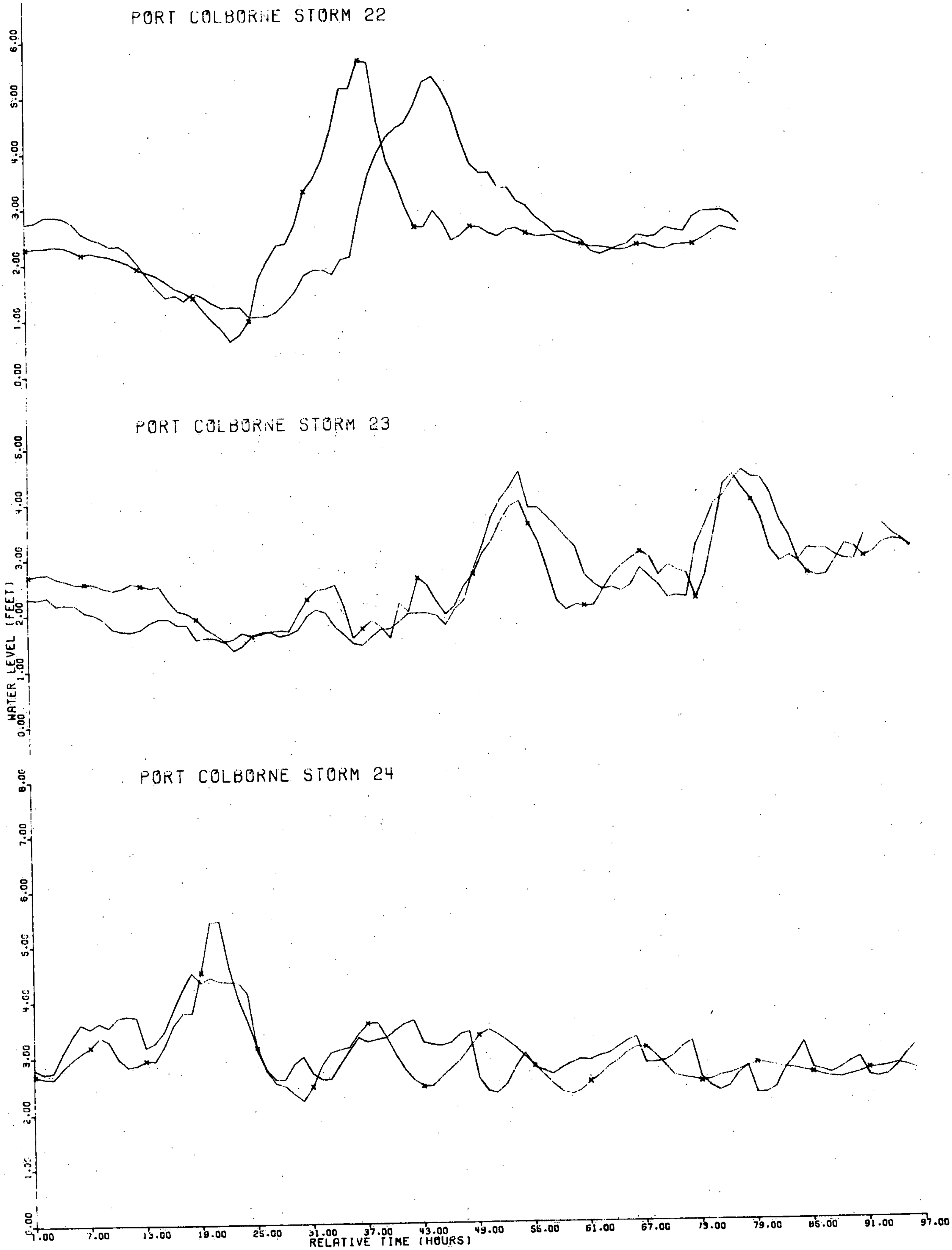


PORT COLBORNE STORM 16
PORT COLBORNE STORM 17
PORT COLBORNE STORM 18
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00


PORT COLBORNE STORM 19
0.00
1.00
2.00
3.00
4.00
5.00


PORT COLBORNE STORM 20
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00


PORT COLBORNE STORM 21
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)


