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Study Report - 2

Hydrological Study
Phase 1

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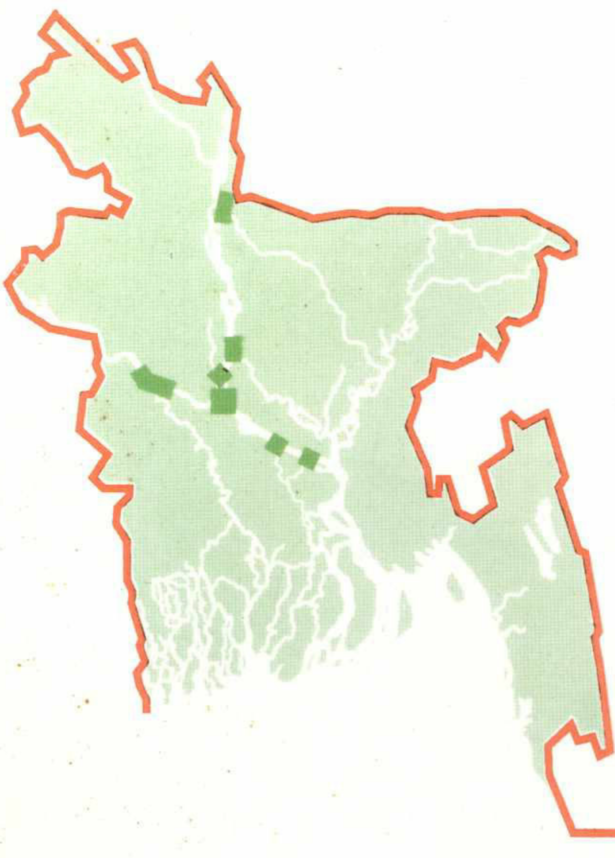

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June 1993

FAP 24 **RIVER SURVEY PROJECT**

Flood Plan Coordination Organization

DELFT-DHI **Commission of the European Communities**

House No. 96,
Road No. 23,
Banani, Dhaka
Tel : 600002, 603175
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June 30, 1993

Chief Engineer
Flood Plan Coordination Organization (FPCO)
7 Green Road, Dhaka

Subject : Hydrological Study Report

Our ref : RSP/9.1/450

Dear Sir,

We are pleased to submit herewith 50 (fifty) copies of the report on the Phase 1 Hydrological Study of the River Survey Project.

We are looking forward to receiving your comments.

Thanking you.

Yours sincerely,

F. G. Koch
Acting Team Leader

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cc: Mr. A. Goodwin, Counsellor, CEC, Dhaka

FAP 24 **RIVER SURVEY PROJECT**

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Hydrological Study, Phase 1

Executive Summary

The River Survey Project (FAP 24) consists of four components of which the Hydrological Study has the overall objective to improve the understanding of the behaviour of the main rivers in Bangladesh by studying hydrological key characteristics of the main river system.

The present report contains the main findings of the hydrological studies carried out during Phase 1 of the River Survey Project and proposals for relevant study topics during Phase 2.

Methodology

During Phase 1 a substantial part of the limited resources available has been allocated to establishment of a data base with long time series of historical data for the main stations in the major rivers and to rigorous checking and improvement of the quality of these data. An improved method for analysing rating curves has been introduced based on the ISO-standards. Various simple but powerfull time series analyses for detecting inconsistencies have been implemented. Based on the updated/corrected time series various statistical analyses have been carried out,i.e. frequency- and duration curves and flood frequency analyses for key locations in the main river system.

Data collection, data processing and data quality control

A number of agencies were approached to obtain information on past and ongoing studies and projects related to the objectives of the FAP 24 hydrological studies. Reports and available data were reviewed, and information on current procedures for collection, processing, checking and storage of data was obtained.

The major source of hydrological data is the Directorate of Surface Water Hydrology-II of BWDB. Most of the historical BWDB-data required for the present study was, however, available in computerized form at FAP 25 from where they were procured. The remaining data required, especially for the recent years after 1989 and for some additional stations, were procured directly from BWDB. The collected long historical time series has been stored in a well organized FAP 24-data base for historical data.

Why FPCO/BWDB should not have copy of them?

A systematic procedure for checking of water-level time series by plotting and comparison with series from adjacent stations has been set up, and the long water-level time series 1966-91/92 from the main discharge stations have been checked and corrected by this procedure.

Remarks Not clear.

An improved method for analysing rating curves has been introduced based on the ISO-standards. The presently applied method in Bangladesh (by BWDB and other FAPs and agencies) often leads to physically unrealistic rating curve equations and unrealistic extrapolations in particular.
New annual rating curves for the period 1966-91/92 for five discharge stations in the main rivers have been developed by applying the improved and consistent rating curve method.

Where are they?

The trends and magnitudes of shift of the annual rating curves have been illustrated by plots of the variation of water-level for selected particular discharges (specific gauge analysis). At the stations in the major rivers there are no consistent long term trends in the water-levels for particular discharges, but variations from year to year up to about 0.5 meter. This indicate that the major rivers (Jamuna, Ganges and Padma) are in a dynamic equilibrium. For Gorai River the analysis, however, clearly shows an increasing trend indicating that the Gorai is aggredating due to deposition of sediments.

Simple but powerfull trend analyses of the long time series of water-levels and discharges from the five discharge stations have been carried out in order to detect obvious inconsistencies in the time series. The analyses have been based on simple plotting and comparisons of the time series of annual peak water-levels, peak discharges and annual monsoon flow volumes. Comparisons between time series from different stations have also been performed. The analyses have detected and confirmed a number of inconsistencies in the BWDB discharge time series, the most important one is for the most important discharge station in the country, namely Bahadurabad in Jamuna River. The trend analyses and several additional special analyses for this station reveals that the discharge measurements and the resulting discharge time series since the major flood in 1988 are generally estimated 20-40% too high for medium to high flow conditions in Jamuna River. The analyses for the important station Baruria in Padma River indicate that the discharge time series for Baruria before 1971 are estimated too low.

BWDB to comment

Apart from the various inconsistencies detected the basic data quality of the historical data analysed may be characterized as satisfactory. They have formed the basis for development of new and fairly consistent rating curves and thus consistent discharge time series which are, generally speaking,not that different from BWDB's time series in the most situations. The study has, however, identified a scope for improvement both in observation methods, data processing and in particular data quality checking procedures.

BWDB to comment

Statistical analyses

The corrected and updated long time series of mean daily water-levels and discharges for the five discharge stations analysed provide an adequate basis for various frequency analysis of the time series. The distribution of daily water-levels and discharges through the year has been presented by means of frequency curves and duration curves for each station.

Furthermore, frequency analyses of the annual maximum peak water-levels and peak discharges have been carried out in order to assess design water-levels and discharges for various return periods. The 3-parameter Log- Normal distribution fit well to the peak water-levels at all stations analysed. For the peak discharges the Gumbel distribution fit well for three stations, whereas the Log-Normal distribution fit much better for the remaining two stations Hardinge Bridge and Gorai Railway Bridge.
The results of the frequency analyses are summarized in Tables 6.1 to 6.3 in Chapter 6, where the results are also compared with former estimates. There are several important deviations between the new and former estimates, and the results in Table 6.3 indicate that the new estimates are very consistent as the return periods calculated for a particular water-level correspond very well to the return period calculated for the corresponding discharge.

Water-level profiles/water surface slopes

Overall water-level profiles for the major rivers have been plotted for various flow conditions (high,medium and low) on the basis of observed water-levels at a number of gauging stations along the rivers. For Jamuna River the overall average slope for high flow conditions is estimated to 7.6 cm. per km for the upper reach and 6.5 cm per km for the lower reach, for Ganges 5.5 cm per km, for Padma 4 cm per km and for Meghna 2.25 cm per km.
The water-level data available has not yet allowed for plotting of more detailed water-level profiles including local variations of slopes between the individual gauging stations due to the uncertainty of the gauge zero levels of the various stations. When the final results of the FAP 24 field checking programme for gauge zero levels are available it will be possible to refine the presented water-level profiles.

Further hydrological studies in Phase 2

Recommendations on special field survey activities during the 1993-monsoon in order to obtain reliable data for a proposed hydrological study topic in Phase 2 have been given. A number of proposed study topics, which can be accounted for within the limited manpower resources available in Phase 2, have been described in some detail in Chapter 9.

1. Introduction

1.1 General

The River Survey Project (FAP 24) is one of the supporting activities of the Flood Action Plan. The main components are:

- o River surveys to collect reliable all season hydrological and morphological data at key locations of the country's main river system
- o Hydrological studies
- o Morphological studies
- o Training

The project period of four years (started in June 1992) is divided into Phase 1 of about one year in which the appropiate survey techniques will be tested and selected, and Phase 2 in which the surveys are implemented. The study and training components are initiated in Phase 1 as well and will be continued in Phase 2 on the basis of a selection of study topics at the end of Phase 1.

The present report contain the main findings and recommendations of the Phase 1-Hydrological Studies, which started in October 1992 . The time schedule and implementation of Phase 1 is, however, such that even after submitting this report additional analyses will be carried out. Those results will be reported in reports during Phase 2.

1.2 Objectives of the Hydrological Studies in Phase 1

The overall objective of the study components of FAP 24 is to improve the understanding of the behaviour of the main rivers in Bangladesh by studying hydrological and morphological key characteristics of the main river system.

Based on the T.O.R, Technical Specifications and the Consultant's proposal the immediate objectives of the hydrological studies in Phase 1 may be be summarized as follows:

One of the Main objective - Flood season data including overland flow measurements.

- o To study and improve methods and procedures for hydrological data collection, data analyses and data quality control
- o To establish a data base with reliable historical time series of water-levels and discharges for the main stations in the main rivers as a basis for reliable frequency analyses and other analyses important for engineering design and for improved understanding of the hydrology of the main river system
- o To establish relevant study topics for Phase 2.

These objectives are very much related to one of the main objectives of the field survey programme of FAP 24 which is to provide new reliable measurements of discharges at 11 stations in the main river system. From the beginning of the studies it was appreciated that the FAP 25 Flood Hydrology Study and other projects (ref. Chapter 3) had allready done valuable work related to the objectives of the present study. There was, however, a need for including detailed analysis of historical time series from several additional stations in the main rivers, and for general improvement of procedures for checking of data quality and consistency of the time series.

1.3 Contents of the report

The present report starts with an Executive Summary and the present introductory chapter. Chapter 2 describes the general methodology applied and its justification, while Chapter 3 provides a short description of the study area and related previous hydrological studies. In Chapter 4, an overview of the data collection carried out by FAP 24 is given.

Chapter 5 describes the comprehensive data quality checking carried out, improved methods for rating curve development and analysis of consistency of time series. In Chapter 6 various statistical analyses of the improved time series are presented,e.g.frequency curves and flood frequency analyses.In Chapter 7 the overall longitudinal water-level profiles of the main rivers for various flow conditions are presented and Chapter 8 contains some recommendations on some field survey activities to be carried out during the coming monsoon 1993 in order to support the hydrological studies in Phase 2. Finally proposals for study topics for the hydrological studies in Phase 2 are presented in Chapter 9.

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2. Methodology

2.1 General methodology

During the execution of the hydrological studies in Phase 1 a substantial part of the limited resources available has been allocated to establishment of a data base with long time series of historical data for the main rivers and to rigorous checking and improvement of the data quality of these data.

In the very beginning of the studies it was agreed to concentrate these activities to the six present discharge stations in the major rivers, namely:

- o Bahadurabad, the only present discharge station in Jamuna River
- o Hardinge Bridge in Ganges River
- o Baruria in Padma River, just downstream the confluence of the Jamuna and Ganges rivers
- o Gorai Railway Bridge in Gorai River
- o Mawa in Padma river
- o Bhairab Bazar in Upper Meghna River

The reason for the emphasis on data quality assurance of these time series is that the data quality is crucial, not only for the analyses to be carried out under this project, but also for the modelling, design, planning and management activities carried out by other projects/ organizations. Spending only a small fraction of the large resources invested on field data collection over many years, on checking the quality of the data, will improve the data bases and thus the results of all these activities.

An improved method for analysing rating curves have been introduced based on the international standards (ISO). Various simple time series analyses for detecting inconsistencies have been implemented. Based on the updated/corrected time series various statistical analyses have been carried out, e.g. frequency curves and flood frequency analyses, and comparisons of flood frequency estimates with former estimates have been done.

2.2 Summary of activities

The detailed activity schedule of the hydrological studies in Phase 1 has included:

- o Collection and review of previous hydrological studies and visits to related projects/organisations
- o Collection and processing of historical BWDB time series procured from FAP 25 and BWDB. Establishment of a FAP 24 data base with historical time series.

- o Development of improved methods for data quality control,e.g check of water-level time series, development of consistent rating curves and various trend analyses to detect inconsistencies in the time series
- o Special investigations to analyse and explain observed inconsistencies at the most important discharge station at Bahadurabad in Jamuna River.
- o Frequency curves and duration curves
- o Flood frequency analyses
- o Analyses of overall longitudinal water-level profiles along the main rivers including desk check of datum of water-level stations
- o Recommendations on field survey activities during the 1993 monsoon to support the hydrological studies in Phase 2
- o Preparation and discussion of relevant study topics for Phase 2
- o A two- week training course in hydrological processes, modelling, hydrometric measurements, data quality checking procedures, rating curve development, time series analyses and frequency analyses
- o Reporting, including a Travel Report of Dec.1992 presenting the preliminary findings of the first two months of hydrological studies, and the present report.

3. Study Area

3.1 Description of the study area

The project components of FAP 24 are all related to the main river system only. Fig.3.1 provides a map of the main river system with an overview of the planned main field survey activities including routine measurements of discharge and sediment transport at 11 sites of the main river system, check of datum for 47 water-level stations and bathymetric surveys at selected key locations. The 11 sites for regular FAP 24 discharge measurements include the present permanent six BWDB-discharge stations in the major rivers selected for detailed analyses, ref. Section 2.1.

The general hydrological characteristics of the complex main river system and the monsoon cycle is described in the FAP 25 Flood Hydrology Study. Some main characteristics on the distibution of flows over the year are presented in Chapter 6 of the present report, and the overall water surface slopes of the major rivers are dealt with in Chapter 7.

3.2 Survey of existing hydrological information related to FAP 24.

A number of agencies have been approached to obtain information on past and ongoing hydrological studies and projects related to the objectives of FAP 24. Reports and available data have been collected and reviewed, and information on current procedures for collection, processing, checking and storage of hydrological data have been obtained.

The agencies visited are:

- o Directorate of Surface Water Hydrology I (SWH-I) of Bangladesh Water Development Board (BWDB)
- o Directorate of Surface Water Hydrology II (SWH-II) of Bangladesh Water Development Board (BWDB)
- o Flood Modelling and Management (FAP 25)
- o Surface Water Modelling Center (SWMC)
- o River Training Studies of the Brahmaputra river (BRTS, FAP 1)
- o Bank Protection and River Training (AFPM) Pilot Project (FAP 21/22)
- o Jamuna Bridge Project
- o Bangladesh Inland Water Transport Authority (BIWTA)
- o Water Resources Planning Organization (WARPO)

In the following a short description is given of the information obtained from the various agencies and the studies, reports and data reviewed in relation to the objectives of FAP 24. An inventory of the collected data is given in Section 4.1.

3.2.1 SWH-I (BWDB)

SWH-I is responsible for hydrological field work in connection with the BWDB network of hydrometric stations.

Water-level observations

BWDB operates about 47 water-level stations in the main rivers of which 5 are also discharge stations. At all these stations the water-levels are measured from wooden staff-gauges five times a day, at 6.00, 9.00, 12.00, 15.00 and 18.00 hours. According to the variation of the water-levels it is often necessary to raise or lower the staff gauges. A new gauge is fixed close to the previous one and the relation between data of the two gauges is determined through simultaneous readings. These frequent shifts may generate some uncertainty in the observations, in particular when several shifts of the gauge occur between two check-levellings from a bench-mark.

Another type of gauge shifts which may create even higher uncertainty occur some times due to bank erosion or non-accessibility to the gauge site during high flows. Often, within a year, the position of the gauge may be shifted upstream or downstream over a stretch of one kilometer (ref. FAP 25, June 1992). Significant differences in water-level may be expected when shifting from one gauge to the other.

Check-levelling of the gauge datum from a nearby bench-mark is carried out weekly or fortnightly, and water-level corrections resembling from these checks are carried out at a field office before the mean daily water-levels are computed and transmitted to SWH-I in Dhaka. The Flood Hydrology Study (FAP 25, June 1992) has raised serious doubts as to which extent the check-levellings have actually been carried out for the last years (at least at the important station Bahadurabad).

Discharge observations

The discharge measurements at the 5 discharge stations in the main rivers are scheduled to have a frequency of once per week during the monsoon period (May-November) and once per fortnight between November and May. However, at Hardinge Bridge the measurements are carried out every day. Daily measurements are also carried out at Bahadurabad since 1 October 1992.

The difficulties for discharge measurements for the large main rivers in Bangladesh have been appreciated by BWDB and noted in former studies.

The potential sources of error in discharge measurements in the Jamuna have been elaborately discussed in the First Interim Report of the Brahamaputra River Training Study (FAP 1, April 1991, ref. Subsection 3.2.5). A variety of potential sources of errors have been acknowledged including micro changes in river morphology during measurement which usually takes at least 48 hours. During rising and falling stage, the bed may change its configuration substantially owing to migrating bed forms. Under such conditions, surveys, requiring periods longer than a few hours, can result in unreliable measurements. Coleman (ref. Coleman, J.M.,, August 1969) commented that until the mechanics and pattern of bed form movement can be more thoroughly documented, any discharge measurement in the Brahmaputra may need to be treated as an estimate.

BWDB measures the flow velocities from a survey boat by non-directional Ott current meter at 0.2 and 0.8 depth of the verticals. The number of verticals applied varies according to the actual flow conditions, but a rule used by BWDB is that one vertical should not represent more than 10% of the total flow in a channel. The required number of verticals becomes often very high and it takes usually about two days to complete one measurement of the total discharge. This implies, in addition to the effect of changing bed forms mentioned above, uncertainty in the relationship between measured discharge and the corresponding water-level (used for rating curve development), in particular during rising and falling stage.

The flow direction at each measurement point across the river is measured in the surface layer by a float with submerged cross-vane. The float positions are measured by sextants.

Other sources of errors are:

- o Velocity measurements made from non-anchored boats may not have perfectly fixed position
- o Inaccurate measurements of depths, especially when measured by current meter instead of echo-sounder, which may lead to an overestimation of depth (i.e. discharge), in particular during high current

3.2.2 SWH-II (BWDB)

SWH-II is responsible for the processing of the field data measured by SWH-I, e.g.:

- o Development of rating curves
- o Generation of mean daily discharge with the aid of rating curves and water-levels
- o Storage and publication of data (water-levels and discharges)

<u>Observed discharge</u>

The total discharge is calculated in the field by SWH-1 from the velocity measurements by the conventional velocity-area mid-section method including flow angle-corrections based on surface float measurements.

<u>Rating curves</u>

Rating curves are developed for each hydrological year based on the actual Stage/Discharge (Q/h) measurements during that year and also some values (especially extreme values) from the previous years for consistency and extrapolation purposes. The Q/h data are plotted on log-log paper, and the correct offset (point of zero flow) is determined by trial and error until the lower Q/h observations form a straight line to the extent possible. Several segments of the curve are considered, but a fixed offset is assumed for all segments which is usually not the case. This can be seen from the log-log plots where the lower part of the Q/h-points may follow a straight line whereas the upper Q/h-points plot as one are two curves. Assuming a fixed offset for all segments is equivalent to fit a straight line through the curved Q/h-points. This will usually lead to unrealistic extrapolations. For more details refer to Subsection 5.2.2.

<u>Shift corrections</u>

When calculating mean daily discharge from observed water-levels and derived rating curves BWDB apply regular shift corrections. Usually a shift correction is applied when the rating curve changes with time due to change in cross-sectional characteristics along the control section. A shift correction is applied to the stage of a discharge measurement to bring it in accordance with the derived mean rating curve. The procedure inherently assumes that the discharge measurements are true, without error. If this is not the case, application of shift correction may introduce new errors. The Flood Hydrology Study (FAP 25, June 1992) has given examples which illustrate that the current application of shift correction by BWDB is questionable.

Storage of data

Most of the historical data on water-levels and discharges are available in BWDB only in paper format (hard-copies). However, in the recent years BWDB has introduced computerized databases for storage and retrieval of data. At present only the most recent years of data are stored in the computer database of BWDB.

FAP 25 (ref. FAP 25, June 1992) recently noticed the lack of a proper data directory at BWDB. Thus FAP 25 developed such a directory based on data available from BWDB and other sources, e.g. WARPO. The directory contains very useful information on station name, code and length of records for all water-level stations and most discharge stations in Bangladesh (ref. FAP 25, June 1992, Volume 2, Annex 1).

3.2.3 Flood Modelling and Management (FAP 25)

This project has carried out the most recent and comprehensive study of existing hydrological data of the main rivers in Bangladesh. The data used and the study carried out by FAP 25 are well documented in the Main Report of the Flood Hydrology Study (FAP 25, June 1992). In the following only a short description of the database and studies with direct relation to FAP 24 will be given.

FAP 25 has established a computerized database with the following data:

- o Mean daily water-levels: 25 years of data (1964-89) from 50 water-level stations including selected main stations in major rivers
- o Mean daily discharges: 25 years of data (1965-1989) from 22 discharge stations including all the six (FAP 24) stations in the main rivers (Bahadurabad, Hardinge Bridge, Baruria, Mawa, Bhairab Bazar and Gorai Railway Bridge)
- o Observed discharges (i.e the Q/h field measurements): 25 years of data (1966-1990) from 10 discharge stations including all stations in main rivers except Gorai Railway Bridge.

Water-level time series

Systematic checking and correction of water-level time series by means of correlation methods was carried out by FAP 25 for selected stations on the Jamuna and Ganges for the years 1964-1989:

- o Jamuna: Chilmari, Kholabari char, Kazipur, Sirajganj, Porabari, Bahadurabad o Ganges/Gorai: Hardinge Bridge, Sengram, Gorai Railway Bridge, Kamarkhali

Rating curves

New annual rating curves (1965-1989) were established for three stations: Bahadurabad, Hardinge Bridge and Baruria.

The procedure used was similar to the procedure used by BWDB (ref. Subsection 3.2.2), and the new rating curves are not much different from BWDB rating curves. The magnitude of shift of the annual rating curves were analysed and appeared to be considerable. The exact reasons for these shifts were not analysed but assumed to be caused by morphological changes, systematic errors in discharge measurements and long term shifts in gauge locations.

Discharge time series

New discharge time series (1965-1989) have been calculated for the three stations above on the basis of the corrected water-level time series and the new rating curves. FAP 25 found the BWDB procedure of shift application questionable and did not apply any shift corrections (ref. Subsection 3.2.2).

Statistical analysis of observed data

FAP 25 has carried out frequency analyses of annual peak water-levels, annual maximum discharges and average seasonal discharge for various stations and has recommended which probability distributions should be used for the various types of data in Bangladesh.

The statistical representatives of the period 1965-1989 for the whole country have been studied based on long term records of hydrological variables (rainfall, water-levels and discharge) from various stations. Trend analyses and peak-frequency analyses indicate that the hydro-meteorological conditions in Bangladesh during the last 25 years are fairly representative for the longer term. In general one may consider the 1965-1989 period as a slightly conservative basis for design, when compared to the last 50-100 years.

3.2.4 Surface Water Modelling Center (SWMC)

SWMC has developed regional hydrodynamic models for all the 6 regions of Bangladesh as well as the General Model (GM) covering the main rivers in the whole country (ref. MPO, July 1992). The models are all based on the MIKE 11 modelling system developed and implemented by the Danish Hydraulic Institute.

The MIKE 11 databases of SWMC cover at present the period 1985-1991 only, and the major part of the hydrological data used for boundary conditions and internal comparison points are basically the water-level and discharge time series supplied by BWDB (SWH-II). SWMC carries out a few basic checks of the water-level input data before using them in the model (visual comparison of the observed water-levels from adjacent stations based on plots year by year). However, the modelling process itself is considered by SWMC as the most rigorous check of the data quality. Furthermore SWMC has developed rating curves for the most recent years of the boundary discharge stations on basis of BWDB's field measurements.

A special version of the General Model was applied by FAP 25 for long term simulations 1964-1989 (ref. FAP 25, June 1992). The boundary stations used in the two model versions are nearly the same, but the most important boundary input data (discharge time series at Bahadurabad and Hardinge Bridge) were corrected by FAP 25 before used in the model. The corrections proved to be a major step forward in the validation of the General Model.

This exercise illustrates the importance of implementation of rigorous data checking procedures of the input data to the various mathematical models, in particular for the model boundary stations. The quality of the output from a model will never be better than the quality of the input data even for very advanced models.

3.2.5 Brahmaputra River Training Study (FAP 1)

FAP 1 has carried out a comprehensive hydrological study for the Brahmaputra River (Jamuna) (ref. FAP 1, April 1991).

The hydrological study was based on the historic hydrological data collected by BWDB. Rainfall, water-level and discharge data for selected stations were collected and stored in a computer database (Lotus-worksheets). For most stations the collected daily data had records back to 1964 or 1965.

Check and analyses of water-levels

For selected water-level stations along the Jamuna River the BWDB time series of mean daily water-levels were checked thoroughly by plotting and comparison of adjacent stations. The annual maximum water-levels were also screened by various rigorous procedures and suspicious data were detected before use in various analyses, which included:

- Frequency histograms and curves for each month over the year
- Frequency histograms and curves for each 10-day period over the year
- Trend analyses of peak flood water-levels
- Specific gauge analyses of water-levels at Bahadurabad
- Frequency analyses of annual peak water-levels
- Water surface profiles along Jamuna for selected events

Discharge analysis

The observed discharges from BWDB at Bahadurabad and the BWDB rating curves were collected and used to illustrate the range of fluctuations in Jamuna flows for the same water-level.

The mean daily discharge data from BWDB at Bahadurabad were used for the following analyses to define the general discharge characteristics of the Jamuna:

- Frequency histograms and curves for each month
- Frequency distribution of mean daily flows (flow duration curve)
- Trend analysis of peak discharges
- Frequency analysis of annual peak discharge

Analysis of discharge measurements, potential errors

FAP 1 has carried out a detailed assessment of potential errors involved in discharge measurements on the Jamuna (ref. FAP 1, April 1991). The assessment is based on consecutive discharge measurements over one week carried out by the FAP 1 survey team. The measurement technique was directional current meter measurements of velocity and flow direction in 0.2 and 0.8 depths, and the depths of the river cross-section was recorded by an echo-sounder.

Errors Too high

With the applied measurement technique the errors of the individual discharge estimates were often 20-30%. It was concluded that for the applied measurement technique the estimation of discharge in the Jamuna would need to be based on at least 4 consecutive measurements if it is to be determined within a standard error of less than 2000 m^3/s.

for which part of the season - round the year or seasonal

3.2.6 Bank protection and river training (FAP 21/22)

The hydrological studies carried out in connection with this project are very limited as the purpose only was to establish hydrological design condition at a few test sites along the Jamuna. The data used and the type of analyses carried out were quite similar to the FAP 25 data analyses already reported above (ref. FAP 21/22, July 1992).

3.2.7 Jamuna Bridge Project

The project has carried out various hydrological analyses for the stations in the Jamuna river with the aim to establish the hydrological design conditions for the potential bridge project. The analyses are described in the Feasibility Report (JBP, August 1989).

Based on BWDB data on water-levels from 7 stations along the Jamuna and the discharges from Bahadurabad frequency analysis of maximum annual water-levels and discharges have been carried out assuming Gumbel extreme value distributions.

An average rating curve at Bahadurabad was fitted by a quadratic equation. Rating curves for 6 water-level station along the river were developed assuming same discharge at all the stations as at Bahadurabad.

In addition to the hydrological analyses comprehensive morphological studies for the Jamuna River have been carried out by the project.

3.2.8 BIWTA

BIWTA operates 45 water-level gauges mainly in the tidal areas of Bangladesh. BIWTA carries out tidal analysis and publishes tidal prediction chart tables. The data from the tidal areas from BIWTA are not directly relevant to the present hydrological studies of FAP 24 but may be relevant to the morphological studies and part of the FAP 24 survey activities.

3.2.9 WARPO

WARPO (Water Resources Planning Organization) carries out studies and planning of water resources in the whole country, mainly on the basis of BWDB data on surface and ground water observations. Various frequency analyses of maximum annual water-levels and discharges have been carried out, and a report on surface water availability has been published. The report is not yet in hand of FAP 24 but is probably not directly relevant for the FAP 24 hydrological studies of the key characteristics of the main rivers only.

4. Data collection and processing

This chapter is divided into a) collection of existing historical hydrological data for the hydrological studies in Phase 1 (secondary data) and b) collection of primary field data measured by the FAP 24 survey team . The new discharge data measured by FAP 24 up to now are of course only very few and all refer to the Bahadurabad station where the test measurements are being carried out during Phase 1.

4.1 Historical data

The major source of hydrological data is the Directorate of Surface Water Hydrology-II of BWDB. Most of the historical BWDB-data required for the present study was, however, available in computerized form at FAP 25 from where they were procured. The remaining data required, especially for the recent years after 1989 and for some additional stations, were procured directly from BWDB.

Despite that most of the data were readily available from FAP 25, the procurement procedures, the necessary processing and checks on availability of the data and following collection of additional data made the establishment of a data base to a very time consuming process. Some of the data procured directly from BWDB were in a form of hard copies only while others were in computerized form but in various formats. The transfer of these data into the FAP 24 data base required development of separate computer programmes.

4.1.1 Collected data

The tables in Appendix 1 provide an up to date detailed overview of all historical hydrological data collected by FAP 24. All the data collected are basically original BWDB-data eventhough the major part of the data were procured from FAP 25. The data series cover basically the period from 1966 to 1992, but there are several gaps, e.g. data for the hydrological year 1971 are not available at all. For details, see the tables in Appendix 1.

In short the collected data are the following:

Stage-Discharge Data ("Observed Discharge Data")

Results from discharge measurements including stage and derived discharge (Q-h measurements) were collected for the six permanent discharge stations in the main rivers. Available BWDB-rating curves for these stations were also procured from BWDB.

Mean Daily Discharge

The mean daily discharge time series derived by BWDB from water-levels and established rating curves were collected for the six discharge stations in the main rivers.

Mean Daily Water Levels

Mean daily water level time series were collected for a number of stations along the main rivers to provide the basis for checking of water level time series at the six discharge stations. For a selected recent year 1990 additional data from a number of water level stations were collected to provide the basis for plotting of water surface profiles along the main rivers. For this purpose information on the chainages of the various stations were also collected from the Surface Water Modelling Centre (SWMC).

