Sensitivity analysis The Entrance Channel Tuggerah Lake Final Report July 1992

Webb McKeown & Associates

Flooding lakes

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WYONG SHIRE COUNCIL

SENSITIVITY ANALYSIS
THE ENTRANCE CHANNEL
TUGGERAH LAKE

Catchment 2

FINAL REPORT

JULY, 1992

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CONSULTING ENGINEERS

WYONG SHIRE COUNCIL

SENSITIVITY ANALYSIS
THE ENTRANCE CHANNEL
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SUMMARY

The Wyong River, Ourimbah Creek and several smaller creeks flow into the Tuggerah Lakes system. The total catchment area to The Entrance is 740km^2 of which approximately 10% (80km^2) comprise Tuggerah Lake, Budgewoi Lake and Lake Munmorah. The perimeters of the lakes have been extensively developed for residential uses, and a number of houses have been inundated in recent times as a result of elevated lake levels.

Wyong Shire Council plans to undertake a Flood Study of Tuggerah Lakes in order to review the current design flood levels. This present study was initiated by Council in order to provide a preliminary assessment of the impact upon flood levels of various alternative states of the ocean entrance channel. The results are intended to provide the basis for establishing the type of modelling appropriate to the Flood Study.

A simple hydrologic (WBNM) and hydraulic (RUBICON) modelling system was established to analyse a range of tidal, flood and entrance conditions. Initially the system was calibrated to the February 1990 and February 1992 recorded lake levels. Subsequently the models were run for a range of scenarios including:

- 3 tidal conditions - Regular Tide (to 0.4m AHD), High Tide (to 1.1m AHD) and Storm Tide (to 2.6m AHD),
- 4 entrance conditions - 50m wide, 100m wide, 200m wide and 300m rectangular entrance with an invert at -2m AHD,
- 1%-24h, 30h, 36h, 48h and 72h storm durations. The 36h storm duration was determined as the critical storm duration,
- 1%, 2%, 5%, 50% and Extreme 36h storm durations for the range of tidal/entrance conditions.

Sensitivity analyses involved the following parameters:

- Manning's 'n' value in the entrance channel,
- relative timing of rainfall/peak ocean level,
- variation of the starting level in the lakes.

The results are presented in Figures 1 to 15 and Tables 4 to 8. They show that:

- the 36h duration storm is the critical storm duration,
- the entrance width has a significant impact upon the peak lake level,
- an elevated ocean level affects the peak lake level and has a greater impact for a wider entrance and a smaller flood,
- the effect of varying the relative timing of the ocean peak and runoff for a Storm Tide produces a 0.5m change in peak lake level for a 200m entrance width,
- the effect of varying the initial lake level is greater for a narrower entrance.

For a 1% flood and a 50m wide entrance channel with a Regular Tide the peak lake level of 2.5m AHD approximates to the currently adopted 1% design level of 2.4m AHD. The results show that widening the channel to 100m produces a reduction in peak lake level of 0.3m. The benefit is reduced to 0.1m in a Storm Tide. But for a 50% event widening the entrance to 100m in a Storm Tide produces an increase in peak lake level of 0.2m.

Future studies must therefore give detailed consideration to the effect of elevated ocean levels and their impact upon a range of flood magnitudes if widening of the entrance or maintenance of a permanent opening is to be undertaken.

This study was not a rigorous hydraulic investigation and the results do not supersede the currently adopted design flood levels in Tuggerah Lakes.

SENSITIVITY ANALYSIS
THE ENTRANCE CHANNEL
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1. INTRODUCTION

1.1 General

The Tuggerah Lakes are a significant water body on the Central Coast. They comprise the three inter-connected lakes - Tuggerah Lake, Budgewoi Lake and Lake Munmorah - and are connected to the Pacific Ocean by a tidal channel at The Entrance.

Wyong Shire Council plans to undertake a Flood Study of Tuggerah Lakes in order to review the current design flood levels. Webb, McKeown & Associates were engaged by Council to provide a preliminary assessment of the impact upon flood levels of various entrance channel alternatives. The results of this study will be used to determine the type of model, and complexity appropriate, for simulation of entrance channel performance in the proposed Flood Study.

This present study is not a rigorous hydraulic investigation and the results do not supersede the currently adopted design flood levels in Tuggerah Lakes which are:

1%	2.40m AHD
2%	2.20m AHD
5%	1.88m AHD

1.2 Catchment Description

The catchment subdivision to The Entrance is shown in Table 1.

TABLE 1

Tuggerah Lakes - Catchment Area

CATCHMENT	AREA km^2
Wyong River	450
Ourimbah Creek	158
Wallarah Creek	32
Tuggerah Lake	60
Budgewoi Lake	12
Lake Munmorah	8
Remainder	20
TOTAL	740

The area of the three lakes ($80km^2$) represents approximately 10% of the total catchment area. The lakes have an average depth of approximately 1.9m below normal water level (0.25m AHD) and the tidal range (change in height) and tidal prism (volume of tidal exchange) are relatively small. The water level is strongly influenced by wave setup and wind setup across the lakes and this may increase levels by 0.1m or greater. An indicative tidal range is 0.025m (Reference 1).

During non-flood periods the entrance channel is affected by shoaling processes and is subject to closure, but in flood times it becomes greatly expanded. Salinity in the lakes varies greatly, from concentrations above those for sea water during droughts, to nearly fresh during flood. The Electricity Commission has undertaken water quality and water level readings for Munmorah Power Station since the 1960's (References 2 and 3).

The Wyong River and Ourimbah Creek catchments are predominantly rural and covered in native forest. Development is concentrated around the fringes of the lakes and immediate hinterland. Approximately 10 to 15km^2 of land surrounding the lakes is at less than 2m AHD elevation and is thus potentially flood liable.

It is estimated by Council that over 5000 building lots around the lakes are flood liable and 1000 to 2000 houses are below the current 1% design flood level of 2.4m AHD. The lowest floor levels are at approximately 0.7m AHD, and if it was possible to reduce the 1% design flood level by approximately 0.2m, this would prevent inundation to over 200 buildings and represent a significant reduction in flood damages.

The main uses of the lakes are for recreational boating and fishing, with Lake Munmorah being used for water cooling of the large thermal power station.

2. APPROACH

2.1 Background

Historically the entrance has been mainly open to the ocean but with only a small tidal exchange. Reference 1 notes that the entrance has closed 9 times in the 100 year period prior to 1979. In recent years the closures appear to have become more common. Wyong Shire Council has an extensive photographic library of entrance conditions since the mid 1980's, and aerial photographs are available since 1941 at approximately 1 to 2 yearly intervals. The Cities Commission report, 1974 (Reference 4) states "As recently as 1955 a natural channel developed from Budgewoi Lake to the sea."

The Inter Departmental Committee report, 1979 (Reference 1) suggests by quotation of answers from long-term residents, that this channel, if it existed, was an intermittent channels which may have formed in periods of very rough seas.

Design flood levels in Tuggerah Lake were established in Reference 4 which extended the earlier work of Reference 5. In these studies a frequency analysis of the lake records combined with a rainfall/runoff approach were undertaken. Recently Council and the Public Works Department (PWD) have investigated the possibility of maintaining a permanently open entrance. References 6 and 7 describe the following two alternative procedures for maintaining an open entrance:

- jet pumping,
- construction of an entrance restraining wall.

The PWD is currently preparing a Compendium of Lake Level Data for the lakes system. Preliminary results include the peak historical levels shown in Table 2.

TABLE 2

Peak Historical Lake Levels

(Preliminary Data Provided by the PWD)

DATE	AHD
1927	1.8m
1946	1.9m
1949	1.9m
1963	1.5m
1964	1.7m
1974	1.3m
1977	1.6m
1988	1.3m
1990	1.7m
1992	1.1m

Note: The 1949 value of 1.9m relates to a point in the channel near the old timber bridge. Council has evidence of a 1949 flood level of approximately 2.1m at Long Jetty.

The peak level resulting from a storm on the catchment depends upon a number of factors including:

- initial lake level,
- volume of runoff,
- initial entrance condition, final entrance condition and opening mechanism (man-made or natural) and the amount of scouring,
- ocean condition.

Wyong Shire Council has a policy of mechanically opening the entrance during periods of heavy rain if the entrance is closed and the lake level reaches a pre-determined value (1.5m AHD or at a level of 1.2m AHD if the water has risen 0.2m in the past six hours) (Reference 7). Because of the potential nature of such events (intense rain, darkness, adverse ocean conditions) it may be impossible to conform precisely to this procedure during an actual flood.

2.2 Approach to the Study

2.2.1 General

The approach adopted for the study was predominantly determined by the preliminary nature of the study, the nominated timeframe (4 weeks) and the availability of data.

The WBNM model (Reference 8) was chosen as the hydrologic model for the following reasons:

- it is a widely used hydrologic model which can be calibrated to historical data and can accommodate areally varying rainfall,
- a calibrated WBNM model was already established for the Upper Wyong River Flood Study (Reference 9) for the Wyong River catchment and could be readily adjusted to cover the entire catchment to The Entrance.

The WBNM model was used to provide surface runoff inflows to the hydraulic model used to simulate the entrance hydraulics, the storage capacity of the lake and the ocean conditions.

RUBICON was chosen as the hydraulic model because it satisfies the following criteria:

- it is a fully dynamic model and can therefore accurately simulate the ocean/lake interchange during a flood,
- the model can be used to represent the lakes as a height/storage relationship and the entrance by a series of cross-sections,
- it can be efficiently set up to run a variety of combinations of options, as requested in the Brief.

The Brief required that the following conditions be examined:

- **Tidal Conditions**

Regular Ocean: Mean High Water Neaps Tide (to 0.4m AHD).
High Ocean: Mean High Water Springs Tide plus barometric storm surge (to 1.1m AHD),
Storm Ocean: Mean High Water Springs Tide plus barometric storm surge plus wave setup (to 2.6m AHD),

- **Entrance Conditions**

Case 1: minimum probable shoaling (i.e. maximum likely conveyance),
Case 2: maximum probable shoaling (taking note of Council's maintenance program),
Case 3: midpoint (average flow area) of *Case 1* and *Case 2,*
Case 4: channel bed uniformly tapered from average depth *(Case 3)* to maximum depth *(Case 1)* in the downstream direction.

- **Storms**

1%, 2%, 5%, 50% and Extreme Flood.

- **Lake Starting Level**

Initially the starting level in the lake was to be 0.8m AHD, but following review by Council and the PWD a starting level of 0.5m AHD was adopted.

- **Sensitivity Analysis**

The following sensitivity analyses were also required:

- storm durations,
- coincidence of ocean peak and runoff,
- lake starting level,
- Manning's 'n' at the entrance.