PORT COLBORNE STORM 22
PORT COLBORNE STORM 23
PORT COLBORNE STORM 24
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
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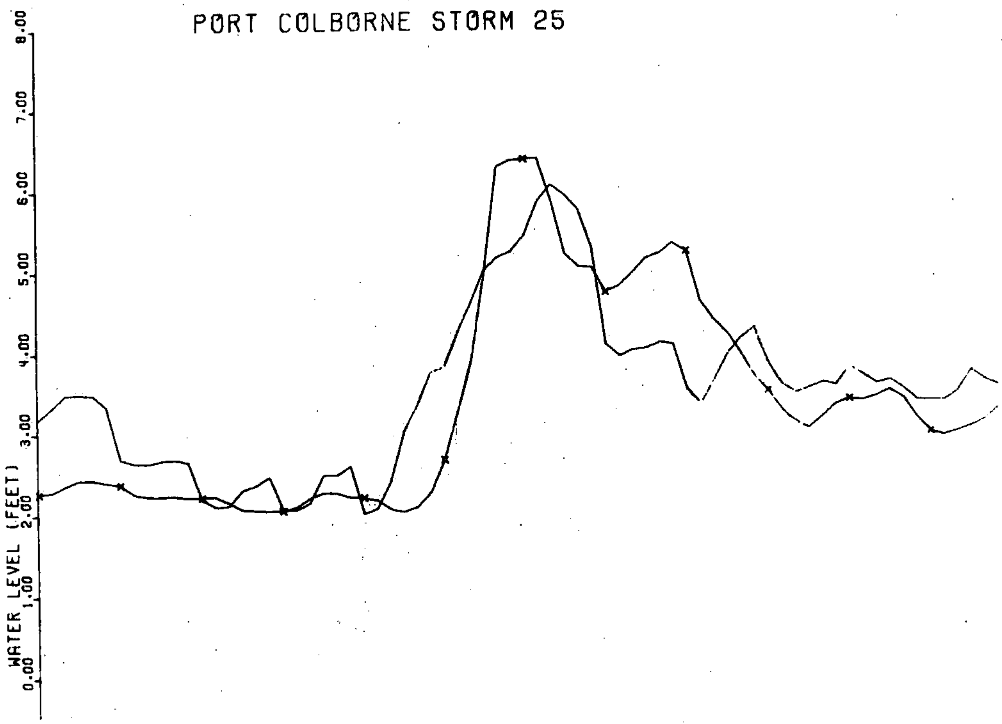
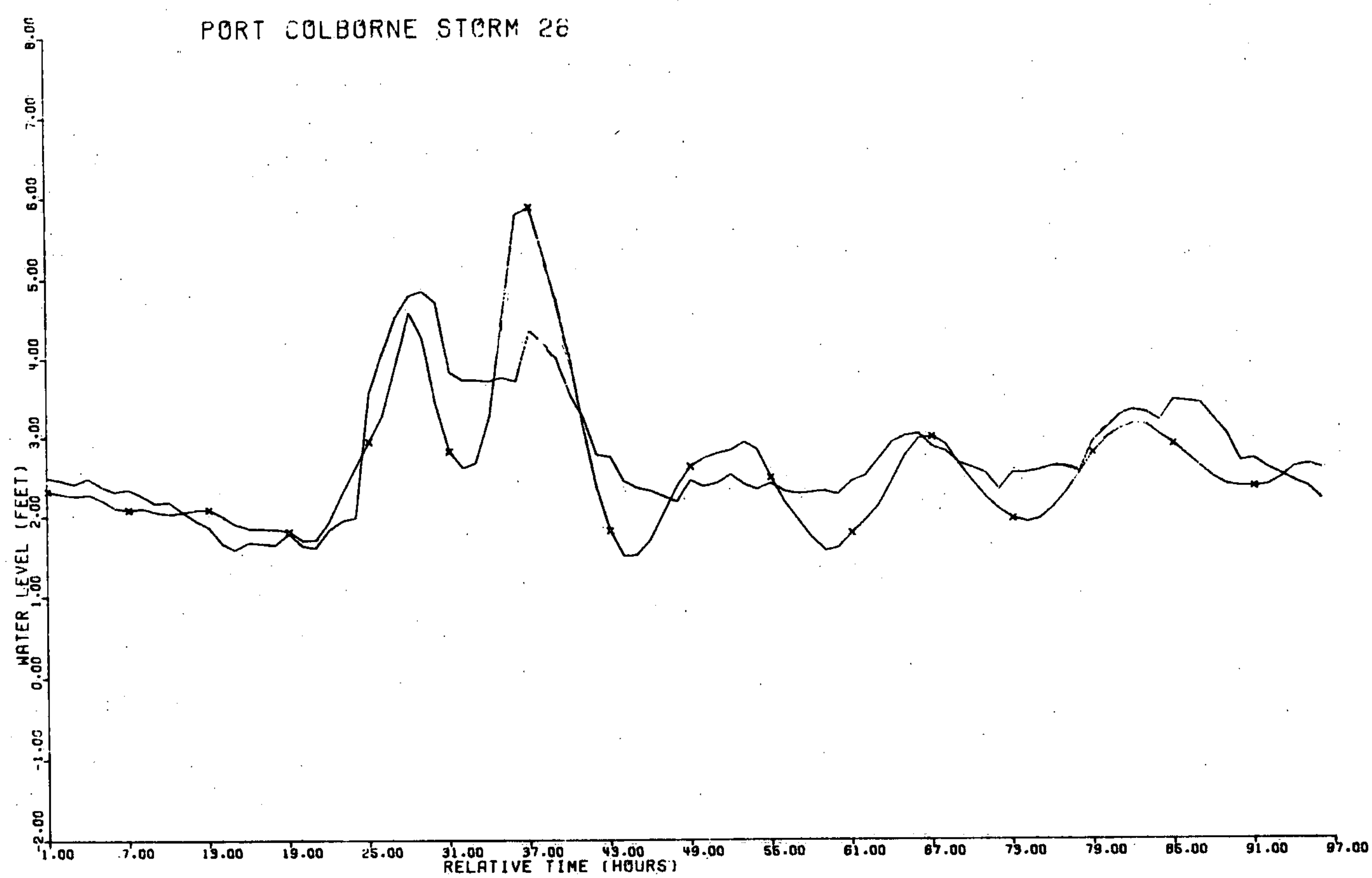
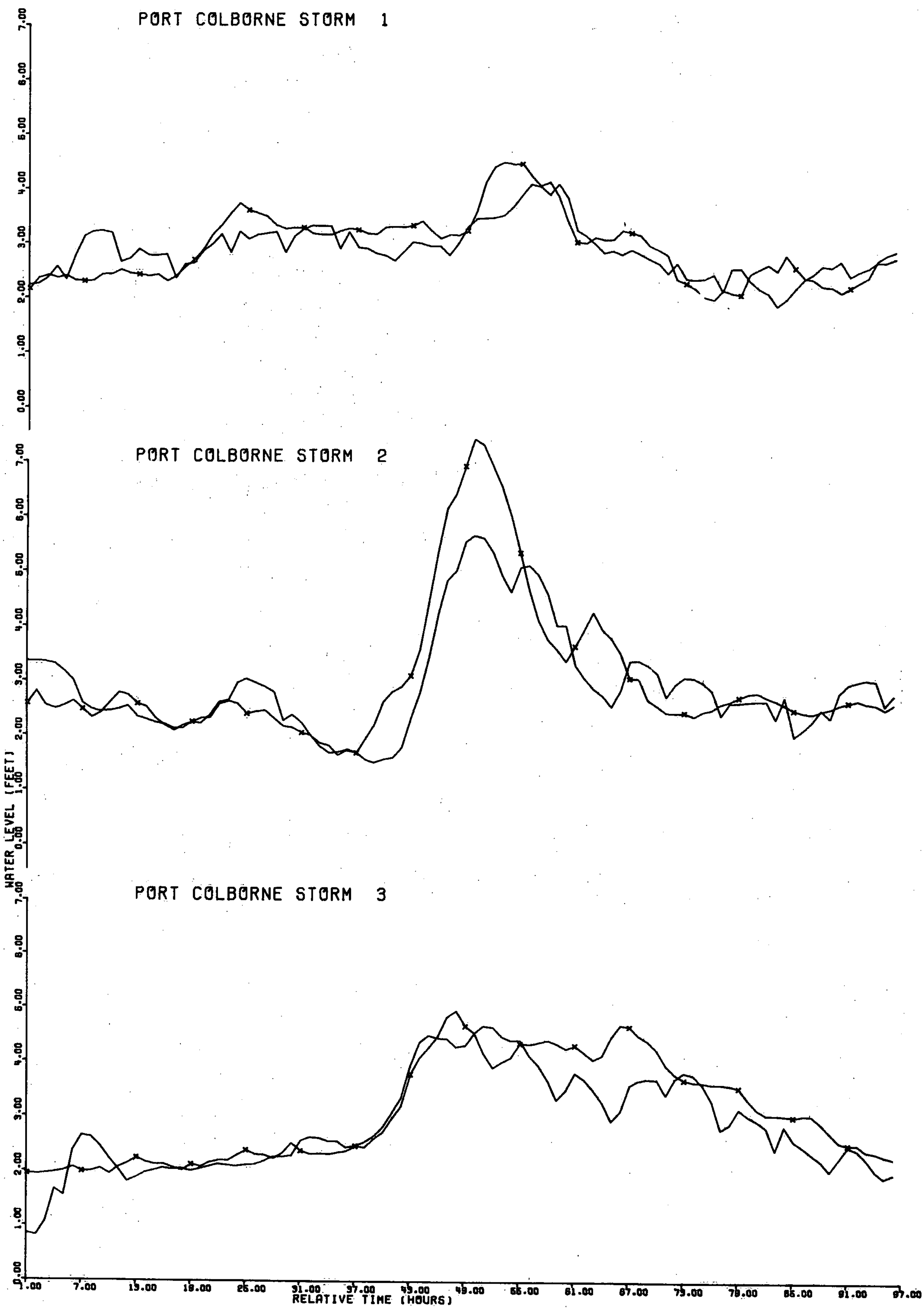
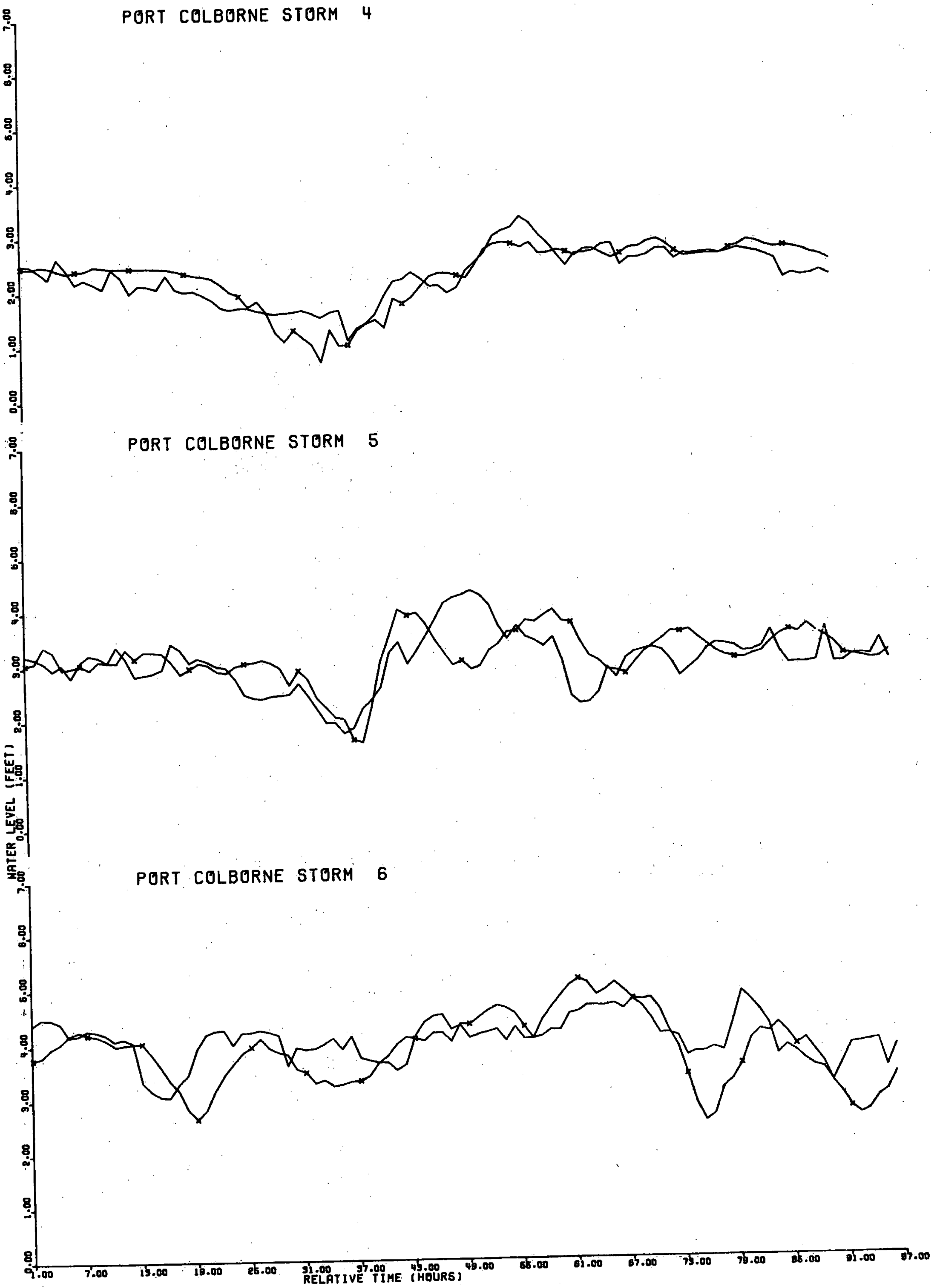
61.00
67.00
73.00
79.00
85.00
91.00
97.00

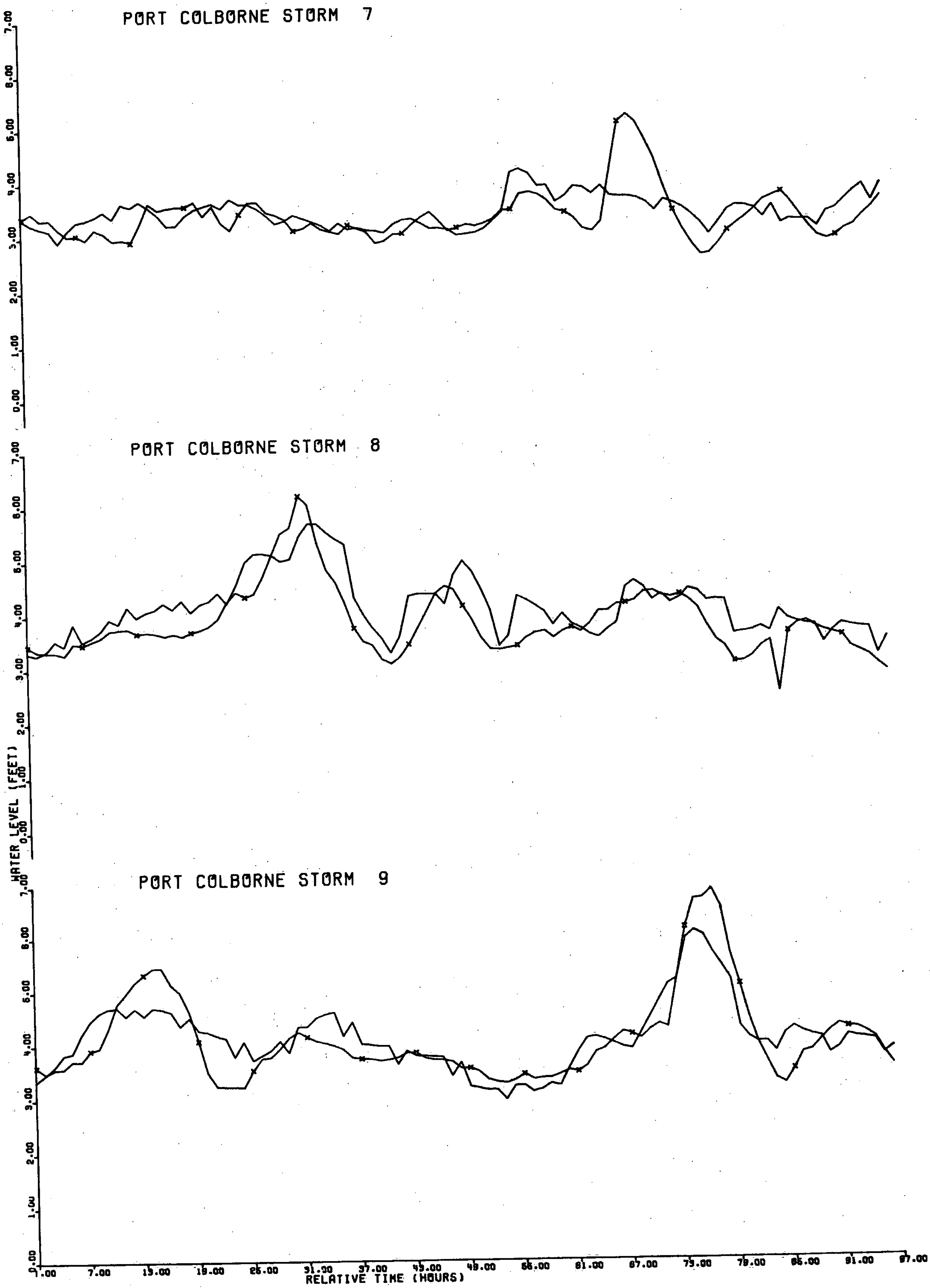

PORT COLBORNE STORM 25
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00


PORT COLBORNE STORM 26
WATER LEVEL (FEET)
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)