4.1.2 FAP 24 data base for historical data

All the historical time series mentioned above have been transferred from various file-formats (lotus-files,BWDB-file-formats and hardcopies) into the HYMOS data base of FAP 24.The HYMOS software package has been used extensively for data validation, development of rating curves and statistical analyses.

When modifying the original data series due to data-corrections, new rating curves etc. as described in the next Chapter 5, the procedure has been to maintain the original data series in the original files and create new files with the modified data. Thus the FAP 24 HYMOS data-base in fact consist of two parallel data bases, the first one with the original BWDB-data procured from FAP 25/BWDB and the second one with all the updated FAP 24 time series.

4.2 New discharge data measured by FAP 24

A few new FAP 24 discharge observations from the test measurements at Bahadurabad are available at present, most of them for low flow conditions only as the regular test measurement programme started only late October 1992 when the water levels were allready rather low. The present available results of FAP 24 discharge measurements (total discharge) at Bahadurabad are summarized in Table 4.1.

Date	H at Bah. (m PWD)	Q(approx.) (m^3/s)
15 - 16 September 1992	17.82	25,600
27 - 29 October 1992	16.5	19,000
14 - 15 January 1993	14.07	5,300
13 - 15 February 1993	13.70	4,250
13 - 16 March 1993	13.92	4,700

Table 4.1 FAP 24 discharge measurements at Bahadurabad

4.2.1 The Anwesha Survey in Sept.1992 at Bahadurabad

The first FAP 24 result from Sept.1992 was a special additional survey carried out with ms. Anwesha at medium flow conditions. The survey techniques and results are reported in the detailed survey report (FAP 24,31.Oct.1992).

As the result was the first and rather surprising a special analysis of this survey was carried out as a part of the hydrological study. This is shortly described in the following. For more details refer to the 1.Interim Report, vol.III.

During the Anwesha survey on 15-16 Sept.1992 the total discharge at Bahadurabad was measured to 25.600 m3/s at a water-level of 17.82 m PWD. The day before (14.Sept) BWDB had measured the discharge to 34230 m3/s at a slightly lower water-level of 17.76 m PWD. The difference of approximately 9000 m3/s corresponds to about 35 % of the FAP 24 result.

Due to the large difference observed the detailed discharge calculation on the basis of the FAP 24 survey results were thoroughly checked. No major errors were found and the large difference of about 9000 m3/s remains.

Additional BWDB-measurements from 1992 up till the actual date of this survey were plotted as shown in Fig. 4.1 and a preliminary rating curve for 1992 was established.

The FAP 24 measurements as listed in Table 4.1 are also plotted in figure 4.1 and the difference between FAP 24 measurements and rating curve values (based on BWDB data) for the same water-level are presented in Table 4.2.

Date	H at Bah. (m PWD)	Q FAP 24 - Q rating curve
15-16 September 1992	17.82	-9000
27-19 October 1992	16.5	-1000
14-15 January 1993	14.07	700
13-15 February 1993	13.70	1050
13-16 March 1993	13.92	1100

Table 4.2 Difference among FAP 24 measured discharges and rating curve values.

The possible reasons for the important difference between the FAP 24 and the BWDB discharge estimates were further analysed by other means reported in the next Chapter 5, and the conclusions are given in Section 5.3.1 and 5.5.

5. Data quality checking and rating curves

5.1 Water-level time series

FAP 25 (ref. FAP 25, June 1992) provided a comprehensive description of eight types of errors detected in mean daily water-level time series in Bangladesh,i.e

- Missing data
- Daily erroneous
- Shifted data for a few days
- Shifted data for a few weeks
- Shifted data for longer periods
- Inconsistent trends
- Static water-level
- Reliability of bench marks/gauge zero levels

FAP 25 carried out checking of water-levels for a number of water-level stations and a few discharge stations in the main rivers. A screening of the time series for Bahadurabad revealed however that a number of errors had not been detected/corrected. It was therefore decided to go more into details and carry out a consistent check of water-levels for the six existing discharge stations in the main rivers. Due to time constraints, however, only the water-level time series 1966-92 for the four stations Bahadurabad, Hardinge Bridge, Baruria and Gorai Railway Bridge have been checked and corrected uptill now (May 1993). The two remaining stations, Mawa and Bhairab Bazar, will be checked in June 1993.

Based on FAP 25's observations and guidelines a systematic checking procedure, which emphasizes the first five error types above, was set up. Trends and gauge zero levels are to some extent dealt with in Section 5.3 and Chapter 7 respectively.

5.1.1 Systematic checking procedure

The BWDB water-level time series 1965 -1992 for the discharge stations in the main rivers were checked and corrected by the following procedure (ref. Figure 5.1):

- For each discharge station to be checked at least 2 adjacent water-level stations are chosen for comparison
- Water-level time series for each discharge station are plotted for every year together with the time series of comparison stations (Figure 5.1a). Erroneous/shifted data are detected from these plots visually
- Plots of the difference in water-level between the station to be

checked and comparison stations are made (Figure 5.1b). This is based on the idea that the differences in water-level should be more or less constant. On these plots a range is indicated of the mean difference plus and minus 2 times standard deviation. If the difference lies outside this range it is marked. The range is chosen based on experience with water-level data at Bahadurabad, but is arbitrary. It can be changed to any other value if that is more practicable. This will not affect the form of the curve

- Furthermore, plots are made of the change in difference (Figure 5.1c). The idea is that the difference in water-level can be larger than the range mentioned above, but that it is suspicious if this difference changes too suddenly. Also here a range is kept of the mean plus or minus 2 times standard deviation

The last two plots above are merely used as an indication. If water-level data are out of range the data marked are double checked.

5.1.2 Corrected water-level data base

In Appendix 1 an overview of FAP 24's water-level data base is given. It should be emphasized that due to time constraints only the data series for the four discharge stations mentioned above have been corrected by the above procedures. The data series from a number of water-level stations were only collected to form the basis for this checking of the discharge stations and these data series are still identical to those obtained from FAP 25 / BWDB (BWDB's original data).

For the four discharge stations analysed the corrected water-level values are listed in Appendix 2 together with the original uncorrected BWDB-values.

5.2 Discharge time series

5.2.1 Observation methodology

The mean daily discharge time series supplied by FAP 25 /BWDB are generated from water-level observations and established rating curves. These rating curves are developed on the basis of actually measured discharges.

Already in Section 3.2 some information on BWDB's discharge observation methodology was given. FAP 25 (ref. FAP 25 June 1992) also provided a good overview of the BWDB procedures and various sources of errors in the discharge measurements. The information will therefore not be repeated here.

FAP 24's observation methodologies are described in details in the 1.Interim Report,Feb.1993 and will neither be repeated here. For the traditional current meter method the main difference between FAP 24' and BWDB's measurement techniques is that FAP 24 in addition to the velocity measurements in each measurement point in a cross-section also measure the flow direction in each point. While BWDB usually only measure the flow direction at each vertical near the water surface by floats and then assume that this is representative for every point below the water surface when the discharge is calculated. That procedure may introduce major errors in the case of very irregular cross-sections with bars and chars and in river bends, where the flow directions at the water surface may be very different from those at various depths, in particular for deep irregular cross-sections/high flow conditions.

5.2.2 Improved method for rating curve analysis

FAP 25 already developed new annual rating curves for three discharge stations in the main rivers, namely Bahadurabad, Hardinge Bridge and Baruria. FAP 25's method for development of rating curves was basically the same as used by BWDB and the resulting rating curves were not much different from the BWDB derived rating curves (ref. FAP 25,June 1992,p.5-13).

The FAP 25/BWDB-procedure (and also FAP 24's) is to fit the general rating curve equation

$$Q = c(h+a)^b \qquad (1)$$

or

$$\log Q = \log c + b \log(h+a) \qquad (2)$$

to the observed Q/h-points every year. When plotted on log-log paper Eq.(2) will plot as a straight line if, and only if, Q is plotted versus (h + a). In most years the rating curve consist of two or three segments, each with its own parameters a,b and c. The equation for the highest segment is used for extrapolation when required. This logarithmic extrapolation method is adequate for relatively short extrapolations as is the case for the actual discharge stations in the main rivers where discharge observations are available for high water-levels.

The only problem with respect to the FAP 25/BWDB procedure is that it assumes a fixed offset value (a) in Eq. (1) for all segments, namely the offset value derived for the lowest segment (corresponding to the river bed level at zero flow).

This is usually not the case and it is not the internationally acknowledged standard method for development of rating curves with several segments, see ISO-standard,1982 and MWEM,1979. This assumption often leads to fitting of straight lines through Q/h-points forming a curve on the log-log plots (for the higher segments) which may result in very uncertain extrapolations and thus wrong estimates of the high flood discharges in particular.

This is illustrated in Figures 5.2 - 5.5 where the observations from Hardinge Bridge for the high flow year 1988 are taken as an example only. The Figures and the following explanation also illustrate the improved rating curve procedure as used by FAP 24 in the present report.

Figure 5.2 is a linear plot of BWDB's observed Q/h-points at Hardinge Bridge in 1988.

Figure 5.3 is a log-log plot of the same observations. This plot forms the basis for assessment of number of required segments and the approximate breakpoints between the different segments . In this case 3 segments. It is obvious that the points for each of the three segments are forming curves and not straight lines. Before we fit straight lines for each segment by Eq.(2) above we have to modify the plot in such a way that the points for each segment form a straight line. This is done by adding a positive or negative constant to the water-levels h, namely the value of the parameter a,so that h is transferred to (h+a) which is the term in the then linear Eq.(2). For each segment the actual a- value can be estimated by trial and error until the points of that segment form a straight line as close as possible.

Starting with the first segment in Figure 5.3 the points of this segment will fit a straight line if a constant of 3 meters are subtracted, i.e. a=-3m. This is shown in Figure 5.4, where the 3 meters have been subtracted from the observed water-levels (for illustration purpose not only for the points of the first segment but for all points).Now the points of the first segment are fitting a straight line whereas especially the points of the 3.segment are still forming a curve.

The correct procedure is therefore to continue with the assessment of separate a-values for the second and third segment by the same trial and error procedure as for the first segment as illustrated in Figure 5.3. When the points of each segment form a straight line the best fitting line for each segment can be obtained by simple linear regression or even simpler graphical or arithmetic standard methods.

BWDB's/FAP 25's procedure is however to fit straight lines for each segment based directly on the plot in Figure 5.4, i.e. assuming that the a-value estimated for the first segment is also the value for the remaining segments.This may lead to fitting of straight lines through curved points which is of course inadequate. In particular inadequate when the straight line is used for extrapolation. The effect on extrapolations is also shown in Figure 5.4 but even more clear in the linear plot in Figure 5.5, where FAP 24's fitted rating curve for 1988 is compared with the one fitted by FAP 25.

FAP 24's rating curve in Figure 5.5 generally fits the observed points better than FAP 25's, in particular for the high water-levels (highest segment used for extrapolation). FAP 25/BWDB's procedure force all segment curves through a fixed point on the h-axis, namely the point h = -a = 2m estimated for the lowest segment. This makes it impossible to obtain a good non-biased fit to the points of the upper segment. In contradiction to FAP 24's procedure where the a-value is not fixed. This is also illustrated in Figure 5.6.

The unrealistic a-values for the upper segments applied by BWDB/FAP 25 also leads to unrealistic exponents b in the rating curve Eq.(1), in order to compensate for the unrealistic a-values. For example, for the 3.segment of the rating curve for Hardinge Bridge 1988 shown in Figure 5.4, FAP 25 estimates an exponent b = 6.629 (and a = -2 m) whereas FAP 24's estimate is b = 2.002 (a=-10 m). In general the exponents b should be in the range 1.3-3.5 depending on the type of river. Exponents higher than 3.5 are highly non-physical and should be avoided by adjusting the corresponding a-value as explained above. The high b = 6.629 leads to overestimate of the discharge if used for extrapolation as illustrated in Figure 5.5.

5.2.3 Development of new rating curves.

Due to the inadequate rating curve method currently applied in Bangladesh as described above it was decided to develop new rating curves for all the six discharge stations in the main rivers applying the improved and consistent method as described above. The actual rating curve development was carried out by means of the HYMOS-software, and a detailed procedure for applying the HYMOS to estimate consistent rating curves for Bangladesh conditions was developed. This procedure is included in Appendix 3.

For each station it was in general necessary to develop a new rating curve for each year of record because the location of the observed Q/h points vary to some extent from year to year, while within most years the actual measurements provide a fairly consistent basis for development of reliable annual rating curves. As FAP 25 already pointed out (ref. FAP 25,June 1992) the annual shift of the rating curves may be partly due to changes in the physical system(erosion,aggregation and moving bed forms) and partly from random or systematic errors in discharge measurements. Loop effects due to varying water surface slopes during rising and receding parts of the flood are not significant in the main rivers. The procedure of development of annual rating curves based on the total number of Q/h-measurements in the hydrological year and also including some values from the previous and the following year(s) is also used by BWDB/FAP 25.

The parameters of the estimated rating curves for five of the six discharge stations analysed are presented in Tables 5.1 to 5.5. Some examples of the estimated rating curves for the recent years are plotted in Figures 5.7 to 5.11.

For the last station Bhairab Bazar in the Upper Meghna River it has not been possible to estimate reliable rating curves based on the procedure above. For this station the scatter of the Q/h-points within each year is very high due to a combination of tidal effects and backwater effects. High flows/water-levels in the downstream Padma River and Lower Meghna River has an effect on the water-levels and slopes in Upper Meghna thus there is no unique relationship between discharge and water-level at the Bhairab Bazar station. Rather a whole family of rating curves each representing certain downstream combined flow/tide conditions. This complicated phenomena makes an assessment of rating curves by traditional curve fitting extremely uncertain resulting in very uncertain discharge time series for this station.

Table 5.1 : Rating Parameters at Bahadurabad, code : 46.9L.

YEAR	INTERVAL-1			Limit-1	INTERVAL-2			Limit-2	INTERVAL-3			REMARKS
	a	b	c		a	b	c		a	b	c	
1966	-9.00	2.163	230.337	15.113	-12.00	1.835	1438.860	18.978	-14.00	2.507	909.174	
1967	-10.00	2.591	158.741	15.721	-13.00	1.408	3560.180	17.800	-15.00	1.611	6155.130	
1968	-9.50	2.502	122.864	15.471	-11.50	2.162	544.405	18.687	13.50	2.554	578.192	
1969	-9.00	2.328	146.048	15.280	-11.00	2.128	477.455	18.943	-13.50	2.950	264.743	
1970	-9.00	2.914	58.731	14.998	-10.00	2.334	254.028	18.969	-13.50	2.814	357.149	
1971												Gauged data not available
1972	-9.00	2.418	111.507	15.138	-11.00	2.331	327.488	18.044	-13.00	2.613	451.744	
1973	-8.00	1.285	412.034	13.683	-11.00	2.004	531.636	18.616	-15.00	2.807	843.172	
1974	-10.00	2.971	66.869	14.000	-10.00	2.828	79.248	19.000	-15.00	2.569	1164.940	
1975	-8.50	2.417	104.670	14.928	-11.00	2.129	509.813	18.952	-13.00	2.753	310.776	
1976	-10.00	1.709	650.338	15.075	-10.00	2.184	300.639	18.210	-14.00	2.306	1085.030	
1977	-9.00	2.065	255.796	15.816	-10.50	2.523	198.746	19.363	-14.50	2.735	646.017	
1978	-9.00	2.373	145.130	15.129	-10.00	2.501	179.671	18.306	-14.00	2.043	1812.120	
1979												Gauged data not available
1980	-10.00	2.006	389.434	15.695	-10.00	2.410	192.765	17.786	-13.00	2.443	591.424	
1981	-10.00	2.170	296.965	16.153	-10.75	2.321	305.457	18.747	-15.00	2.278	1877.270	
1982	-8.00	2.847	37.807	15.842	-10.00	2.978	69.382	17.916	-13.00	2.374	749.649	
1983	-10.00	2.179	304.600	17.952	-13.00	2.260	750.930	19.064	-15.00	2.447	1426.830	
1984	-10.00	2.454	178.712	18.043	-13.00	2.371	643.588	19.116	-15.00	2.275	1884.260	
1985	-10.00	2.413	194.811	18.500	-15.00	2.022	2927.670					Gauged data not available
1986	-10.00	2.340	228.315	17.800	-13.00	2.022	1182.580	18.613	-15.00	2.022	2927.670	
1987	-10.00	2.344	229.718	17.537	-12.00	2.780	224.407	18.160	-14.00	2.479	961.873	
1988	-10.00	2.565	154.594	17.332	-13.00	1.906	1566.740	18.456	-15.00	1.909	3726.380	
1989												
1990												
1991												
1992												

Note:
1. Limit-1 is the Upper limit Water level for interval-1.
2. Limit-2 is the Lower limit Water level for interval-3.
3. Rating Equation : $Q = c(WL + a) ^\wedge b$.
4. For 1989-1992,1988 rating parameters are used.

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Table 5.2 : Rating Parameters at Hardinge Bridge, code : 90

YEAR	INTERVAL-1			Limit-1	INTERVAL-2			Limit-2	INTERVAL-3			REMARKS
	a	b	c		a	b	c		a	b	c	
1966	-3.00	2.577	45.317	10.748	-5.50	2.781	88.128	13.598	-8.50	2.798	310.332	
1967	-3.00	2.552	46.959	10.250	-5.00	2.846	64.970	12.900	-8.00	2.843	249.367	
1968	-2.00	2.805	21.666	10.071	-5.00	2.811	78.979	12.872	-7.00	2.845	169.768	
1969	-3.00	2.122	128.830	9.970	-5.00	2.813	89.063	13.408	-7.00	2.499	342.353	
1970	-1.00	2.678	18.878	9.810	-5.00	2.836	75.158	13.100	-7.00	2.951	137.766	
1971												Gauged data not available
1972	-2.00	2.593	40.977	9.895	-4.00	2.865	53.987	12.552	-7.00	2.570	308.679	
1973	-1.00	2.823	16.437	8.440	-3.00	2.643	54.435	11.901	-6.25	2.984	100.123	
1974	-1.00	2.680	20.125	8.051	-3.00	2.937	32.457	12.227	-7.00	2.537	333.950	
1975	-2.00	2.576	37.421	9.099	-4.00	2.958	47.098	12.310	-6.00	2.574	215.675	
1976	-2.00	2.553	29.574	9.200	-5.00	2.864	77.818	12.367	-8.00	2.176	959.866	
1977	-3.00	2.597	49.161	10.064	-5.00	2.869	75.112	13.335	-9.00	2.418	948.592	
1978	-2.50	2.877	27.088	10.803	-5.50	2.620	151.032	12.733	-8.00	2.284	772.768	
1979	-2.00	2.954	17.074	9.300	-4.00	2.673	70.350	12.390	-7.00	2.799	185.719	
1980	-2.00	2.684	24.307	8.916	-5.00	2.642	118.432	12.355	-6.00	2.778	135.428	
1981												Gauged data not available
1982												Gauged data not available
1983	-3.00	2.461	63.012	10.258	-5.00	2.611	108.668	13.051	-8.00	2.994	197.125	
1984	-3.00	2.548	54.856	11.430	-6.00	2.799	112.121	13.700	-9.00	2.925	376.545	
1985	-3.00	2.571	58.995	10.627	-6.00	2.533	226.016	13.694	-7.00	2.985	136.158	
1986	-2.50	2.857	30.125	11.003	-5.00	2.837	84.432	12.347	-7.00	2.702	260.818	
1987	-2.00	2.809	18.630	8.977	-5.00	2.702	104.810	13.286	-9.00	2.500	834.676	
1988	-3.00	2.605	41.077	10.640	-6.00	2.752	123.801	12.930	-10.00	2.002	3019.930	
1989	-2.00	2.939	17.913	10.639	-5.25	2.802	90.339	12.627	-8.00	2.281	741.880	
1990	-2.00	2.652	27.073	9.163	-5.00	2.830	88.584	13.407	-8.00	3.097	196.843	
1991	-2.00	2.862	18.858	10.520	-5.50	2.683	114.336	12.926	-8.00	2.718	325.609	
1992												Gauged data not available

Note:
1. Limit-1 is the Upper limit Water level for interval-1.
2. Limit-2 is the Lower limit Water level for interval-3.
3. Rating Equation: Q = c(WL + a) ^ b.

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Table 5.3 : Rating Parameters at Baruria, code : 91.9L.

YEAR	INTERVAL-1			Limit-1	INTERVAL-2			Limit-2	INTERVAL-3			REMARKS
	a	b	c		a	b	c		a	b	c	
1966	2.00	2.802	96.836	4.784	0.00	2.166	697.588	7.668	-2.00	2.923	361.212	
1967	2.00	2.460	155.330	4.505	0.50	2.492	280.957	7.050	-1.50	2.799	357.483	
1968	1.50	2.147	330.648	5.341	0.50	2.858	132.368	7.191	-1.50	2.972	256.807	
1969	2.00	2.314	202.920	4.972	0.50	2.889	133.845	7.548	-1.50	2.931	283.296	
1970	2.00	2.630	119.251	4.982	0.00	2.547	331.027	7.452	-2.00	2.607	662.862	
1971												Gauged data not available
1972	2.00	2.640	118.320	4.830	0.00	2.846	213.663	6.133	-1.00	2.556	569.453	
1973	1.50	2.606	150.005	5.446	-0.50	2.885	232.570	7.470	-1.75	2.978	349.669	
1974	1.50	2.693	135.564	5.472	-0.50	2.871	253.427	6.544	-1.75	2.717	627.418	
1975	1.00	2.072	481.652	4.625	0.00	2.598	323.189	7.129	-2.50	2.798	730.427	
1976	2.50	2.654	103.916	5.606	-0.25	2.984	179.177	7.279	-1.75	2.864	450.816	
1977												Gauged data not available
1978												Gauged data not available
1979	2.00	2.410	217.323	5.852	-1.50	2.785	518.673	7.115	-1.50	2.683	619.263	
1980												Gauged data not available
1981	2.00	2.463	186.595	4.829	0.00	2.712	295.724	7.061	-1.00	2.962	285.573	
1982	2.00	2.026	459.875	5.748	-1.00	2.641	475.699	7.186	-1.50	2.987	325.783	
1983	0.00	1.571	1968.960	5.200	0.00	2.363	533.930	7.293	-2.00	2.775	573.221	
1984	1.75	2.266	314.788	5.660	-1.00	7.629	515.119	7.914	-1.50	2.751	500.350	
1985	2.00	2.638	137.250	4.983	0.00	2.868	230.883	6.803	-1.00	2.545	642.488	
1986	0.00	1.706	1277.560	5.418	-1.00	2.839	335.776	7.400	-2.00	2.754	622.289	
1987	2.00	2.681	113.486	5.567	0.00	2.932	167.950	7.806	-1.00	2.870	282.978	
1988	2.00	2.742	108.968	5.835	-0.50	2.850	261.021	7.594	-1.00	2.916	283.668	
1989	2.00	2.626	143.283	5.785	0.00	2.819	222.704	7.256	-1.00	2.801	349.442	
1990	2.00	2.695	122.294	5.475	0.00	2.756	255.097	7.416	-1.00	2.595	512.857	
1991	2.00	2.620	140.057	5.765	-0.50	2.929	231.782	7.615	-1.00	2.916	294.278	
1992												Gauged data not available

Note:
1. Limit-1 is the Upper limit Water level for interval-1.
2. Limit-2 is the Lower limit Water level for interval-3.
3. Rating Equation : $Q = c(WL + a)$ ^ b.

Table 5.4 : Rating Parameters at Mawa, code : 93.5L.

YEAR	INTERVAL-1 a	INTERVAL-1 b	INTERVAL-1 c	Limit-1	INTERVAL-2 a	INTERVAL-2 b	INTERVAL-2 c	Limit-2	INTERVAL-3 a	INTERVAL-3 b	INTERVAL-3 c	REMARKS
1966												Gauged data not available
1967	2.00	2.536	281.618	4.397	-5.00	2.755	734.864	5.341	-2.00	2.402	3125.600	
1968	2.00	2.143	2182.262	3.650	0.00	2.724	591.546	5.598	-1.00	2.653	1126.590	
1969	2.00	2.505	340.875	4.961	0.00	2.901	422.271	5.916	-2.00	2.578	2171.320	
1970	1.00	2.030	1044.510	4.701	0.00	2.722	529.105	6.012	-2.00	2.488	2205.400	
1971												Gauged data not available
1972	2.00	3.001	140.964	4.067	0.00	2.561	868.704	21.682	0.00	2.775	624.232	
1973	1.00	2.140	938.306	4.103	-0.50	2.728	929.614	4.525	-1.00	2.299	2293.610	
1974	2.00	2.731	223.566	3.773	0.00	2.406	1100.420	5.223	0.00	2.707	669.117	
1975												Gauged data not available
1976	2.00	2.891	167.770	3.663	0.00	2.616	844.252	4.782	0.00	2.699	741.284	
1977	2.00	2.807	207.775	4.450	-0.50	2.742	925.131	5.355	-1.00	2.869	1033.450	
1978	2.00	2.570	322.584	3.929	0.00	2.868	616.955	5.188	0.00	2.712	798.039	
1979	2.00	2.467	359.399	4.862	0.00	2.867	446.793	5.821	-1.00	2.486	1396.450	
1980	2.00	2.603	254.083	3.687	-1.00	2.087	2974.860	5.727	-1.00	2.180	2575.450	
1981												Gauged data not available
1982	1.50	2.765	295.009	3.723	0.50	2.607	665.787	5.089	0.00	2.820	601.728	
1983	2.00	2.326	411.624	3.355	0.50	2.559	645.705	4.802	0.00	2.873	508.373	
1984	2.50	2.972	125.000	3.848	0.00	2.628	880.235	4.803	-0.50	2.559	1298.330	
1985	1.50	2.823	289.875	2.897	1.00	2.643	520.737	4.724	0.00	2.839	479.691	
1986	2.00	2.016	667.029	3.906	0.00	2.792	533.155	4.772	-1.00	2.631	1850.750	
1987	1.00	2.754	315.304	5.084	-1.00	2.928	740.152	5.873	-2.00	2.453	2756.520	
1988	1.50	2.822	258.675	4.411	1.00	2.254	866.744	5.722	0.00	2.419	933.444	
1989	0.00	2.555	905.242	4.690	0.00	2.555	905.242					Gauged data not available
1990	0.00	2.272	1442.320	5.375	0.00	2.280	1415.730					Gauged data not available
1991	0.00	2.165	1904.200	5.744	0.00	2.041	2365.470					Gauged data not available
1992												Gauged data not available

Note:
1. Limit-1 is the Upper limit Water level for interval-1.
2. Limit-2 is the Lower limit Water level for interval-3.
3. Rating Equation : Q = c(WL + a) ^ b.

Table 5.5 : Rating Parameters at Gorai Rly Bridge, code : 99

YEAR	INTERVAL-1			Limit-1	INTERVAL-2			Limit-2	INTERVAL-3			REMARKS
	a	b	c		a	b	c		a	b	c	
1966	-2.50	1.898	53.936	10.539	-3.00	2.528	17.071	11.118	-3.30	2.769	11.442	
1967												Gauged data not available
1968	-3.65	1.537	147.070	10.244	-3.75	2.217	42.222	10.950	-4.00	2.362	35.044	
1969	-3.50	1.852	85.081	11.674	-4.25	2.791	15.463					Gauged data not available
1970	-3.75	1.935	65.743	11.270	-4.00	2.534	21.390	11.733	-4.50	2.828	14.176	
1971												Gauged data not available
1972	-3.25	2.842	17.275	7.221	-3.50	2.151	51.558	10.419	-3.50	2.563	23.213	
1973	-3.00	2.273	34.702	10.258	-3.50	2.416	31.082					Gauged data not available
1974	-2.75	1.846	62.964	9.505	-3.50	2.789	14.429	11.950	-4.00	2.605	25.251	
1975												Gauged data not available
1976	-3.25	1.987	50.811	10.184	-3.40	2.839	10.383	11.881	-5.00	2.465	38.690	
1977												Gauged data not available
1978												Gauged data not available
1979												Gauged data not available
1980												Gauged data not available
1981												Gauged data not available
1982												Gauged data not available
1983	-3.00	2.255	27.288	9.516	-3.75	2.312	32.524	11.853	-4.50	2.872	13.317	
1984	-2.75	2.305	20.436	10.591	-4.00	2.719	13.979	12.421	-5.20	2.952	13.399	
1985	-2.50	2.199	22.368	9.682	-4.75	2.517	30.738	11.969	-5.00	2.887	16.387	
1986	-2.40	2.255	17.234	9.432	-4.00	2.992	8.859	11.204	-4.00	2.816	12.553	
1987	-3.00	2.142	32.928	9.439	-4.00	2.414	29.797	12.181	-4.00	2.779	13.837	
1988	-3.75	1.782	75.122	9.468	-4.50	2.319	40.802	11.772	-5.00	2.679	24.198	
1989	-4.00	2.437	27.790	9.578	-4.00	2.623	20.160	10.771	-5.00	2.183	66.291	
1990	-3.75	2.137	37.723	9.703	-4.00	2.891	11.129	10.863	-4.50	2.686	20.214	
1991	-3.75	2.315	28.785	10.570	-4.50	2.602	22.469	11.872	-5.00	2.917	14.692	
1992												Gauged data not available

Note:
1. Limit-1 is the Upper limit Water level for intervel-1.
2. Limit-2 is the Lower limit Water level for interval-3.
3. Rating Equation : $Q = c(WL + a)$ ^ b

For Mawa the rating curves for some years are also very uncertain. For most years the scatter of the observed Q/h points at Mawa is limited, but in some years the observed points do only provide a very uncertain basis for fitting a representative average rating curve. This is in particular the case in high flow years as 1987 and 1988 as shown in Figure 5.10, where many of the observed Q-h points are located very high compared to other years, i.e the observed discharge for a given water-level is very low. For 1988 the resulting fitted average curve is thus very different (higher) from all other years. In principle the reason could be backwater effects as in the case of Bhairab Bazar, but it is more likely that the discharges are measured too low during high flow conditions due to excessive flooding.

Due to the rating curve problems at Bhairab Bazar and to some extent at Mawa a proposal for a special model investigation in Phase 2 with the objective to generate more reliable discharge time series at these two stations has been outlined in Chapter 9.

5.2.4 Shifting rating curves

A simple but very illustrative way to present the shift of the annual rating curves is to plot the time series of water-levels derived from the annual rating curves for selected fixed discharges (Specific Gauge Analysis). This is shown in Figures 5.12 to 5.16 for the five stations analysed. For each selected discharge a trend line through the corresponding water-levels have also been estimated by simple linear regression.