2.2.2 Calibration

The study required that the hydrologic and hydraulic models be calibrated to historical data. The extent of the calibration was to be determined by the availability of data within the allocated timeframe.

Initially it was proposed that calibration be undertaken for the following events:

- June 1964,
- February 1990,
- February 1992.

Rainfall and flood height data are readily available for the latter two floods from both the PWD and the Bureau of Meteorology (BOM). Data for the June 1964 flood were available from Reference 9.

Preliminary results indicated that the lake level is extremely sensitive to the assumed ocean entrance, tidal condition and rainfall data. Because of the lack of such data for the June 1964 flood, combined with the limited quantity of recorded lake level data (only 1 peak level) this flood was not used further in the calibration of the models.

Calibration to tidal data was considered, but was not possible within the timeframe available. Tidal gaugings have been undertaken by the PWD in 1975 and 1976 (Reference 7) and other tidal data may be available. It is recommended that calibration to tidal data be undertaken in the Flood Study to ensure that the modelled entrance hydraulics are verified for a range of events.

3. MODELLING

3.1 Hydrologic Model

3.1.1 Background

The WBNM model which had been established in Reference 9 was adopted without alteration for this study. This model had been calibrated to historical flow data for the following events:

- June 1967,
- August 1967,
- June 1974,
- March 1977,
- March 1978, .
- November 1984,
- October 1985.

The adopted parameters were:

C	=	1.5
Initial Loss	=	15mm
Continuing Loss	=	2.5mm/h

3.1.2 Calibration

Ourimbah Creek catchment and the remainder of the catchment to The Entrance were divided into sub-catchments and included in the model. The parameters described above were adopted for all calibration and design events. A single outflow hydrograph from the model was obtained for input into the hydraulic model.

Daily rainfall data were collected from the readily available daily read stations and pluviograph data from the PWD gauges for the two events. Because of the time constraints, flow data from the DWR gauging stations and other rainfall data were not collected as part of this study.

A single pluviograph station was used to represent the temporal distribution of rainfall over the catchment (Mardi Dam in 1992 and Chittaway in 1990) and a weighted average rainfall value derived to represent the areal rainfall. The rainfall so derived was input to the WBNM model to derive the flow hydrographs.

No calibration of the computed flows to recorded gauged flow data were undertaken because of time constraints.

3.1.3 Design

Design flows were obtained using Australian Rainfall and Runoff (AR&R) (Reference 10) rainfall data. AR&R shows a rainfall gradient across the catchment, but for simplicity a single areally weighted rainfall value was used over the whole catchment. The values are shown in Table 3 together with the peak flows.

TABLE 3

Rainfall (mm) and Peak Flow (m^3/s) for the Design Storms

1% Event

Duration (h)	24	30	36	48	72
Rainfall Flow	325 4640	356 4860	383 5220	427 4830	488 3350

Adopted 36h Critical Duration Storm

Frequency	2%	5%	50%	Extreme
Rainfall Flow	317 4500	265 3820	146 1590	766 11740

An areal rainfall reduction factor of 0.95 was adopted for all design events. A range of durations was used to find the critical duration for the 1% event. This was subsequently adopted for all the other design floods. The Extreme rainfall was taken as twice the 1% rainfall.

3.2 Hydraulic Model

3.2.1 Background

A simple one-dimensional model was constructed which included:

- one inflow hydrograph at the upstream end,
- a tidal (stage) hydrograph at the downstream end (the ocean),
- Tuggerah Lakes and adjoining floodplain represented by a height/area relationship,
- the channel from The Entrance Bridge to the ocean (approximately 800m) represented by cross-sections.

It was assumed that there was no gradient or head loss between the three lakes or in Tuggerah Lake upstream of The Entrance Bridge.

3.2.2 Entrance Configuration

Available survey data and aerial and oblique photographs were reviewed in order to establish the entrance configurations nominated by Council. Preliminary results highlighted the importance of the entrance configuration and the fact that considerable scouring of the entrance occurs during a flood. In consultation with Council it was decided to adopt rectangular sections at the entrance with varying widths to represent the 4 entrance configurations. The primary reason for this approach was that waterway area is the most important hydraulic parameter. A non-uniform shallow wide channel has a very similar hydraulic conveyance to a uniform channel of the same waterway area as the hydraulic radius would vary only marginally.

The following rectangular channel widths were adopted for the four cases:

- 50m,
- 100m,
- 200m,
- 300m.

A width of 50m represents the likely narrowest channel and a width of 300m represents the likely widest channel. An invert at -2m AHD was assumed for all channels. This value was adopted as being representative of an average depth to the underlying rock bar. The channels were assumed to have vertical sides thus the width at -2m AHD is the same as at +4m AHD.

An infinite number of entrance configurations are possible, but it was intended that the above combinations would provide a measure of the range of possible configurations. A Manning's 'n' of 0.025 was adopted as being a realistic value for a sandy entrance.

3.2.3 Tidal Hydrographs

Tidal data were obtained from the Fort Denison gauge for the February 1990 and February 1992 events. The three nominated design tides were constructed by fitting a sine curve to the nominated Highs and Lows. A tidal cycle of 12.5 hours was adopted.

Regular Tide

+0.4 to -0.4m AHD tidal cycle.

High Tide

+0.65m to -0.65m AHD tidal cycle plus a surge of 0.45m.

Storm Tide

+0.65m to -0.65m AHD tidal cycle plus a surge of 1.95m.

The same Regular Tide was adopted for all storm durations and no consideration was given to matching the peak outflow to a high tide. For the High Tide and the Storm Tide, it was necessary to have the time of the high tide coincident with the peak of the surge in order to produce the nominated peak level (1.1m AHD High Tide and 2.6m AHD Storm Tide).

It was assumed that the surge started at 0m at the start of the rainfall and peaked on a high tide (+0.65m) midway through the design storm duration. Thereafter the surge was assumed to taper to 0m at a time 2.5 days after the peak. For example, in a 36h design Storm Tide, the peak ocean level of 2.6m AHD (0.65m + 1.95m) is reached at 18 hours, and at 78 hours after the start of the storm the surge reduces to 0m. The adopted 36h tides are shown on Figure 3.

This procedure is based upon Reference 11 which assumes that the peak rainfall (assumed to be midway through the storm) and peak ocean level for a long duration storm, are produced by the same mechanism and are thereby coincident.

4. RESULTS

4.1 Calibration Runs

For both calibration events a 50m wide channel was assumed for the entrance. The results of the calibration to the February 1990 and February 1992 data are shown on Figures 1 and 2. It should be noted that in both events the shape and peak are reasonable but the model results are approximately 12h early. It is likely that this is due to the storage routing undertaken within the WBNM model which tends to produce a flood peak earlier than the recorded data. The calibration could be improved by:

- using more than 1 pluviograph,
- adjusting the assumed entrance channel to reflect the scouring which undoubtedly occurred during these floods,
- re-examination of the rainfall isohyetal pattern,
- calibration to the DWR streamflow data.

It was concluded that the calibration was satisfactory for this preliminary study.

4.2 Design Runs

The following design runs were undertaken and the results are shown on the accompanying Figures and Tables.

4.2.1 Determination of Critical Storm Duration

The 1%-24h, 30h, 36h, 48h and 72h storm durations were run for each of the 3 tidal conditions (Regular, High, Storm) and the 4 entrance widths (50m, 100m, 200m, 300m). The results are shown on Figures 4 to 6 and in Table 4.

The following conclusions can be made:

- the most common critical duration for all conditions is the 36h storm (the exceptions are - Regular Tide (50m and 100m entrance widths) in which cases the 72h and 48h levels are higher by less than 0.04m),
- there is approximately a 0.3m to 0.6m range in peak level between the different storm durations for the range of entrance configurations and tides.

4.2.2 Design Results

The 1%, 2%, 5%, 50% and Extreme floods for the 36 hour storm duration were run for each of the 3 tidal conditions and the 4 entrance widths. The results are shown on Figures 7 to 9 and on Table 5. Hydrographs for the 1% flood for the 4 entrance widths and three tidal conditions are shown on Figures 13 to 15.

The following conclusions can be drawn:

- for the Storm Tide the peak levels for the 1%, 2% and 5% events are similar for all entrance widths,
- the Storm Tide and High Tide have a greater impact for a wider entrance. For a 50m entrance - Storm Tide, the 1% level is 0.25m above the 50m entrance - Regular Tide. For a 300m entrance the difference is 1.3m,
- the Storm Tide reduces the difference between the 1% and 50% levels for all entrance widths,
- the height differences between the 1% and 5% levels range from 0.3m to 0.7m depending upon the tidal conditions and the entrance configuration,
- the extreme flood is up to 2.0m above the 1% flood level for a 50m wide entrance and up to 1.0m above for a 300m wide entrance. At these levels it is likely that additional openings to the ocean may develop.

4.2.3 Sensitivity of the Timing of the Peak Ocean and Peak Flow - Storm Tide

The effect of varying the relative timing of the peak ocean (2.6m AHD) and the peak flow was analysed for the 1%-36h - 200m wide entrance - Storm Tide. The time of peak ocean level was set at the following times relative to the start of the rainfall:

6h	(minus 12h)
18h	(base case)
30h	(plus 12h)
42h	(plus 24h)

The results are shown on Figure 10 and on Table 6.

The following conclusion can be drawn:

- the effect of varying the timing of the ocean peak produces a change of approximately 0.5m in the peak level in the lakes for the 200m wide entrance.

4.2.4 Sensitivity of the Manning's 'n' in the Entrance Channel

The effect of varying the Manning's 'n' of the entrance channel by ±0.005 (from 0.025 to 0.020 and 0.030) was modelled for the 1%-36h - Regular Tide - for the 4 entrance widths. The results are shown on Figure 11 and Table 7.

The following conclusions can be drawn:

- for a 50m wide entrance the range in peak lake level is approximately ±0.05m,
- for a 300m wide entrance the range in peak lake level is approximately ±0.1m.

4.2.5 Sensitivity of the Starting Level in Tuggerah Lake

The effect of varying the starting level in Tuggerah Lake was analysed for the 1%-36h - Regular Tide - for the 4 entrance widths. The following starting levels (m AHD) were assumed:

0.25m	(normal lake level)
0.50m	(adopted starting level)
0.75m	
1.00m	

The results are shown on Figure 12 and on Table 8.

The following conclusion can be drawn:

- the effect of varying the starting level from 0.25m AHD to 1.00m AHD for each of the entrance widths produces a range in peak level from 0.5m (50m entrance width) to 0.1m (300m entrance width).