INDEPENDENT STORMS


PORT COLBORNE STORM 1
PORT COLBORNE STORM 2
PORT COLBORNE STORM 3
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00


PORT COLBORNE STORM 4
PORT COLBORNE STORM 5
PORT COLBORNE STORM 6
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)


PORT COLBORNE STORM 7
PORT COLBORNE STORM 8
PORT COLBORNE STORM 9
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)

APPENDIX 6

The convention adopted in the plots following is:

-x-x-x-x- observed water levels

———— computed water levels

Lake Erie (Kingsville) Storm Dates

Sl. No.	Dependent Storms yr/mo/day/hr (EST)		Sl. No.	Independent Storms yr/mo/day/hr (EST)	
	Start	End		Start	End
1	63/06/08/07	63/06/12/18	1	72/01/05/04	72/01/10/03
2	63/09/11/13	63/09/14/18	2	72/01/23/04	72/01/28/03
3	64/11/19/13	64/11/23/12	3	72/02/02/04	72/02/07/03
4	65/11/25/19	65/11/30/00	4	72/03/12/04	72/03/16/03
5	67/02/14/07	67/02/17/06	5	72/04/15/04	72/04/20/03
6	67/04/21/07	67/04/24/06	6	72/10/14/04	72/10/19/03
7	67/10/24/07	67/10/30/06	7	72/10/21/04	72/10/26/03
8	69/04/16/13	69/04/21/06	8	72/11/30/04	72/12/06/03
9	69/05/07/19	69/05/12/18	9	72/12/10/04	72/12/18/03
10	70/03/25/07	70/03/28/06			
11	70/04/02/07	70/04/04/18			
12	70/04/18/07	70/04/23/00			
13	70/09/03/07	70/09/07/00			
14	71/01/25/07	71/01/29/00			

STORM SURGE PREDICTION EQUATIONS

Lake Erie at Kingsville

$$S_0 = -9.826520 - 0.08836P_{(3,-6)} + 0.08688P_{(4,-6)} + 0.07556P_{(6,-6)} - 0.07278P_{(7,-6)}$$
$$-0,02061P_{(1,0)} + 0.04234P_{(3,0)} - 0.06566P_{(4,0)} - 0.06430P_{(6,0)} +$$
$$0.11660P_{(7,0)} + 0.010590(T_A - T_W)_0$$

$$S_1 = -5.398950 - 0.06271P_{(3,-6)} + 0.06439P_{(4,-6)} + 0.07142P_{(6,-6)} -$$
$$0.07728P_{(7,-6)} - 0.02841P_{(1,0)} + 0.03330P_{(3,0)} - 0.05608P_{(4,0)} -$$
$$- 0.06846P_{(6,0)} + 0.12917P_{(7,0)} + 0.009840(T_A - T_W)_0$$

$$S_2 = -0.053900 + 0.06540P_{(6,-6)} - 0.05975P_{(7,-6)} - 0.04656P_{(1,0)} -$$
$$0.06885P_{(6,0)} + 0.10983P_{(7,0)} + 0.011020(T_A - T_W)_0$$

$$S_3 = -1.228570 + 0.01423P_{(3,-6)} + 0.05289P_{(6,-6)} - 0.06565P_{(7,-6)} -$$
$$0.03811P_{(1,0)} - 0.02210P_{(3,0)} - 0,04964P_{(6,0)} + 0.10959P_{(7,0)} +$$
$$0.011990(T_A - T_W)_0$$

$$S_4 = -4.340570 + 0.04961P_{(1,-6)} - 0.02199P_{(2,-6)} - 0.04308P_{(7,-6)} -$$
$$0.03664P_{(1,0)} - 0.05161P_{(3,0)} + 0.10803P_{(7,0)} + 0.013490(T_A - T_W)_0$$

$$S_5 = -3,920300 + 0.05633P_{(3,-6)} - 0.05595P_{(4,-6)} - 0.02239P_{(7,-6)} -$$
$$0.04397P_{(1,0)} + 0.01709P_{(2,0)} - 0.09097P_{(3,0)} + 0.07248P_{(4,0)} +$$
$$0.02343P_{(6,0)} + 0.04781P_{(7,0)} + 0.011020(T_A - T_W)_0$$

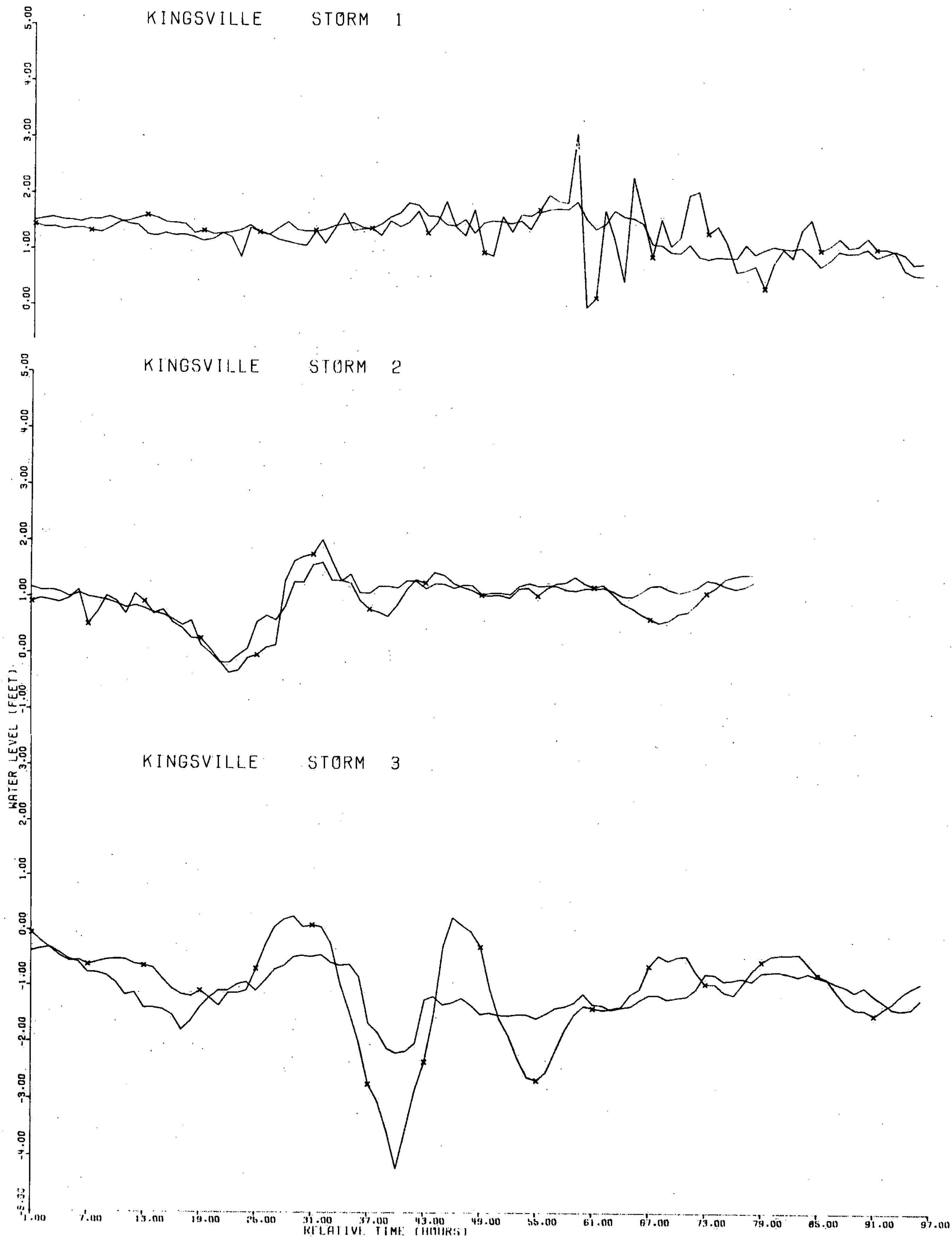
where

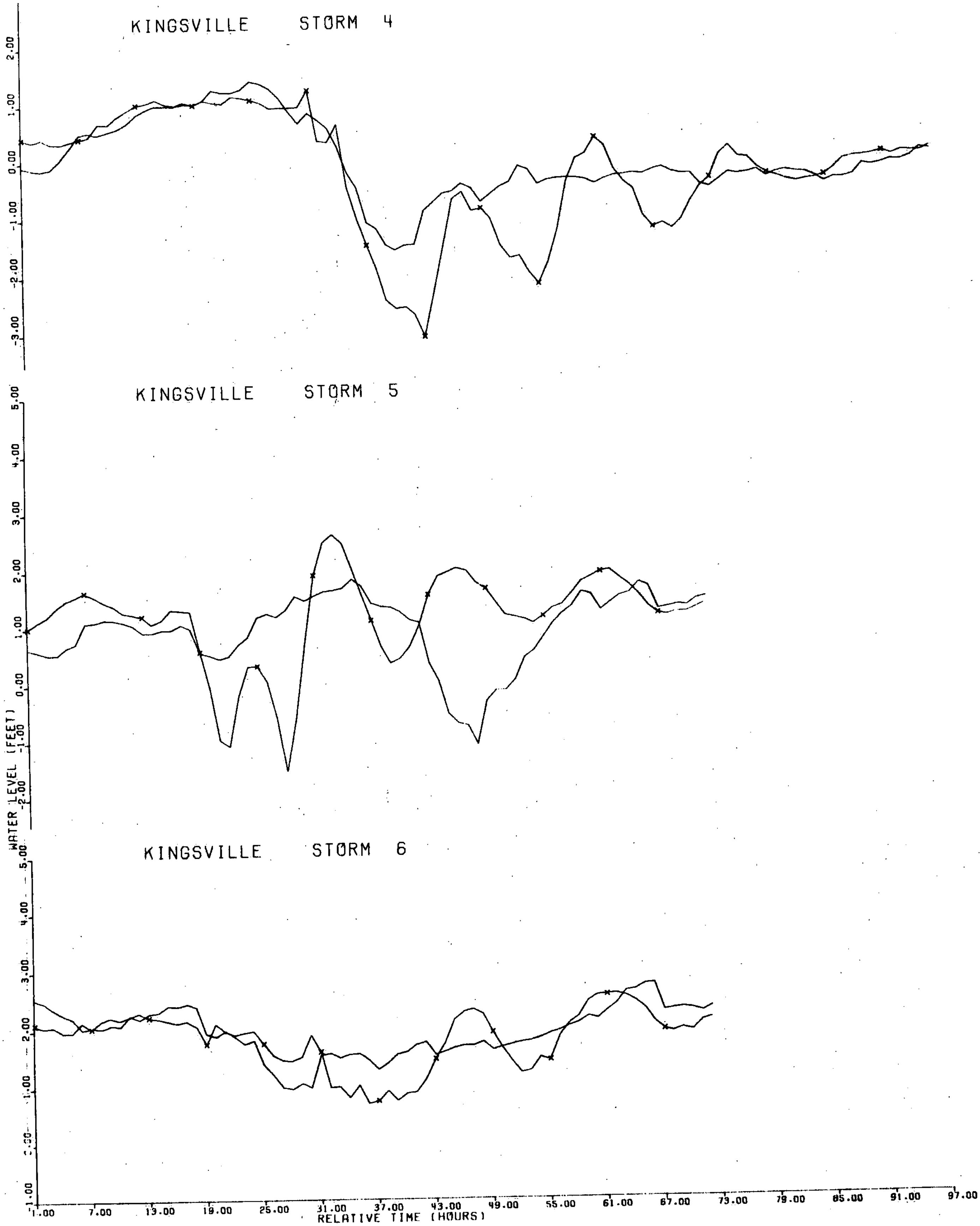
S = Surge in feet, with the subscript representing the number of hours after the time of the pressure forecast