BAHADURABAD
The results for Bahadurabad in Figure 5.12 show very slight trends for the period 1966-1988, for some discharges slightly increasing water-levels and for others slightly decreasing. There are no real significant long term trends which indicate that the Jamuna River appears to be in dynamic equilibrium.

The changes from year to year is however considerable, up to a maximum of about 0.5 meters. Stage changes like this are characteristic of a large, braided river with a highly mobile bed. The passage of macro-scale bed forms such as sand waves, and the shifting of braid bars and chars can radically alter the resistance characteristics and water surface topography, so altering the stage-discharge relationship (ref.BRTS,Dec.1991). The degree of variability observed in the rating curves is, therefore, to be expected.

(In Figure 5.12 only the data for Bahadurabad up to 1988 have been used for the above analysis. The reason is that the following analyses in Section

5.3 raise serious doubt about the adequacy of the discharge measurements at this station since 1988 and thus the resulting rating curves, see also Section 5.3 and Figure 5.33).

HARDINGE BRIDGE
Figure 5.13 shows no trends in the water-levels for low and medium flows, but a slightly decreasing trend for high flow conditions.It might be an effect of local morphological changes at or downstream the bridge itself. The maximum change from year to year is also in this case about 0.5 meters.

BARURIA
Figure 5.14 was prepared before the inconsistency in the discharge measurements/rating curves at Baruria for the years before 1971 was detected as described in Section 5.3 and 5.3.1 below. The period 1966-71 should be disregarded. Doing so the decreasing trends in Figure 5.14 would change to insignificant trends indicating that Padma River is in dynamic equilibrium as well. The maximum change from year to year is about 0.5 meters.

MAWA
Figure 5.15 shows no clear consistent trends at Mawa. The variations from year to year are in some cases very high,about 0.75 m, e.g.from 1978 to 1979 and from 1987 to 1988. This is probably due to uncertain rating curves/discharge measurements during high flow years as mentioned in the preceding section.

GORAI RAILWAY BRIDGE
For this station the trends are very different from the trends in the major rivers. The obvious increasing trends in the water-levels for all discharge conditions indicate that the Gorai river is aggredating due to deposition of sediments. The effect on the water-levels of such an aggredation is, as expected, highest for low flow conditions where the flow is confined to the deeper parts of cross-sections where the sediments will be deposited first.

5.2.5 FAP 24's corrected discharge data base.

Based on the corrected water-level time series and the updated annual rating curves for the five discharge stations analysed new discharge time series have been generated. No shift corrections within a year as applied by BWDB have been applied, according to the recommendations by FAP 25 (ref.FAP 25,June 1992),which demonstrated that such shift corrections may introduce new errors if the basic discharge measurements are somewhat uncertain.

As mentioned above the rating curves for the last station, Bhairab Bazar, are very uncertain due to backwater effects etc., and new discharge time series have not been generated for this station. At present the only available discharge time series in the data base for this station is, therefore, the original BWDB-series based on BWDB's rating curves and shift corrections.

For Bahadurabad the generated discharge series for the period 1989-92 have been based on the 1988 rating curve and not the rating curves for the actual years 1989-92. The reason is that the following analysis in Section 5.3 raise serious doubt about the adequacy of the discharge measurements and thus the resulting rating curves since 1989 for this station. This is further explained and analysed in Section 5.3, and its implications for the generated discharge time series for 1989-92 is described in Section 5.5.

For Baruria the generated discharge time series before 1971 should not be used uncritically as the analyses in the following Section 5.3 raise serious doubt about the reliability of the BWDB - as well as FAP 24 - time series 1966-71, while the remaining FAP 24 - time series 1972-1991 for Baruria seems very consistent. An attempt to improve the suspicious discharge time series 1966-71 for Baruria has not yet been done. For Mawa the generated discharge time series are generally more uncertain than the other stations analysed due to more scatter in the Q-h measurements, in particular in high flow years as 1984 and 1988 as already mentioned in Section 5.2.3 and further illustrated in the following Section 5.3

5.3 Analyses of trends in water-level and discharge time series

The purpose of the following analyses of trends is to detect obvious inconsistencies in the time series rather than analysing long term trends in a statistical sense. The trend analyses are therefore performed stationwise by very simple but useful means, namely by simple plotting of long time series and comparisons.

BAHADURABAD
Fig 5.17 is a plot of the series of annual peak water-levels and the corresponding peak discharges based on FAP 24's rating curves. As expected there is a large variation of the peaks from year to year whereas there is no obvious long term trend in the time series. As expected the two graphs are very similar which is an indication of the consistency and reliability of FAP 24's rating curve extrapolations.

In Figure 5.18 a comparison between FAP 24 and BWDB estimates of peak discharges is shown. In most years the difference is small, but for some years,e.g.1981 and 1983,the BWDB estimates do not seem consistent when comparing with the corresponding peak water-levels in Fig 5.17. The most obvious difference is, however, in 1991 where BWDB estimates the peak discharge to approx. 109.000 m3/s against the FAP 24 estimate of approx. 83.000 m3/s (25 % difference) on the basis of the 1988 rating curve (if using a FAP 24 rating curve fitted to the actual measurements for 1991 the peak discharge would be estimated to 113,500 m^3/s close to the BWDB estimate). The BWDB estimate is even higher than the 1988 peak discharge of approx. 100.000 m3/s although the peak water-level was much lower in 1991 than in 1988,see Figure 5.17. The reasons for these inconsistencies are elaborated in Section 5.3.2.

In Figure 5.19 the annual series of total stream flow volume during the flood season (May 1 - Nov.30) is plotted. The upper part of the Figure is based on FAP 24's updated discharge time series whereas the lower part is based on BWDB's time series (1992 data not yet available from BWDB).

The FAP 24 monsoon flow volumes do not vary much from year to year, they are consistently between 450 and 700 billion m3 per year, and there is no obvious trend in the time series.The flow volumes based on BWDB's data series 1965-1988 seem fairly consistent and they are not much different from FAP 24's estimated volumes. But from 1989 and forward they are far above the general level and exceeding 800 billion m3/year in 1991.

The shift in the BWDB discharge data since 1989 is not due to very high water-levels these years which is illustrated in Figure 5.20 showing the average water-level during the monsoon period each year. The average water-levels in 1989-91 are not significantly higher than in other years, while the average monsoon flow volumes based on BWDB data are much higher. The reasons for these inconsistencies are elaborated in Section 5.3.2 below.

When comparing the FAP 24 flow volumes in Figure 5.19 with the average water-levels in Figure 5.20 the FAP 24 discharge data seems to be much more consistent.

Finally it can be noticed that even though the FAP 24- and BWDB monsoon flow volumes are similar for the most years before 1989 as mentioned above, the underlying individual mean daily discharges are quite different in many cases, which has already been illustrated in Figure 5.18. The reason is that when averaging the mean daily discharges over longer time periods the random errors in the mean daily data will also be averaged with the result that the uncertainty of the flow volumes over longer time periods will be much less than for the individual daily values.

HARDINGE BRIDGE

Figure 5.21 shows the monsoon flow volumes for Hardinge Bridge estimated on the basis of FAP 24's updated discharge time series as well as BWDB's series. The two series of flow volumes are very similar, and there are no obvious trends or inconsistencies. The variation from year to year is much higher at this station in Ganges River than in the Jamuna River at Bahadurabad.

Figure 5.22 is plot of the series of annual peak water-levels and the corresponding peak discharges based on FAP 24's rating curves. The pattern of the two series is very similar and thus consistent except that the peak discharge in 1980 seems very low when compared to the peaks in 1987 and 1988 despite that the water-levels were very similar. The reason is very few measurements for high water-levels in 1980 so that the rating curve in the high range for that year is in fact determined by one measurement only (close to the peak). That discharge measurement might have been erroneous, that is too small. No measurements for similar high flow conditions from adjacent years are available to assess a more consistent rating curve for 1980.

BARURIA

In Figure 5.23 the FAP 24- and BWDB monsoon flow volumes are compared. The two series are very similar. Looking on the whole series 1966-91 there seems to be a slightly increasing trend, but looking only on the series 1972-1991 there is no significant trend. In fact we should not expect any trend in this time series for Baruria as there were no trends in the corresponding time series for Bahadurabad and Hardinge bridge contributing the major part of the stream flow at Baruria. This indicates that the flow volumes for the period 1966-71 may be too low compared to the period 1972-1991.

This inconsistency at Baruria (shift around 1971) is more obvious in Figure 5.24, where the annual peak water-levels are compared with the annual peak discharges. There is no trend in the series of peak water-levels at Baruria, but the very low corresponding peak discharges in 1966-71 give rise to a seemingly trend. If excluding 1966-71 there is no obvious trend in the remaining discharge times series 1972-91, and the peak discharges resemble the peak water-levels very well apart from the suspicious years 1966-71. The inconsistency detected is further elaborated on in Section 5.3.1.

MAWA

In Figure 5.25 the FAP 24 - and BWDB monsoon flow volumes are compared. The two series are very similar except for a few years. For 1979 the FAP 24-volume is probably too small, but too high for 1984. The 1988 flow volume seems also too low when comparing with other years. The reason for these deviations is, as already noted in Section 5.2.3, the large scatter in the basic discharge measurements at Mawa for some years resulting in uncertain curves and discharge time series for those years.

Apart from this there is no significant trends in the time series in Figure 5.25. When comparing the peak water-levels and discharges in Figure 5.26 the same observation as described above are made: The peak discharge is estimated too low in 1979 and 1988 and too high in 1984. Apart from these years there is a reasonable correspondence between the peak water-levels and discharges, and there are no trends in the time series.

GORAI RAILWAY BRIDGE

Figure 5.27 shows a slightly decreasing trend in monsoon flow volumes at Gorai Bridge, maybe in particular for the last ten years. The peak discharges in Figure 5.28 reveal the same tendency, for example the 1988 peak is not significant higher than in several other years. Also when comparing with Hardinge Bridge (Figure 5.22) the discharges at Gorai seem decreasing during the last decade compared to previous years. On the other hand, the peak water-levels in Figure 5.28 are not decreasing, rather slightly increasing.

These observations compare very well with the results of the specific gauge analysis in Section 5.2.4 indicating that the Gorai river is aggredating due to deposition of sediments, which may result in decreasing inflow from Ganges River into Gorai and in higher water-levels for a given discharge.

COMPARISON BETWEEN STATIONS (WATER BALANCES)

In Figure 5.29 the monsoon flow volumes for Baruria are plotted against the total flow volumes from the upstream stations Bahadurabad and Hardinge Bridge contributing to the flow at Baruria. However, the offtake to Gorai River downstream Hardinge Bridge has also been taken into account by subtracting the flow volumes at Gorai Railway Bridge.

This comparison plot has been prepared on the basis of FAP 24 data as well as BWDB data as shown in the upper and lower part of Figure 5.29 respectively.

The FAP 24 plot (which include a gap between 1977-82 due to some missing data for one or more of the four comparison stations) shows that the flow volumes at Baruria are very close to the total flow volumes of (Bahadurabad + Harding Bridge - Gorai) except in the years before 1971 when the Baruria volumes are 10 - 15% lower. This is a clear confirmation of the above mentioned inconsistency of the Baruria time series before 1971. For the year 1990 there is the same tendency, but that is probably due to uncertainty in the FAP 24 estimated 1990 time series for Bahadurabad which was based on the 1988 rating curves as explained in Section 5.2.5.

The lower plot in Figure 5.29 based on the BWDB - data series shows the same pattern for the period before 1971. Furthermore, for the period 1989-91 the total volumes from upstream also exceed the Baruria volumes to a large extent, while for most other years after 1972 the volumes are very similar. The reason for this inconsistency 1988 - 91 is the detected too high BWDB discharge time series at Bahadurabad since the major 1988 - flood as described above and further analysed in Section 5.3.2 below. Finally, the plot also indicate that the BWDB data series for 1977-79 are somewhat doubtful.

In Figure 5.29A a comparison between the flow volumes at the two stations Baruria and Mawa in Padma River has been made. There are several gaps in the series due to some missing data either at Baruria or at Mawa; so only the years with complete data series for both stations have been plotted. When analysing the figure it should be kept in mind that the discharge time series for Mawa are very uncertain for some years as outlined above, e.g. the 1984 - series and volume for Mawa is too high.

Apart from this year, the Baruria flow volumes in general exceeds the Mawa volumes for all years after 1972. This is to be expected as some flow volume in Padma River is diverted into the offtake Arial Khan between Baruria and Mawa. For the years before 1971, however, Figure 5.29A shows higher volumes at Mawa than at Baruria, which is again a confirmation of the detected shift around 1971 at Baruria, so that the flow volumes at Baruria before 1971 are estimated 10-15% too low.

5.3.1 Inconsistencies in discharge time series at Baruria.

The apparent inconsistency detected by FAP 25 by simulation with the General Model is partly due to the fact that FAP 25 did not include Goalando channel flow in the total Padma flow at Baruria.

A revised calculation by including Goalando channel flow (BWDB-data) indicates that the previously identified trend decreases.

It therefore needs a revision of the entire trend analysis after developing the stage-discharge curve for Goalando by FAP 24 standard and regeneration of discharge time series for the Baruria+Goalando channels.

The discharge series at Baruria before 1971 has not been corrected by FAP 24 but instead excluded from the various frequency analyses in Chapter 6. The corresponding water-level time series, however, for the whole period 1966-91 seemed consistent according to the above trend analyses (Figure 5.24, no trends or obvious inconsistencies) and also according to the FAP 25 model results, so the complete time series 1966-

91 for water-levels at Baruria has been applied for the frequency analyses in Chapter 6.

5.3.2 Inconsistencies in discharge time series at Bahadurabad

The trend analyses in Section 5.3 for the Bahadurabad station indicated that since 1989 the total monsoon flow volumes based on BWDB's mean daily discharge time series were far too high. The maximum peak discharge in 1991 was also far above the normal range.

In this Section these inconsistencies and their possible explanations are further analysed because such inconsistencies in the time series for the recent years may have important implications for not only FAP 24 but also for other FAP projects and modelling activities for the main rivers. The Bahadurabad station is the most important discharge station in Bangladesh as it measures the major part of all available surface water resources in the whole Bangladesh. Reliable discharge time series from this station is also crucial for SWMC's General Model (with Bahadurabad as the most important upper discharge boundary station) and for design of flood control works along the Jamuna River.

BWDB's discharge time series are based on their regular discharge measurements and the fitted rating curves through the observed Q/h - measurements. As shown in Section 5.2.4 the rating curves up to 1988 vary up and down within a limited range. After the major flood at the end of August 1988, however, a systematic shift of the Q/h -measurements have occurred. This is illustrated in Figure 5.30, where the rating curve for 1988 is compared with several years of Q/h - points before and after the major flood in August 1988. Before this flood almost all measurements are on or above the curve and fairly consistent (i.e. only small changes from year to year), whereas after the flood almost all measurements are located under the curve and very scattered, in particular in the high level range. The points for 1992 still remain very low, four years after the major 1988- flood.

Figure 5.31 and 5.32 show the similar plots for Hardinge Bridge and Baruria. At these two stations there is no systematic shift of Q/h- points after the 1988 - flood as observed at Bahadurabad.

The shift at Bahadurabad is also illustrated in Figure 5.33, which shows the result of a specific gauge analyses as described in Section 5.2.4 already, but now including the years after 1988 also. The basis for the figure are the rating curves fitted through the measured Q/h - points. For the years 1989 and forward the curves are far below the normal levels.

The dramatic shift of Q/h -measurements at Bahadurabad since the 1988 - flood may have several potential explanations, e.g.

- o Dramatic morphological changes (deepening and widening) of Jamuna River from Bahadurabad and a long reach downstream controlling the stage-discharge relationship at Bahadurabad.
- o Systematic errors (over-estimates) in discharge measurements at Bahadurabad since the 1988 - flood.
- o Systematic errors (under-estimates) in the water-level readings or datum at Bahadurabad since the 1988-flood
- o A combination of the issues above.

During the comprehensive checking of water-levels carried out there are no indications of systematic errors in the observed water-levels at Bahadurabad. Furthermore the field check of the gauge zero level executed by FAP 24 in Dec.1992 revealed that the datum was correct within a few cm . Thus, Issue 3 above can be ruled out.

Regarding Issue 1 above such morphological changes of the whole Jamuna river is very unlikely to have occurred for morphological reasons. Even though such changes should have occurred it would not have affected significantly BWDB's calculation of discharges which are based on actual Q/h-measurements and the resulting shifted rating curves since 1989.

As the estimated discharge volumes (and high peaks) since 1989 seem far too high as concluded in Section 5.3 above, there is basically only one possible explanation left, namely that Issue 2 above is responsible for the inconsistencies in the Q/h-measurements and the resulting too high BWDB discharge time series since the 1988 -flood.

- Check with BWDB
- Period

This preliminary conclusion is also supported by the few available FAP 24 discharge measurements at Bahadurabad listed in Section 4.2. They are plotted in Figure 5.30 as well. For medium flow the measured FAP 24 point from 1992 is outside the range of BWDB measurements since the 1988-flood whereas it within the normal range before the flood.

Conclusions

The various observations discussed above all indicate that BWDB's discharge measurements at Bahadurabad for medium to high flows are too high since the major 1988-flood. For the wet year 1991 these overestimates of the observed discharges result in an over-estimate of the 1991 monsoon flow volume and the peak flood discharge of roughly 25 % , whereas in dry years like 1992 (lower water-levels) the effect is less.

A more firm conclusion and explanation of the too high discharge measurements can be arrived at after the 1993 monsoon when FAP 24 has carried out more measurements for medium and high flows. Recommendations on direct comparison measurements by BWDB and FAP 24 during the coming monsoon period are given in Chapter 8.

As the indicated errors in the discharge measurements at Bahadurabad since the 1988-flood are systematic overestimates rather than random errors, they may most probably be explained by a very skew velocity distribution in BWDB's measurement profile across the river during medium to high flows. The large flood may have resulted in a local change of the plan forms, channel pattern and cross-section which again may have resulted in a much skewer velocity distribution than before the flood. As BWDB at Bahadurabad does not have the equipment for measuring the flow direction at each measurement point of the cross-section, the effect of such a skew distribution on the discharge estimates may have become much more important, because BWDB's procedure for correction for flow directions based on surface floats only may give much more uncertain results (over-estimates) now than before the 1988-flood.

5.4 Overall uncertainties in water-level and discharge time series.

Due to the large number of possible sources of errors in the historical measurements and processing of water-levels and discharges in Bangladesh it is very difficult to quantify the uncertainties in the resulting time series. The uncertainties will vary from station to station and from year to year and even within the individual years according to the actual flow conditions, the number of measurements available, the measurement techniques and accuracy, the data processing methods applied, etc.

Therefore, in this Section only some rough assessments of the overall uncertainties based on the general experience obtained during the work with the historical data will be given.

Water-level time series

After correction of the mean daily water-level time series for gauge shifts etc. by the systematic procedures outlined in Section 5.1 it is believed that the individual mean daily water-levels (apart from systematic gauge-zero errors in the PWD-system, ref. Chapter 7) are correct within a few centimeters.

Discharge time series

Discharge time series are generally much more uncertain than the water-level time series because they are not measured directly, but generated from the water-level time series and established rating curves, which are again based on

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occasional discharge measurements only with a number possible sources of measurement errors. The reliability of the rating curves are not only a function of these possible errors in the basic measurements, but also of the number of measurements in a given period and the selected method of establishing the rating curves. The more measurements available for any flow condition the higher the reliability of the corresponding rating curve segments.

For each analysed station the general uncertainty of the resulting individual values of mean daily discharges has been roughly assessed on the basis of the observed scatter of the basic Q-h measurements, the number of measurements available and the basis for and degree of necessary extrapolations of the rating curves. The results are given in Table 5.6.

Station	Uncertainty of individual mean daily discharges (1966-92)			
	In the range of Q-h measurements	Remarks	Extrapolated values (high discharges)	Remarks
Bahadurabad	≤ 15 - 20%		≤ 25%	
Hardinge Bridge	≤ 10%		≤ 10%	Little extrapolation required
Baruria	≤ 15 - 20%	1972-92 only Before 1971: underesti-mated by 10-25%	≤ 15 - 20%	Some years higher due to missing measurements in high range
Mawa	≤ 20 - 30%	a few years even higher	≤ 30 - 50%	a few years even higher
Gorai Railway Bridge	≤ 15%		≤ 15 %	Little extrapolation required

Table 5.6 Assessment of uncertainty of mean daily discharges.

It should be emphasized that when averaging the mean daily discharges over longer time periods, e.g. when calculating monthly,seasonal or annual flow volumes, the random errors in the individual daily discharge data will also be averaged with the result that the uncertainty of the flow volumes over longer periods will be much less than for the individual daily values.

5.5 Concluding Remarks

In this first phase of the FAP 24 Hydrological studies the larger part of the limited resources available have been used for development of new rating curves, data quality checking of the historical time series and establishment of a consistent data base for the discharge stations in the main rivers.

The study has revealed that the basic data quality in broad terms may be characterized as satisfactory, but it has also identified a scope for improvement both in observation methods, data processing and data quality checking procedures.

An improved method for analysis of rating curves has been introduced providing more physically realistic exponents of the rating curve equations resulting in more realistic and improved extrapolations. Various trend analyses have been introduced to check the consistency of the historical time series. By such simple means several important and rather obvious inconsistencies in the discharge time series for Baruria and Bahadurabad have been detected.

The new and updated FAP 24 time series data base in general seem very consistent when compared with the BWDB - time series. The most important inconsistency in the BWDB time series were detected at the important Bahadurabad station in (the only present discharge station in Jamuna river). There are several strong indications that the discharge measurements for medium to high flow conditions since the large 1988-flood are generally too high (20-40 %) resulting in too high estimated flow volumes and peak flows since then.

Therefore FAP 24 has not used the observed discharges at Bahadurabad since the 1988-flood as the basis for establishment of discharge time series since then. As a first "best estimate" the 1988 rating curve, established on the basis of observed discharges in 1988 before the Aug.-flood, has been applied for the period 1988 - 1992. Of course the resulting time series will only be approximate as we know that there would in fact be some variations in the rating curves from year to year also in that period. Basically, however,we have no reliable discharge measurements since the 1988-flood to assess better rating curves for the years 1989 - 1992.

For 1993 it should be possible to establish reliable rating curves at Bahadurabad on the basis on the coming FAP 24 measurements during the monsoon period. Comparison of these results with BWDB's measurements using their traditional observation method may also provide a basis for some improvement of the rating curves and time series since the 1988 -flood, see also Chapter 8.

6. Statistical analyses

The corrected and updated long time series of mean daily water-levels and discharges for the various discharge stations analysed provide an adequate basis for various frequency analyses of the time series. This Chapter presents for each station:

- Distribution of water-levels and discharges through the year represented by frequency curves and averagė duration curves.
- Results of flood frequency analyses of annual peak water-levels and peak discharges, i.e. flood estimates for for various return periods.

6.1 Frequency curves and duration curves.

A convenient way to show the variation of the of water-levels and discharges through the year for a given station is by means of frequency curves, where each frequency curve indicates the magnitude of the water-level/discharge for a selected specific probability of non-exceedance.

In all cases the 90%, 50% and the 10% probabilities have been selected together with the maximum and minimum values in the years considered.

The frequency curves presented are based directly on the corrected and updated the mean daily time series for all the years available, i.e.using a time step of one day.

The corresponding average duration curve gives the average number of days a given value was not exceeded in the years considered.

The frequency curves and average duration curves for water-levels as well as discharges are presented station-wise in Figures 6.1 to 6.20. The figures also provide information on the number of years used for the frequency analyses for each station. For Baruria the years before 1971 have been excluded due to the apparent inconsistency as explained in Chapter 5.

Comparing the frequency curves for Bahadurabad and Hardinge Bridge in Figures 6.1 and 6.5 (or Figure 6.3 and 6.7) it is obvious that the Jamuna River is generally topping before the Ganges River, and the flows in these two rivers are not in phase. At Baruria (Figure 6.9/6.11) downstream the confluence of Jamuna and Ganges the flows and the resulting frequency curves are a combination of these non-phased flows in Jamuna and Ganges. At Mawa the 10%, 50% and 90% - curves are as expected very similar to those of Baruria, but the maximum curves are different mainly due to unreliable flows at Mawa for some high flow years, e.g. 1988, as explained before. At Gorai the timing and distribution of the flows through the years is, as expected, very similar to that of Hardinge Bridge as the Gorai river is mainly fed by flow from Ganges.

6.2 Flood frequency analyses

6.2.1 Selection of probability distributions

FAP 25 Flood Hydrology Study carried out comprehensive tests for the selection of the most appropiate probability distributions for use in Bangladesh, and provided recommendations for suitable distributions for various hydrological variables. The tests and the resulting recommendations were in particular referring to stations in the main river system, so the recommendations are very usefull for the presently analysed five discharge stations:

- For frequency analysis of annual maximum mean daily water-levels ("peak water-levels") the general FAP 25 recommendation is to apply the 3-parameter log-normal distribution.
- For annual maximum mean daily discharges ("peak discharges") the general FAP 25 recommendation is to apply the 2-parameter Gumbel distribution (or alternatively the 3-parameter General Extreme Value-2 distribution, GEV-2).

These general recommendations have been applied in the present analyses, but with precaution: If the analysed pak data for a given station do not fit well to the recommended distributions, alternative distributions have been tested.

For fitting of the various distributions to the data series available (with other words: for estimating the parameters of the distributions) the Maximum Likelihood Method has been applied like in the FAP 25 study.

6.2.2 Results of flood frequency analyses

The results of fitting of the above recommended probability distributions to the time series of annual peak water-levels and discharges are shown stationwise in Figures 6.21 to 6.32.

In general the recommended distributions fit well to the data, but in a few cases another distribution turned out to provide a much better fit. A few comments to the analyses for the individual stations are given in the following:

BAHADURABAD
The recommended probability distributions fit well to the time series of

peak water-levels and discharges for this station. For the peak discharges two frequency distributions have been presented in Figure 6.22 and 6.23, the first one based on the data series 1966-88 only, the other on the complete series 1966-92. The reason is the doubt about the basic discharge measurements at Bahadurabad since 1988 as explained in Chapter 5, so the daily discharges for 1989-92 have been generated applying the 1988-rating curve, which is of course is an approximation.

The two resulting frequency distributions for the peak discharges are, however, nearly identical which gives some confidence in the said approximation for the period 1988-92. If the BWDB- peak discharges for that period had been included in the analysis in stead, the frequency distribution would have changed very much in particular due to high BWDB-estimate of approx.110.000 m3/s for 1991 which would then have been the highest in the record.

HARDINGE BRIDGE

Peak water-levels: As allready mentioned in FAP 25 Flood Hydrology Study the frequency distibution of peak water-levels for Hardinge Bridge is very different from for other stations, as the lower part of the annual maxima belong to another distribution than the highest maxima.Therefore FAP 25 carried out a special analysis of the peak water-levels for this station applying substantial left censoring discarding all levels below a certain treshold value. Due to time constraints and due to the fact that the peak water-levels of FAP 25 and FAP 24 are basically identical (apart from a few more recent years of data available now,1990-92) this special analysis has not been repeated here.

Peak discharges: The recommended Gumbel distribution does not fit the peak discharges at Hardinge Bridge satisfactorily,see Figure 6.24.It turns out that a 3-parameter log-normal distribution provides a much better fit, see Figure 6.25, and this has then been applied in stead.

BARURIA

The peak discharge data for the years before 1971 have been excluded from the analysis due to the detected inconsistency of these data compared to the data for 1972-91 used for the analyses. For the peak water-levels, however, the complete series 1964-91 has been applied as they seem consistent, ref.Chapter 5.

The recommended probability distributions fit satisfactorily to the data for this station, see Figure 6.26 and 6.27.

MAWA
The peak water-levels as well as peak discharges fit satisfactorily to the recommended distribution, see Figure 6.28 and 6.29.

GORAI RAILWAY BRIDGE
The peak water-levels fit satisfactorily to the recommended log-normal distribution, see Figure 6.30, but as in the case of Hardinge Bridge the peak discharges fit much better to a log-normal distribution than to the recommended Gumbel distribution, see Figure 6.31 and 6.32.

6.2.3 Summary of flood estimates and comparison with former estimates.

The calculated peak water-levels and peak discharges for selected return periods have been summarized in Table 6.1 and 6.2 respectively. For comparison also the available corresponding estimates made by FAP 25 Flood Hydrology Study have been listed in the tables.

Station	Source	Return Period (year)					
		2	5	10	25	50	100
Bahadurabad	FAP 24 FAP 25	19.76 19.78	20.04 20.04	20.20 20.21	20.37 20.42	20.48 20.57	20.59 20.73
Hardinge Bridge	FAP 24 FAP 25	- 14.72	- 14.80	- 14.85	- 14.92	- 14.97	- 15.02
Baruria	FAP 24 FAP 25	8.19 8.14	8.55 8.51	8.77 8.76	9.06 9.08	9.27 9.32	9.47 9.57
Mawa	FAP 24 FAP 25	5.91 5.91	6.21 6.22	6.43 6.44	6.73 6.76	6.98 7.01	7.24 7.27
Gorai Rlw.Bridge	FAP 24 FAP 25	12.91 12.91	13.28 13.30	13.47 13.51	13.68 13.73	13.82 13.88	13.94 14.01

Table 6.1 FAP 24 and FAP 25 calculated peak water-levels for selected return periods.

From Table 6.1 it appears that the FAP 24- and FAP 25 peak water-level estimates are very similar. That was expected as the basic peak water-level data and selected probability distribution (log-normal) are in fact identical except that the present FAP 24 analyses include a few years of additional data (1990-91/92). This has resulted in slightly lower FAP 24-peak water-level estimates for high return periods, especially for Bahadurabad where the peaks in 1990 and 1992 were very low (Figure 5.17).

Station	Source	Return Period (years)					
		2	5	10	25	50	100
Bahadurabad	FAP 24 FAP 25	67000 67000	76000 78000	81500 85000	89000 94000	95000 100500	100500 107000
Hardinge Bridge	FAP 24 FAP 25	51000 49000	59000 59500	63500 66500	68500 76000	71500 82500	74500 89000
Baruria	FAP 24 FAP 25	92000 86000	105500 101000	114500 110500	126000 123000	134500 132500	143000 141500
Mawa	FAP 24 FAP 25	86000 -	99500 -	108500 -	120000 -	128000 -	136500 -
Gorai Rlw.Bridge	FAP 24 FAP 25	6350 -	7200 -	7600 -	8100 -	8400 -	8700 -

Table 6.2 FAP 24 and FAP25 calculated peak discharges for selected return periods

Table 6.2 shows more pronounced differences between the FAP 24- and FAP 25-estimates of peak discharge for various return periods. This is due to 1) additional recent data as mentioned above, 2) new FAP24 rating curves developed by the improved method especially providing physically more correct extrapolations and thus peak discharges, and 3) for some stations different probability distributions applied as explained in Section 6.2.2 above (Hardinge Bridge and Gorai Railway Bridge).