TABLE 4
DETERMINATION OF CRITICAL STORM DURATION

ENTRANCE WIDTH/TIDE		1% 24h	1% 30h	1% 36h	1% 48h	1% 72h
50m/REGULAR						
LAKE	(m AHD)	2.215	2.365	2.491	2.522	2.528
ENTRANCE	(m3/s)	576	615	649	659	661
ENTRANCE	(m/s)	3.1	3.1	3.2	3.2	3.2
100m/REGULAR						
LAKE	(m AHD)	1.904	2.015	2.188	2.200	1.786
ENTRANCE	(m3/s)	1003	1047	1133	1143	946
ENTRANCE	(m/s)	2.9	2.9	3.0	3.0	2.8
200m/REGULAR						
LAKE	(m AHD)	1.489	1.609	1.664	1.634	1.194
ENTRANCE	(m3/s)	1611	1703	1772	1743	1352
ENTRANCE	(m/s)	2.6	2.6	2.7	2.7	2.4
300m/REGULAR						
LAKE	(m AHD)	1.231	1.355	1.405	1.364	0.912
ENTRANCE	(m3/s)	2081	2195	2271	2227	1695
ENTRANCE	(m/s)	2.4	2.5	2.5	2.5	2.2
50m/HIGH						
LAKE	(m AHD)	2.216	2.383	2.524	2.502	2.417
ENTRANCE	(m3/s)	581	624	663	663	637
ENTRANCE	(m/s)	3.1	3.2	3.3	3.3	3.2
100m/HIGH						
LAKE	(m AHD)	1.971	2.156	2.285	2.212	1.779
ENTRANCE	(m3/s)	1023	1126	1199	1161	937
ENTRANCE	(m/s)	2.9	3.0	3.1	3.1	2.8
200m/HIGH						
LAKE	(m AHD)	1.672	1.835	1.956	1.772	1.356
ENTRANCE	(m3/s)	1765	1941	2066	1873	1474
ENTRANCE	(m/s)	2.7	2.8	2.9	2.8	2.5
300m/HIGH						
LAKE	(m AHD)	1.470	1.623	1.699	1.542	1.155
ENTRANCE	(m3/s)	2394	2611	2716	2447	1914
ENTRANCE	(m/s)	2.6	2.7	2.7	2.6	2.3
50m/STORM						
LAKE	(m AHD)	2.412	2.605	2.729	2.671	2.617
ENTRANCE	(m3/s)	-689	680	717	704	681
ENTRANCE	(m/s)	-3.3	3.3	3.4	3.3	3.3
100m/STORM						
LAKE	(m AHD)	2.358	2.553	2.667	2.611	2.403
ENTRANCE	(m3/s)	-1376	-1347	1358	1369	1231
ENTRANCE	(m/s)	-3.3	-3.2	3.3	3.3	3.1
200m/STORM						
LAKE	(m AHD)	2.259	2.471	2.591	2.593	2.395
ENTRANCE	(m3/s)	-2736	-2631	2719	2611	2318
ENTRANCE	(m/s)	-3.3	-3.2	3.3	3.2	3.0
300m/STORM						
LAKE	(m AHD)	2.209	2.417	2.556	2.607	2.424
ENTRANCE	(m3/s)	-4061	-3857	4004	3731	3319
ENTRANCE	(m/s)	-3.3	3.1	3.3	3.1	2.9

TABLE 5
DESIGN RUNS - 36h DURATION

ENTRANCE WIDTH/TIDE		50% FLOOD	5% FLOOD	2% FLOOD	1% FLOOD	EXTREME FLOOD
50m/REGULAR						
LAKE	(m AHD)	0.934	1.815	2.179	2.491	4.448
ENTRANCE	(m3/s)	287	479	570	649	1849
ENTRANCE	(m/s)	2.2	2.8	3.0	3.2	6.7
100m/REGULAR						
LAKE	(m AHD)	0.761	1.530	1.875	2.188	3.845
ENTRANCE	(m3/s)	502	821	980	1133	3057
ENTRANCE	(m/s)	2.1	2.6	2.8	3.0	6.1
200m/REGULAR						
LAKE	(m AHD)	0.559	1.214	1.454	1.664	3.128
ENTRANCE	(m3/s)	824	1359	1576	1772	4593
ENTRANCE	(m/s)	1.8	2.4	2.6	2.7	5.2
300m/REGULAR						
LAKE	(m AHD)	0.504	1.005	1.215	1.405	2.680
ENTRANCE	(m3/s)	1080	1727	2010	2271	5600
ENTRANCE	(m/s)	1.7	2.2	2.4	2.5	4.6
50m/HIGH						
LAKE	(m AHD)	1.099	1.894	2.217	2.524	4.512
ENTRANCE	(m3/s)	314	496	580	663	1926
ENTRANCE	(m/s)	2.3	2.9	3.1	3.3	6.9
100m/HIGH						
LAKE	(m AHD)	1.016	1.728	2.011	2.285	3.946
ENTRANCE	(m3/s)	587	909	1050	1199	3175
ENTRANCE	(m/s)	2.2	2.7	2.9	3.1	6.2
200m/HIGH						
LAKE	(m AHD)	0.934	1.504	1.714	1.956	3.262
ENTRANCE	(m3/s)	1114	1630	1827	2066	4878
ENTRANCE	(m/s)	2.2	2.6	2.8	2.9	5.4
300m/HIGH						
LAKE	(m AHD)	0.893	1.356	1.533	1.699	2.823
ENTRANCE	(m3/s)	-1637	2243	2478	2716	6060
ENTRANCE	(m/s)	2.1	2.5	2.6	2.7	4.9
50m/STORM						
LAKE	(m AHD)	1.595	2.218	2.485	2.729	4.744
ENTRANCE	(m3/s)	-689	-685	-680	717	2012
ENTRANCE	(m/s)	-3.3	-3.3	-3.3	3.4	7.0
100m/STORM						
LAKE	(m AHD)	1.797	2.235	2.457	2.667	4.314
ENTRANCE	(m3/s)	-1374	-1358	-1343	1358	3534
ENTRANCE	(m/s)	-3.3	-3.3	-3.2	3.3	6.5
200m/STORM						
LAKE	(m AHD)	1.973	2.243	2.423	2.591	3.824
ENTRANCE	(m3/s)	-2711	-2648	-2607	2719	5961
ENTRANCE	(m/s)	-3.3	-3.2	3.1	3.3	5.9
300m/STORM						
LAKE	(m AHD)	2.040	2.302	2.431	2.556	3.512
ENTRANCE	(m3/s)	-3986	-3876	-3807	4004	7846
ENTRANCE	(m/s)	-3.2	-3.1	3.1	3.3	5.5

TABLE 6
SENSITIVITY OF TIMING OF PEAK OCEAN LEVEL
1% 36h DURATION 200m ENTRANCE STORM TIDE

		6h LAG	18h LAG	30h LAG	42h LAG
LAKE	(m AHD)	2.625	2.591	2.502	2.119
ENTRANCE	(m3/s)	2782	2719	2317	-2337
ENTRANCE	(m/s)	3.3	3.3	3.0	2.9

TABLE 7
SENSITIVITY OF MANNING'S 'n'
1% 36h DURATION

ENTRANCE WIDTH/TIDE		n = 0.020	n = 0.025	n = 0.030
50m/REGULAR				
LAKE	(m AHD)	2.458	2.491	2.517
ENTRANCE	(m3/s)	687	649	587
ENTRANCE	(m/s)	3.5	3.2	2.9
100m/REGULAR				
LAKE	(m AHD)	2.121	2.188	2.240
ENTRANCE	(m3/s)	1245	1133	1032
ENTRANCE	(m/s)	3.4	3.0	2.7
200m/REGULAR				
LAKE	(m AHD)	1.564	1.664	1.749
ENTRANCE	(m3/s)	1939	1772	1630
ENTRANCE	(m/s)	3.0	2.7	2.5
300m/REGULAR				
LAKE	(m AHD)	1.295	1.405	1.499
ENTRANCE	(m3/s)	2460	2271	2109
ENTRANCE	(m/s)	2.8	2.5	2.3

TABLE 8
SENSITIVITY OF STARTING LEVEL IN TUGGERAH LAKE
1% 36h DURATION

ENTRANCE WIDTH/TIDE		LAKE=0.25m	LAKE=0.50m	LAKE=0.75m	LAKE=1.00m
50m/REGULAR					
LAKE	(m AHD)	2.329	2.491	2.670	2.828
ENTRANCE	(m3/s)	608	649	673	-4603
ENTRANCE	(m/s)	3.1	3.2	3.3	0.0
100m/REGULAR					
LAKE	(m AHD)	2.072	2.188	2.330	2.482
ENTRANCE	(m3/s)	1076	1133	1203	1276
ENTRANCE	(m/s)	3.0	3.0	3.1	3.2
200m/REGULAR					
LAKE	(m AHD)	1.613	1.664	1.715	1.788
ENTRANCE	(m3/s)	1724	1772	1821	1891
ENTRANCE	(m/s)	2.7	2.7	2.7	2.8
300m/REGULAR					
LAKE	(m AHD)	1.374	1.405	1.430	1.461
ENTRANCE	(m3/s)	2231	2271	2304	2345
ENTRANCE	(m/s)	2.5	2.5	2.5	2.5