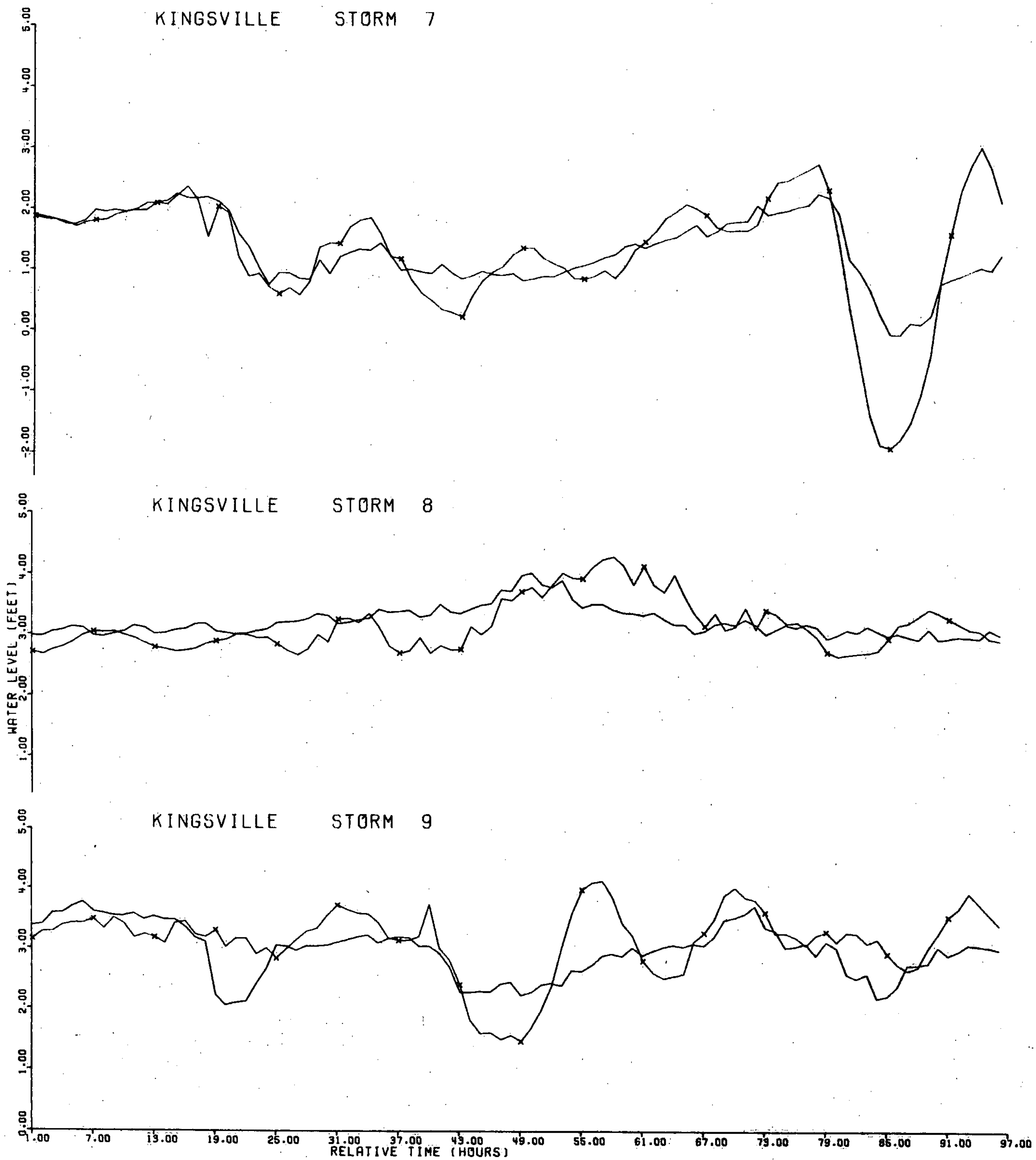
$P_{(N,T)}$ = Pressure in millibar at grid point number N (see Figure 1) and lag time T hours

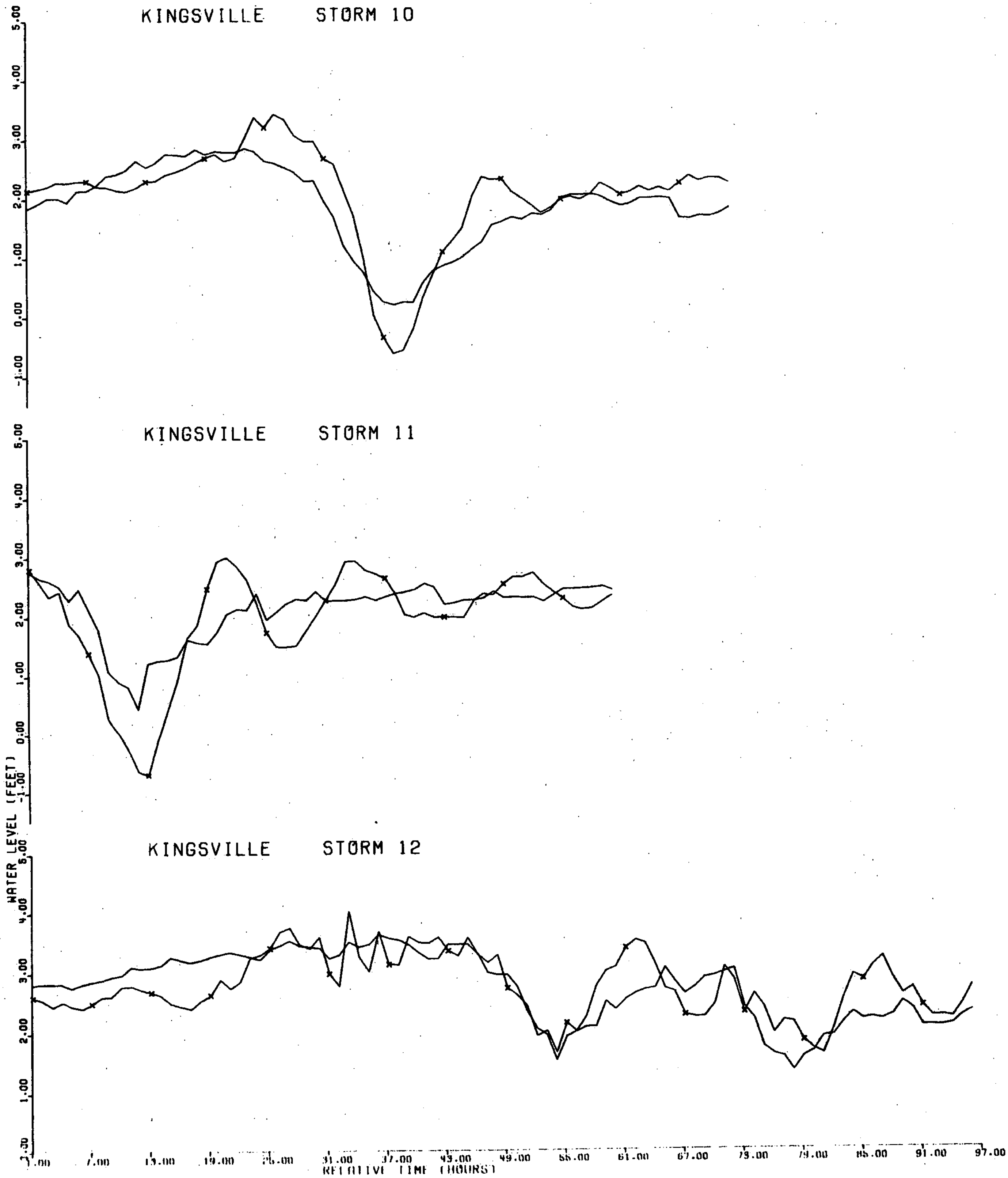
$(T_A - T_W)_T$ = Air-water temperature difference at the water level station at a lag time of T hours