Furthermore, for Baruria the suspect very low discharge time series 1966-71 was excluded from the FAP 24 frequency analysis, while FAP 25 used the whole series 1966-89.

It appears from Table 6.2 that the combined effects of these differences is higher FAP 24-peak discharge estimates for Baruria for all the selected return periods, but lower estimates for Bahadurabad and Hardinge Bridge for all return periods higher than 2 years. For the remaining two stations analysed, Mawa and Gorai, FAP 25 did not provide peak discharge estimates so comparison is not possible.

Table 6.3 illustrates that the FAP 24 frequency estimates for peak water-level and discharge are very consistent. The table gives the calculated return periods corresponding to the observed peak water-level and estimated peak disharge for the major flood in 1988. For all the stations with reliable 1988-data the FAP 24 estimate of return period for the peak discharge is very close that of the corresponding peak water-level. This is an additional indication of the consistency of the updated FAP 24 rating curves and resulting discharge time series and of the reliability of the frequency analyses performed.

Station	Source	Peak water-level 1988		Peak discharge 1988	
		m.PWD	Return Period	m^3/s	Return period
Bahadurabad	FAP 24 FAP 25	20.61 20.61	110 60	100000 98400	100 40
Hardinge Bridge	FAP 24 FAP 25	14.87 14.87	- 13	72000 72300	50 17
Baruria	FAP 24 FAP 25	9.35 9.35	67 55	138000 137000	67 72
Mawa	FAP 24 FAP 25	7.06 7.06	60 58	1988 data not reliable -	 -
Gorai Rlw.Bridge	FAP 24 FAP 25	13.65 13.65	20 17	7950 -	19 -

Table 6.3 Comparison of calculated return periods corresponding to the 1988 peak water-level and discharge, based on FAP 24 data as well as FAP 25 data.

7. Water-Level Profiles/ Water Surface Slopes

7.1 Background

In the T.O.R. of the Hydrological Study of FAP24 it is mentioned that water-level profiles along the main rivers should be plotted for different times of the year corresponding to different streamflow conditions.

Water surface slope is an important index of river behaviour and hydraulic and sediment transport capacity. Plots of longitudinal water-level profiles on the basis of water level gaugings along the rivers can provide usefull information for

- o Determination of water surface slopes
- o Check of datum of water-level gauges/bench-mark connections
- o Check of water level data

7.2 Data collection

One important activity in the field programme of FAP 24 is the field check of datum (zero level) of 47 water level gauging stations along the main rivers,ref.the Interim Report Section 2.9.4. As the plotting of the water-level profiles can provide a support and double-check of datums, the same 47 stations were selected as basis for the plots (except the stations upstream Bhairab Bazar in Upper Meghna).

Water-level data for one recent year, namely 1990/91, were collected from BWDB for the 33 remaining selected stations. More recent data for 1991/92 were not yet available from BWDB for all the stations. The stations are listed in Table 7. 1 for Jamuna, Ganges, Padma and Meghna River respectively.The data were checked by the procedures explained in Section 5.1 (plotting and comparison of neighbour stations).

In order to plot the longitudinal water-level profiles the chainages of the various stations must be known. Information on the chainages of a number of the selected stations were obtained from the Surface Water Modelling Center (SWMC) as they use them in their General Model for the main rivers. The chainages of the remaining stations were assessed from the map with the location of the various BWDB gaging stations. This assessment is, however, somewhat uncertain due to the complicated planforms of the rivers and the general uncertainty of the exact locations on the map.

Table 7.1 gives the estimated chainages of the selected stations in Jamuna, Ganges, Padma and Meghna River respectively.

1. Jamuna River					
		Chainage o	Water level (m PWD)		
St. No.	Name	(KM)	1. Aug' 90	1. Nov' 90	1. March'91
45	Noonkhawa	0	25.74	22.42	20.02
45.5	Chilmari	37.1	23.33	20.5	17.61
46	Kamariani	(50)	21.06	18.47	15.42
46.7L	Kholabarichar	(75)	19.99	16.94	15.16
46.9R	Fulcharighat	(84)	18.86	15.85	12.88
46.9L	Bahadurabad	84.7	19.29	16.49	13.35
15 J	Mathurapara	(115)	17.07	14.19	10.7
49.A	Kazipur	139	15.43	12.51	9.14
48	Jagannathganj	(144)	14.59	11.8	7.67
49	Serajganj	162.4	13.9	10.83	7.76
50	Porabari	188.2	11.78	8.67	5.26
50.3	Mathura	220	10.25	6.82	3.01
50.6	Teota	235.4	9.26	6.11	2.58
2. Ganges River					
88	Rampur Boalia	(−33)	17.57	13.24	9.18
89	Sardah	(−17)	16.87	12.44	8.44
90	Hardinge Bridge	35.2	13.74	9.91	5.39
91	Talbaria	48.0	12.77	9.02	4.87
99	Gorai RWB	(62)	12.41	7.85	3.67
91.1	Sengram	77.5	11.5	8.05	4.28
91.2	Mahendrapur	97.2	10.45	6.63	2.72
3. Padma River					
St. No.	Name	(KM)	Jan'90	Nov'90	March'91
91.9R	Goalundo	(9)	8.74	5.68	2.37
91.9L	Baruria	11.6	8.22	5.31	1.92
93.4L	Bhagyakul	(59)	6.25	3.95	1.45
93.5L	Mawa	71.5	5.81	3.55	1.41
94	Tarpasha	(88)	5.33	3.26	1.22
95	Sureswar	88)	4.71	2.74	0.67
4. Meghna River					
273	Bhairab Bazar	27	5.95	4.26	1.51
230.1	B. B. railw Br.	(31)	5.96	4.26	1.5
274	Narsingdi	(57)	5.28	3.73	1.16
275	Baidar Bazar	90.5	5.26	3.48	1.68
275.5	Meghna Ferry Ghat	96.1	5.02	3.19	1.45
276	Satnal	0(109)	4.41	2.53	0.91
277	Chandpur	(136)	3.48	2.34	0.84

o Chainages in brackets are estimated from station map (approximate) while remaining chainages were obtained from SWMC.

Table 7.1 : Selected Water-level stations for plotting of Water-level profiles

Jamuna River		
St. No.	Est. from water surface profile 1990 X	Field checks by FAP 24 1992/1993 O
45	-----	+0.23
45.5	−0.4	+0.02
46	+0.5/0.6	−0.12
46.7	-----	N.A
46.9L	-----	−0.04
46.9R	+0.5/0.6	+0.63
15J	-----	−0.29
49A	-----	N.A
48	+0.5	−0.47
49	-----	−0.39
50	+0.3/0.4	+0.39
50.3	-----	−0.05
50.6	-----	−0.12
Ganges River		
88	-----	−0.25
89	-----	−0.03
90	-----	−0.06
91	-----	+0.37
99	-----	−0.01
91.1	-----	−0.26
91.2	-----	−0.02
Padma River		
91.9R	−0.5	−0.06
91.9L	-----	−0.03
93.4	-----	N.A
93.5	-----	N.A
94	-----	N.A
95	+0.6	−0.11
Meghna River		
273	-----	−0.01
230.1	-----	N.A
274	-----	−0.03
275	−0.75	N.A
276.5	−0.6	−0.02
276	-----	0.00
277	-----	0.00

X Numbers given are to be added to present BWDB zero gauge levels
O N.A. = BWDB or FAP−24 gauge zero levels not yet available

Table 7.2 : Estimated and measured errors in gauge zero levels.

7.3 Plot of water-level profiles

Water-level data for three different dates have been selected, namely

- 1 August 1990, when the streamflow was near maximum that year (Q = 60068 m3/s at Bahadurabad)
- 1 November 1990, average streamflow conditions (Q = 18732 m3/s at Bahadurabad)
- 1 March 1991, low flow conditions(Q = 3435 m3/s at Bahadurabad)

The actual mean daily water-levels measured those days at the various selected stations are listed in Table 7.1, and plotted in Figs.7.1, 7.2 and 7.3 for Jamuna River, Ganges-Padma River and Meghna River respectively.

Due to the uncertainty of the zero-gauge levels and the actual chainages of the various stations the water-level profiles through the plotted points have initially been approximated by the best possible smoth lines representing the overall water surface profiles.

It should be emphasized that this method has the drawback that any local changes of slope are disregarded. This also mean that a given station for which the plotted water-levels deviate from the overall profile does not necessarily have a wrong zero-gauge level. The comparison with the overall profiles does only provide a rough indication of possible datum errors which are to be verified and quantified by field checks.

7.4 Discussion of results

JAMUNA RIVER

From Figure 7.1 the overall water surface slope is estimated to approximately $7.6*10^{-5}$ (7.6 cm per km) for the upper reach of Jamuna River and 6.5 cm per km for the lower reach.

For several stations (45.5, 46, 46.9R, 48 and 50) the plotted water-level points are consistently above or below the plotted overall profile for all three selected streamflow conditions. As mentioned above this could indicate datum error at these stations. The differences between the points and the profile (i.e. possible approximate datum errors) estimated from the figure are listed in Table 7.2.

A number of field checks of gauge-zero levels have already been carried out by FAP 24, and the results for the actual stations are also listed in Table 7.2 for comparison. For some stations the two sets of datum errors correspond very well but for other stations there are large differences. As mentioned above this may be an effect of local changes of slope or uncertain estimates of chainages. Another reason for the differences may be shift of zero-gauge levels by BWDB

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since 1990.

The most remarkable datum error detected by both methods is for station 46.9R Fulcharighat. The water-levels measured at the left bank (46.9L Bahadurabad) and at the right bank deviates about 0.6 m due to this datum error.

GANGES - PADMA RIVERS
From Figure 7.2 the approximate overall water surface slope for Ganges River is estimated to 5.5 cm per km and for Padma River 4 cm per km for high flow conditions.

From the figure no obvious consistent datum error for Ganges River are detected, while the field checks detected a few, see Table 7.2.

In Padma the water-levels at station 91.9R Goalundo are approximately 0.5 m higher than at 91.9L Baruria a little downstream on the other side of the river. The FAP 24 field checks of these two stations, however, did not detect such high datum errors. The difference in water-levels at these two stations may be a local effect of the confluence between Jamuna and Ganges-Padma Rivers.

At stations 94 and 95 on each side of Padma River there is a remarkable difference in water-levels. This would indicate a datum error at either station 94 or station 95. The field checks detected a small error at station 95, but for station 94 the BWDB zero level is not yet available so the possible error can not yet be assessed for this station.

MEGHNA RIVER
The plotted overall profiles in Meghna River in Figure 7.3 are uncertain due to the influence of the tide. However, the profile for high flow conditions seems to be approximated with a more or less straight line from Bhairab Bazar to Chandpur with an average slope of 2.25 cm per km.

For two stations, 275 and 275.5 the water-levels are consistently very high compared to the plotted profile. There seems to be major datum errors at these two stations, see Table 7.2. The FAP 24 field check for station 275.5, however, did not detect any significant datum error, while at station 275 the result is not available due to missing information on BWDB gauge zero level.

7.5 Concluding remarks

The presented water surface profiles for the major rivers are overall average profiles for various flow conditions. When all the results from the FAP 24 field check programme for gauge-zero levels are available it will be possible to correct the observed water-levels according to the detected datum errors and thus refine the water surface profiles to include local variation of slopes. In this context it would also be an advantage if more recent water-level data from 1992/1993 were used (when available from BWDB), because the field checks have been carried out during that period. Finally more accurate information on the chainages of the various stations, if available, will also improve the accuracy of the plotted water surface profiles. See also Section 9.2, Topic 5, for further study in Phase 2.

8. Recommendation on field survey activities during the 1993-monsoon

The various analyses in Chapter 5 indicated that BWDB's discharge measurements at Bahadurabad during the recent years in general resulted in over-estimates of the discharges, in particular for medium to high flow conditions. In order to obtain full documentation and an improved basis for explanation of these over-estimates it is recommended to carry out the following field surveys in cooperation with BWDB during the coming monsoon period 1993 :

- During high flow conditions at Bahadurabad to carry out simultaneous discharge measurements separately by BWDB and FAP 24
- The measurements by BWDB and FAP 24 shall be carried out the same day and in the same river cross-section, namely in BWDB's traditional cross-section where at least the BWDB measurements for the years 1988 to 1992 have been carried out.
- BWDB shall apply their traditional survey techniques as applied at least during 1988-1991/92
- FAP 24 shall measure the discharge,flow areas, velocity profiles and directions by the ADCP equipment several times during the day to ensure that the true discharge has been measured. If necessary and practical also measurements by alternative methods, e.g. current meter/S4
- For each discharge measurement the corresponding stage at Bahadurabad and Fulcharighat shall be measured.

In order to obtain the best possible basis for explanation (and thus maybe a basis for correction) of the observed overestimates during the recent years it is important to follow the above recommendations very strict. For example, the magnitude of the overestimates is most probably related to the flow conditions in the actual BWDB cross-section used during the recent years, so the same cross-section should be used for the comparison measurements.

Preferably the simultaneous BWDB/FAP24 surveys should be carried out more than once during the 1993 monsoon in order to compare measurements for different flow conditions and to improve the general reliability of the comparisons.

The original detailed field sheets with the results of BWDB's measurements shall be made available for FAP 24 for the purpose of a detailed analysis of the comparison measurements, ref. Chapter 9, study topic no.1 for Phase 2.

9. Study topics for Phase 2

9.1 Background

According to the T.O.R for FAP 24 relevant study topics for Phase 2 shall be formulated at the end of Phase 1. During the proposal phase a list was prepared on tentative study topics, and in the 1.Interim Report (Table 7.8) an updated list was prepared and described in some detail.

For the Hydrological Study component the tentative list includes the following topics:

1.1 Water surface slopes
1.2 Water balances
1.3 Changes in rating curves
1.4 Loops in rating curves
1.5 Extrapolation of rating curves
1.6 Overland flow (flow from rivers to catchment during high floods in the rivers)

Topics 1.1,1.3 and 1.5 have been intensively dealt with allready in Phase 1 and reported in the present report. As new FAP 24 field measurements become available during Phase 2 there will of course be a need for follow-up on these topics to some limited extent. Topic 1.2 has only been dealt with to a very limited extent up to now by comparison of monsoon flow volumes from various disharge stations. This topic should be taken up more intensively in Phase 2, and it may also provide some information for the assessment of the last topic 1.6 Overland flow.

On the basis of the studies of rating curves during Phase 1 Topic 1.4 is not considered very significant in the main rivers which are not flashy rivers with rapidly varying unsteady flows. However, loops in rating curves may also be caused by time-lag in bed form development in rivers with high sediment transport. This may result in changing hydraulic roughness and thus water-level for a given discharge, i.e. loops in rating curves. The possible importance and implications of such morphological effects will be studied in connection with the morphological study programme.

In addition to the considerations above the hydrological analyses carried out during Phase 1 has generated ideas for related special topics to be studied further in Phase 2. In the following a short description of each proposed hydrological study topic for Phase 2 has been given including an estimate of expatriate and counterpart-input required for each topic. The total required input for all 6 topics proposed has been summarized at the end of next Section 9.2

9.2 Proposed hydrological study topics for Phase 2

Topic 1: Further documentation/explanation of the indicated systematic discharge overestimates at Bahadurabad during the recent years.

Description:
The proposed simultaneous discharge measurements by BWDB and FAP 24 at BWDB's traditional cross-section at Bahadurabad during the coming 1993 monsoon (see Chapter 8) will be analysed in details to reach a final conclusion and explanation of the observed too high BWDB discharge measurements and time series during the recents years.

Approach:
The simultaneous FAP 24 and BWDB disharge measurements will be compared. For the purpose of detailed comparisons the original field sheets from BWDB's survey should be made available for FAP 24. The effect on the FAP 24 discharge estimate by applying BWDB's procedure for correction for flow directions will be calculated in order to see directly if the flow directions can explain the observed differences. Possible differences in other measured parameters, e.g. the flow areas, will also be analysed as required.

Expected result:
Full documentation and explanation of the systematic discharge overestimates during the recent years at Bahadurabad.Based on this an attempt to establish improved approximate rating curves and discharge time series for the same years.

Required input :

Survey engineer	1 man-week + Hydrologist 1 man-week
Counterpart	2 man-weeks.

Topic 2: Separate rating curves for left and right channel at Bahadurabad for improvement of the accuracy of the discharge time series.

Description:
Comparison of historical water level data from Bahadurabad on the left bank and from Fulcharighat on the right bank shows that the stage in the left and right channel are very similar during the major part of the year but different during the rising flood in the beginning of the monsoon period. Therefore it would probably be more accurate to apply separate rating curves for the left and right channel in stead of the present procedure where the total measured discharge is related to the

stage in the left channel only. The effect of applying two rating curves in stead of one may not be that big due to the facts that 1) the larger part of the total discharge is flowing in the left channel and 2) the difference in water levels is only observed in a small part of the year as mentioned above. It will however be worth to quantify the effect by simple comparison of the results of applying both procedures.

Approach:
Based on the new FAP 24 discharge measurements at Bahadurabad in 1993 separate rating curves for the left and right channel will be established, and the observed 1993- time series of mean daily water levels at Fulcharighat and Bahadurabad will be converted into correspnding discharge time series.

The traditional single rating curve for the total discharge will also be established, and the 1993-time series of mean daily water levels at Bahadurabad will be converted into corresponding discharge time series. The two generated 1993-time series of total discharge will be compared to assess the effects of applying two separate rating curves in stead of one.

If the results show that the effect is important for the accuracy of the discharge time series at Bahadurabad it should be considered to carry out a special study for improvement of the historical time series 1966-92 as well. That will involve comprehensive data collection of additional separate data for each channel from BWDB and establishment of two rating curves for each year. Such a study is not included in the estimate of required input below.

Expected result:
Assessment of the effect on estimated discharge time series at Bahadurabad 1993 of applying separate rating curves for the left and right channels in stead of one rating curve for the whole river cross-section.

Required input:
Hydrologist 1 man-week
Counterpart 1 man-week

Topic 3: Mathematical model study to generate improved historical discharge time series at Bhairab Bazar and Mawa.

Description:
The hydrological studies during Phase 1 of FAP 24 revealed that the traditional curve fitting technique for establishment of rating curves in general did not provide satisfactory results for Bhairab Bazar in Meghna River, and this was also to some extent the case for some years at Mawa in Padma River. The reason is that the Q-h measurements are very scattered due to the combined effect of

backwater from the downstream confluence of Padma and Meghna and tidal effects. This means that there exists no unique relationship between water-level and discharge at the two stations, but rather a whole family of rating curves each corresponding to a certain combination of downstream flow/tide conditions. This complicated phenomena makes an assessment of rating curves by traditional curve fitting methods extremely uncertain resulting in very uncertain discharge time series.

It is therefore proposed to describe these complicated phenomena by means of a hydrodynamic model of the actual river system which can then be used to generate more reliable discharge time series at the two stations.

Approach:
A reduced version of SWMC's General Model will be set up, covering the area between Baruria, Bhairab Bazar as the main upstream boundaries and the Bay of Bengal with the existing water-level stations as downstream boundaries (or alternatively Chandpur as downstream water-level boundary). For Baruria FAP 24's updated discharge time series will be used as Q-boundary while Bhairab Bazar has to be a H-boundary.

The model will be calibrated and tested applying all available H-and Q time series from stations along the rivers in the model area. New detailed 1993 measurements by FAP 24 may be used for refinement of the model calibration.

The calibrated model will be run for all years with data available for the boundary stations and will as a result directly provide complete discharge time series at Bhairab Bazar and Mawa (as well as H-and Q time series at any other point of interest within the model area). The calibrated model may also be used to establish family rating curves at the two stations as various model runs can generate water levels as a function of discharge at the actual stations and downstream water-level/discharge.

Expected result:
Hydrodynamic model able to describe the complicated flow patterns in Padma and Meghna rivers and their interactions. Generation of more reliable discharge discharge time series at Bhairab Bazar and Mawa.

Required input:
Hydrodynamic modelling expert (from SWMC) 4 man-weeks
Hydrologist 1 man-week.
Counterpart 4 man-weeks.

Topic 4: Water Balances and Overland Flow

Description:

Water balances for the main rivers on the basis of comparison of streamflow volumes from the available discharge stations can provide 1) check of the consistency of the discharge time series from the individual discharge stations and 2) assessment of inflows to or outflows(off-takes or overland flow) from the rivers between the discharge stations under various flow conditions.

Approach:

Historical time series of annual and seasonal flow volumes for the discharge stations in the main rivers will be calculated from the updated time series of mean daily discharges. Several water balances for areas between stations will be set up, e.g

- o Comparison of Baruria and Mawa, which should be similar apart from the off-take to Arial Khan and local minor inflows/outflows
- o Flow volumes at Hardinge Bridge minus Gorai Railway Bridge plus Bahadurabad should be similar to those of Baruria apart from local inflows or outflows in the area between these stations

Outflows from rivers in form of overland flow during high flow conditions are known to be a particular important issue in the Jamuna River where the overland flow is diverted into the catchments in the North-Central Region. An assesment of the magnitude and importance of this overland flow on the basis of the present few available discharge stations is not possible. The field programme of FAP 24 however include continuous water-level measurements and regular discharge measurements at two additional stations along the Jamuna (at Serajganj and Aricha) and in the off-take of Dawleswari at Tilly. Based on these new data it should be possible to establish water balances during high floods in Jamuna River for the areas between the stations to quantify the overland flow more or less as the difference between the discharge volumes upstream and downstream. However, as the magnitude of overland flow most probably is small compared to the high flows in Jamuna during floods the assessment based on differences of large and somewhat uncertain flood discharges will of course be a rough estimate only.

Too scanty – what about overbank flow?

Expected results:

Additional consistency checks of discharge time series by water balances between stations. Information on the importance and magnitude of overland flow in various areas along the Jamuna River during high floods.

Required input:
Hydrologist 3 man-weeks.
Counterpart 3 man-weeks.

Topic 5 : Water-level profiles/ water surface slopes.

Description:
Allready during Phase 1 of the hydrological study the overall water-level profiles and slopes for the major rivers were studied on the basis on observed water-levels from the stations along the rivers, ref. Chapter 7. As mentioned in Section 7.5 several improvements, e.g.assesment of local slopes between stations, will be possible when the final results of FAP 24's field checks of gauge datums and more recent BWDB-water level data become available.

Furthermore, SWMC's hydrodynamic model for the main river system, the General Model, directly provide detailed simulations of the water-level profiles for each time step. These simulated water-level profiles include the dynamic routing effects when a flood wave moves from upstream to downstream and they include simulated local slope variations in great detail.

Approach:
Refinements of the plotted water-level profiles on the basis of new and datum-corrected observed water-levels from the gauging stations along the major rivers. Comparisons with simulated water-level profiles from SWMC's General Model for the same selected flow situations and assesment of local slope variations.

Expected results:
Refined water-level profiles/ water surface slopes including local variations.

Required input:
Hydrologist 2 man-weeks.
Counterpart 2 man-weeks.

Topic 6: Regular updating of Phase 1 hydrological studies of historical data by including new data 1993 and onwards.

Description:
The new FAP 24 discharge measurements at 11 sites in the main river system during the coming years will provide the basis for regularly updating of the various analyses carried out for the historical time series during Phase 1 by including the new data, e.g. :

- o Establishment of rating curves for 1993 and onwards based on FAP 24's new discharge measurements for 11 sites.

- o Check of measured FAP 24 water-level time series for the 11 sites for 1993 and onwards by the procedures described in Chapter 5.

- o Generation of discharge time series for 1993 and onwards on the basis of the above water level time series and rating curves.

- o When available, collection of BWDB-data from 6 of the above 11 sites (BWDB's permanent discharge stations) for 1993 and onwards and comparisons with the FAP-data including rating curves and estimated discharge time series.

- o Consistency check of rating curves and discharge time series for preceeding years by comparison with new rating curves and time series for 1993 and onwards. Updating of the various presented trend analyses (Chapter 5) by including the additional time series for 1993 and onwards.

- o Updating of presented frequency curves and flood frequency estimates(Chapter 6) by including the additional time series for 1993 and onwards.

Required input:
Hydrologist 6 man-weeks.
Counterpart 6 man-weeks.

Total required input for the 6 topics above.

Hydrologist	:	14 man-weeks
Survey Engineer	:	1 man-week
Hydrodynamic modelling expert (SWMC)	:	4 man-weeks
Counterpart	:	18 man-weeks

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APPENDICES

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Appendix 1

FAP 24 data base for historical data.
- Lists of data available

W. A. R. P. O.
LIBRARY

MEAN DAILY WATER LEVEL DATA collected by FAP 24

STATION NO.	NAME OF STATION	TYPE	NAME OF RIVER	STATUS OF DATA	WATER YEAR (april 1 – march 31) 64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
								L				L				L				L				L				L				L	
15J	Mathurpara		Brahm. Jamuna																												B	–	
45	Noon Khawa		Brahm. Jamuna																												B	–	
45.5	Chilmari		Brahm. Jamuna	H	–	F	F	F	F	F	F 53	F 70	F	F	F	F	F	F	F	–	F	–	–	F	F	F	F	F 60	F	FB	FB 1	B	–
46	Kamarjani		Brahm. Jamuna																												B	–	
46.7L	Kholabarichar		Brahm. Jamuna	H	–	F	F	F	F	F	F	–	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	FB	B	B	–
46.9L	Bahadurabad		Brahm. Jamuna	H	F	F	F	F	F	F	F	–	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	FB	FB	B	B 121
46.9R	Fulcharighat		Brahm. Jamuna																												B	–	
48	Jagannathganj		Brahm. Jamuna																												B	–	
49	Shirajganj		Brahm. Jamuna	H	F	F	F	F 1	F	F	F	–	F	F	F	F 1	F	F	F	F 1	F	F 61	F	F 1	F	F	F	F 1	F	FB	FB	B	–
49A	Kazipur		Brahm. Jamuna	H	–	–	–	F	F	F	F	–	F	F	F	F	F 13	F	F	F 2	F	F	F	F	F	F	F	F	F	FB	B	B	–
50	Pombari		Brahm. Jamuna	H	F	F	F	F	F	F	F	–	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	FB	B	B	–
50.3	Mathura		Brahm. Jamuna	H	–	F	F 4	F 1	F	F	F	–	F	F	F	F	F	F 7	F	F	F	F 122	F	F	F	F	F	F	F	FB	B	B	–
50.6	Teota		Dhaleswari																												B	–	
88	Rampur Boalia		Ganges																											B	B	–	
89	Sardah		Ganges																												B	–	
90	Hardinge Bridge		Ganges	H	F	F	F	F	F	F	F 11	–	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	FB	FB	B	–
91	Talbaria		Ganges																												B	–	
91.1	Sengram		Ganges	H	F	F	F	F	F 7	F	F	–	–	F	F	F	F	F	F	F	F	F	–	F	F	F	F	F	F	FB	FB	B	–
91.2	Mahendrapur		Ganges	H	hc	F	F	F	F	F	F	–	F	–	F	F	F 1	F	F	F	F	F 16	F	F	–	F	F	F	F	FB	FB	B	–
91.9L	Baruria		Padma	H	F	F	F	F	F	F 2	F	–	F	F	F	F	F	F	F	F	F	F	F 2	F	F	F 2	F	F	F	FB	FB	B	–
91.9R	Goalundo Transit		Padma	H	F	F	F	F	F	F	F	F 1	F	F	F	F	F	F 43	F 54	F 151	F 132	F 121	F 185	F	F	B	B	B	F 201	FB	B	B	–
93.4L	Bhagyakul	T	Padma	H	–	–	–	–	F	F	F	F	F	F	F	F	–	F	–	–	–	F	–	F 1	F 1	F	B	B	B	B	B	B	–
93.6L	Mawa	T	Padma	H	–	F 61	F	F	F	F	–	–	F	F	F	F	F	F	F	F	F	F	F	F 1	F	F 122	F	B	F	FB	B	B	–
94	Tarpasha	T	Padma																												B	–	
95	Sureshwar	T	Padma																												B	–	
99	Gorai Railway Bridge		Gorai	H	F	F	F	F	F	F	F 4	–	F	F	F	F	F	F	F	F 1	F	F	F	F	B	B	F	F 91	F	FB	B	B	–
230.1	Bhairab Bazar Rly. Br.	T	Old Brahmaputra	H	F 116	F	F	F	F	–	F 11	–	F	F 1	F	F 122	F	F	F	F	F	F 4	F	F	F	F	F	F	B	B	B	B	–
272	Madna	T	Surma–Meghna																												B	–	
272.1	Austagram	T	Surma–Meghna																												B	–	
273	Bhairab Bazar	T	Surma–Meghna	H	F	F	F	F	F	F	F 11	–	F	F 8	F	F	F	F	F	F	F	F	B	F	F	F	F	F	F	FB	B	B	–
274	Narsingdi	T	Surma–Meghna																												B	–	
275	Baidyer Bazar	T	Surma–Meghna	H	–	–	–	–	F	F	F	F	F	F 1	F	F	F	F	–	F	F	F	F	F 1	F 1	F	F	–	F	FB	B	B	–
275.5	Meghna ferry ghat	T	Surma–Meghna	H	–	–	–	–	F	F	F	F 67	F 1	F 1	F	F 1	F	B	–	–	F	B	B	B	B	–	F	F	F	FB	B	B	–
276	Satnal	T	Surma–Meghna																												B	–	
277	Chandpur	T	Surma–Meghna																												B	–	

(shaded) = DISCHARGE / WATERLEVEL STATION

TYPE : T = Tidal station
STATUS : H = Data transfered to HYMOS

Remarks: – in case of incomplete years, additional data are not available at BWDB.