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FIGURES

FIGURE 1
CALIBRATION
FEBRUARY 1990 FLOOD

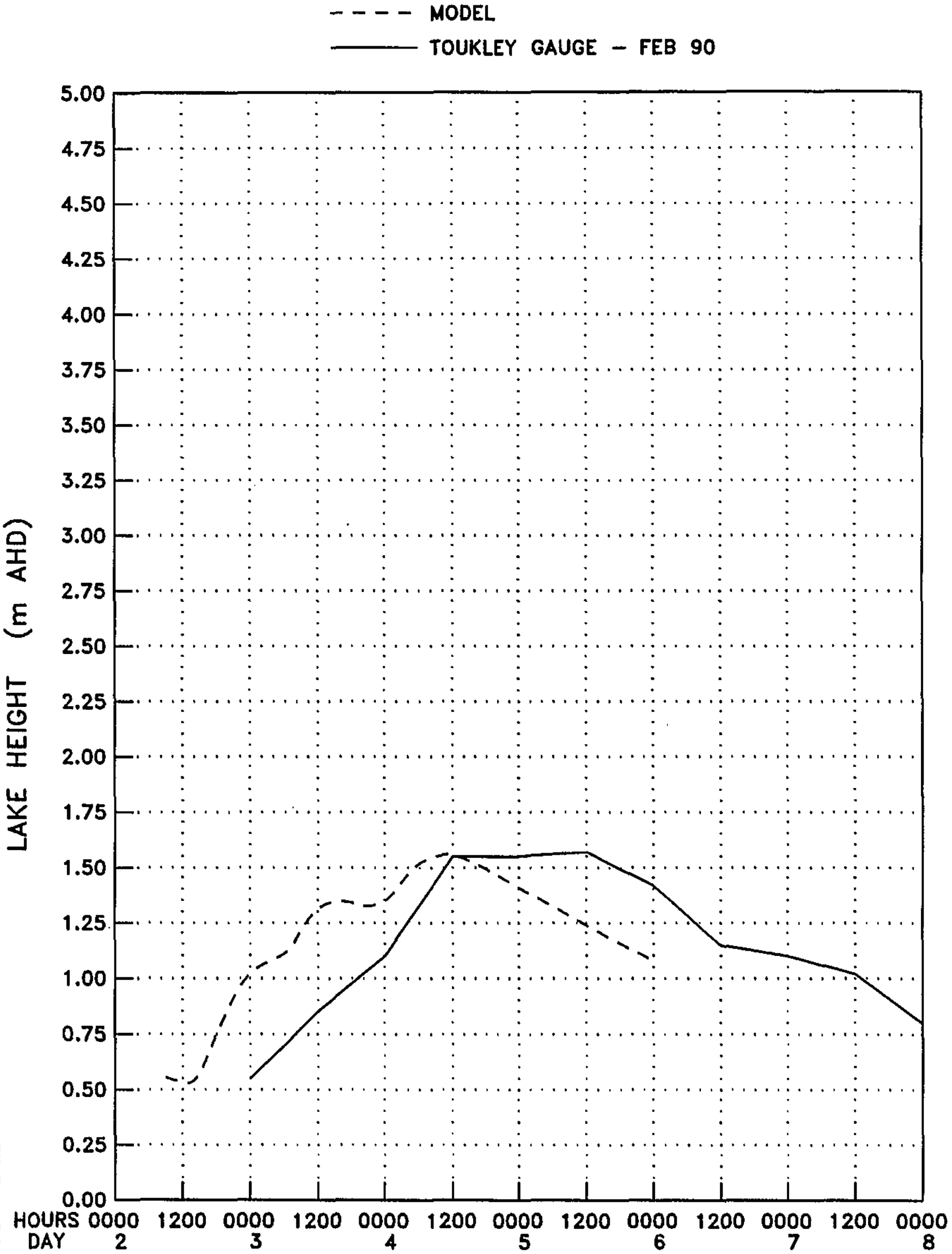


FIGURE 2
CALIBRATION
FEBRUARY 1992 FLOOD

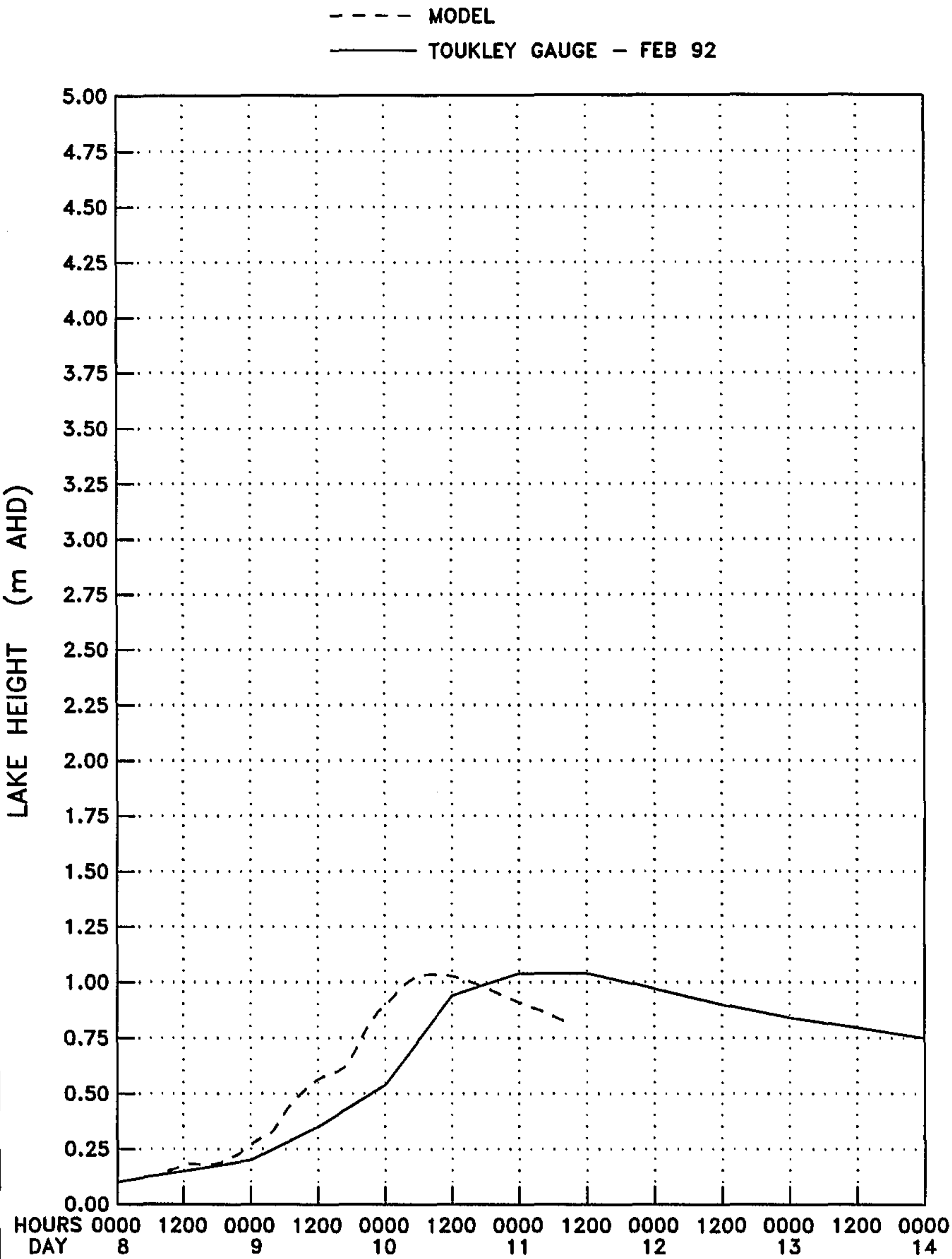


FIGURE 3
TIDAL HYDROGRAPHS
36h DURATION

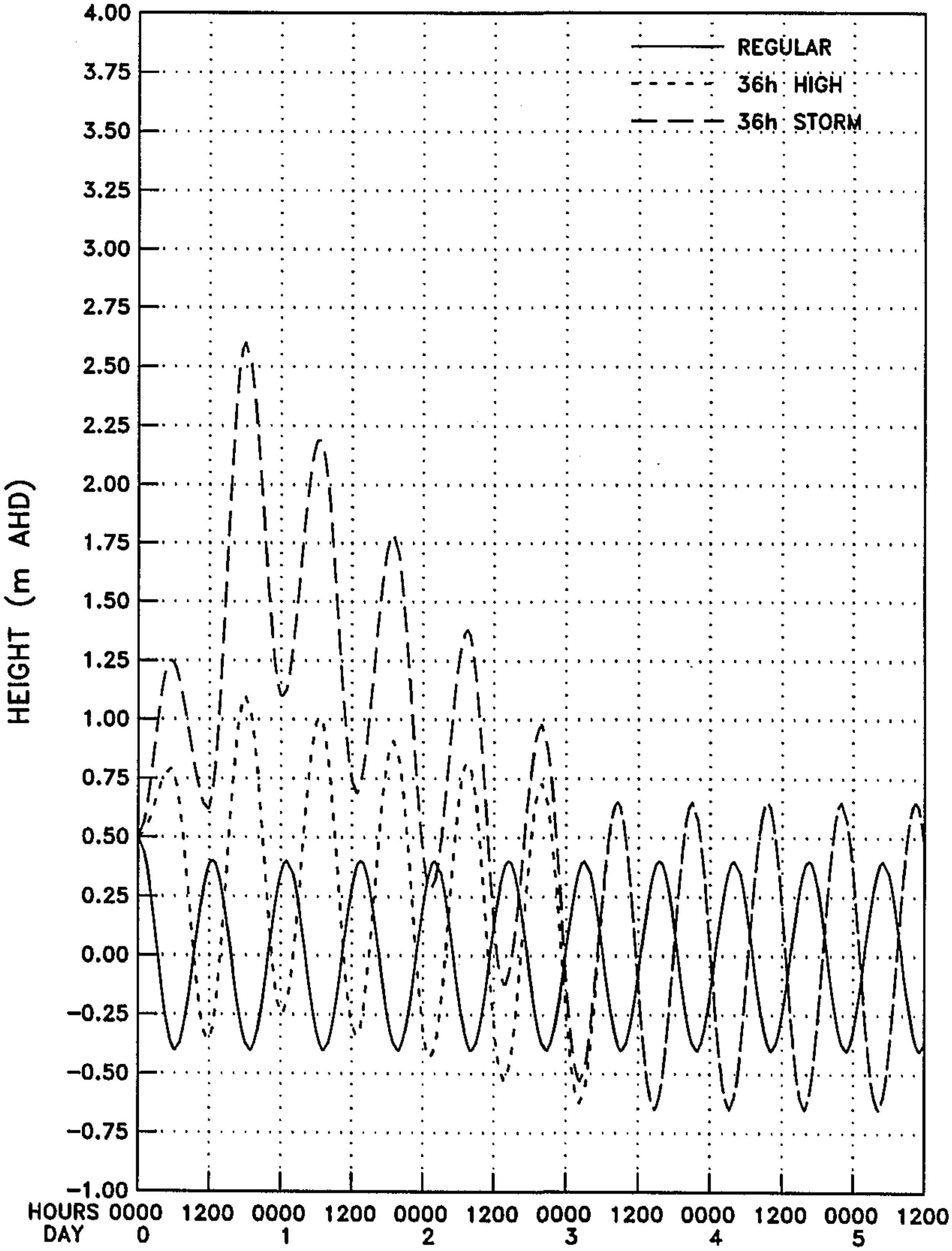