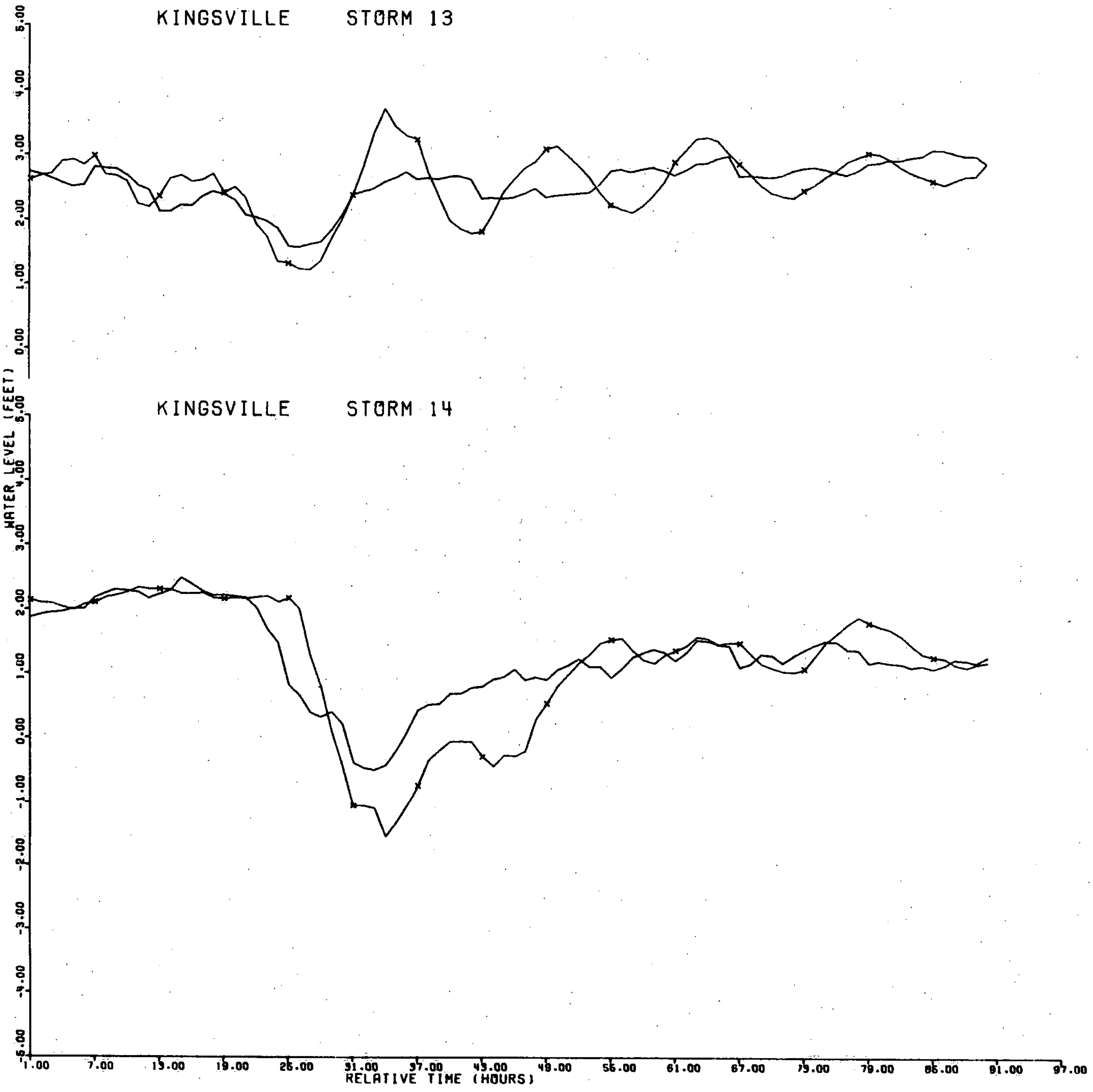
DEPENDENT STORMS


KINGSVILLE STORM 1
KINGSVILLE STORM 2
KINGSVILLE STORM 3
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00


KINGSVILLE STORM 4
KINGSVILLE STORM 5
KINGSVILLE STORM 6
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00

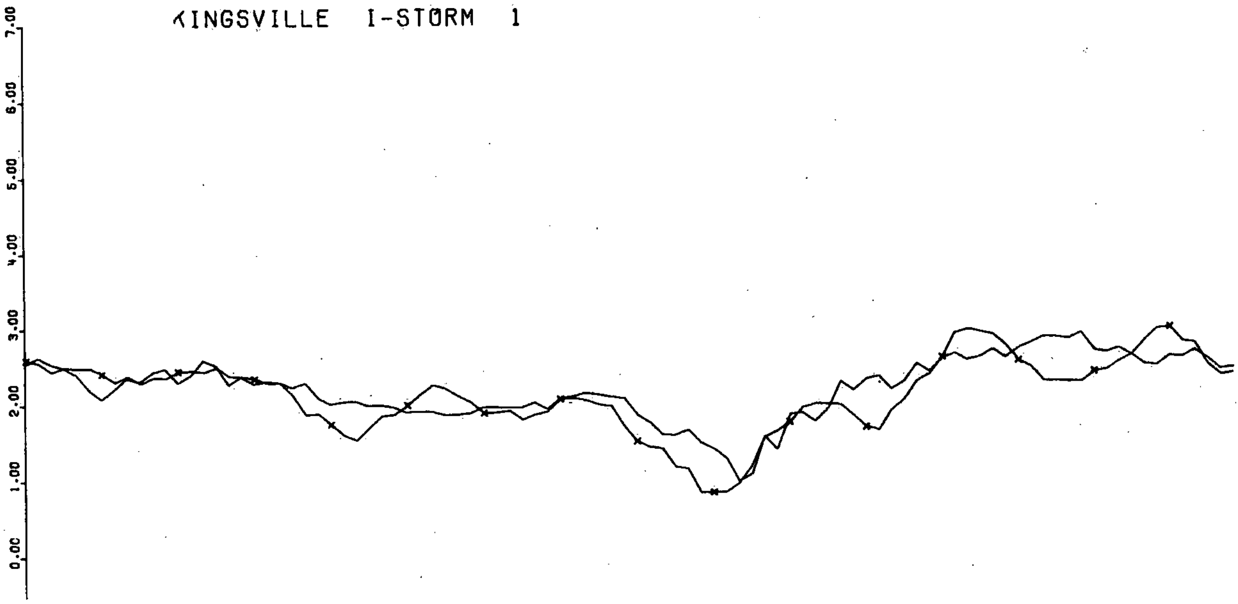

KINGSVILLE STORM 7
KINGSVILLE STORM 8
KINGSVILLE STORM 9
WATER LEVEL (FEET)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)

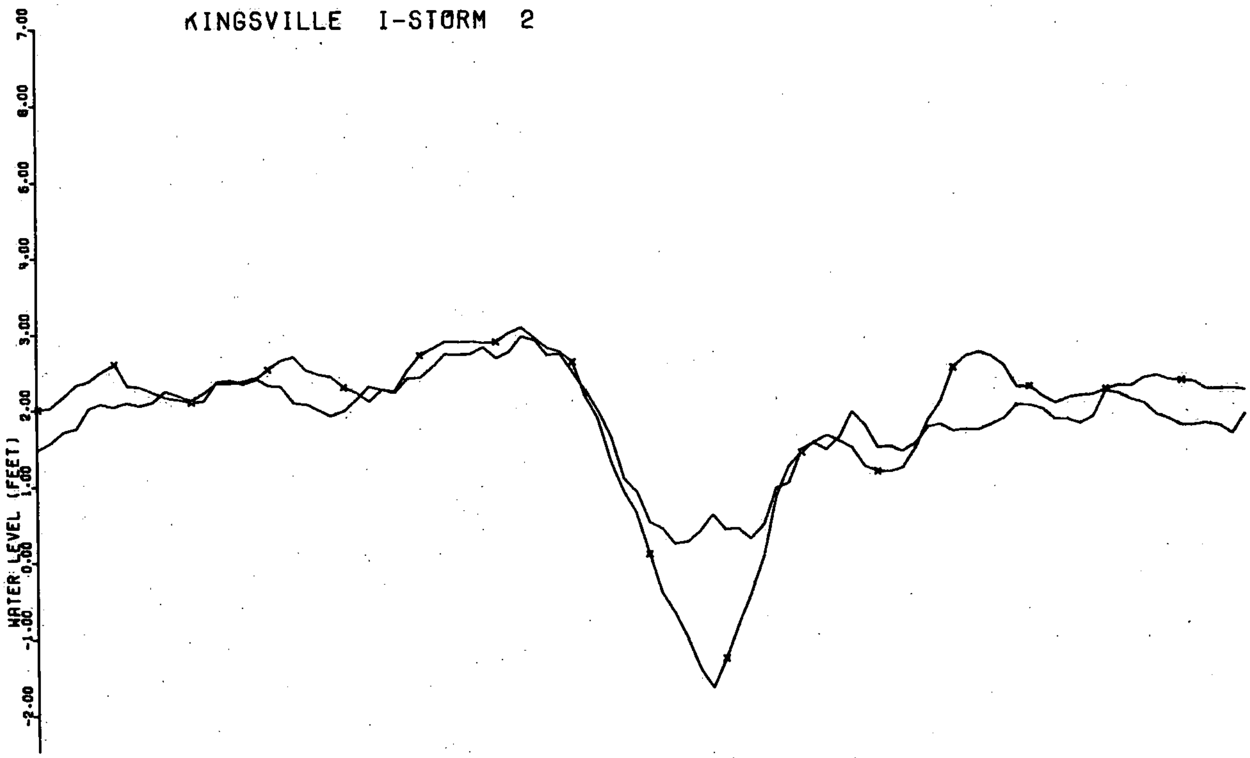

KINGSVILLE STORM 10
KINGSVILLE STORM 11
KINGSVILLE STORM 12
WATER LEVEL (FEET)
RELATIVE TIME (HOURS)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00