WATER YEAR: L = Leap year

(shaded) = DATA AVAILABLE FROM: B = BWDB (with number of missing days)
F = FAP 25 "
(1st source mentioned is used for analysis)

[–] = DATA REQUIRED

MEAN DAILY DISCHARGE DATA collected by FAP 24

1/2

WATER YEAR (April–March)	STATION: 46.9L Bahadurabad		STATION: 90 Hardinge Bridge **		STATION: 91.9L Baruria		STATION: 93.5L Mawa (tidal)	
	Status	Source	Status	Source	Status	Source	Status	Source
64	–	–	H	F	–	–	–	–
65	H	F	H	F	–	–	H	F 186
66	H	F*	H	F*	H	F*	H	F
67	H	F*	H	F*	H	F*	H	F
68	H	F*	H	F*	H	F*	H	F
69	H	F*	H	F*	H	F*	H	F
70	H	F*	H	F* 11	H	F*	H	F 7
71	–	–	–	–	–	–	–	–
72	H	F*	H	F*	H	F*	H	F
73	H	F*	H	F*	H	F*	H	F
74	H	F*	H	F*	H	F*	H	F
75	H	F*	H	F*	H	F*	–	–
76	H	F*	H	F*	H	F*	H	F
77	H	F*	H	F*	H	F	H	F
78	H	F*	H	F*	H	F	H	F
79	H	F	H	F*		Only parameters available	H	F
80	H	F*	H	F*	H	F*	H	F
81	H	F*	H	F*	H	F*	H	F
82	H	F*	H	F*	H	F*	H	F
83	H	F*	H	F*	H	F*	H	F 41
84	H	F*	H	F*	H	F*	H	F 43
85	H	F*	H	F*	H	F* 2	H	F 98
86	H	F*	H	F*	H	F* 39	H	F 90
87	H	F*	H	F*	H	F*	H	F 218
88	H	F*	H	F*	H	F*	H	F 224
89	H	F* (B)	H	F* (B)	H	F* (B)	H	B 224
90	H	B	H	B	H	B 13	H	B 219
91	H	B	H	B	H	B	L	B
92	–	–	–	–	–	–	–	–

Status: H = Data transfered to HYMOS
L = Data available in spreadsheet format.

[–] = DATA REQUIRED

Source: B = data available from BWDB (with number of missing days)
F = data available from FAP 25
(1st source mentioned is used for analysis)

* Rating curve parameters also available
** Also available 60 – 63

MEAN DAILY DISCHARGE DATA collected by FAP 24

2/2

WATER YEAR (April–March)	STATION: 99 Gorai Railway Bridge		STATION: 230.1 Bhairab B Rw.Br. (tidal)		STATION: 273 Bhairab Bazar (tidal)	
	Status	Source	Status	Source	Status	Source
64	H	F	–	–	H	F 170
65	H	F	–	–	H	F
66	H	F	–	–	H	F
67	H	F	–	–	H	F
68	H	F	–	–	H	F
69	H	F	–	–	H	F 2
70	H	F	–	–	H	F 12
71	–	–	–	–	–	–
72	H	F	H	F 243	H	F
73	H	F	H	F 243	H	F
74	H	F	H	F 257	H	F
75	H	F	H	F 274	H	F 213
76	H	F	–	–	H	F 212
77	H	F	H	F 273	–	–
78	H	F	H	F 267	–	–
79	H	F	H	F 225	–	–
80	H	F	H	F 211	–	–
81	H	F	–	–	H	F 221
82	H	F	H	F 253	H	F 226
83	H	F	–	–	H	F 202
84	H	F	–	–	H	F 197
85	H	F	–	–	H	F 266
86	H	F	–	–	H	F
87	H	F	–	–	H	F
88	H	F	–	–	H	F 134
89	H	F (B)	H	B 244	H	F 203 (B 203)
90	H	B	–	–	H	B
91	L	B	–	–	L	B
92	–	–	–	–	–	–

Status: H = Data transfered to HYMOS
L = Data available in spreadsheet format.

[–] = DATA REQUIRED

Source: B = data available from BWDB (with number of missing days)
F = data available from FAP 25
(1st source mentioned is used for analysis)

OBSERVED DISCHARGE DATA collected by FAP 24

1/2

WATER YEAR (April–March)	STATION: 46.9L Bahadurabad				STATION: 90 Hardinge Bridge				STATION: 91.9L Baruria			
	First OD	Last OD	Status	Source with #OD's	First OD	Last OD	Status	Source with #OD's	First OD	Last OD	Status	Source with #OD's
66	5 apr	27.mar	H	B48 (F39)	10 apr	30 mar	H	B48 (F48)	10 apr	27 aug	H	B21 (F21)
67	3 apr	25 mar	H	B53 (F39)	5 apr	27 mar	H	B54 (F54)	6 apr	28 mar	H	B53 (F53)
68	1 apr	25 mar	H	B52 (F38)	3 apr	29 mar	H	B77 (F77)	11 apr	27 mar	H	B50 (F50)
69	1 apr	3 mar	H	B49 (F38)	2 apr	28 mar	H	B79 (F79)	3 apr	26 mar	H	B53 (F53)
70	7 apr	24 mar	H	B49 (F38)	1 apr	13 feb	H	B61 (F61)	2 apr	21 jan	H	B34 (F34)
71	–	–	–	–	–	–	–	–	–	–	–	–
72	2 may	28 mar	H	B33 (F33)	7 apr	14 mar	H	B41 (F41)	7 apr	29 mar	H 42	B41 (F41)
73	3 apr	27 jan	H	B33 (F33)	5 apr	27 mar	H	B46 (F46)	5 apr	28 mar	H	B41 (F41)
74	3 apr	23 feb	H	B16 (F13)	3 apr	23 mar	H	B40 (F56)	4 apr	27 feb	H	B29 (F29)
75	1 jul	17 feb	H	B25 (F25)	2 apr	15 mar	H	B47 (F163)	5 apr	18 mar	H	B29 (F29)
76	6 apr	29 mar	H	B49 (F38)	1 apr	26 mar	H	B60 (F215)	1 apr	31 mar	H	B52 (F52)
77	5 apr	20 mar	H	B41 (F38)	2 apr	29 mar	H	B52 (F254)	–	–	–	–
78	17 apr	19 mar	H	B35 (F35)	5 apr	27 mar	H	B51 (F174)	–	–	–	–
79	–	–	–	–	3 apr	22 jan	H	B45 (F96)	5 apr	24 jan	H	B32 (F32)
80	8 apr	16 mar	H	B25 (F22)	1 apr	30 mar	H	B45 (F134)	–	–	–	–
81	1 apr	27 mar	H	B31	–	–	–	–	9 apr	25 mar	H	B37 (F37)
82	7 apr	28 mar	H	B29 (F29)	–	–	–	–	8 apr	31 mar	H	B35 (F35)
83	12 apr	19 mar	H	B39 (F38)	7 apr	31 mar	H	B51 (F130)	13 apr	29 mar	H	B36 (F36)
84	4 apr	25 mar	H	B33 (F33)	7 apr	31 mar	H	B51 (F142)	12 apr	29 mar	H	B36 (F36)
85	8 apr	24 mar	H	B32 (F32)	17 apr	31 mar	H	B48 (F131)	11 apr	20 mar	H	B36 (F36)
86	7 apr	30 mar	H	B41 (F38)	2 apr	25 mar	H	B49 (F137)	3 apr	28 mar	H	B41 (F41)
87	12 apr	21 mar	H	B32 (F32)	2 apr	29 mar	H	B50 (F118)	10 apr	31 mar	H	B36 (F36)
88	11 apr	20 mar	H	B30 (F30)	6 apr	30 mar	H	B49 (F130)	14 apr	30 mar	H	B37 (F37)
89	3 apr	19 mar	H	B35 (F35)	5 apr	31 mar	H	B49 (F144)	13 apr	22 mar	H	B37 (F37)
90	2 apr	25 mar	H	B30 (F30)	1 apr	31 mar	H	B147	5 apr	28 mar	H 35	B36 (F35)
91	8 apr	30 mar	H	B32	1 apr	30 mar	H	B144	11 apr	31 mar	H	B37
92	13 apr	10 nov	H	B43	1 apr	27 dec	L	B139	16 apr	24 sep	L	B21

Status: H = Data transfered to HYMOS, with number of data if different from source:
- if more, extra point(s) added for fitting of rating curve
- if less, suspicious data have been disregarded.

L = Data available in spreadsheet format.

[–] = DATA REQUIRED

Source with #OD's: B = data available from BWDB
F = data available from FAP 25
(1st source mentioned is used for analysis)

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OBSERVED DISCHARGE DATA collected by FAP 24

2/2

WATER YEAR	STATION: 93.5L Mawa (tidal)				STATION: 99 Goral Railway Bridge				STATION: 273 Bhairab Bazar (tidal)			
(April–March)	First OD	Last OD	Status	Source with #OD's	First OD	Last OD	Status	Source with #OD's	First OD	Last OD	Status	Source with #OD's
66	2 dec	31 mar	H	F18	1 apr	29 mar	H	B46	–	–	–	–
67	7 apr	29 mar	H	F52	–	–	–	–	24 jun	11 nov	H	F17
68	5 apr	28 mar	H	F52	2 apr	31 mar	H	B77	17 jun	9 nov	H	F22
69	4 apr	27 mar	H	F52	3 apr	30 mar	H	B62	14 jun	1 nov	H	F20
70	3 apr	24 mar	H	F52	6 apr	22 feb	H	B48	–	–	–	–
71	–	–	–	–	–	–	–	–	–	–	–	–
72	6 apr	28 mar	H	F44	3 apr	27 mar	H	B34	3 jul	30 oct	H	F18
73	11 jul	26 oct	H	F16	9 apr	25 mar	H	B32	29 may	6 nov	H	F21
74	13 jun	13 mar	H	F20	18 jun	24 mar	H	B37	27 jun	6 nov	H	F20
75	9 apr	31 mar	H	F16	–	–	–	–	–	–	–	–
76	7 apr	9 mar	H	F49	5 apr	21 mar	H	B53	–	–	–	–
77	13 apr	30 mar	H	F47	–	–	–	–	–	–	–	–
78	12 apr	21 mar	H	F36	–	–	–	–	–	–	–	–
79	4 apr	27 mar	H	F52	–	–	–	–	–	–	–	–
80	2 apr	19 mar	H	F32	–	–	–	–	19 apr	15 nov	H	F28
81	–	–	–	–	–	–	–	–	17 jun	7 nov	H	F14
82	8 apr	29 mar	H	F32	–	–	–	–	19 jun	4 nov	H	F10
83	14 apr	27 mar	H	F28	11 apr	28 mar	H	B53	30 may	10 nov	H	F13
84	11 apr	20 mar	H	F25	4 apr	27 mar	H	B53	25 may	28 mar	H	F16
85	5 apr	26 mar	H	F23	4 apr	26 mar	H	B52	1 apr	31 mar	H	F22
86	11 apr	31 dec	H	F32	2 apr	30 mar	H	B43	13 apr	30 mar	H	F24
87	2 jun	27 oct	H	F19	16 apr	30 mar	H	B38	16 apr	19 mar	H	F28
88	7 jun	25 oct	H	F19	13 apr	29 mar	H	B39	4 apr	24 dec	H	F29
89	7 jun	25 oct	H	F19	12 apr	28 mar	H	B37	25 may	2 nov	H	F23
90	13 jun	31 oct	H	B20 (F21)	11 apr	20 mar	H	B37	24 may	29 nov	H	B26 (F27)
91	17 jul	30 oct	H	B14	10 apr	25 mar	H	B40	16 may	28 nov	H	B27
92	3 jun	28 oct	L	B19	–	–	–	–	4 jun	26 nov	L	B26

Status: H = Data transfered to HYMOS, with number of data if different from source:
- If more, extra point(s) added for fitting of rating curve
- If less, suspicious data have been disregarded.

L = Data available in spreadsheet format.

[–] = DATA REQUIRED

Source with #OD's: B = data available from BWDB
F = data available from FAP 25
(1st source mentioned is used for analysis)

Appendix 2

Lists of water-level data corrected

CORRECTIONS OF MDWL FOR BAHADURABAD, CODE : 46.9L

Water Year	Month	Day	Day No.	Original WL (m/PWD)	Corrected WL (m/PWD)	Method of Correction
1965	April	23	23	14.17	14.36	Interpolation
1965	June	20	18	17.28	17.04	"
1966	April	25	25	14.45	14.08	"
1968	September	14	167	18.14	17.83	"
1968	September	15	168	18.11	17.76	"
1968	September	16	169	18.61	17.69	"
1970	April	13	13	14.74	14.44	"
1970	April	15	15	14.40	14.35	"
1970	May	15	45	16.17	16.50	"
1970	July	20	111	19.34	19.66	"
1970	September	18	171	18.67	18.16	"
1970	October	14	197	17.89	17.71	"
1970	November	2	216	16.31	16.14	"
1970	December	7	251	14.19	14.29	"
1970	January	3	278	13.38	13.59	"
1970	January	4	279	13.38	13.57	"
1973	December	7	251	14.11	14.19	"
1973	December	12	266	14.65	14.16	"
1973	December	18	256	14.21	14.07	"
1973	December	22	262	14.22	14.24	"
1974	July	25	116	19.95	19.74	"
1974	August	1	123	20.10	20.05	"
1975	Septmber	23	176	18.28	18.58	"
1976	Septmber	3	156	18.74	18.56	"
1976	January	18	293	13.56	13.25	"
1977	May	26	56	17.12	17.22	"
1977	August	26	148	19.91	19.76	"
1981	April	22.23	22.23	13.87	14.53	"
1981	January	28	303	13.12	13.23	"
1982	May	7	37	15.85	15.93	"
1982	May	9	39	15.58	15.87	"
1983	June	21	82	17.13	17.86	"
1983	Jaun	24	85	18.40	18.44	"
1983	Septmber	10	163	18.88	18.72	"
1983	December	9	253	14.22	14.14	"
1983	February	20	326	13.23	13.17	"
1984	January	12	287	13.97	13.87	"
1990	January	27	302	13.65	13.56	"
1991	October	18	201	17.31	17.60	"

CORRECTIONS OF MDWL FOR HARDINGE BRIDGE, CODE : 90

Water Year	Month	Day	Day No.	Original WL (m/PWD)	Corrected WL (m/PWD)	Method of Correction
1965	July	11	102	10.01	10.98	Interpolation
1966	August	6	128	12.37	12.97	"
1967	November	27	241	8.71	9.01	"
1970	April	30	30	6.25	6.64	"
1970	September	17	170	13.83	13.51	"
1973	November	19	233	10.18	9.90	"
1974	April	30	30	7.1	6.82	"
1974	July	25	116	12.44	12.73	"
1975	December	23	267	7.87	7.57	"
1975	February	13	319	6.35	6.23	"
1975	March	13	348	5.65	5.39	"
1976	December	26	270	8.75	7.54	"
1991 1791	May	12	42	9.15	6.15	"
1991	December	17	261	8.24	7.23	"
1991	December	19	263	8.2	7.16	"
1977	July	24	115	13.22	13.33	"

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CORRECTIONS OF MDWL FOR BARURIA, CODE: 91.9L

Water Year	Month	Day	Day No.	Original WL (m/PWD)	Corrected WL (m/PWD)	Method of Correction
1964	September		154	8.12	7.94	Interpolation
1966	April		23	2.25	2.84	"
1967	February		332	2.56	2.26	"
1967	February		333	2.56	2.27	"
1968	January		292	2.69	2.50	"
1968	February		320	2.35	2.23	"
1969	November		220	4.97	4.60	"
1972	June		73	6.08	5.26	"
1974	April		30	4.08	4.24	"
1974	August		141	4.79	8.08	"
1976	June		81	6.45	6.73	"
1979	February		323	1.63	1.78	"
1980	March		352	1.55	1.83	"
1982	July		116	7.05	7.22	"
1983	November		237	4.01	4.12	"

CORRECTIONS OF MDWL FOR GORAI RLY BRIDGE, CODE : 99

Water Year	Month	Day	Day No.	Original WL (m/PWD)	Corrected WL (m/PWD)	Method of Correction
1965	July	24	115	9.12	9.92	Interpolation
1965	September	25	178	11.96	11.15	"
1965	December	7	251	6.01	6.07	"
1965	December	25	269	5.78	5.58	"
1965	January	25	300	4.96	4.27	"
1967	Jun	21	82	6.93	5.93	"
1970	February	22	328	5.25	5.13	"
1972	Jun	2	63	5.95	5.76	"
1973	July	28	119	11.74	11.580	"
1973	December	27	271	6.38	6.30	"
1974	May		42	5.20	5.41	"
1975	August	29	151	12.64	12.75	"
1975	August	31	153	12.63	12.76	"
1975	September	15	168	12.02	12.14	"
1976	Jun	28	89	7.28	7.08	"
1981	July	10	101	10.67	10.80	"
1983	July	25	116	9.71	10.01	"
1988	October	1	184	9.86	9.75	"
1991	April	8	8	3.32	3.62	"
1991	May	18	48	7.81	4.86	"

Appendix 3

Procedure for rating curve analyses with HYMOS

PROCEDURE FOR RATING CURVE ANALYSES WITH HYMOS

1. For each discharge station : For all years available plot year by year the available Q/H-measurements on linear plot and log-log plot (i.e. 2 plots for each year). In order to obtain plots in an appropriate scale, in particular the log-log plots, it is necessary to adjust the scales by trial and error, i.e. the selected values of Hmin, Hmax, Qmin, Qmax. These are of course selected according to the range of H and Q for the actual stations. But on the log-log plot HYMOS automatically assumes Hmin and Qmin to be either 0.01, 0.1, 1.0, 10, 100 etc, so select the highest of these values which are still less than the minimum observed H and Q.

Important: For each station use same scale for all years.

Examples of scale applied for various stations in Bangladesh:

"." should not be used for Q

Station	Min Q	Max Q	Step Q	Min H	Max H	Step H
46.9 BAH	1001	100.000	10.000	10.01	21.0	1.0
90.0 HAB	101	100.000	10.000	1.0	16.0	1.0
91.9L BAR	1001	150.000	10.000	0.1	10.0	1.0
93.5L MAW	1001	150.000	10.000	0.1	10.0	1.0
273. BBZ	1001	24.000	2.000	0.1	10.0	1.0
99.0 GRB	0.1	10.000	1.000	1.0	15.0	1.0

2. **For each station/year : On the linear plot :**

- o Draw by hand approximate rating curve through the Q/H - points.
- o Mark which points are non-reliable (i.e. far away from the curve)
- o Compare the approximate rating curve for each year with the curve for the year before and after in order to determine if the same or similar rating curves can be used for successive years, or if major changes have occurred (e.g. after big floods).
- o Note on the plot for each year the maximum observed mean daily water level that year, in order to assess the importance of extrapolation.
- o Determine the need for extra points for extrapolation of rating curve, e.g. by using a high Q/H point measured the year before or after if the rating curves seem similar.

3. **For each station/year: On the log-log plot :**

- o Determine the approximate location of break points and number of segments (maximum 3 segments in HYMOS)

o Determine approximate values of Ho for each segment using following guide-lines (see also Figure 5.3 in the report)
  - If the Q/H-points for a segment plot as a straight line : Ho approximately equal to the selected Hmin on the H-axis.
  - If the Q/H-points for a segment plot as a curve bending upward : Ho > selected Hmin
  - If bending downward : Ho < selected Hmin
  - Usually the Ho-value is higher for upper segments than for lower segments

4. Fitting rating curves with HYMOS

With the preliminary results of Activity 2 and 3 for each year in mind, start the fitting of the appropriate rating curve for each year by HYMOS using the "Standard Procedure". The aim is to fit the best possible rating curve through the observed Q/H-points each year using the Power function option.

$$Q = c\,(H+a)^b \;=\; c\,(H-Ho)^b$$

i.e. to fit the best possible parameters a(= - Ho), b and c for each segment and to determine the most appropriate break points between segments.

In the following some guidelines and hints for rating curve analysis with HYMOS are given. The following steps should be done for each year of rating curve analyses.

Guideline ? for whom - who is to follow ? BWDB SWMC FAP-25 WARPO

4.1 If it seemed from Activity 2 above that the same rating curve can be used for two successive years, for which a HYMOS-rating curve has already been developed for the first year, then check it by plotting the Q/H-points for the actual year together with the already developed rating curve for the other similar year (using the option "Validation of rating curves" in main menu). If it fits nice, then store the same parameters/break points in the rating curve data base for the actual year and continue to 4.5. If it does not fit well, continue with 4.2 below.

4.2 Using the option "Adjust" Q-H data use flag O to "delete" non-reliable Q-H points from the following analyses.

4.3 First use the option "a not fixed".

  o Fill in the number of segments
  o Fill in the lower and upper limits for each segment (use an overlap around estimated break point(s)).
  o Calculate and plot rating curve on the screen.

- o Based on the linear plot, get a first impression of the fit of each segment and adequacy of estimated break points.
- o On log-log plot : The points of the lowest segment should have a unbiased fit to the straight line. If not, the calculated value of a for the lowest segment is not correct.
- o If required for obtaining reasonable extrapolations, include extra high Q/H-points from other years.
- o In option "Error Analysis" the calculated break points and parameters a, b, and c for each segment are listed. Evaluate the estimated a-values and exponents b. The values of b should usually be in the range of 1.5 - 3.0. If b is too high the Ho value should be higher (i.e. a = -Ho smaller). Use experience from other years from same station as a guideline to assess reasonable a-values.

4.4 Then use the option "a fixed"

- o Fix a-value for each segment and calculate and plot the rating curve again.
- o On the linear plot : Evaluate the fit of the rating curve for all segments, in particular the upper segment used for extrapolations.
- o If necessary for obtaining good extrapolation, include high Q/h points from other years as extra points
- o On the log-log plot : Check that the points of the lowest segment fit unbiased to the straight line.
- o On linear plot : If the fit is not satisfactory, modify location of break point(s) to obtain a better fit.
- o If required, modify a-values again and repeat the exercises 4.4 above again until the best possible fit for each segment is obtained, in particular for the upper segment used for extrapolation.

4.5 When a good fit is obtained for all segments, store the obtained parameters for that year.

4.6 Using option "Validation of rating curves" in Main menu :

Plot on printer of

- o Parameters
- o Linear plot + log-log plot of "final" rating curve together with the Q/H-points.

4.7 Compare the resulting rating curves for successive years and check the similarity of the curves, in particular with respect to extrapolations. If necessary modify the upper segment curves (used for extrapolations) for the individual years so that they become more similar/consistent.

FIGURES

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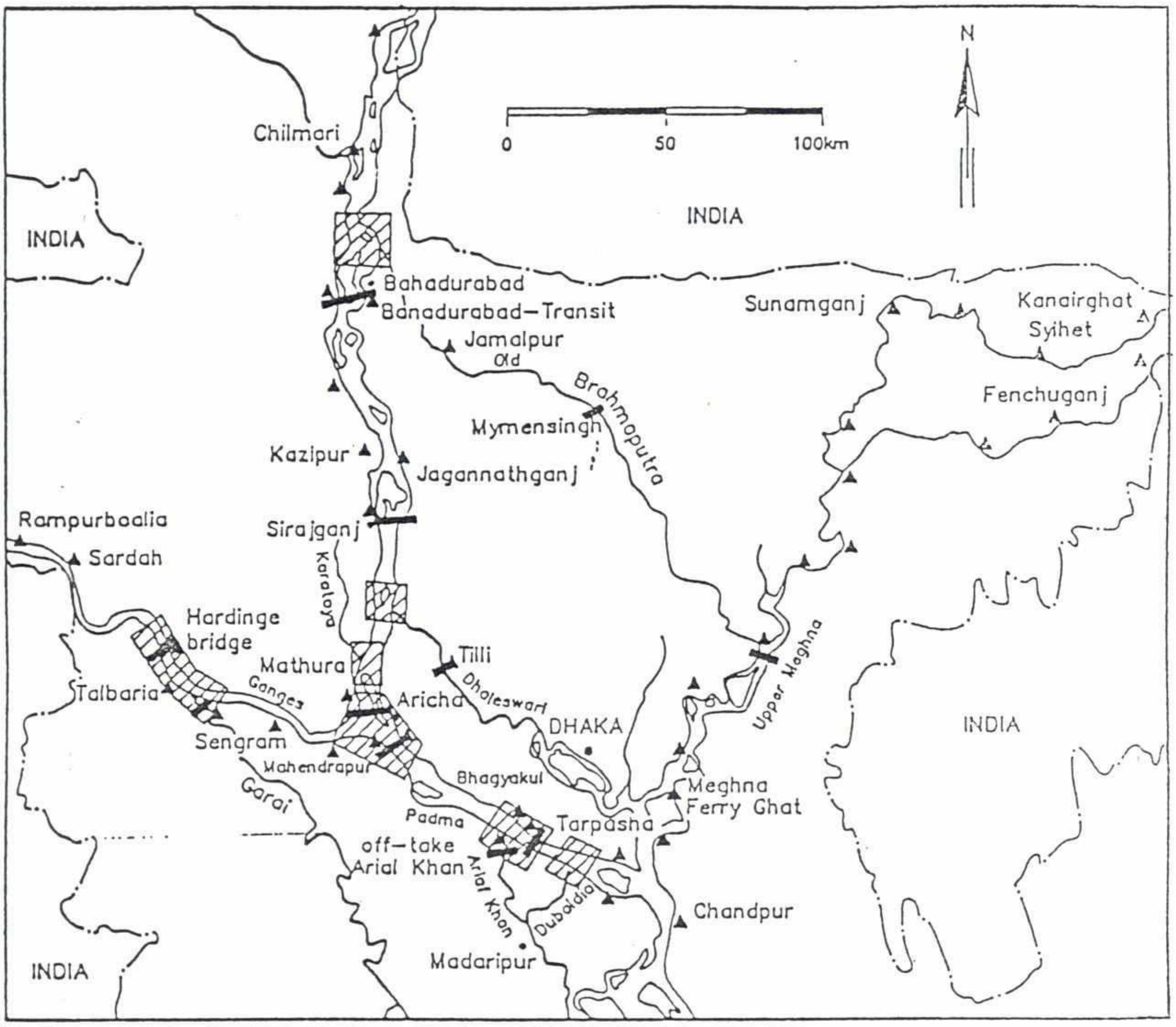

▲ Sites for waterlevel gauges.

▬ Cross–section, discharge and sediment measurements.
June – October : fortnightly
November – May : every 6 weeks

▨ Indicative sites for pre– and post monsoon bathymetric surveys.

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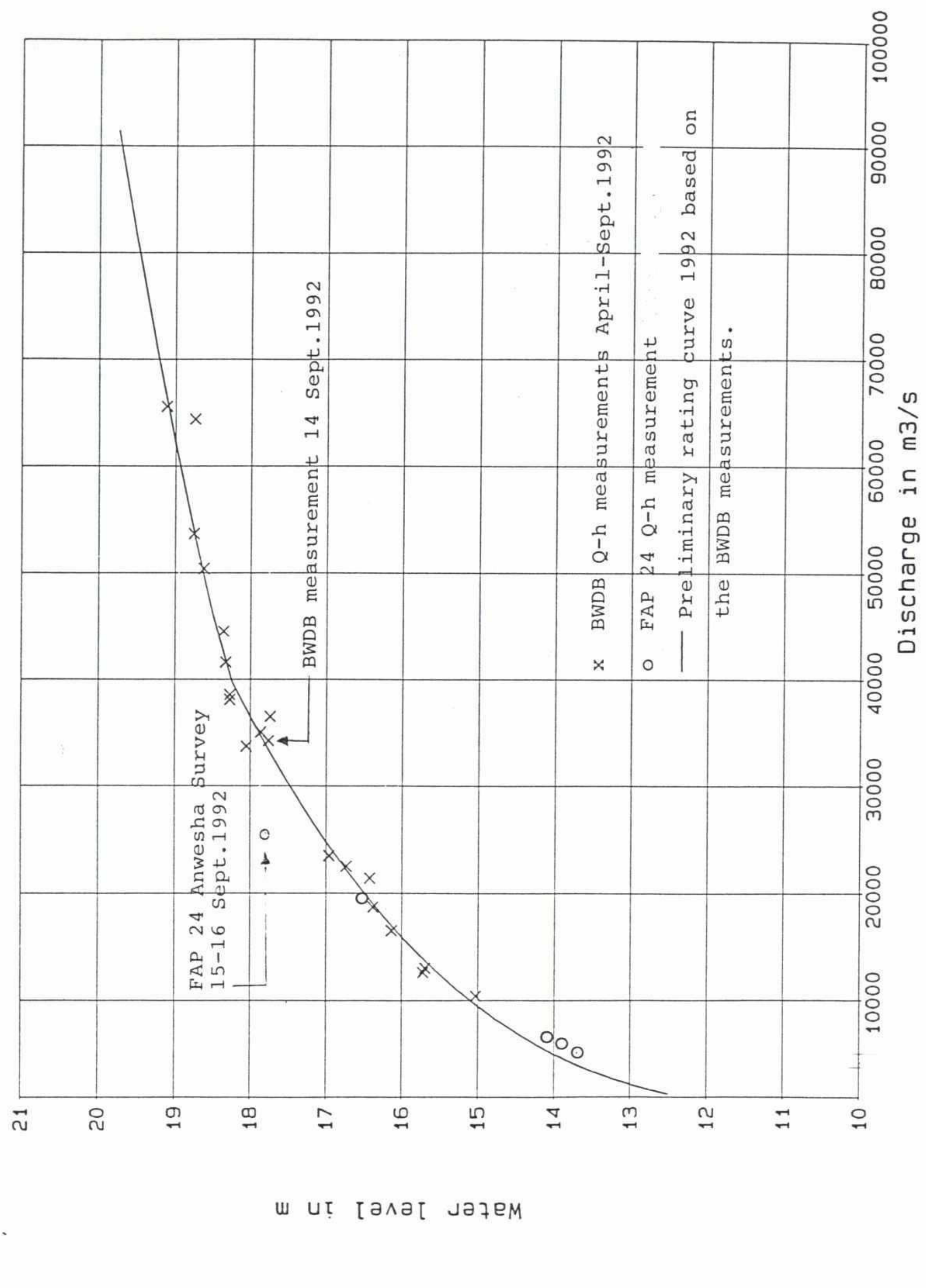
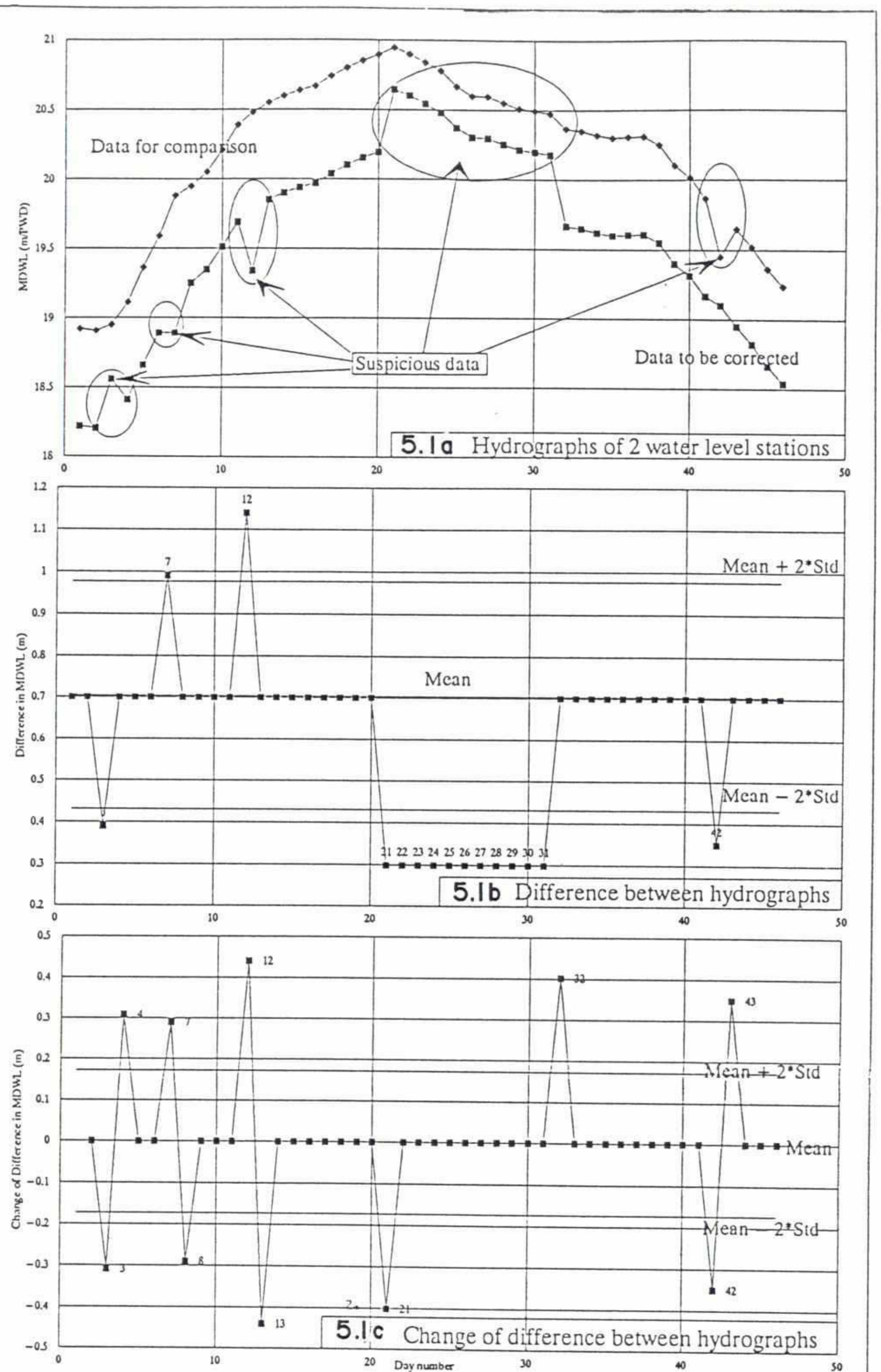
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT–DHI		FAP 24 field survey activities.	
File:	Date:	Hydrological Study Phase 1	Fig. 3.1
Scale:	Init:		