FIGURE 4
1% FLOOD – REGULAR TIDE
24h 30h 36h 48h 72h DURATIONS

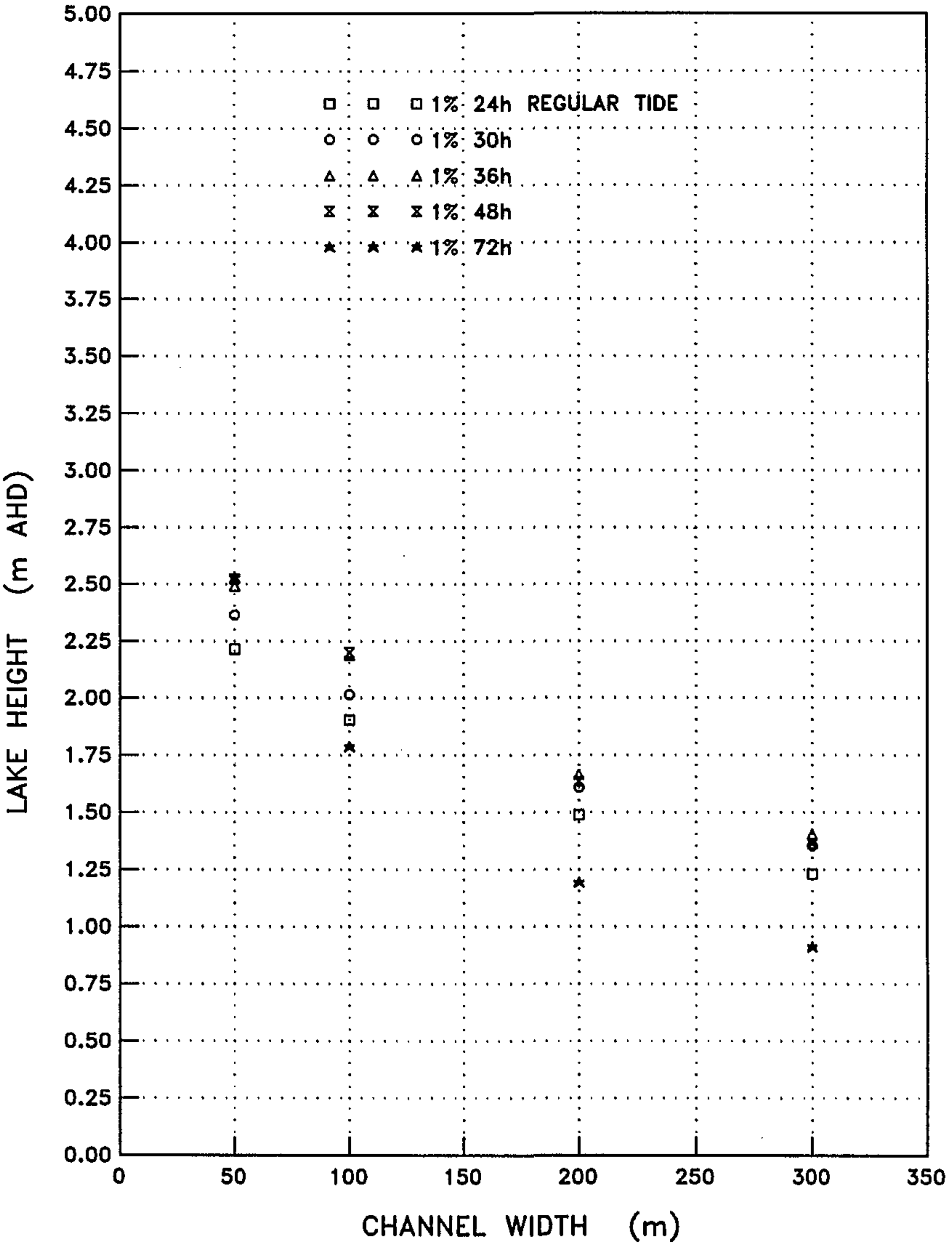


FIGURE 5
1% FLOOD – HIGH TIDE
24h 30h 36h 48h 72h DURATIONS

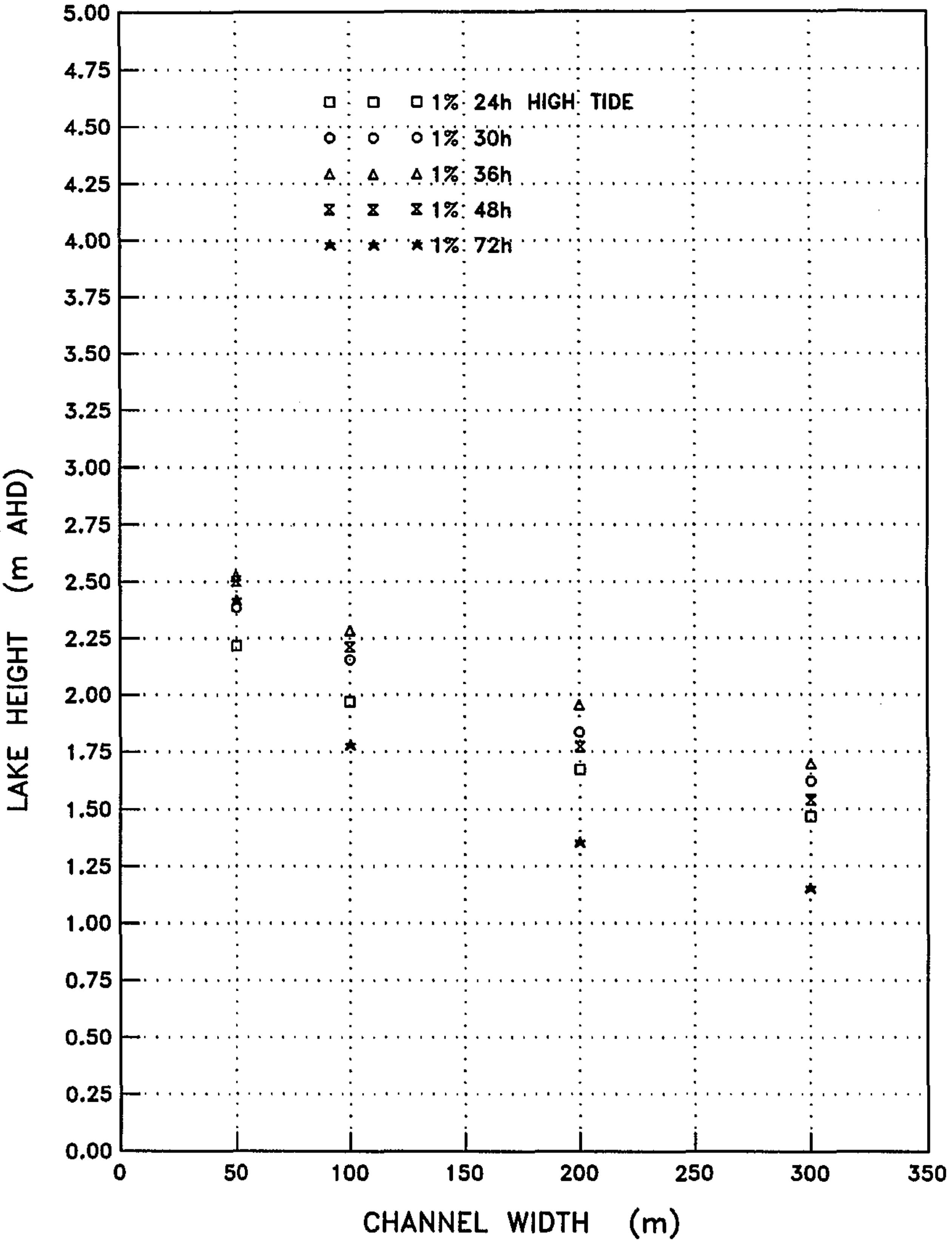


FIGURE 6
1% FLOOD – STORM TIDE
24h 30h 36h 48h 72h DURATIONS

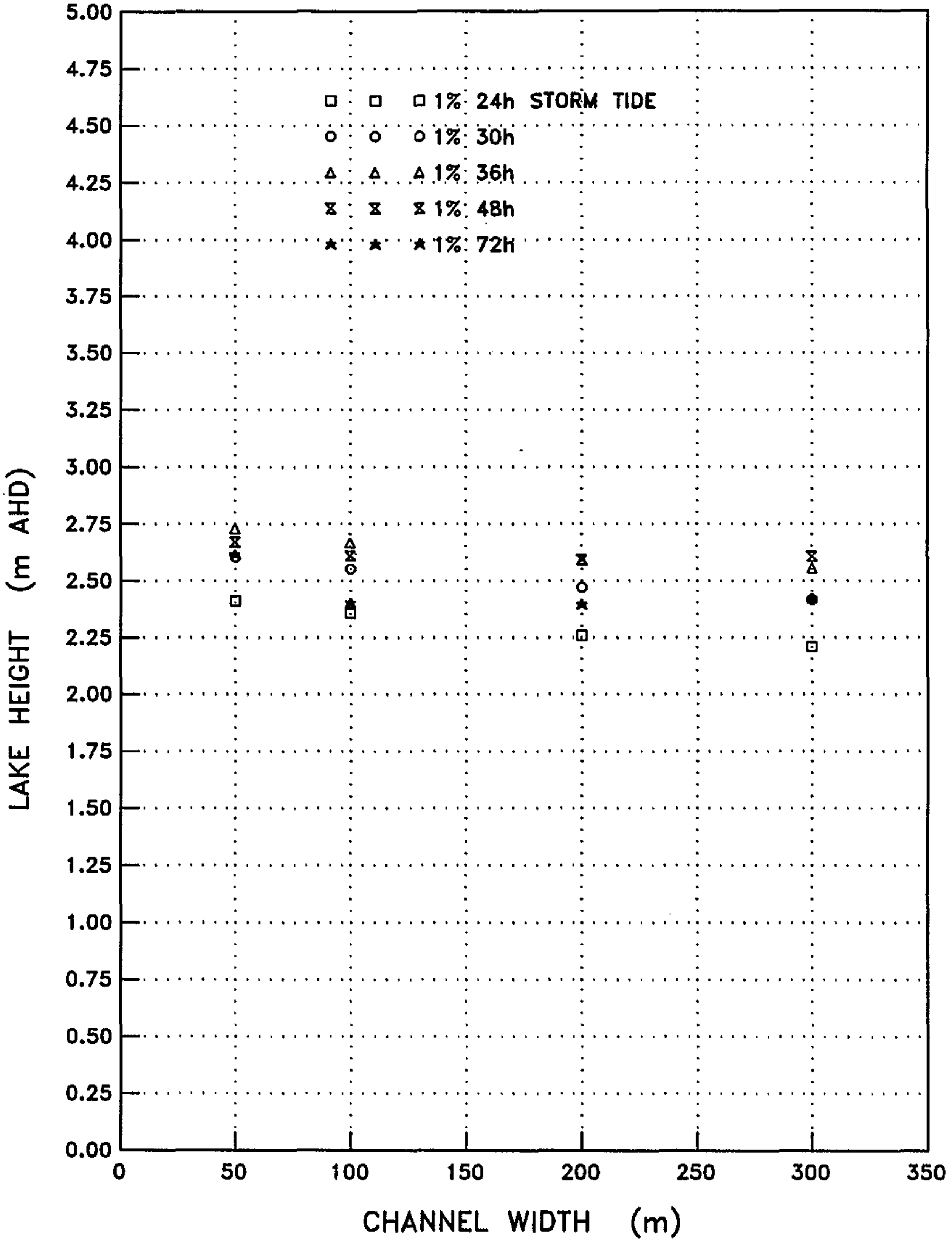