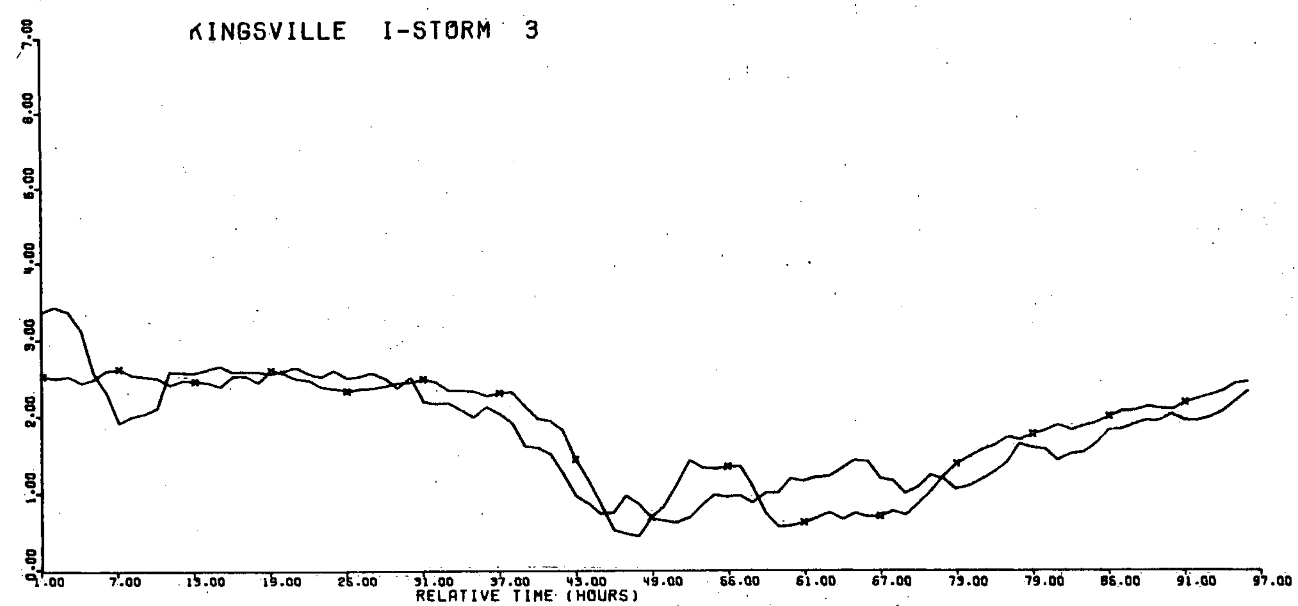


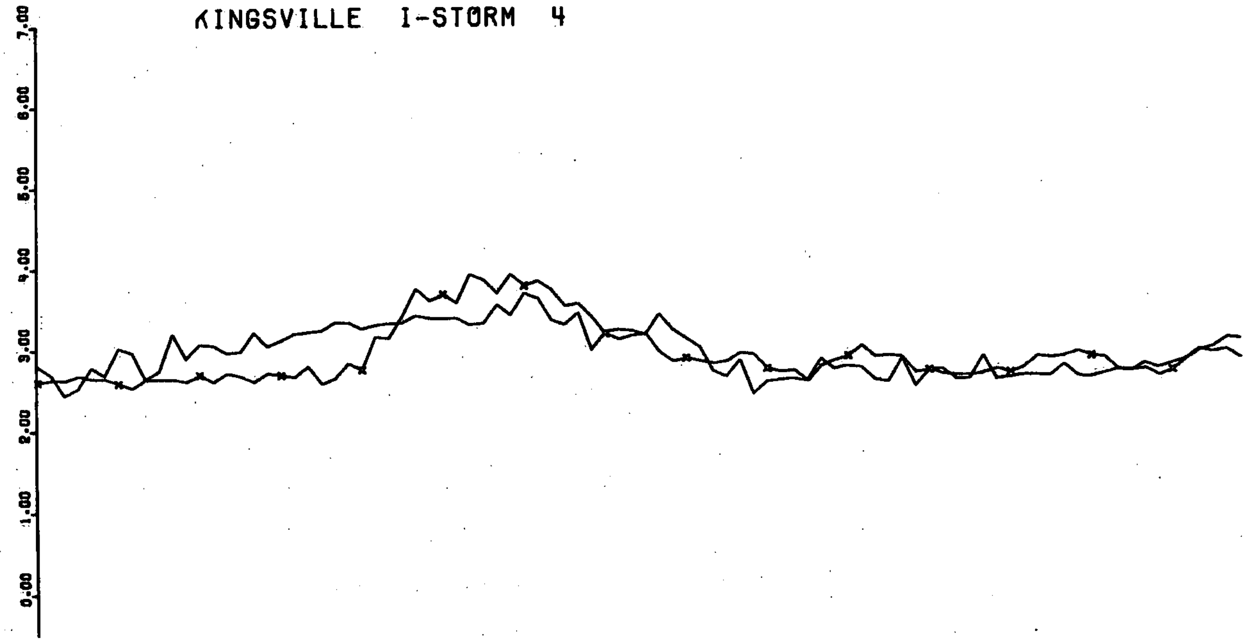
KINGSVILLE STØRM 13
KINGSVILLE STØRM 14
WATER LEVEL (FEET)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)

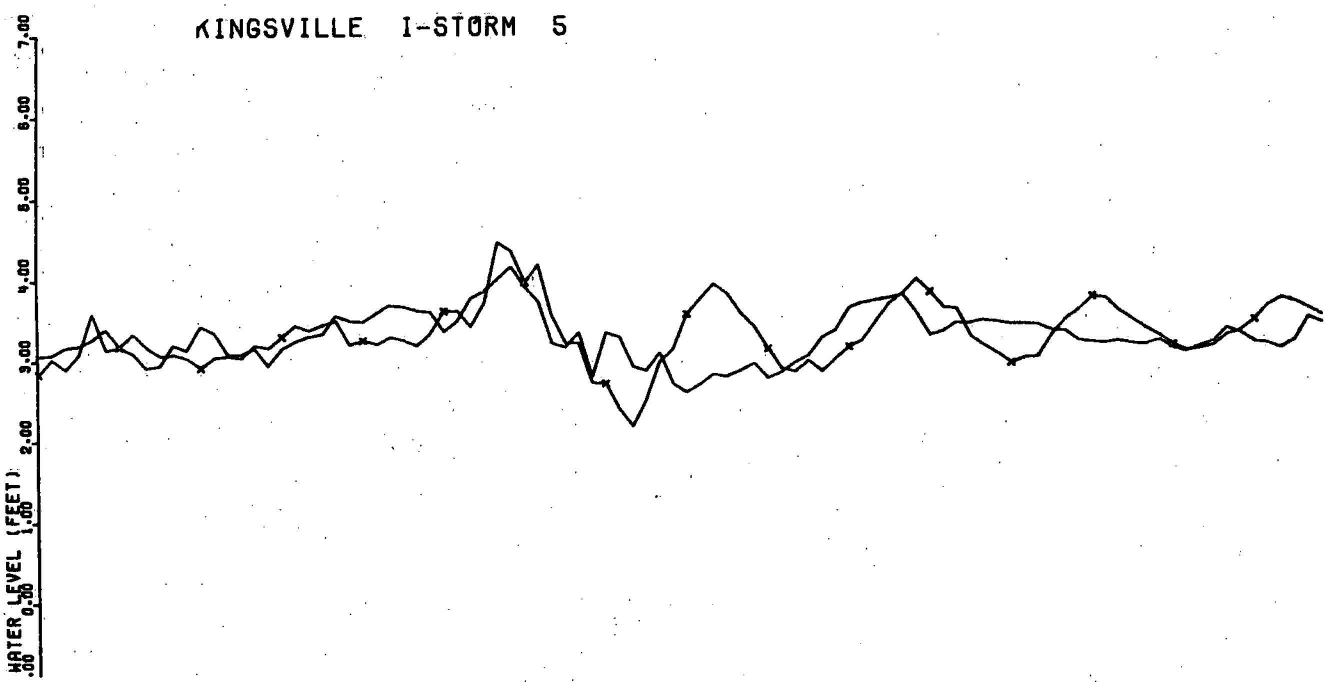
INDEPENDENT STORMS

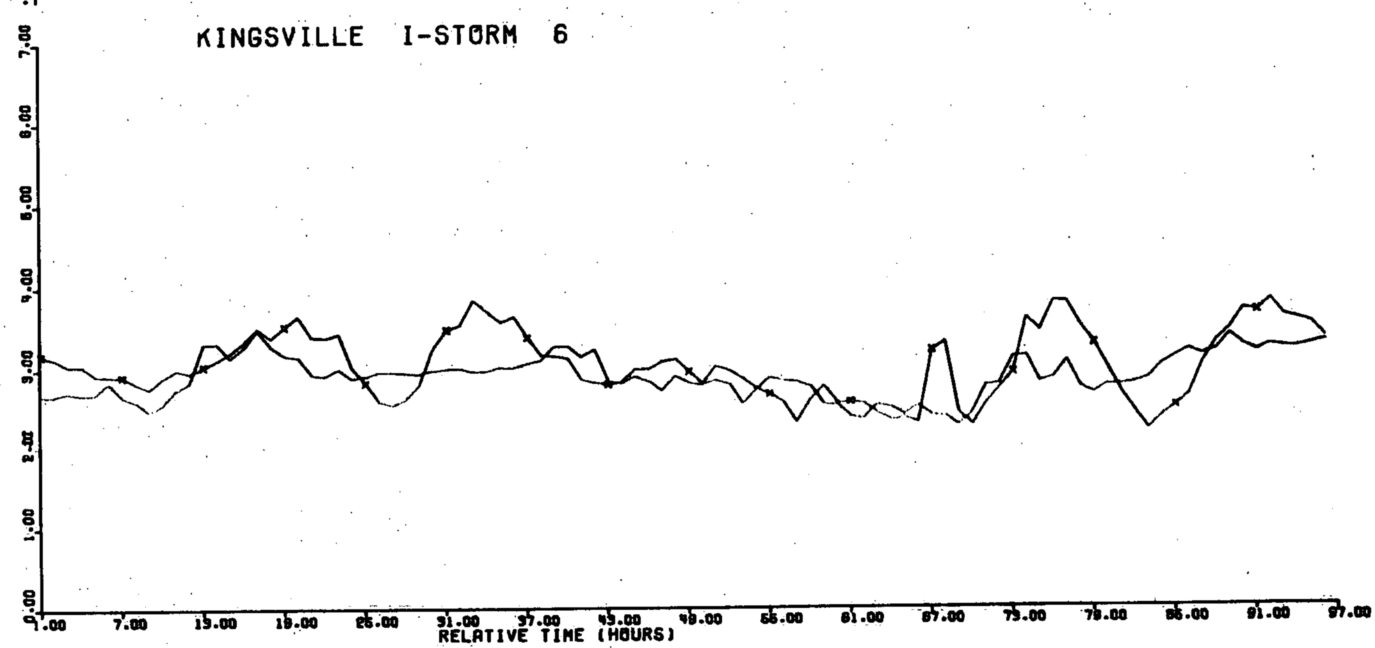

KINGSVILLE I-STORM 1
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00

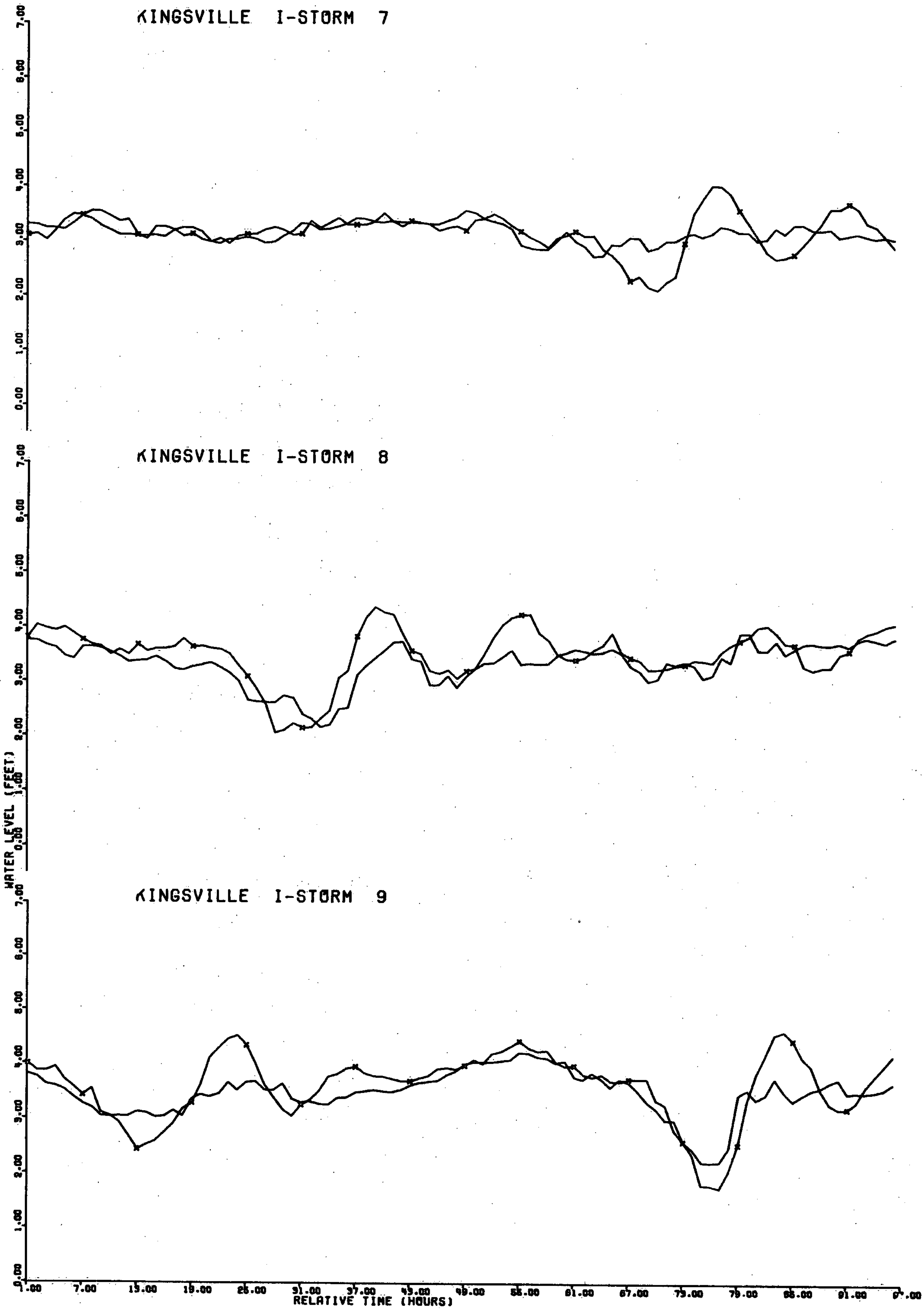

KINGSVILLE I-STORM 2
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
WATER LEVEL (FEET)