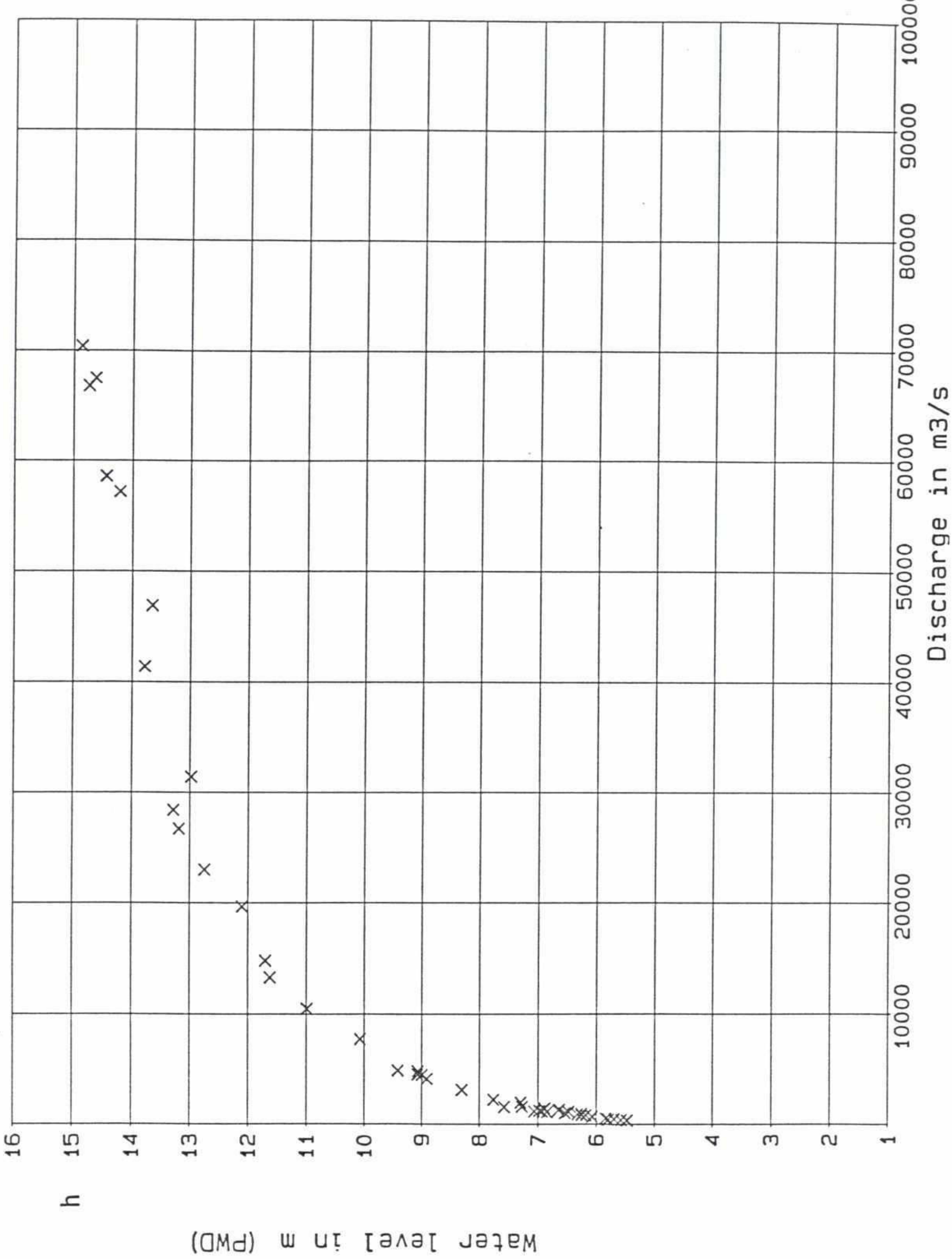


FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI	Bahadurabad: First FAP 24 discharge measurement Sept.92 compared with preliminary rating curve 1992	
File: / Date:	Hydrological Study Phase 1	Fig. 4.1
Scale: / Init:		

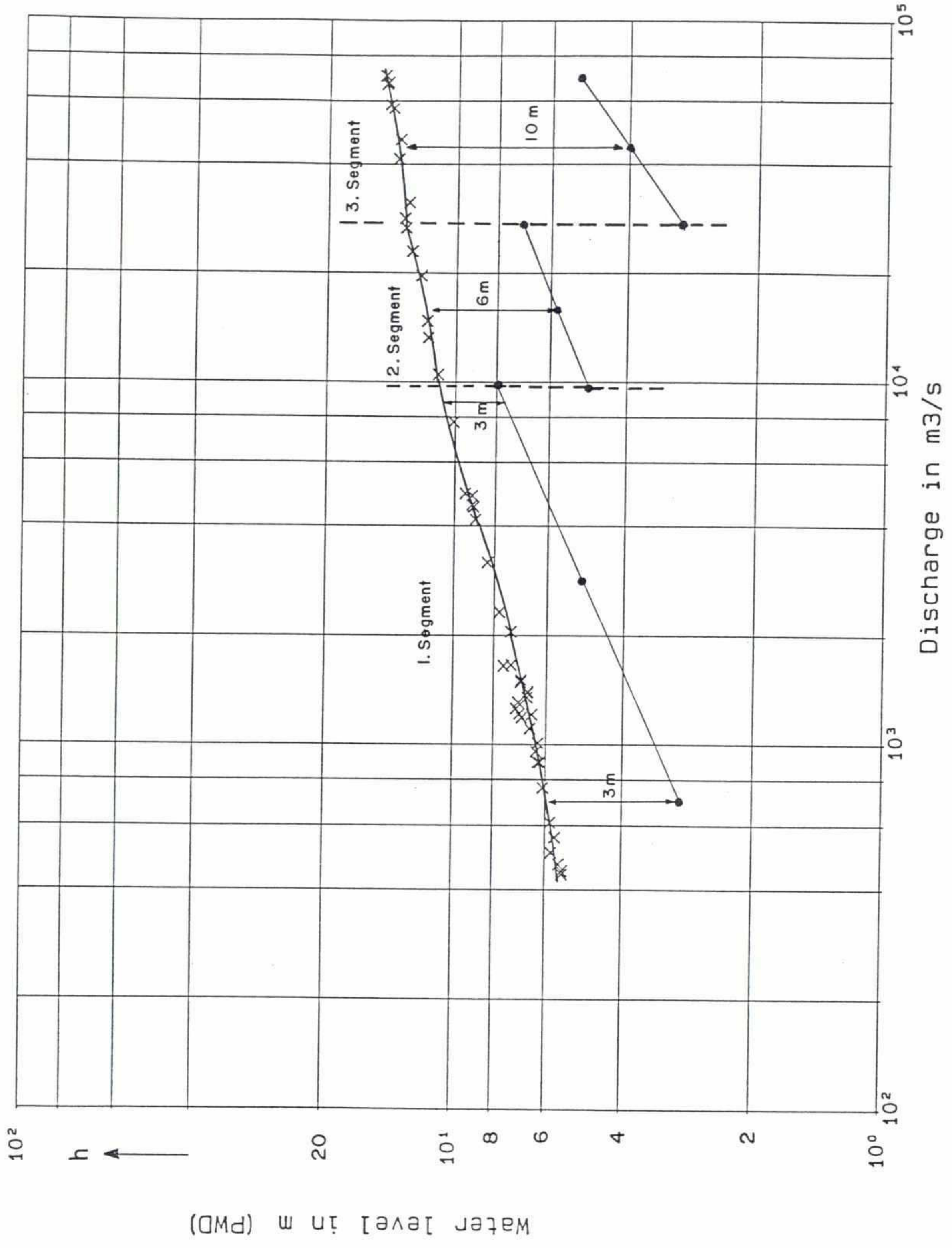


Remarks: Plots in this illustration do not cover a whole year's data.
However, values for the mean and the standard deviation are based on a full year.

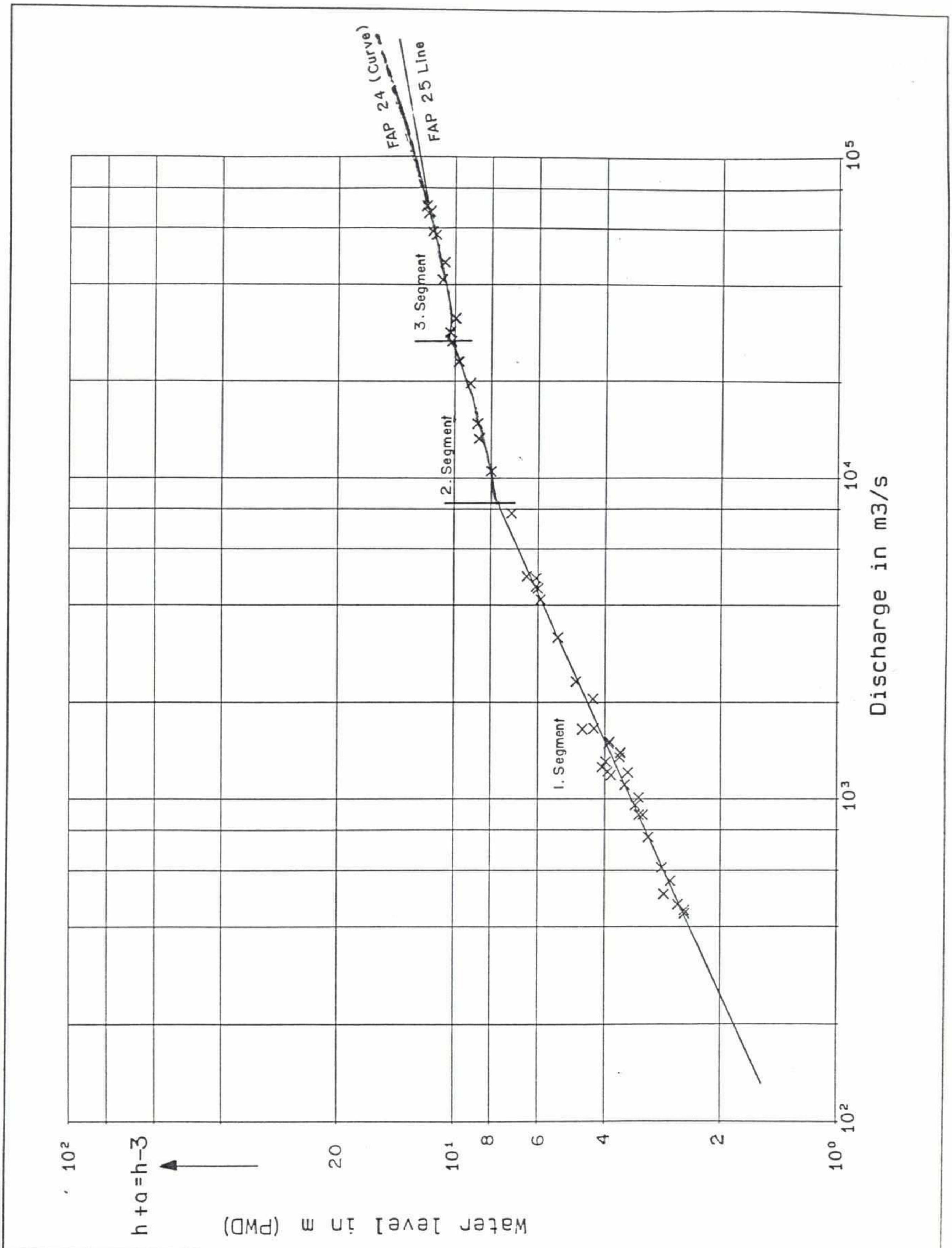
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Illustration of procedure for water-level checking	
File:	Date:	Hydrological Study Phase 1	Fig. 5.1
Scale:	Init:		



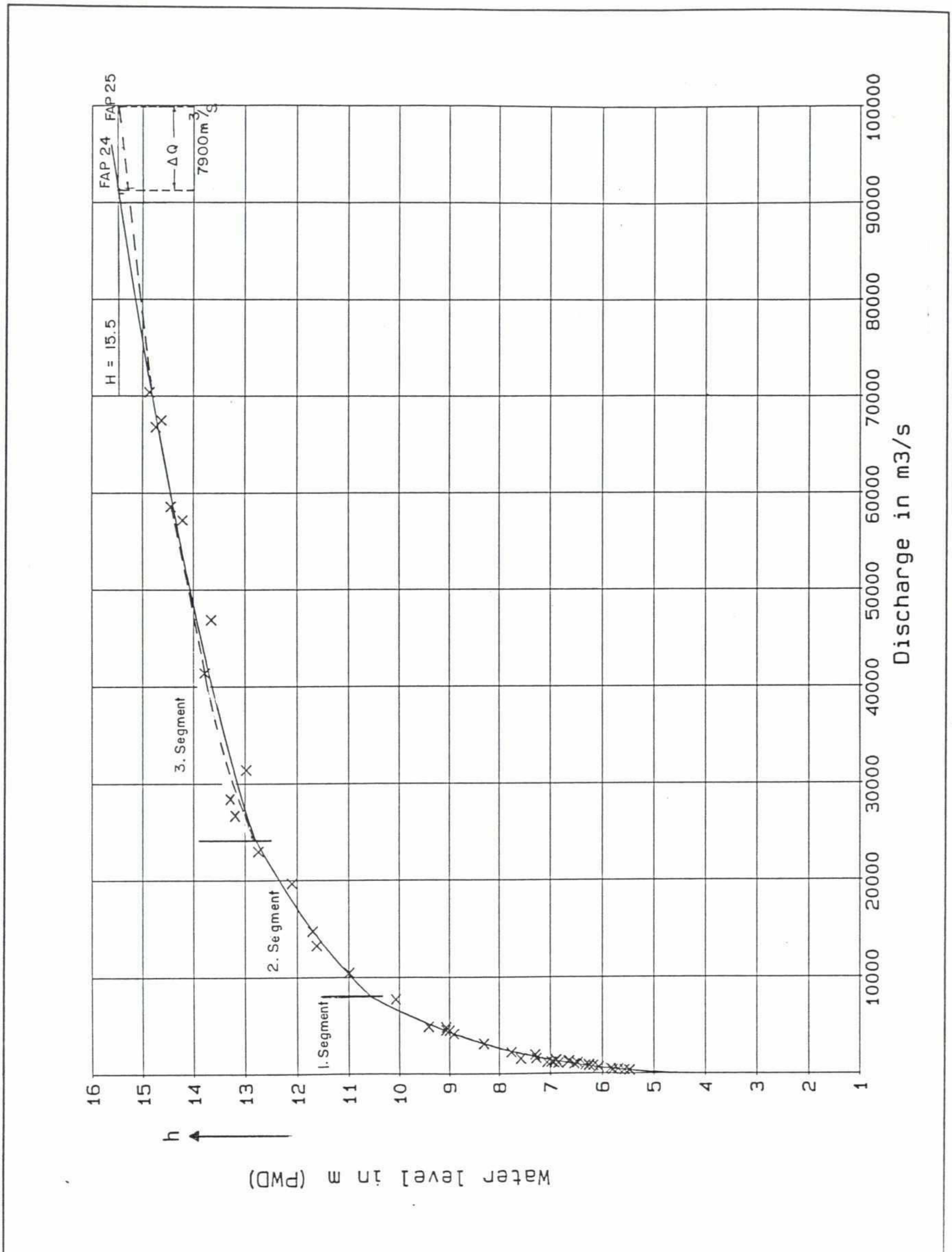
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Rating curve, Hardinge Bridge 1988. Q-h measurements 1988, linear plot	
File:	Date:	Hydrological Study Phase 1	Fig. 5.2
Scale:	Init:		



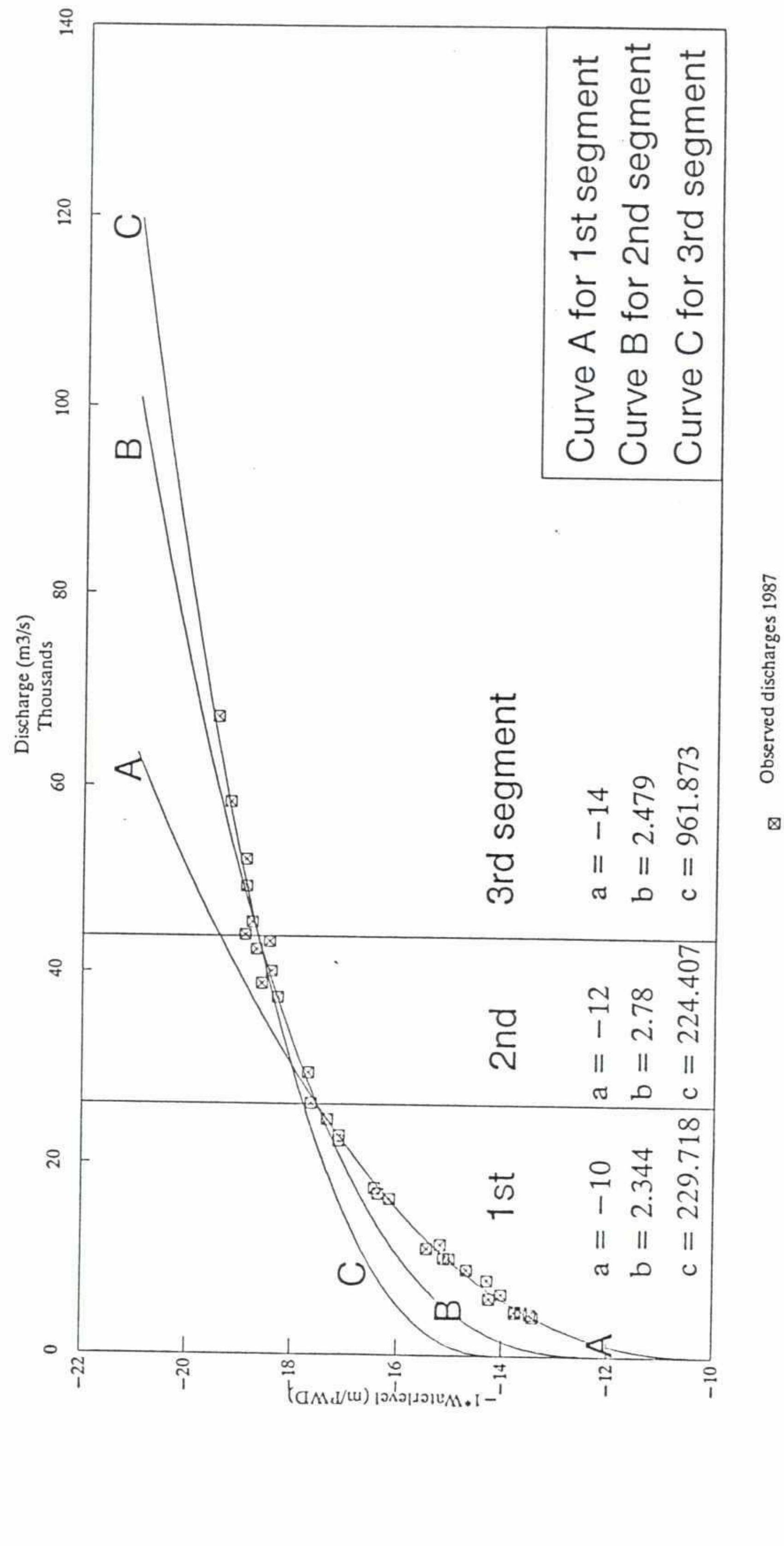
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Rating curve, Harding Bridge 1988 Illustration of procedure for estimation of a Q - values	
File:	Date:	Hydrological Study Phase 1	Fig. 5.3
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Rating curve, Hardinge Bridge 1988 **Illustration of procedure for estimation of Q - values**	
File:	Date:	Hydrological Study Phase 1	Fig. 5.4
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Rating curve, Hardinge Bridge 1988. Comparison of FAP 24 and FAP 25 rating curves.	
File:	Date:	Hydrological Study, Phase 1	Fig. 5.5
Scale:	Init:		



Remarks: – Configuration of the figure requires negative values for the water-levels. The minus signs can be ignored.

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Fitting of rating curve; as fitted for Bahadurabad 1987	
File:	Date:	Hydrological Study Phase 1	Fig. 5.6
Scale:	Init:		

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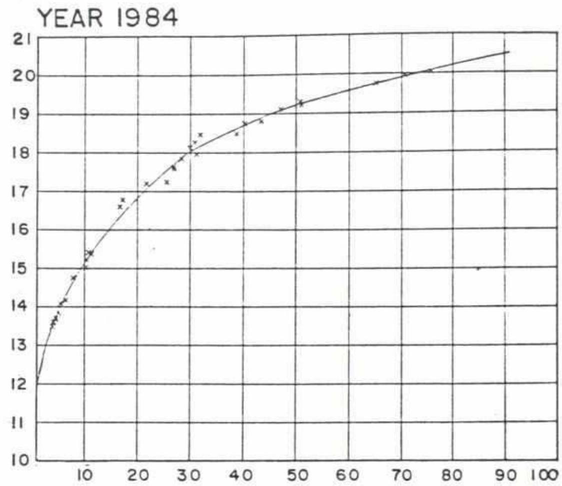
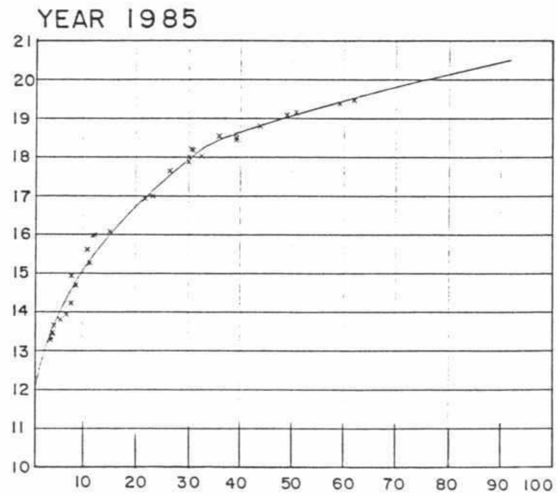
RATING CURVES (POWER FUNCTION)

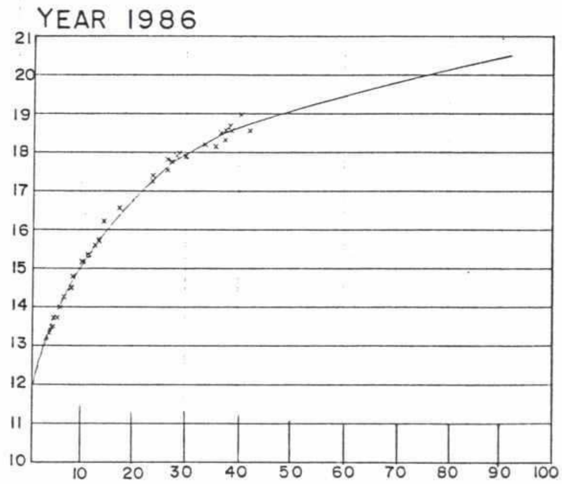
STATION : BAHADURABAD
RIVER : JAMUNA

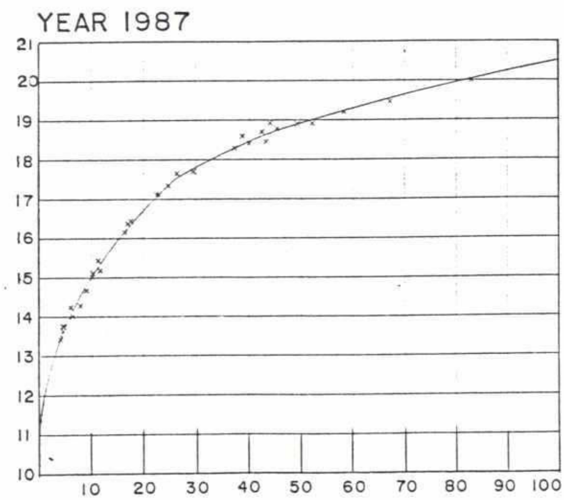
Legend :

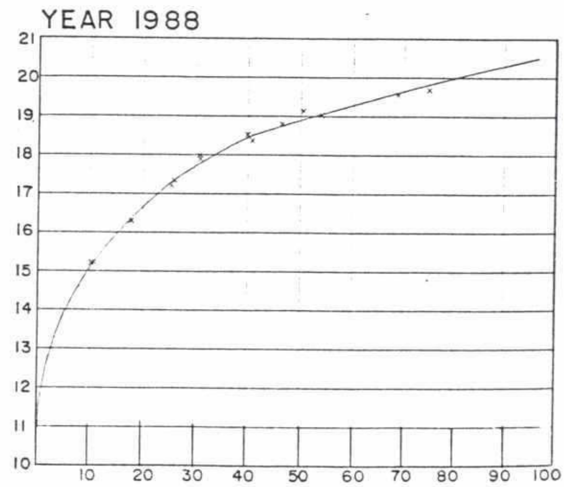
X - axis	=	Discharges in thousand cumecs
Y - axis	=	Water-levels in meter (PWD)
x	=	Gauged data











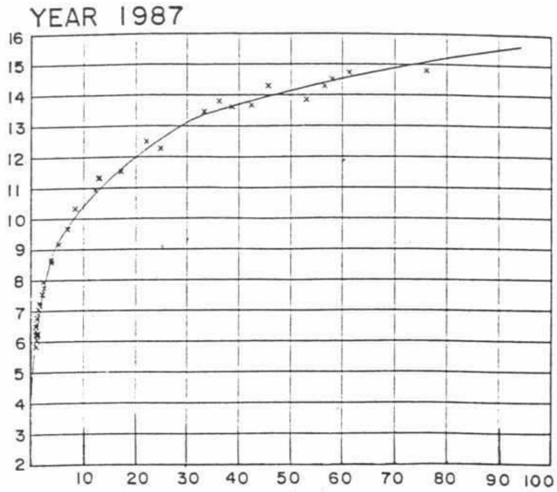
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI	Bahadurabad. Rating curves 1984 - 1988
File: / **Date:** / **Scale:** / **Init:**	Hydrological Study Phase 1 — **Fig.** 5.7

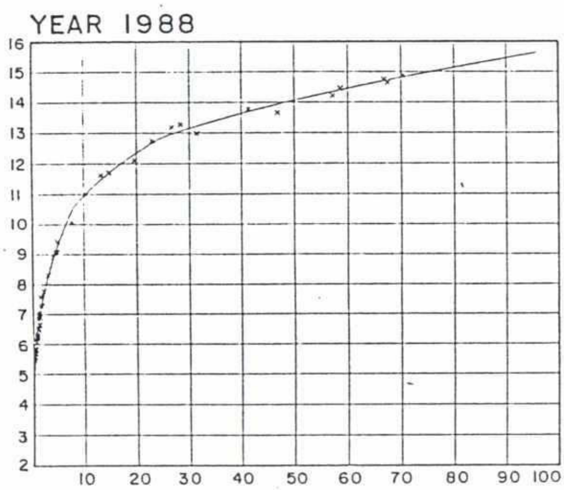
RATING CURVES (POWER FUNCTION)

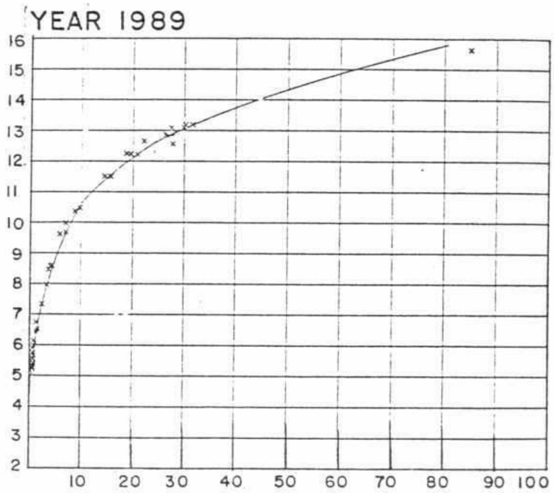
STATION : HARDINGE BRIDGE
RIVER : GANGES