FIGURE 7
36h DURATION – REGULAR TIDE
1% 2% 5% 50% EXTREME FLOODS

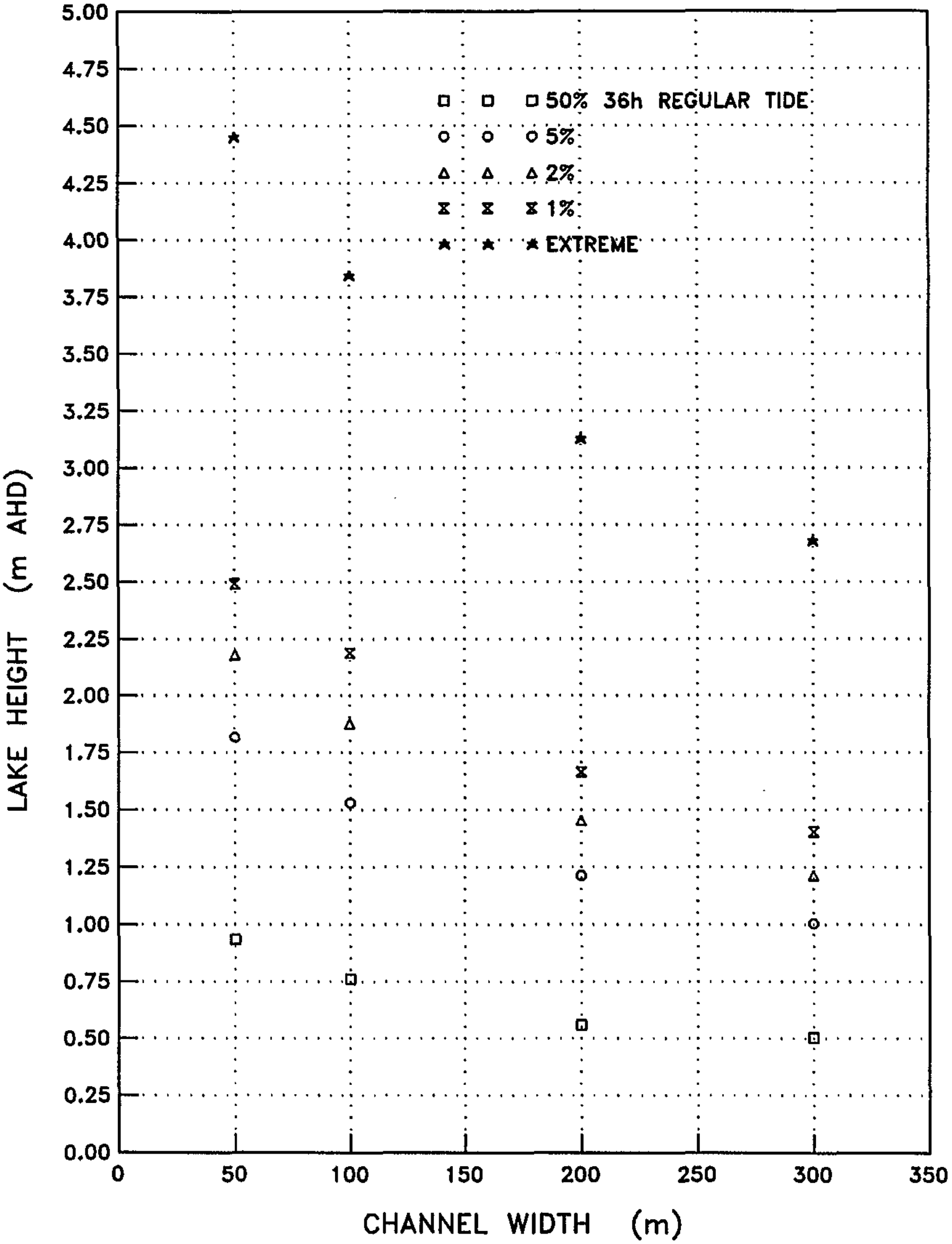


FIGURE 8
36h DURATION – HIGH TIDE
1% 2% 5% 50% EXTREME FLOODS

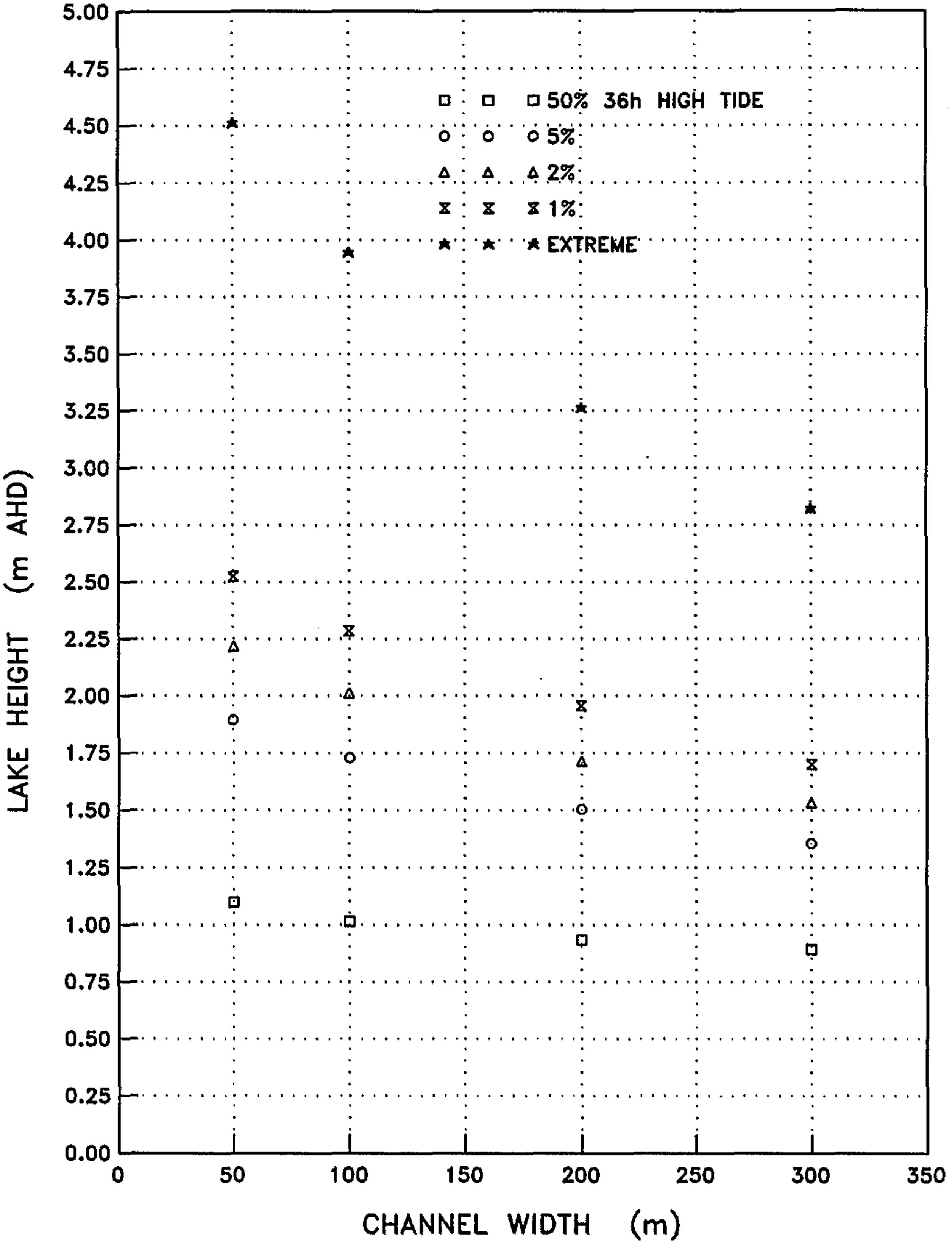


FIGURE 9
36h DURATION – STORM TIDE
1% 2% 5% 50% EXTREME FLOODS