KINGSVILLE I-STORM 3
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)


KINGSVILLE I-STORM 4
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00


KINGSVILLE I-STORM 5
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
WATER LEVEL (FEET)


KINGSVILLE I-STORM 6
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
97.00
RELATIVE TIME (HOURS)


KINGSVILLE I-STORM 7
KINGSVILLE I-STORM 8
KINGSVILLE I-STORM 9
WATER LEVEL (FEET)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1.00
7.00
13.00
19.00
25.00
31.00
37.00
43.00
49.00
55.00
61.00
67.00
73.00
79.00
85.00
91.00
RELATIVE TIME (HOURS)

APPENDIX 7

Magnetic Tapes Listing

Tape #	Density (BPI)	Contents
19347	800	5 minute water levels for station numbers 11965, 13150, 11500, 11940, 12865 and 12065
TCW 30	800	1972 hourly water levels for Great Lakes water level stations
TCW 29	556	1973 hourly water levels for station numbers 11940, 11965, 12065 and 13750

Meteorological Data

Tape #	Density (BPI)	Contents	
THC 701	800	Hourly observations - Wiarton	(YVV)
702	800	- Muskoka	(YQA)
703	800	- Mount Forest	(YMN)
704	800	- Windsor	(YQG)
705	800	- Kingston	(YGK)
706	800	- Ottawa Int'l A.	(YOW)
707	800	- Earlton	(YXR)
708	800	- Val d'Or	(YVO)
709	800	- Roberval	(YRJ)
710	800	- Toronto Int'l A.	(YYZ)
711	800	- Trenton	(YTR)
712	800	- White River	(YWR)
713	800	- Sault Ste. Marie	(YAM)
714	800	- Timmins	(YTS)
715	800	- London A.	(YXU)
716	800	- Simcoe	(WMK)
WA 634	800	Hourly observations - Columbus (CMH), Wilkes Barre (AVP), Massena (MSS)	
635	800	- Houghton Lake (HTL), Toledo (TOL)	
636	800	- Bradford (BFD), Oscada (OSC)	
638	800	- Fort Wayne (FWA)	
639	800	- Sault Ste. Marie (SSM)	
640	800	- Youngstown (YNG)	
641	800	- Erie (ERI)	
642	800	- Huntington (HTS), Beckley (BKW), Elkins (EKN)	
643	800	- Roanoke (ROA), Cincinnati (CVG), Lexington (LEX).	

APPENDIX 8

Computer Program For Multiple Regression Analysis

The main program is primarily used to input the data required for the multiple regression analysis. The important variables are specified in the main program itself. Amongst those not specifically mentioned, the important ones are:

NSTORM = Number of dependent storms

NZL(I) = Initial water level for each storm (I = 1, NSTORM)

X(I) = Independent/Dependent (I=J) variables (I = 1, NP1)

The other variables are used only to code the data in the proper form.

Subroutines FLUFF and MAP together carry out the multiple regression. Complete regression statistics will be printed out if NF>MREJ with the table of residuals being printed if NF<NREJ. NF is initially set arbitrarily equal to 21 in the main program. The original multiple regression program obtained from Mr. Ter Heijden of Marine Sciences Directorate, Ottawa, was modified to suit the requirements of this project.

```
      C
      C   *****************************************************************
      C   *****************************************************************
      C
      C       THE FIRST CARD OF THE DATA SET IS THE CONTROL CARD WHICH SPECIFIES
      C       THE NUMBER OF VARIABLES , WHICH VARIABLE IS DEPENDENT , MINIMUM F
      C       LEVEL , WHETHER OR NOT THERE IS A WEIGHING FACTOR , AND AN
      C       ALPHANUMERIC LINE USED AS A TITLE
      C
      C
      C       THERE MAY BE A MAXIMUM OF 51 VARIABLES.
      C
      C       IF MWT ON THE CONTROL CARD IS ZERO OR NEGATIVE THEN ALL THE WEIGHT
      C       FACTORS ARE ASSUMED EQUAL TO ONE
      C
      C       IF MWT ON THE CONTROL CARD IS A POSITIVE INTEGER THEN A WEIGHT
      C       FACTOR IS READ AS THE LAST VARIABLE OR THE NP1+1 TH ON THE
      C       CONTROL CARD
      C
      C       THE WEIGHT FACTOR MAY BE LEFT BLANK IF IT HAS THE VALUE ONE
      C
      C***********************************************************************
      C
              DIMENSION X(52),ALPHA(17),MX(52)
              DIMENSION I1(5)
              COMMON/COMA/NF,NZL(40),NSTORM,NREC(40),WL(400),NCODE,MM
              KT=1
              MT=2
              NCODE=1
              NFILE=1
              NF=21
              MM=6
              NSTORM=26
              READ(60,1)(NREC(I),I=1,NSTORM)
      1       FORMAT(26(I2,1X))
              READ(60,1000)(NZL(I),I=1,NSTORM)
      1000    FORMAT(15(I3,1X)/15(I3,1X))
      2       ONE=1.0
              REWIND 5
              NCARD=0
              NSAVE=0
              MQ=1
      C
      C       NP1 = TOTAL NUMBER OF VARIABLES
      C
      C       J SIGNIFIES WHICH VARIABLE IS DEPENDENT
      C
      C       CUTOFF = MINIMUM F LEVEL REQUIRED FOR THE REGRESSION TO CONTINUE
      C
      C       MWT = NO WEIGHT FACTOR IF 0 OR BLANK
      C
      C       ALPHA IS A TITLE 68 CHARACTERS LONG WHICH APPEARS ON THE OUTPUT
      C
              READ(60,5)NP1,J,CUTOFF,MWT,(ALPHA(I),I=1,17)
```

```
      5     FORMAT(2I2,F4.1,I2,17A4)
            IF(NP1-51)9,9,250
      9     NP=NP1-1
            IF(MWT)21,21,20
      20    NX=NP1+1
            GO TO 25
      21    NX=NP1
      25    NQ=NREC(MQ)
            IF(MQ.GT.NSTORM)GO TO 23
            READ(5,22)KK,(WL(I),I=1,KK)
       22   FORMAT(I5,20(1X,20F6.2/))
       23   CONTINUE
            IF(NFILE.EQ.1)WRITE(61,141)KK,(WL(I),I=1,KK)
            DO 38 NPQ=1,NQ
            LPQ=(NPQ-1)*6+NFILE
      C  ********************************************************************
            READ(KT,26)ND,(MX(I),I=1,14)
       26   FORMAT(I2,14(1X,I5),F6.2)
      C     READ(KT,26)ND,(MX(I),I=1,NP1)
      C26    FORMAT(I2,15(1X,I5))
      C  ********************************************************************
            IF(IFEOF(KT).EQ.-1)GO TO 40
            DO 27 I=1,12
      27    X(I)=MX(I)/10.
            X(13)=MX(13)
            X(14)=MX(14)
      C  ********************************************************************
            X(15)=WL(LPQ)-NZL(MQ)/100.+5.
      C     X(15)=(MX(15)-NZL(MQ))/100.
      C  ********************************************************************
            IF(NCARD-NSAVE)29,28,29
      28    NCARD=0
      29    IF(MWT)33,33,30
      30    IF(X(NX))31,31,32
      31    X(NX)=1.0
      32    ONE=X(NX)
      33    WRITE(54)(X(I),I=1,NP1),ONE
      35    CONTINUE
            NCARD=NCARD+1
            NSAVE=0
      38    CONTINUE
            MQ=MQ+1
            GO TO 25
      40    CONTINUE
            REWIND 54
            CALL FLUFF(NP,NCARD,CUTOFF,ALPHA,J)
            NSAVE=NCARD
            NFILE=NFILE+1
            IF(NFILE.GT.MM)GO TO 41
            GO TO 2
      41    REWIND 35
            REWIND 36
            INCR=MM/2-1
            DO 150 NO=1,NSTORM
```

FORTRAN(2.3)/MASTER INTEGER WORD SIZE = 1 , * OPTION IS OFF , 0 OPTION IS OFF

```
            N=NO
            L=1
            K=NREC(N)
            DO 45 I=1,K
            M=L+INCR
            READ(35,43)(WL(II),II=L,M)
      43    FORMAT(12F6.2)
            LL=M+1
            MN=LL+INCR
            READ(36,43)(WL(II),II=LL,MN)
      45    L=L+MM
            K=NREC(N)*MM
            WRITE(MT,140)K,(WL(I),I=1,K)
     140    FORMAT(I5,20(1X,20F6.2/))
            WRITE(61,141)K,(WL(I),I=1,K)
     141    FORMAT(1H ,I5/20(1X,20F6.2/))
     150    CONTINUE
            ENDFILE MT
            STOP11
     250    STOP15
            END
```