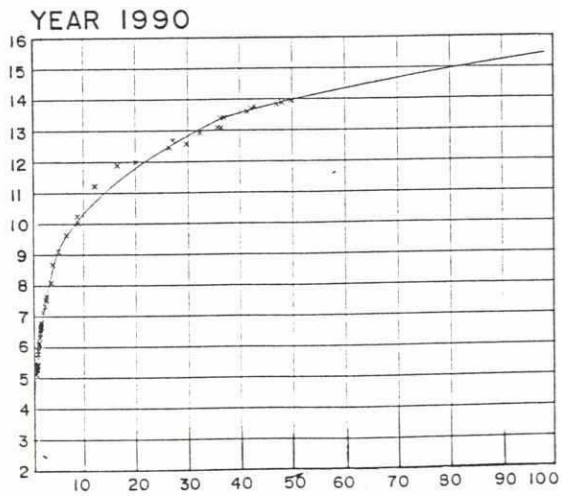
Legend :

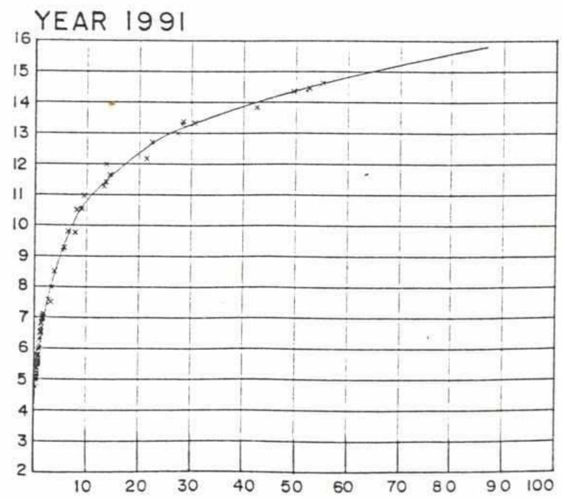
X - axis = Discharges in thousand cumecs
Y - axis = Water-levels in meter (PWD)
x = Gauged data











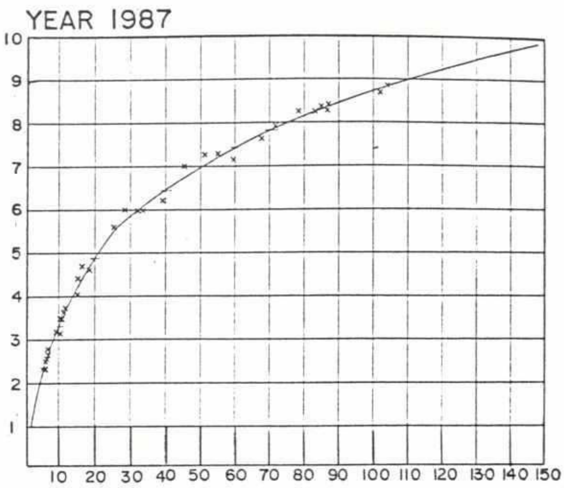
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Hardinge Bridge. Rating curves 1987 - 1991	
File:	Date:	Hydrological Study Phase 1	Fig. 5.8
Scale:	Init:		

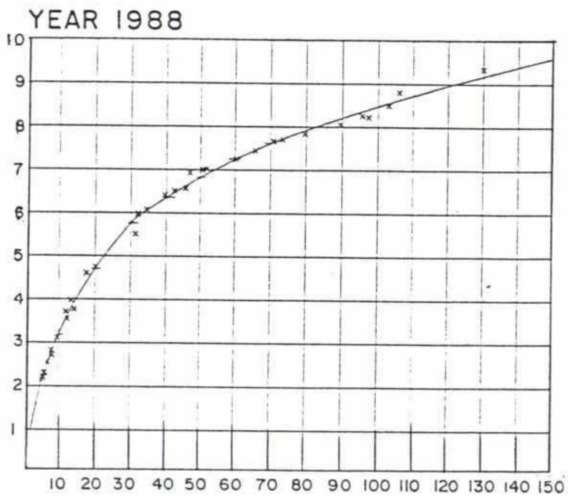
RATING CURVES (POWER FUNCTION)

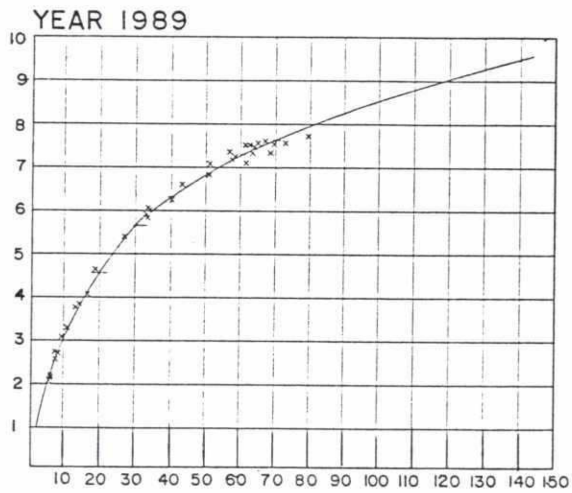
STATION : BARURIA
RIVER : PADMA

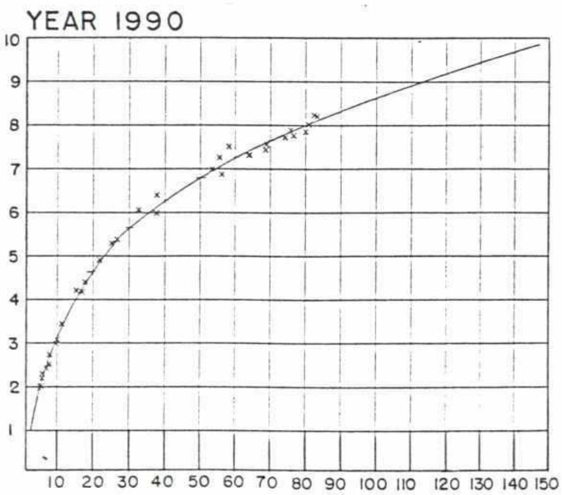
Legend :

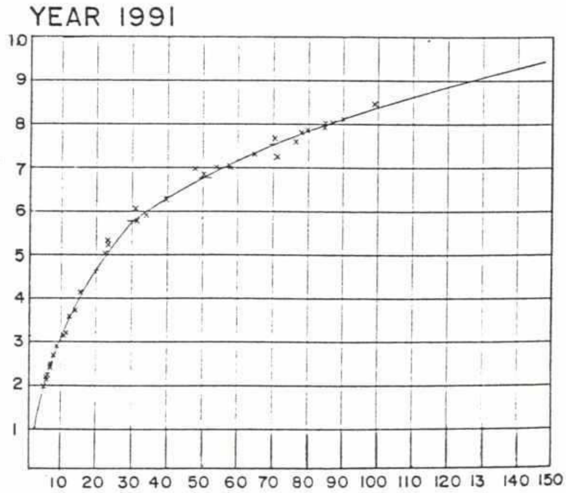
X - axis = Discharges in thousand cumecs
Y - axis = Water-levels in meter (PWD)
x = Gauged data











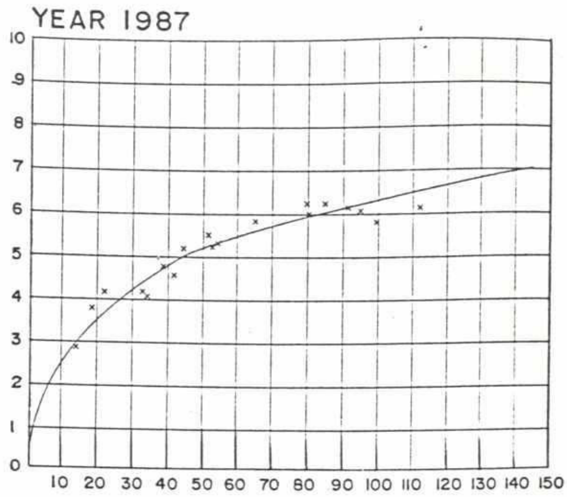
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Baruria.	
		Rating curves 1987 - 1991	
File:	Date:	Hydrological Study Phase 1	Fig. 5.9
Scale:	Init:		

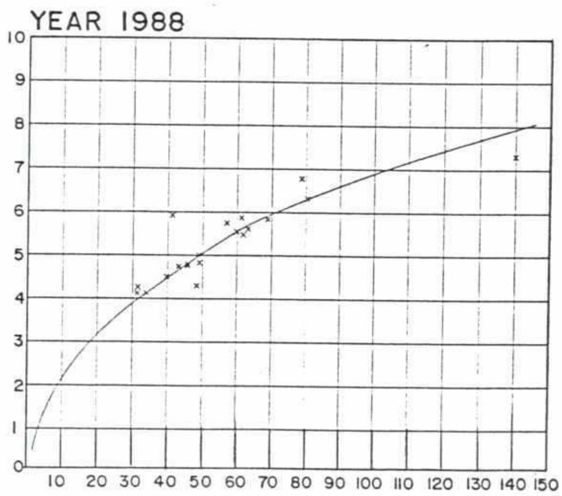
RATING CURVES
(POWER FUNCTION)

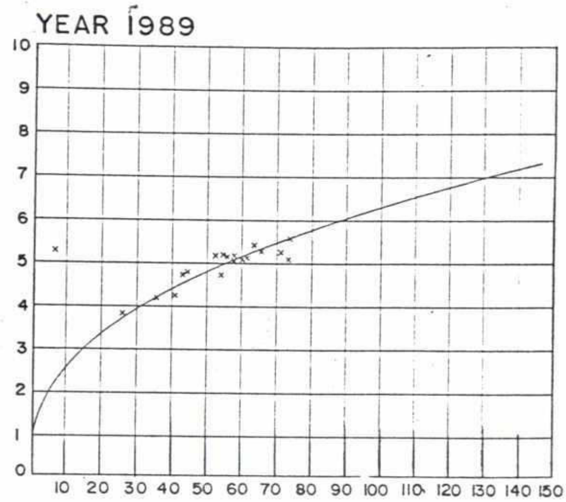
STATION : MAWA
RIVER : PADMA

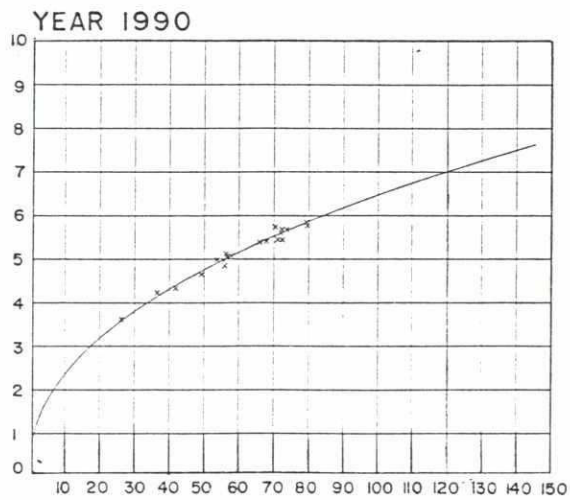
Legend :

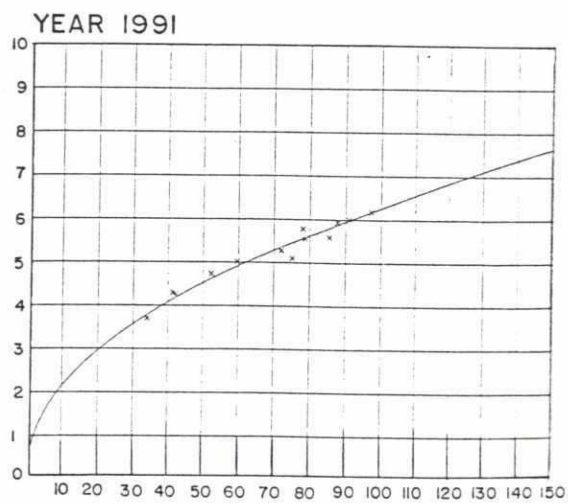
X - axis = Discharges in thousand cumecs
Y - axis = Water-levels in meter (PWD)
x = Gauged data











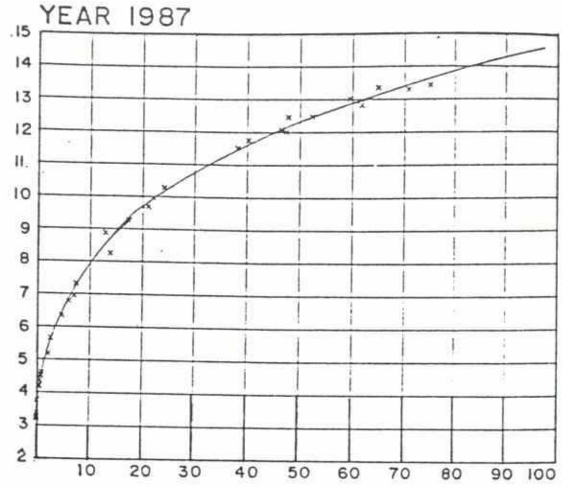
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Mawa.	
		Rating curves 1987 - 1991	
File:	Date:	Hydrological Study Phase 1	Fig. 5.10
Scale:	Init:		

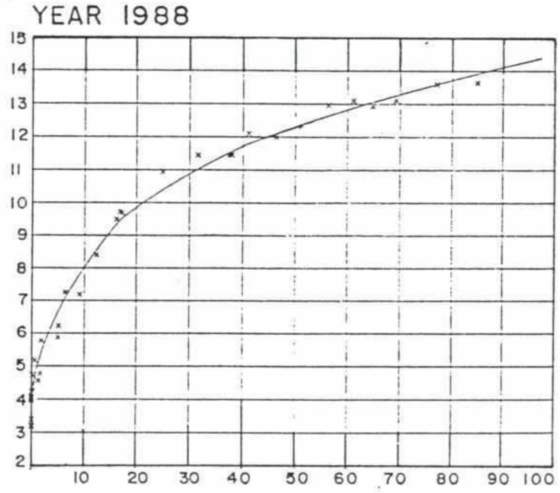
RATING CURVES (POWER FUNCTION)

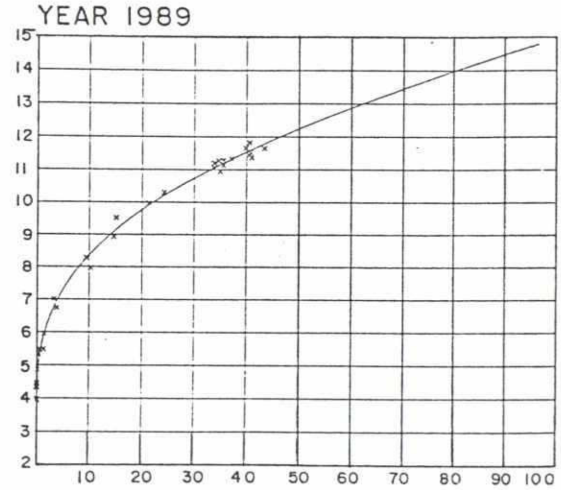
STATION : GORAI RLY BRIDGE
RIVER : GORAI

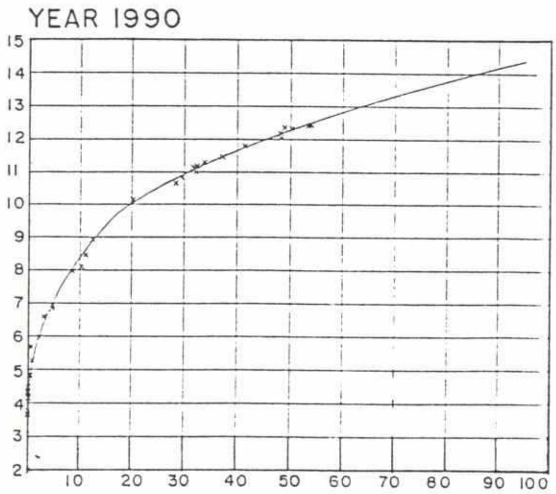
Legend :

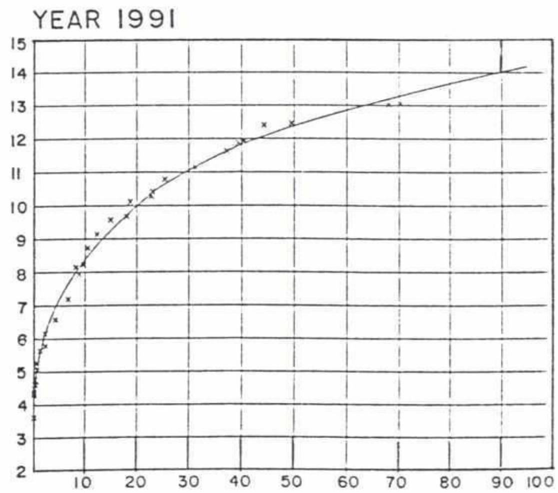
X - axis = Discharges in thousand cumecs
Y - axis = Water-levels in meter (PWD)
x = Gauged data



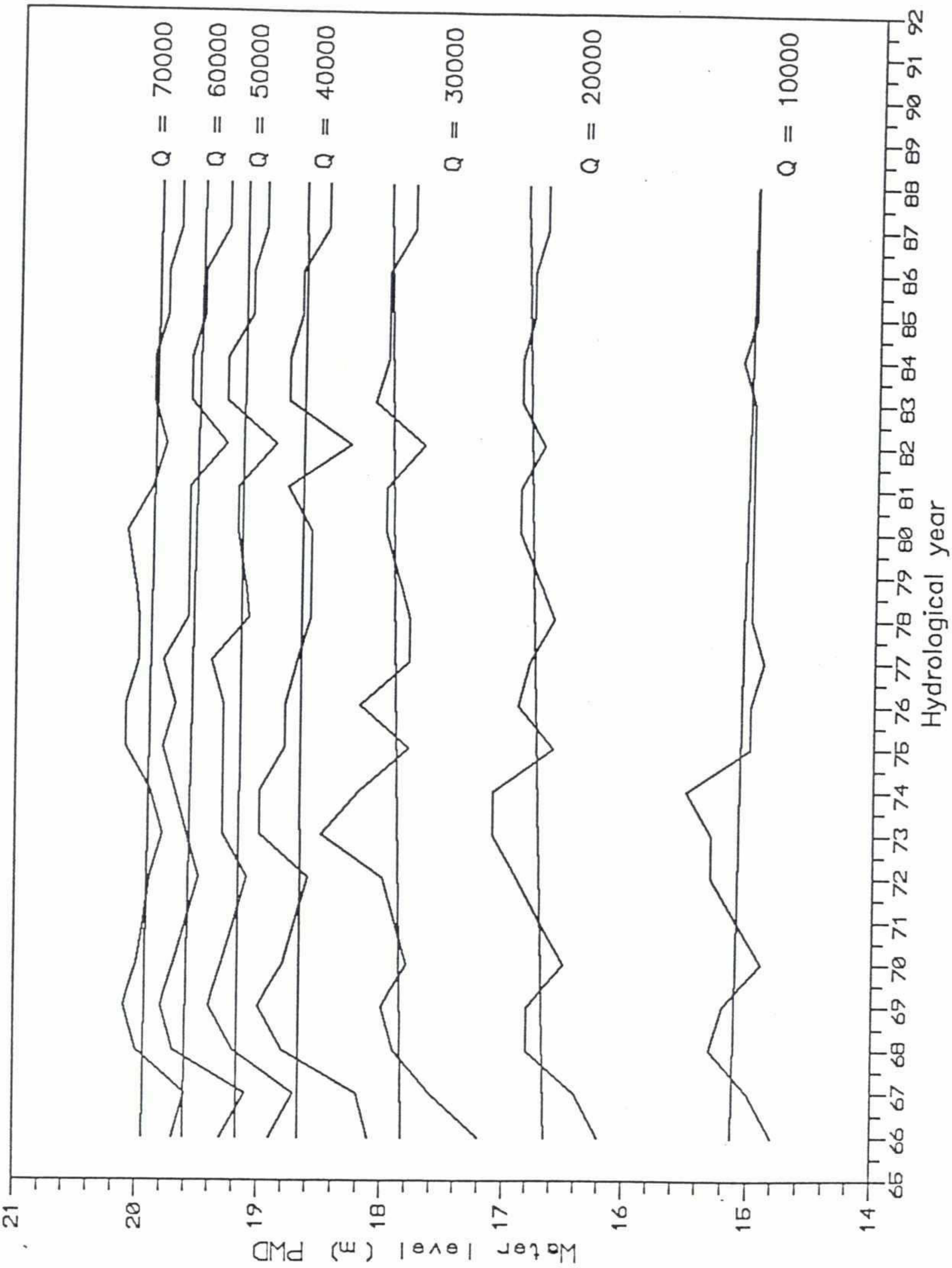




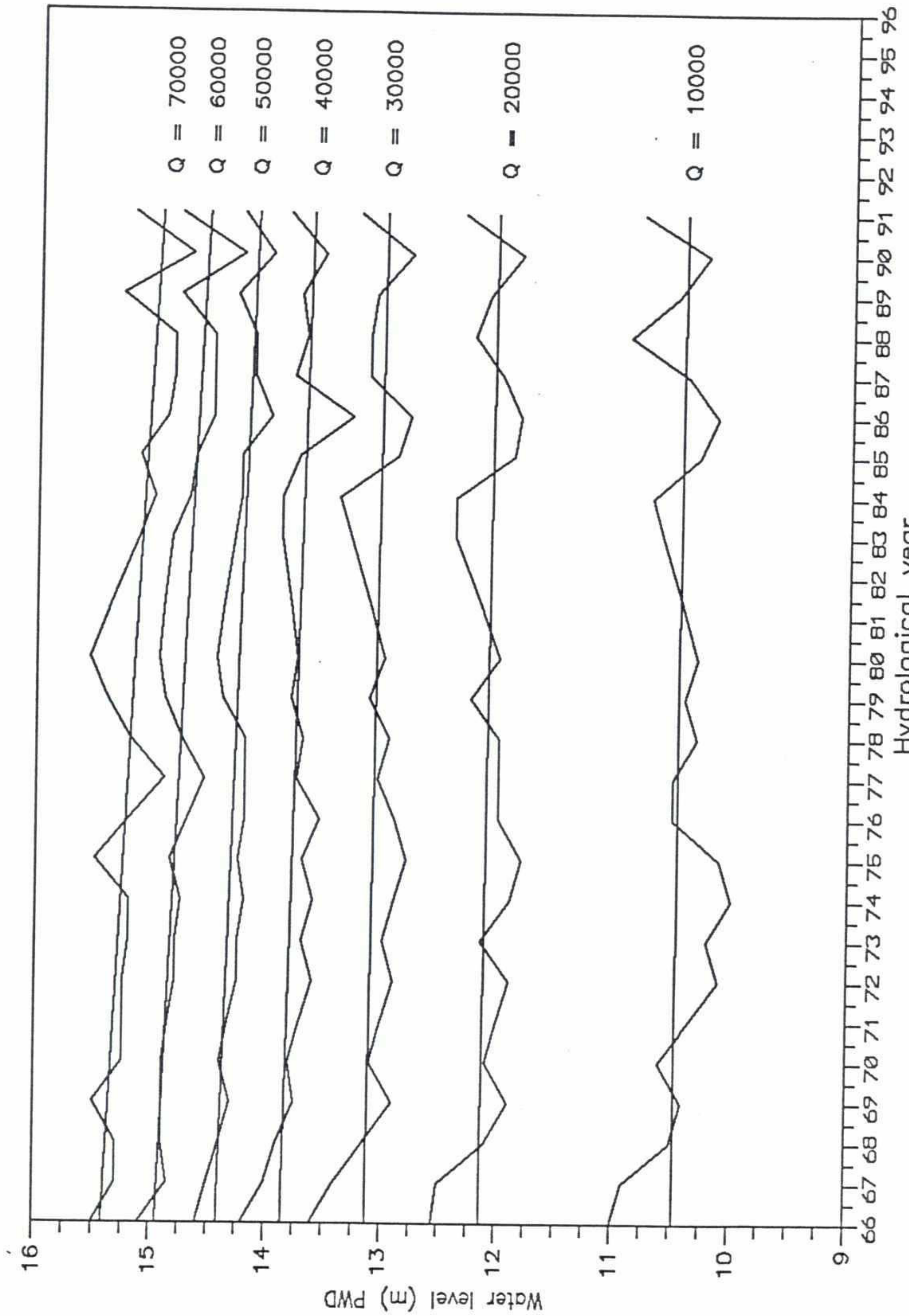




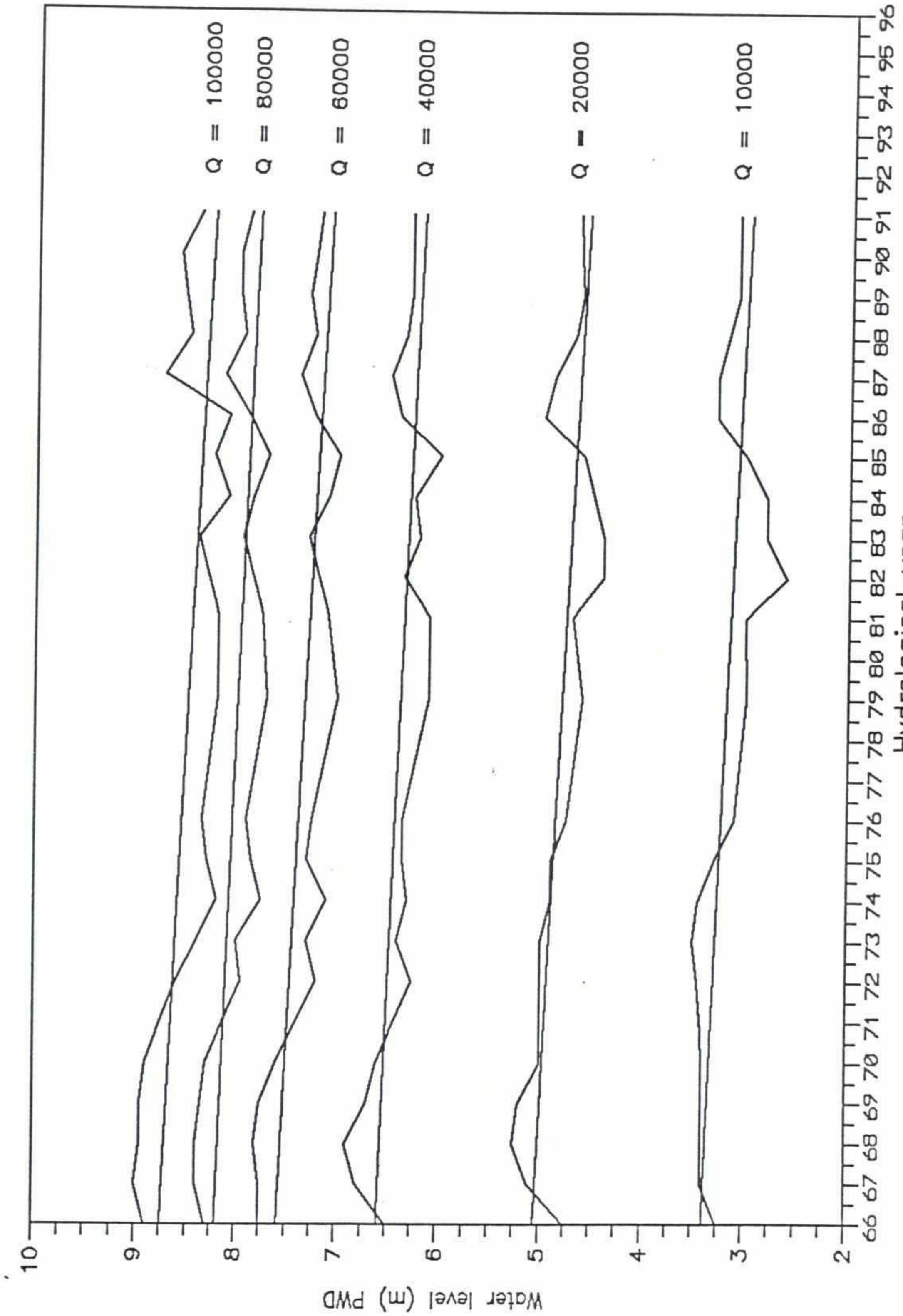
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Gorai Railway Bridge. Rating curves 1987 - 1991.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.11
Scale:	Init:		



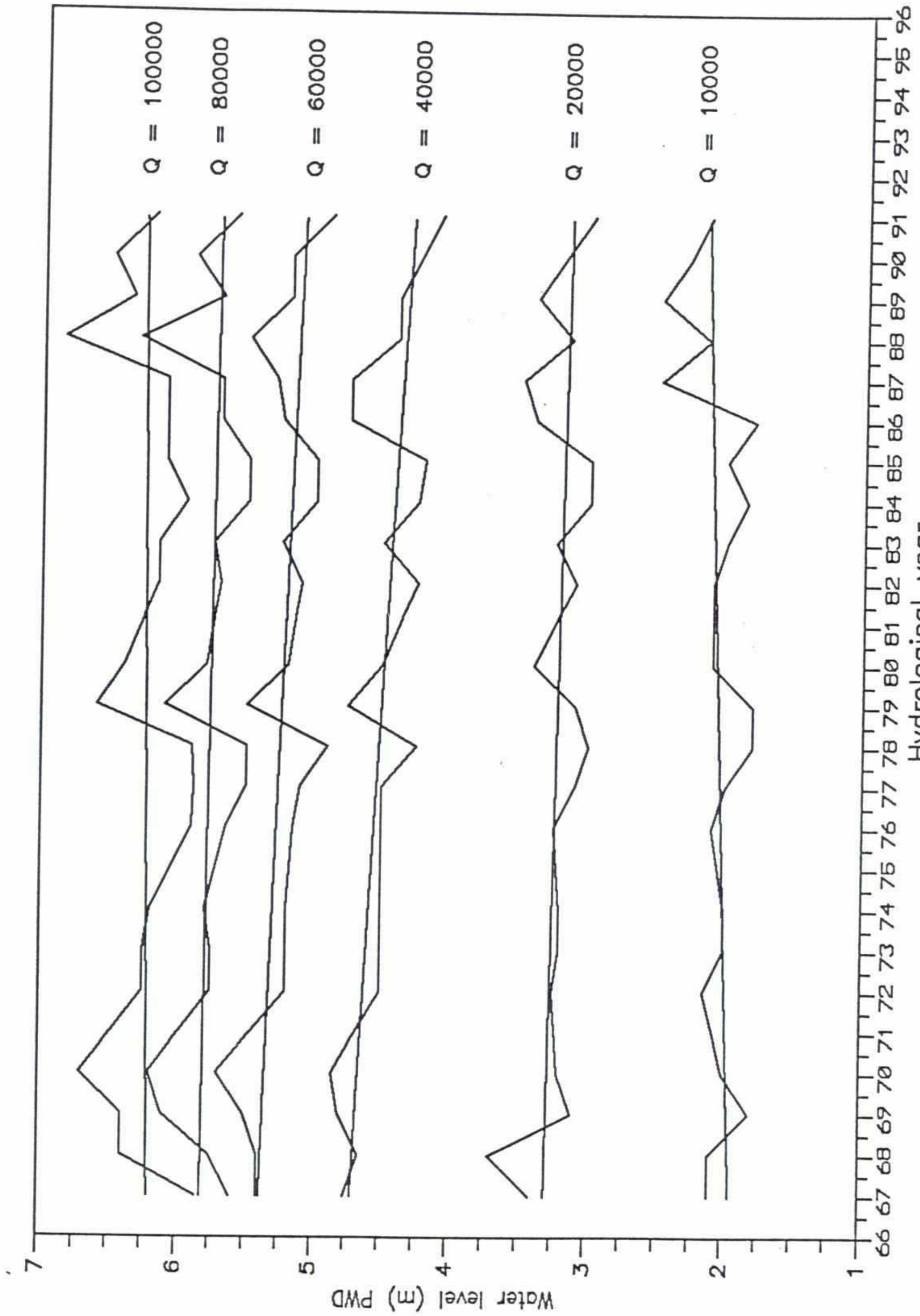
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics Danish Hydraulic Institute in association with Osiris Appritech Hydroland DELFT-DHI		Bahadurabad. Specific gauge analysis 1966 - 1988	
File:	Date:	Hydrological Study Phase 1	Fig. 5.12
Scale:	Init:		