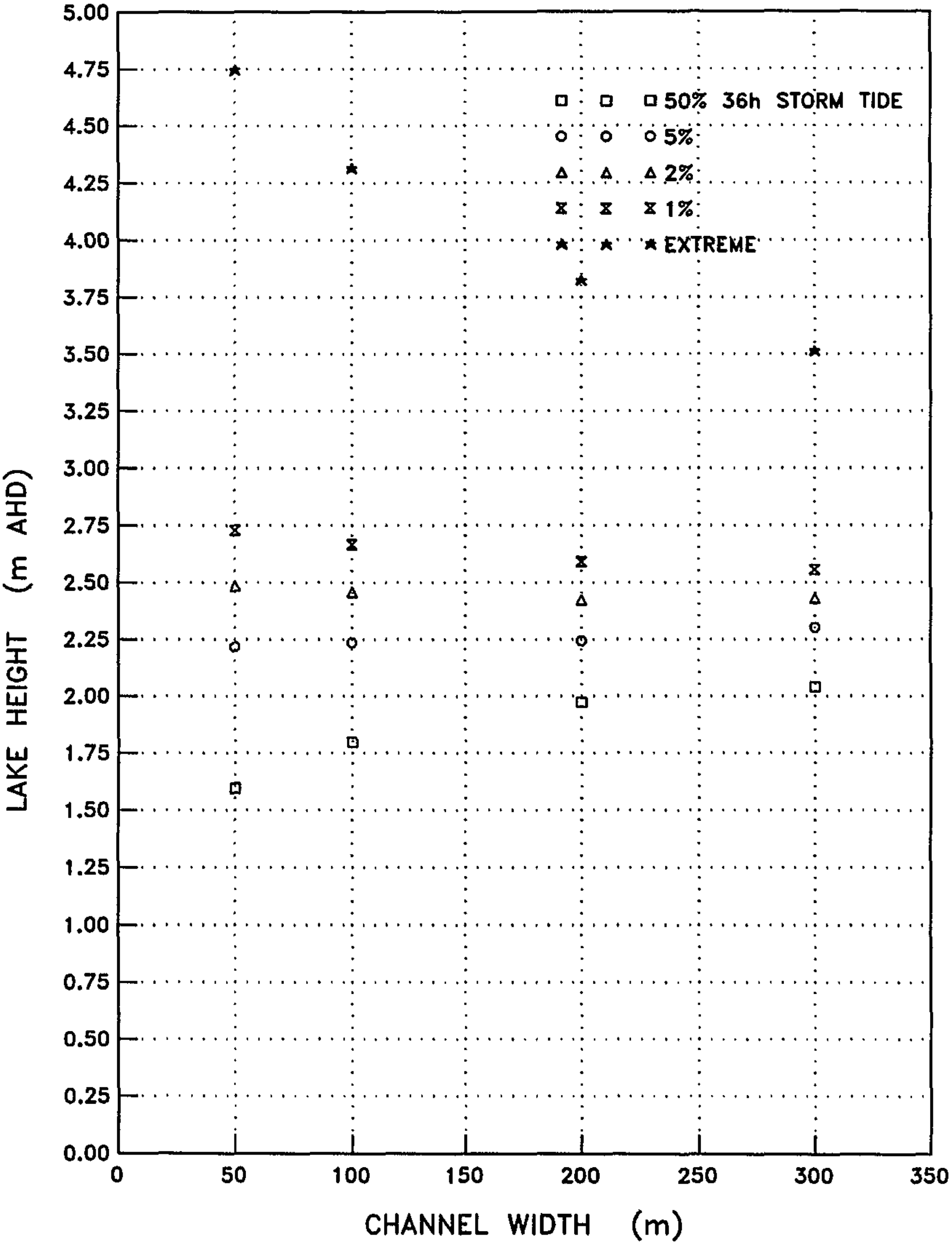


FIGURE 10
SENSITIVITY OF TIMING OF PEAK OCEAN LEVEL
1% 36h DURATION STORM TIDE

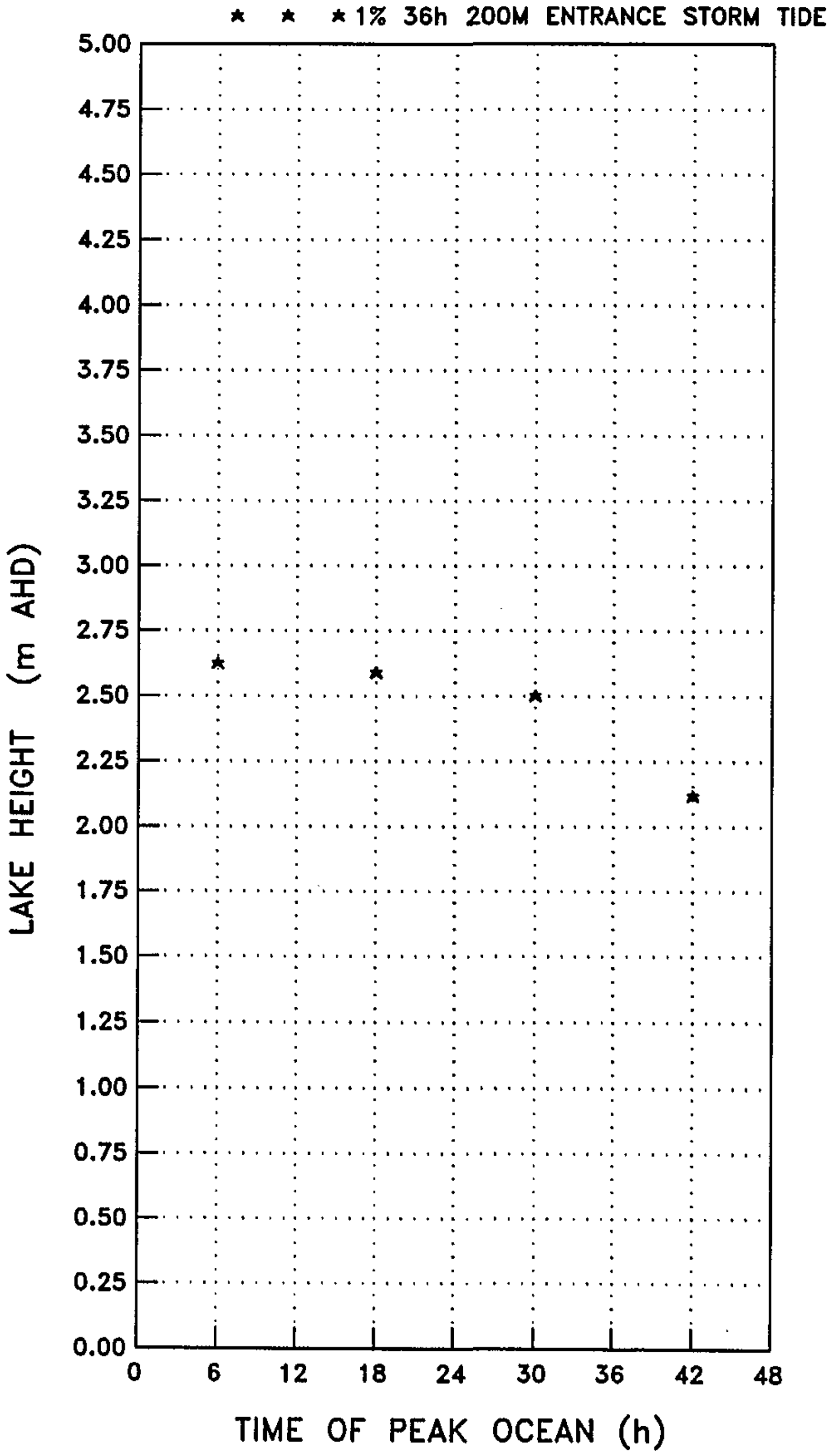


FIGURE 11
SENSITIVITY OF MANNINGS 'n'
1% 36h DURATION 200M ENTRANCE REGULAR TIDE

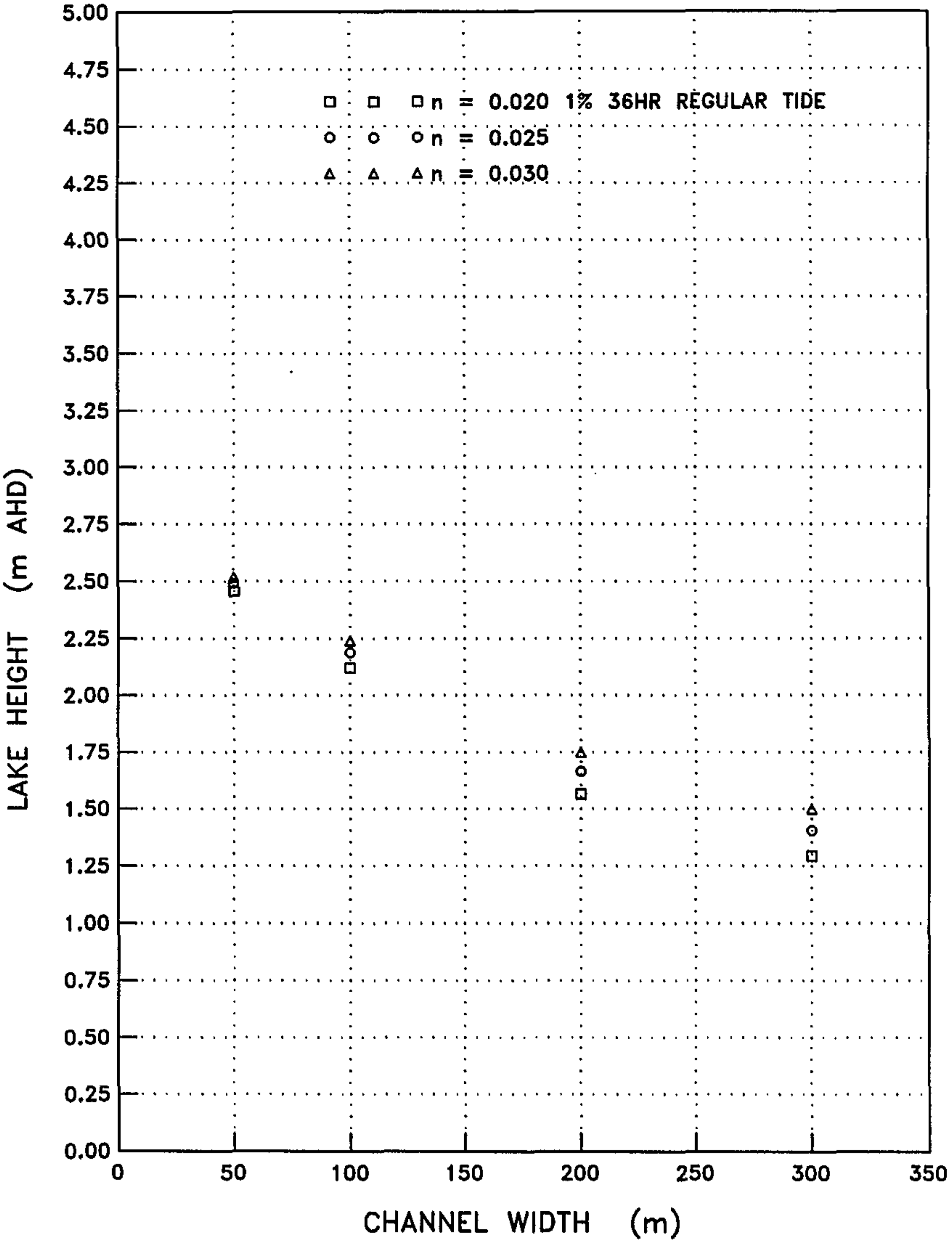
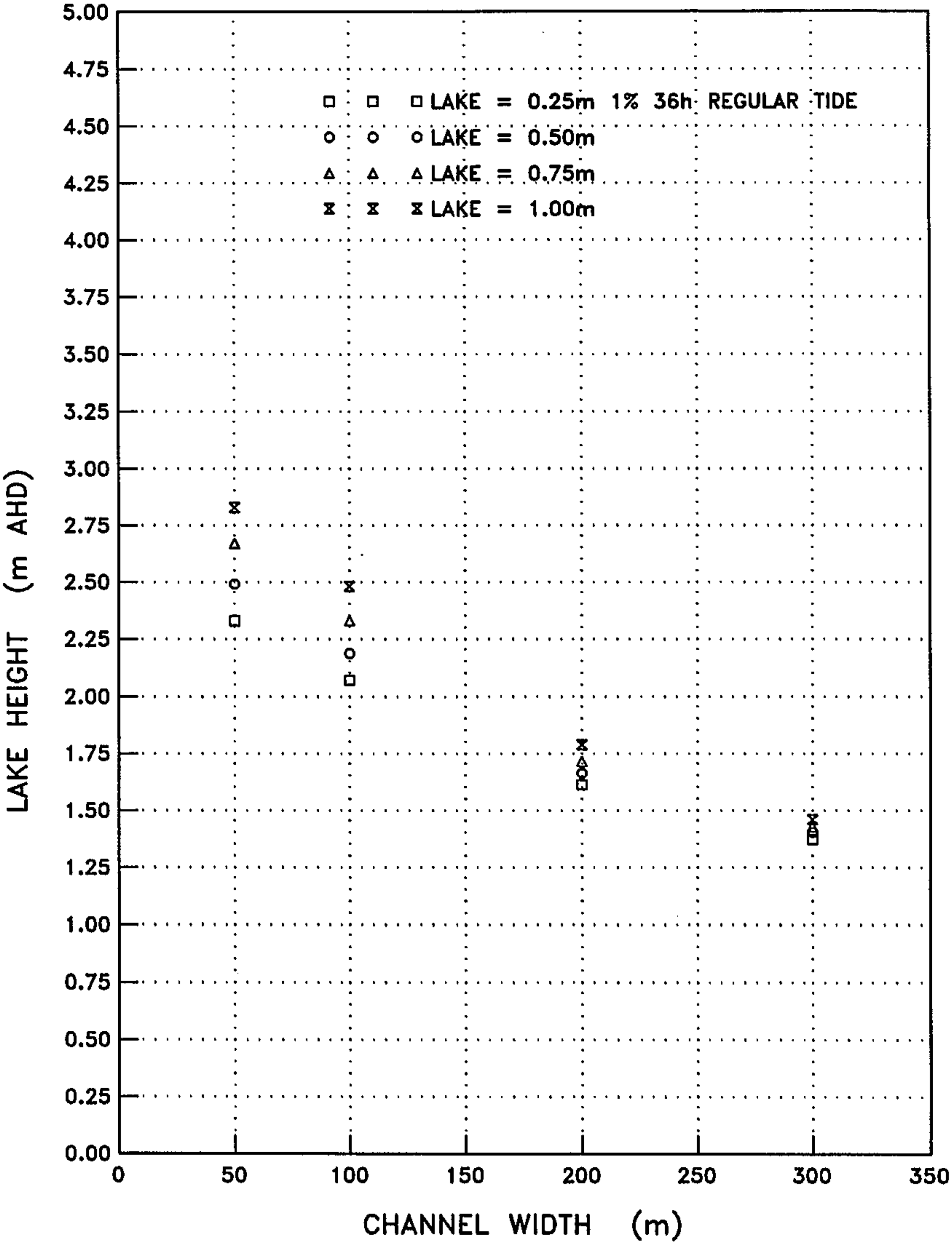