USASI FORTRAN DIAGNOSTIC RESULTS FOR FTN.MAIN

NO ERRORS

LLOWING ARE COMMON BLOCK NAMES OR NAMES NOT ASSIGNED STORAGE

A

NREFERENCED STATEMENT LABELS

35

```
      SUBROUTINE FLUFF(NP,N,CUTOFF,ALPHA,JS)
C
      DIMENSION S(51,51),SUM(51),SD(51),X(51),CR(50),AV(50),IORD(50),
     1B(50), T(50),NORD(50),SEB(50),ALPHA(17)
      COMMON/COMA/NF,NZL(40),NSTORM,NREC(40),WL(400),NCODE,MM
C
C  REGRESSION STATISTICS WILL NOT BE PRINTED FOR NF LESS THAN MREJ.
C  TABLE OF RESIDUALS WILL NOT BE PRINTED FOR NF GREATER THAN NREJ.
      MREJ=20
      NREJ=20
      SWT=0.0
      DO 1 I=1,NP
    1 NORD(I)=I
      NP1=NP+1
      DO 2 I=1,NP1
      SUM(I)=0.0
      DO 2 J=I,NP1
    2 S(I,J)=0.0
C
      DO 3 IPIV=1,N
      READ(54)(X(I),I=1,NP1),WT
      IF(JS-NP1)100,101,101
  100 SAVE=X(JS)
      DO 102 L=JS,NP
  102 X(L)=X(L+1)
      X(NP1)=SAVE
  101 SWT=SWT+WT
      DO 3 I=1,NP1
      A=X(I)
      SUM(I)=SUM(I)+A*WT
      DO 3 J=I,NP1
    3 S(I,J)=S(I,J)+A*X(J)*WT
      SST=S(NP1,NP1)-SUM(NP1)**2/SWT
      REWIND 54
C
C     IF(NF.LT.MREJ)GO TO 310
C
      WRITE(61,88)(ALPHA(L),L=1,17)
   88 FORMAT(25H1MULTIPLE REGRESSION.....,17A4//)
      WRITE(61,4)
    4 FORMAT(47H0VARIABLE  AVERAGE VALUE AND STANDARD DEVIATION/)
310   CONTINUE
      DO 5 I=1,NP1
      SUM(I)=SUM(I)/SWT
      SD(I)=SQRT((S(I,I)-SWT*SUM(I)**2)/(SWT-1.0))
      CALL MAP(JS,I,J,NP1)
C
C     IF(NF.LT.MREJ)GO TO 5
C
      WRITE(61,6)J,SUM(I),SD(I)
5     CONTINUE
    6 FORMAT(3X,I3,5X,F14.5,4X,F14.5)
C
      DO 8 I=1,NP
```

```
      CALL MAP(JS,I,J,NP1)
      WRITE(61,7)J
    7 FORMAT(42H0CORRELATION COEFFICIENT BETWEEN VARIABLES,I3,4H AND/)
      A=SUM(I)
      CR(I)=S(I,I)-SWT*A**2
      S(I,I)=1.0
      K=I+1
      DO 8 J=K,NP1
      S(I,J)=((S(I,J)-SWT*A*SUM(J))/(SWT-1.0))/(SD(I)*SD(J))
      CALL MAP(JS,J,M,NP1)
      WRITE(61,9)S(I,J),M
    9 FORMAT(1X,F14.5,13H ------------,I4)
    8 CONTINUE
C
      NPM1=NP-1
      DO 10 I=1,NPM1
      K=I+1
      DO 10 J=K,NP
   10 S(J,I)=S(I,J)
      TOT=0.0
      IDFT=SWT-1.0
      SSR=0.0
C
      IPIV=0
   40 IPIV=IPIV+1
      RMAX=0.0
      DO 12 I=IPIV,NP
      R=S(I,NP1)**2/S(I,I)
      IF(R-RMAX)12,12,11
   11 RMAX=R
      NEXT=I
   12 CONTINUE
      K=NORD(NEXT)
      NORD(NEXT)=NORD(IPIV)
      NORD(IPIV)=K
C
      IORD(IPIV)=K
      OLDSSR=SSR
      SSR=SSR+SST*RMAX
      SSD=SST-SSR
      IDFD=IDFT-IPIV
      FDFD=IDFD
      SMD=SSD/FDFD
      FPIV=IPIV
      SMR=SSR/FPIV
      F=SMR/SMD
      FLEV=(SSR-OLDSSR)/SMD
      IF(IPIV.EQ.1)GO TO 59
      IF(FLEV-CUTOFF)42,51,51
   51 IF(F-CUTOFF)42,59,59
   42 CONTINUE
      IPIV=IPIV-1
      GO TO 41
   59 DO 13 J=1,NP1
```

```
          SAVE=S(NEXT,J)
          S(NEXT,J)=S(IPIV,J)
       13 S(IPIV,J)=SAVE
          DO 14 I=1,NP
          SAVE=S(I,NEXT)
          S(I,NEXT)=S(I,IPIV)
       14 S(I,IPIV)=SAVE
    C
          P=S(IPIV,IPIV)
          S(IPIV,IPIV)=1.0
          DO 15 J=1,NP1
       15 S(IPIV,J)=S(IPIV,J)/P
          DO 18 K=1,NP
          IF(IPIV-K)16,18,16
       16 P=S(K,IPIV)
          S(K,IPIV)=0.0
          DO 17 J=1,NP1
       17 S(K,J)=S(K,J)-P*S(IPIV,J)
       18 CONTINUE
    C
          BO=SUM(NP1)
          Y=SD(NP1)
          A=100.0*RMAX+0.005
          AV(IPIV)=A
          I=100.0*A
          A=I
          TOT=TOT+A/100.0
          DO 19 I=1,IPIV
          K=IORD(I)
          B(I)=Y*S(I,NP1)/SD(K)
          SEB(I)=SQRT(SMO*S(I,I)/CR(K))
          T(I)=B(I)/SEB(I)
       19 BO=BO-B(I)*SUM(K)
    C
          A=SQRT(SMO)
    C
          IF(NF.LT.MREJ)GO TO 315
    C
          WRITE(61,20)(ALPHA(L),L=1,17),IPIV
       20 FORMAT(25H1MULTIPLE REGRESSION.....,17A4//6X,14HSELECTION.....I2//
         $)
          WRITE(61,95)JS
       95 FORMAT(/1H0,33HTHE DEPENDENT VARIABLE IS NUMBER ,I2/)
    C
          WRITE(61,75)
       75 FORMAT(1H0,8HVARIABLE,7X, 4HMEAN,6X, 8HSTANDARD,5X, 10HREGRESSION,
         $4X, 10HSTD. ERROR,5X, 8HCOMPUTED,4X, 10HPROPORTION/4X,3HNO.,19X,
         $9HDEVIATION,4X, 11HCOEFFICIENT,3X, 12HOF REG.COEF.,3X, 7HT VALUE,
         $5X, 12HOF VARIATION)
    315   CONTINUE
          DO 21 I=1,IPIV
          CALL MAP(JS,IORD(I),M,NP1)
          L=IORD(I)
    C
```

```
          IF(NF.LT.MREJ)GO TO 21
      C
          WRITE(61,22)M,SUM(L),SD(L),B(I),SEB(I),T(I),AV(I)
      21  CONTINUE
       22 FORMAT(1H ,I4,6F14.5)
      C
          IF(NF.LT.MREJ)GO TO 320
      C
          WRITE(61,77)B0,A,FLEV
       77 FORMAT(1H0/10H INTERCEPT,13X,F13.5//23H STD. ERROR OF ESTIMATE,F13
         $.5//8H F LEVEL,15X,F13.5)
      320 CONTINUE
          IF(FLEV-CUTOFF)441,420,420
      420 IF(F-CUTOFF)441,400,400
      441 WRITE(61,442)
      442 FORMAT(1H ,42HF LEVEL IS LESS THAN THE MINIMUM SPECIFIED)
      400 CONTINUE
      C
          IF(NF.LT.MREJ)GO TO 325
      C
          WRITE(61,78)
       78 FORMAT(1H0,21X,39HANALYSIS OF VARIANCE FOR THE REGRESSION//5X,19HS
         $OURCE OF VARIATION,7X,7HDEGREES,7X,6HSUM OF,10X,4HMEAN,12X,7HF VAL
         $UE/30X,10HOF FREEDOM,4X,7HSQUARES,9X,7HSQUARES)
          WRITE(61,79)IPIV,SSR,SMR,F,IDFD,SSD,SMD
       79 FORMAT(30H ATTRIBUTABLE TO REGRESSION   ,I6,3F16.5/30H DEVIATION F
         $ROM REGRESSION    ,I6,2F16.5)
          WRITE(61,80)IDFT,SST
       80 FORMAT(1H ,5X,5HTOTAL,19X,I6,F16.5)
      325 CONTINUE
          IF(IPIV-NP)40,41,41
       41 CONTINUE
          IF(NF.GT.NREJ)GO TO 301
          WRITE(61,20)(ALPHA(L),L=1,17),IPIV
          WRITE(61,95)JS
          WRITE(61,81)
       81 FORMAT(1H ,15X,18HTABLE OF RESIDUALS//9H         ,5X,7HY VALUE,5X,
         $10HY ESTIMATE,6X,8HRESIDUAL)
      301 CONTINUE
          DO 28 NO=1,NSTORM
          NQ=NREC(NO)
          DO 305 NPQ=1,NQ
          READ(54)(X(J),J=1,NP1),WT
          IF(JS-NP1)200,201,201
      200 SAVE=X(JS)
          DO 202 L=JS,NP
      202 X(L)=X(L+1)
          X(NP1)=SAVE
      201 SAVE=B0
          DO 27 J=1,IPIV
          K=IORD(J)
       27 SAVE=SAVE+B(J)*X(K)
          Y=X(NP1)-SAVE
          IF(NF.GT.NREJ)GO TO 304
```

```
      WRITE(61,82)X(NP1),SAVE,Y
   82 FORMAT(1H ,6X,F15.5,2F14.5)
  304 SAVE=SAVE+NZL(NO)/100.-5.0
      WRITE(NF)SAVE
  305 CONTINUE
   28 CONTINUE
      PRINT302,NF
  302 FORMAT(1H ,*NUMBER OF FILES COMPLETED =*,I3)
      MMM=20+MM/2
      MMN=MM/2
      IF(NF.NE.MMM)GO TO 390
      IF(NCODE.EQ.1)MF=35
      IF(NCODE.EQ.2)MF=36
      DO 350 I=21,MMM
      NF=I
  350 REWIND NF
      DO 370 NO=1,NSTORM
      NQ=NO
      NF=21
      NI=1
      DO 360 NFF=1,MMN
      K=(NREC(NQ)-1)*MMN+NI
      DO 355 I=NI,K,MMN
  355 READ(NF)WL(I)
      NF=NF+1
  360 NI=NI+1
      K=NREC(NQ)*MMN
      WRITE(MF,365)(WL(I),I=1,K)
C     ********************************
  365 FORMAT(3F6.2)
C     ********************************
      WRITE(61,367)K,(WL(I),I=1,K)
  367 FORMAT(1H ,I5/20(1X,4(3F6.2,4X)/))
  370 CONTINUE
      MF=MF+1
      DO 380 I=21,MMM
      NF=I
  380 REWIND NF
      NF=20
      NCODE=2
  390 NF=NF+1
      REWIND 54
      RETURN
      END
```

```
FORTRAN(2.3)/MASTER      INTEGER WORD SIZE = 1 , * OPTION IS  OFF , D OPTION IS   OFF

      SUBROUTINE MAP(JS,I,J,NP1)
      COMMON/COMA/NF,NZL(40),NSTORM,NREC(40),WL(400),NCODE,MM
      IF(I-JS)1,2,2
    1 J=I
      GO TO 5
    2 IF(I-NP1)3,4,4
    3 J=I+1
      GO TO 5
    4 J=JS
    5 RETURN
      END

   USASI FORTRAN DIAGNOSTIC RESULTS FOR MAP

        NO ERRORS

LLOWING ARE COMMON BLOCK NAMES OR NAMES NOT ASSIGNED STORAGE
```

Date Due