FIGURE 12

IN TUGGERAH LAKE

TION REGULAR TIDE

FIGURE 12
SENSITIVITY OF STARTING LEVEL IN TUGGERAH LAKE
1% 36h DURATION REGULAR TIDE



Lake - ocean response at high lake levels is explained by:-

Rate of fall of Lake = Nett outflow ÷ Lake area

Nett outflow = Q IN − Q OUT

When rain hydrograph is large, Q OUT is only slightly more than Q IN and small changes in tailwater level (say 30% in figure 13) could produce 15% change in Q OUT and thereby make nett outflow zero or negative.

Later when rain eases this is not so.

Also the effect is much less for wide channel where Q OUT is much larger.

FIGURE 13
HYDROGRAPHS
1% 36h DURATION REGULAR TIDE

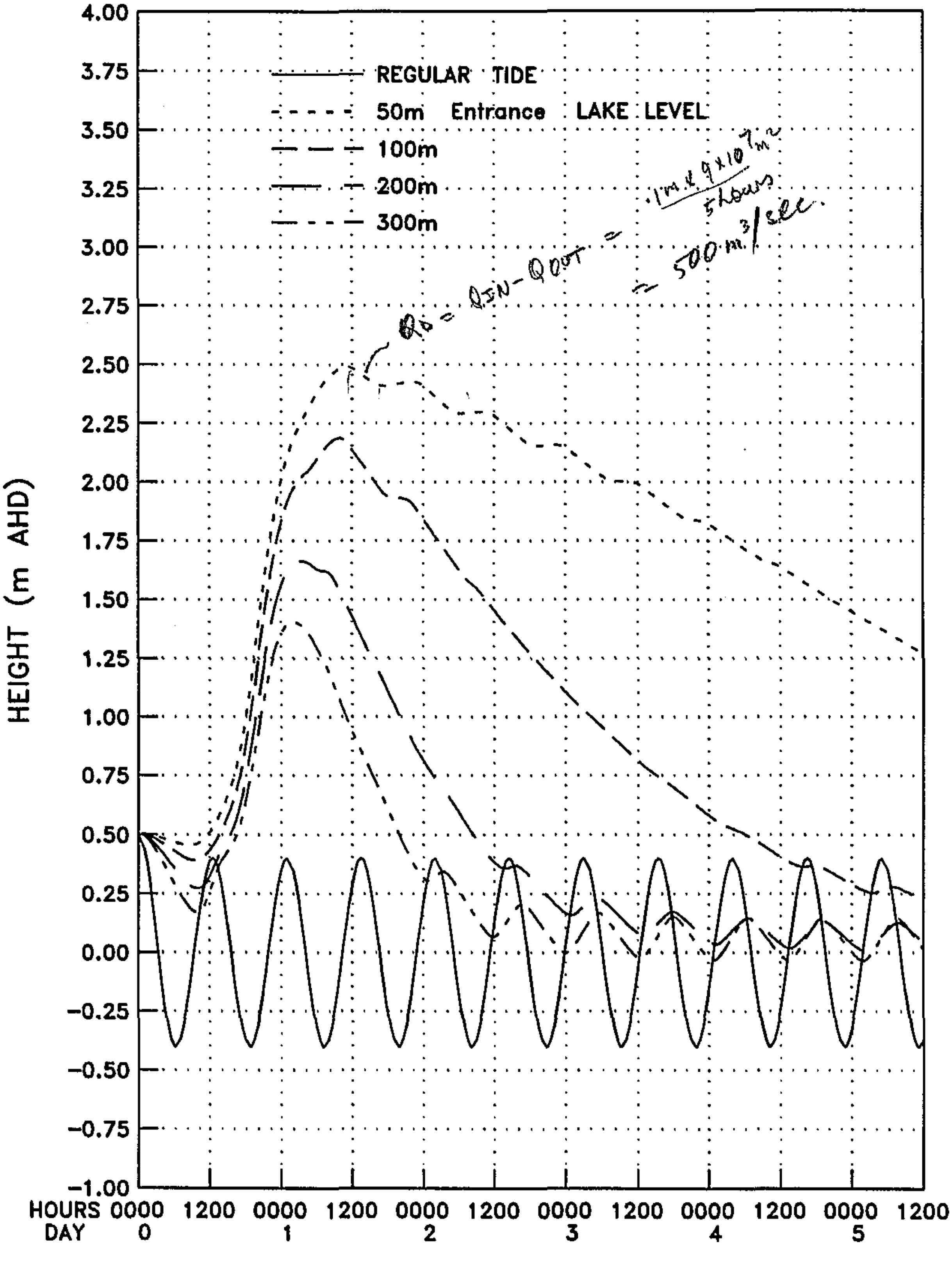


FIGURE 14
HYDROGRAPHS
1% 36h DURATION HIGH TIDE

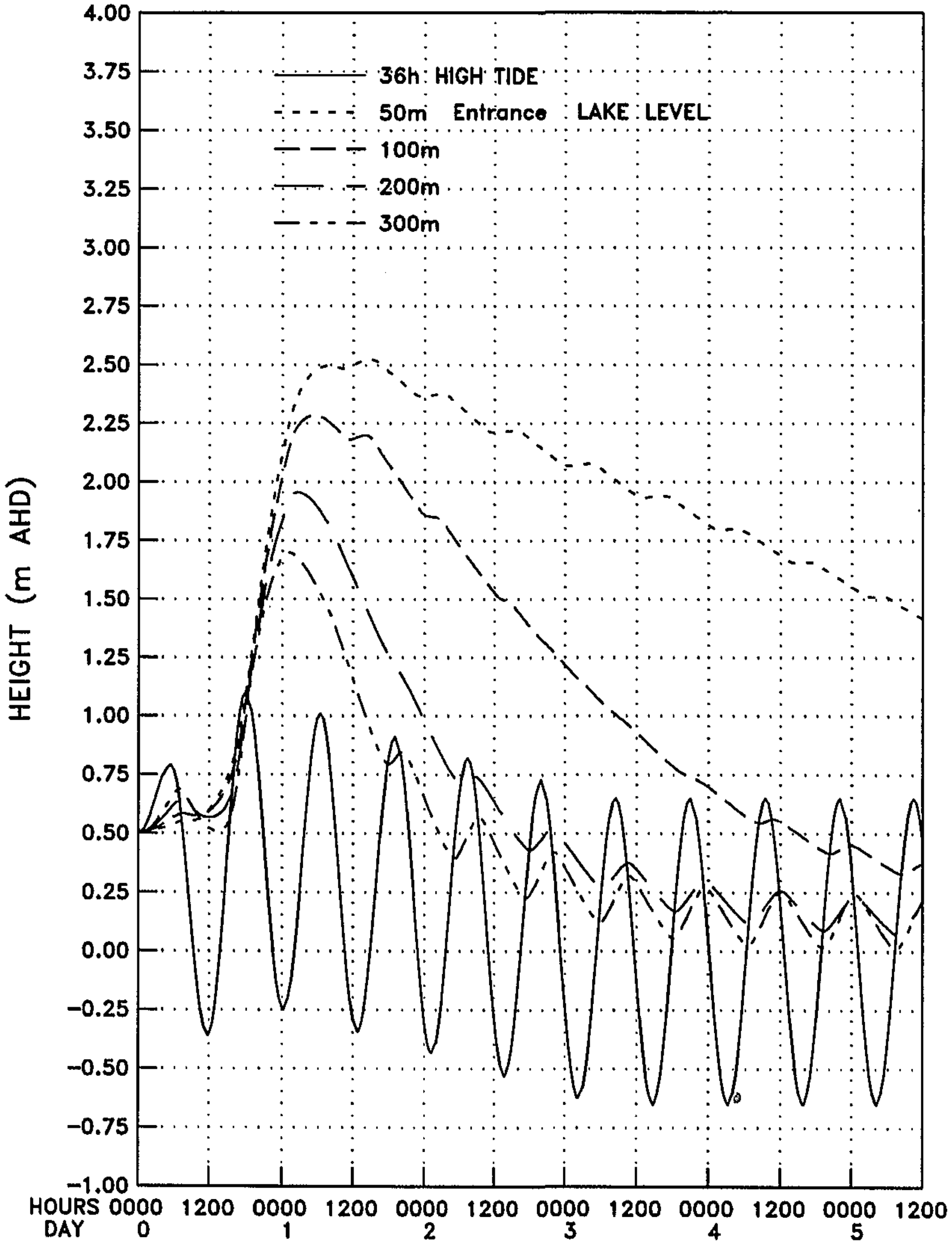


FIGURE 15
HYDROGRAPHS
1% 36h DURATION STORM TIDE