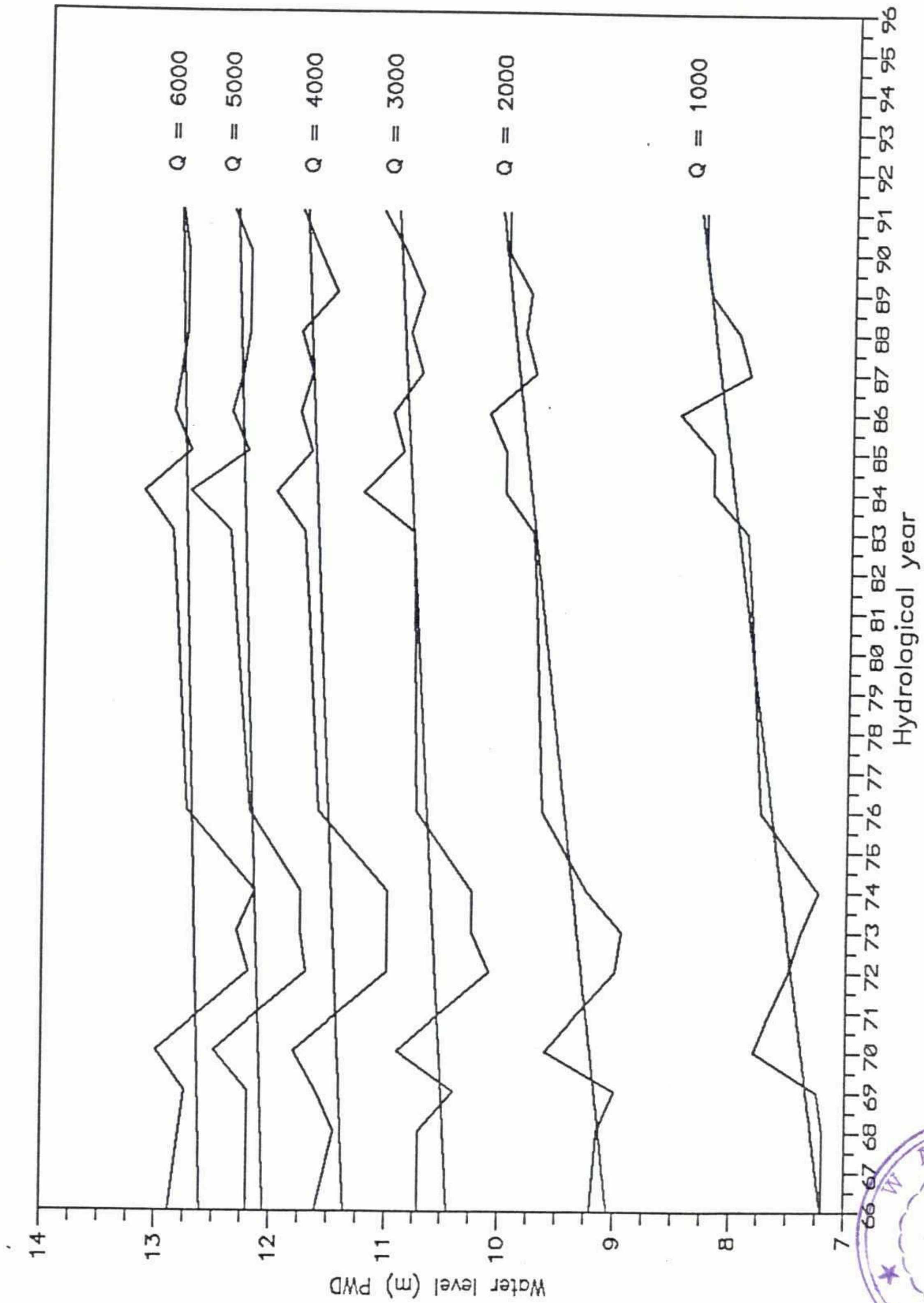
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics Danish Hydraulic Institute in association with Osiris Approtech Hydroland DELFT-DHI		Hardinge Bridge. Specific gauge analysis.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.13
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics Danish Hydraulic Institute in association with Osiris Approtech Hydroland DELFT-DHI		Baruria.	
		Specific gauge analysis	
File:	Date:	Hydrological Study Phase 1	Fig. 5.14
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics Danish Hydraulic Institute in association with Osiris Approtech Hydroland DELFT-DHI		Mawa. Specific gauge analysis.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.15
Scale:	Init:		



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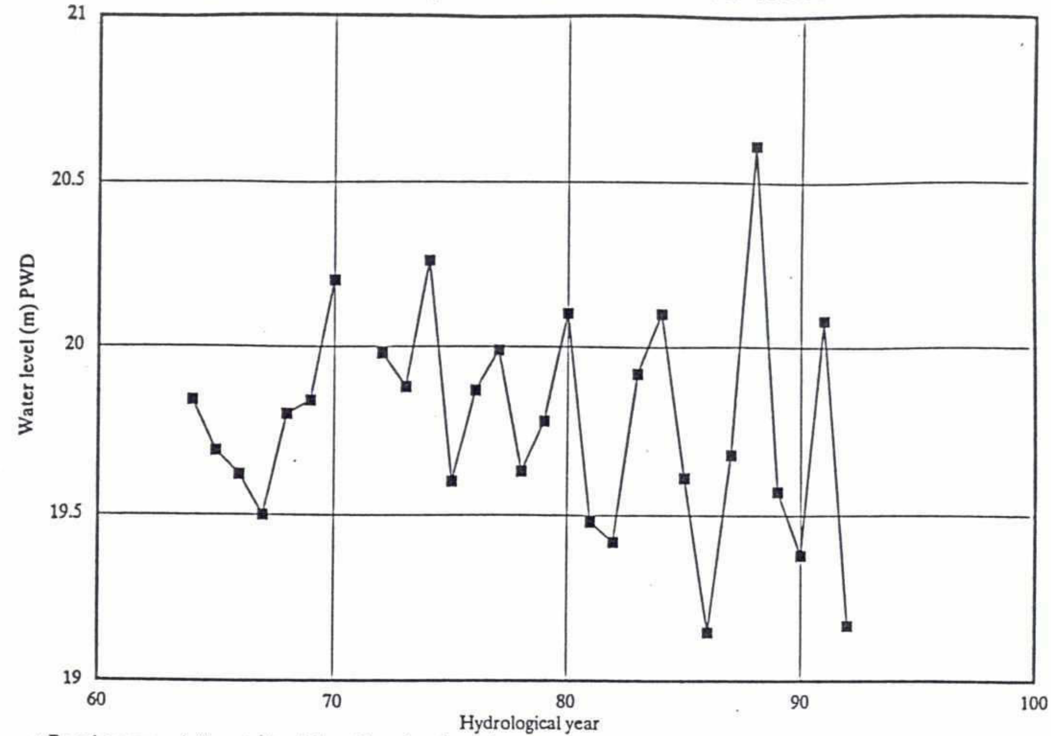
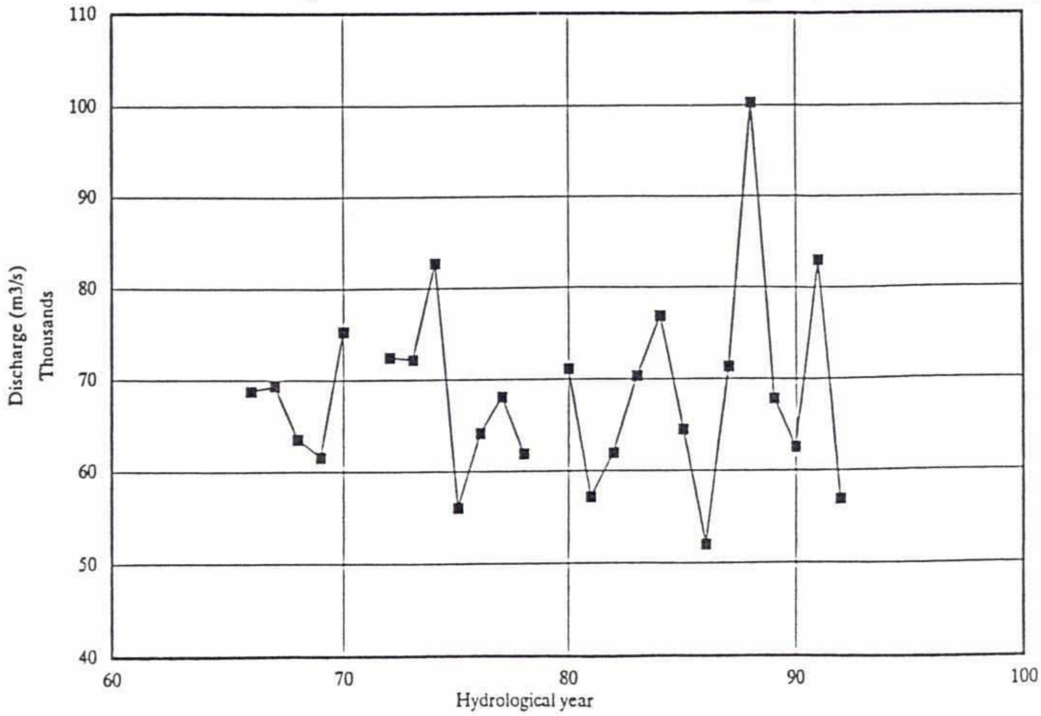
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech Hydroland DELFT-DHI		Gorai Railway Bridge. Specific gauge analysis.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.16
Scale:	Init:		

Bahadurabad, Annual maximum water level.



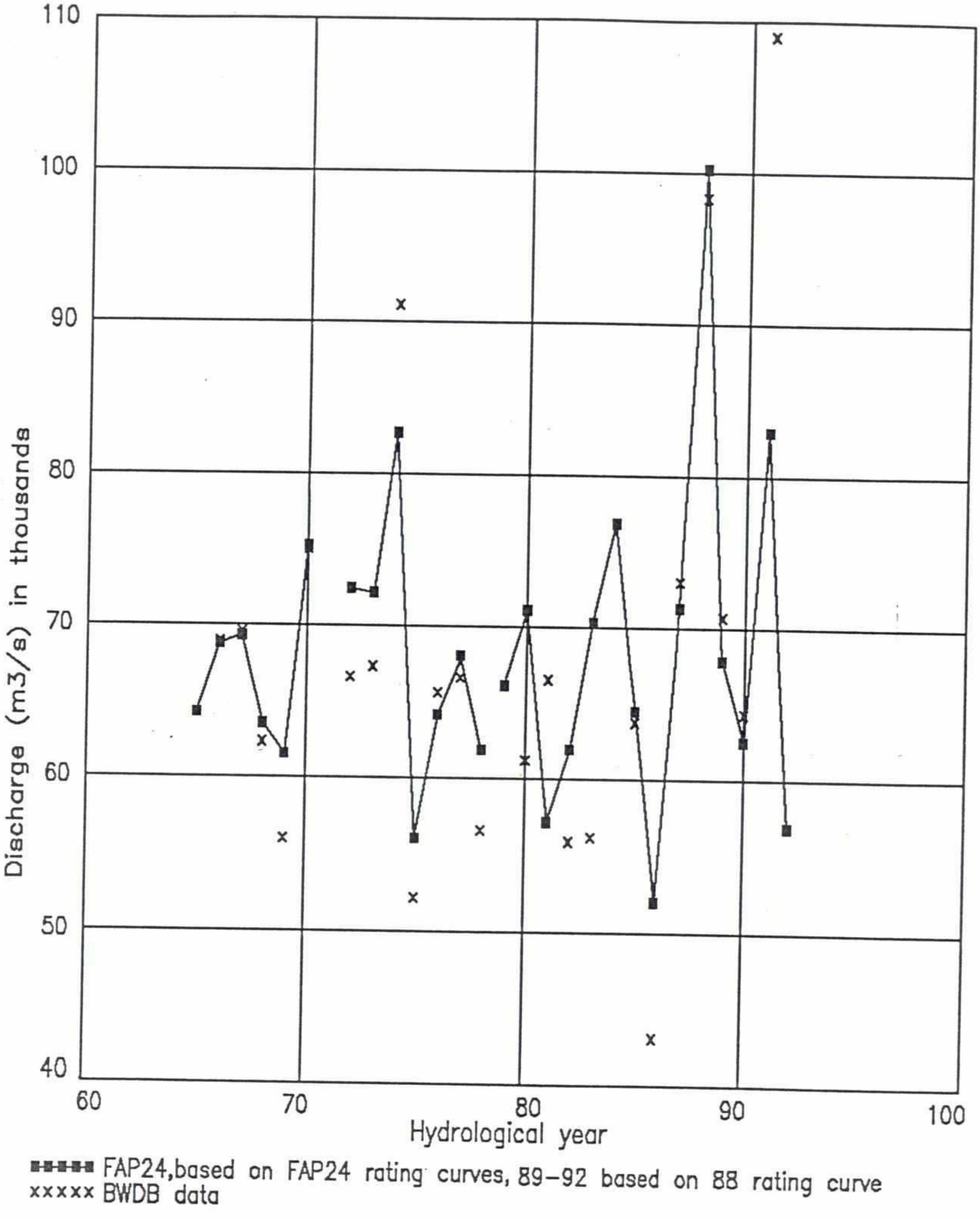
o Based on mean daily water level data, 71 – data is missing.

Bahadurabad, Annual maximum discharge (FAP24–data)

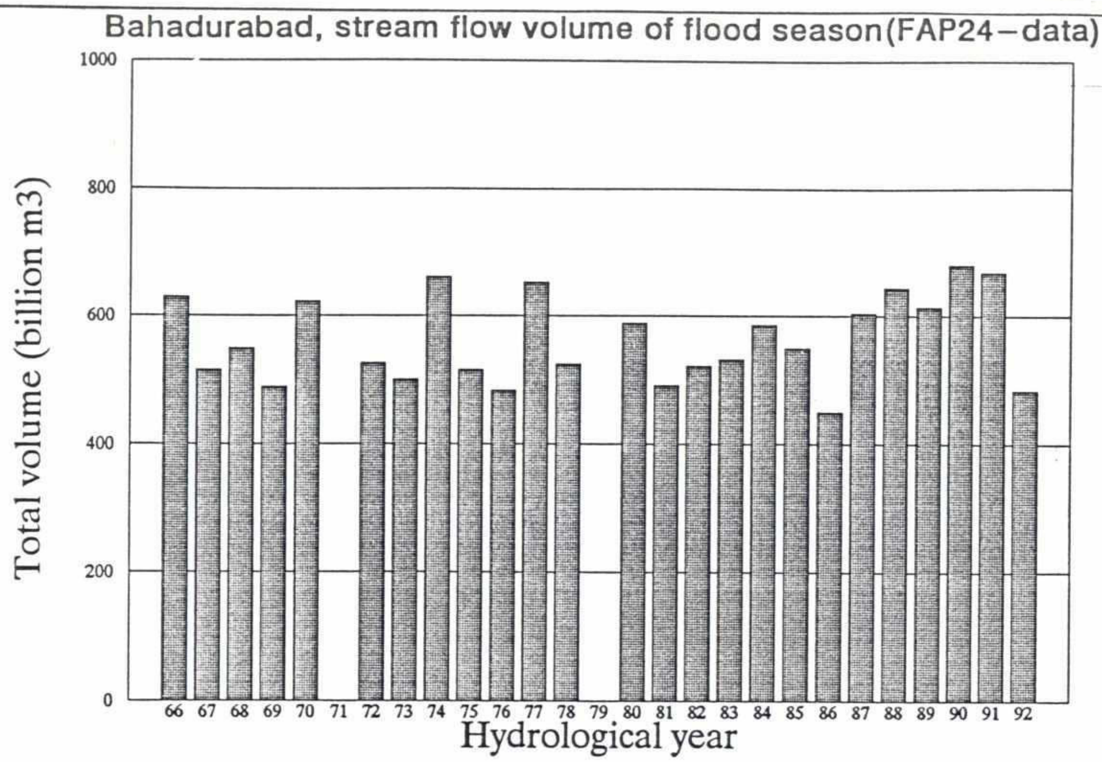


o Based on FAP24 rating curves.
o 1989 – 1992 data based on 1988 rating curve.

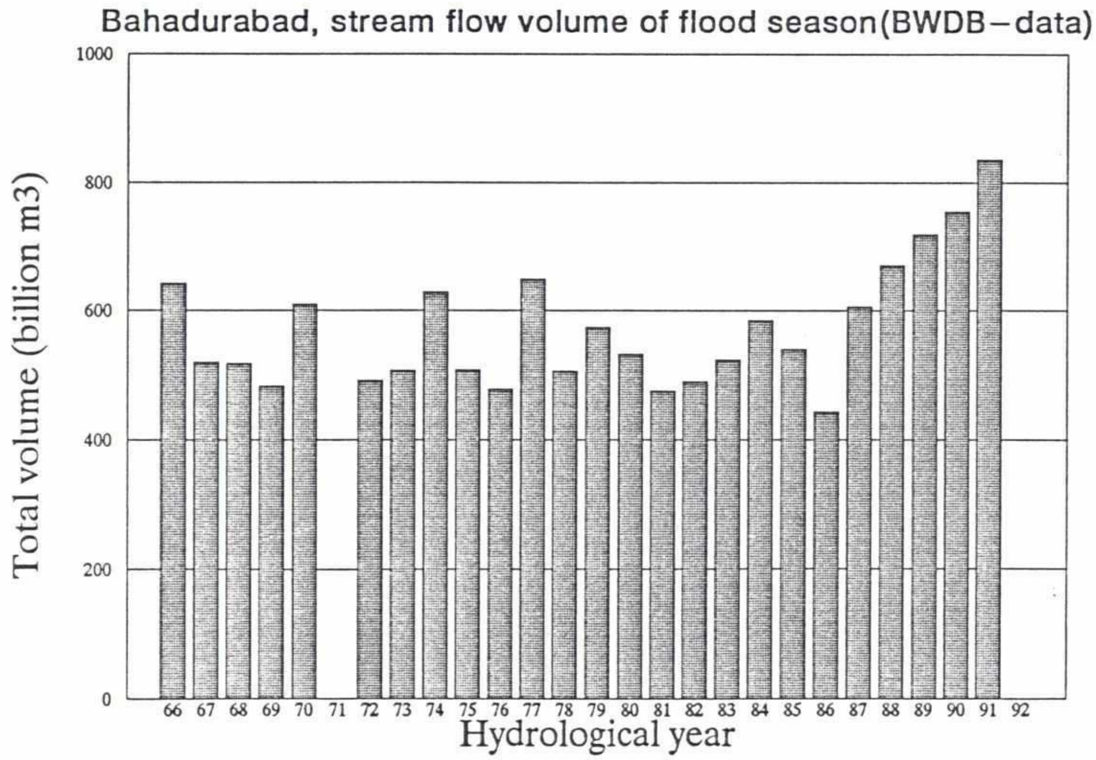
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Bahadurabad. Annual maximum water-levels and discharges.
File:	Date:	Hydrological Studies Phase 1.
Scale:	Init:	Fig. 5.17



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Bahadurabad. Comparison of BWDB and FAP24 estimates of annual maximum discharges.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.18
Scale:	Init:		

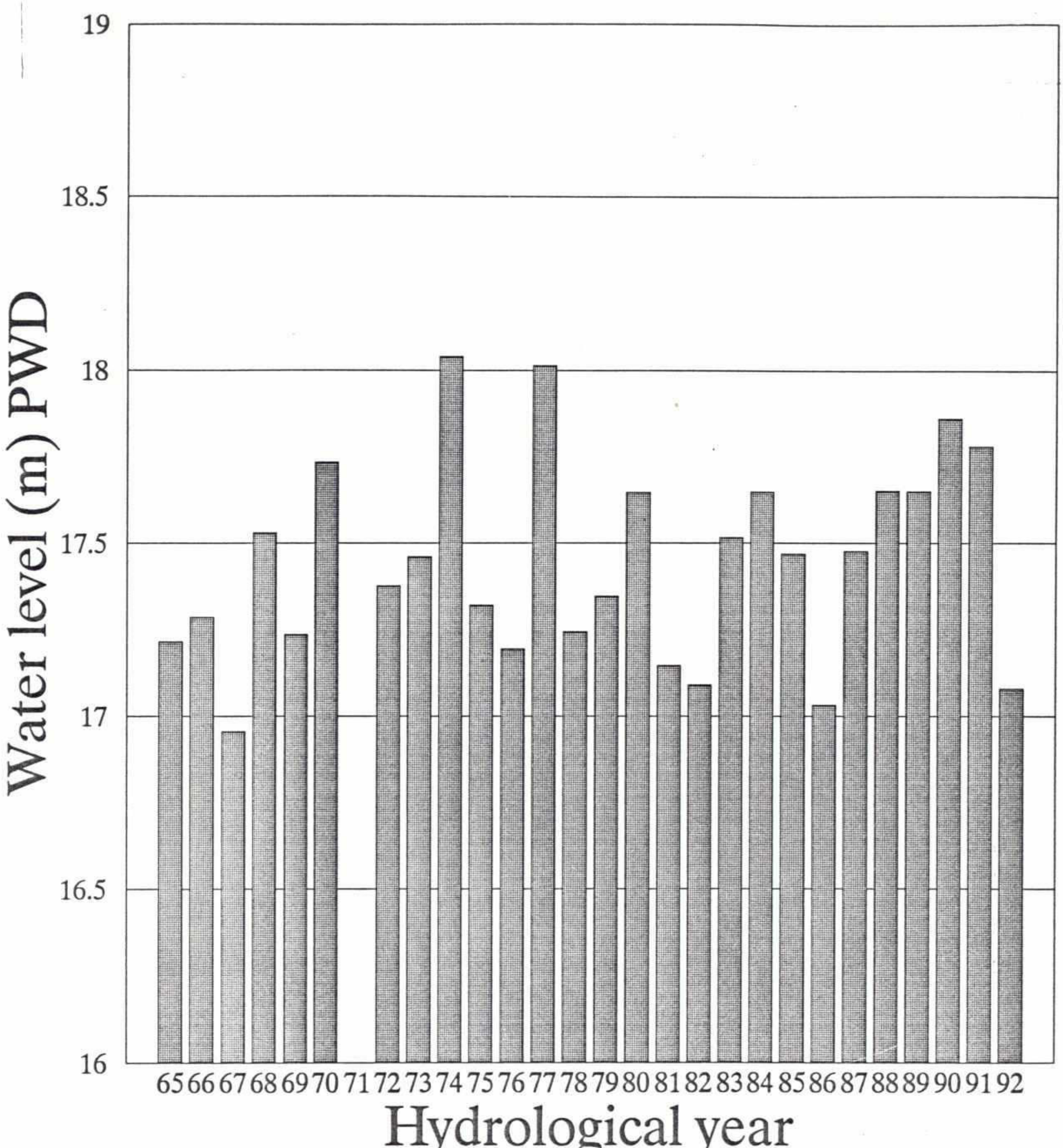


o Volume based on FAP24 rating curves; 1989-92 based on 1988 rating curve
o Flood season=May 1-Nov 30;data are missing in 71 and 79



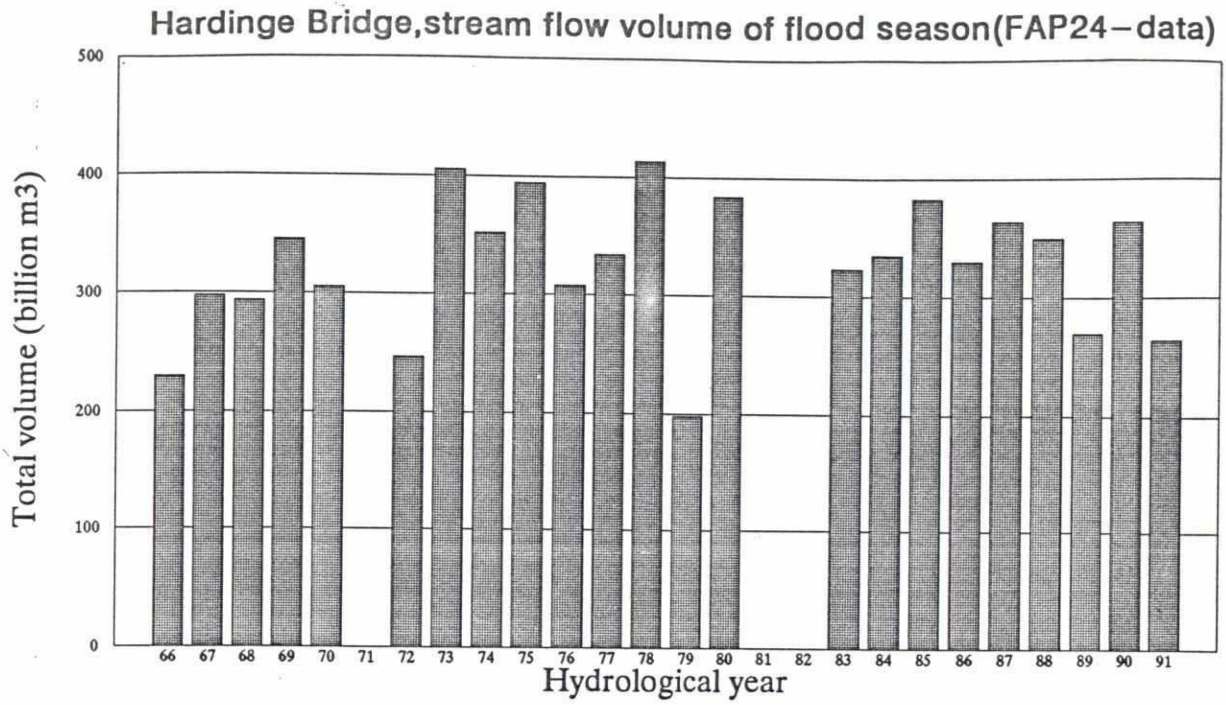
o Based on Mean Daily Discharge data from BWDB
o Flood season=May 1-Nov 30

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Bahadurabad. Comparison of BWDB and FAP 24 estimates of flow volumes.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.19
Scale:	Init:		

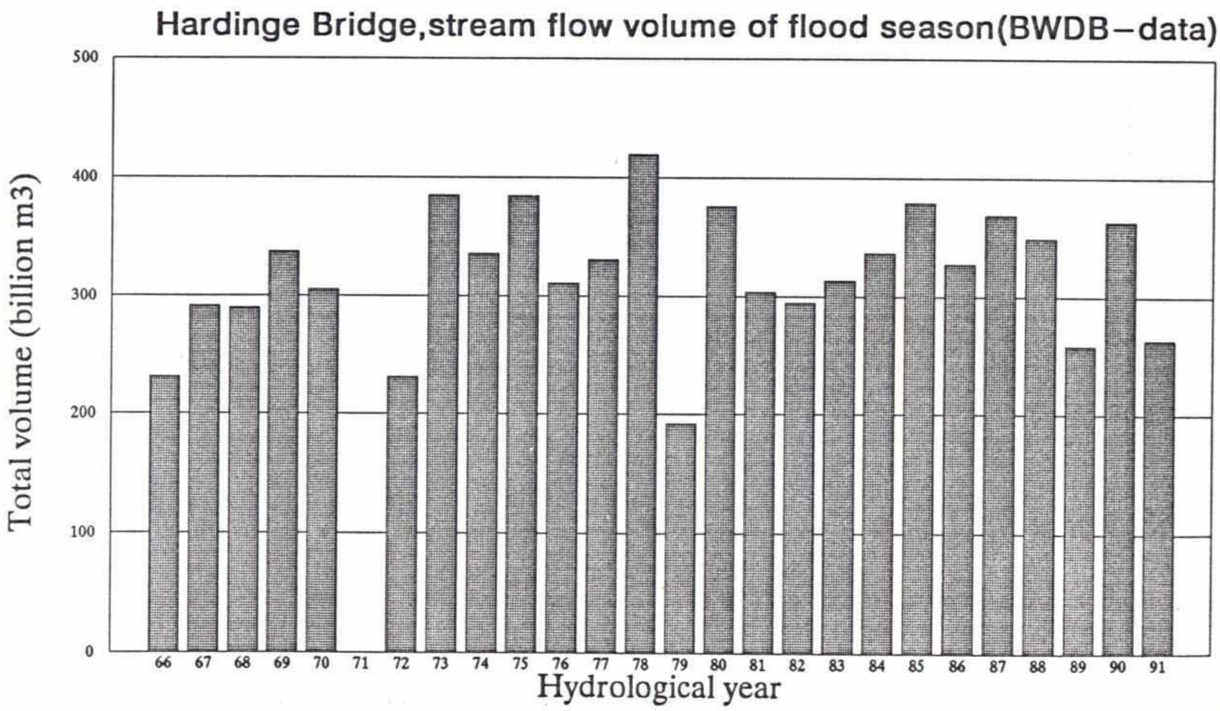


o Based on Mean Daily Water level data
o Flood season = May 1–Nov 30

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Bahadurabad. Average water-levels during flood season.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.20
Scale:	Init:		



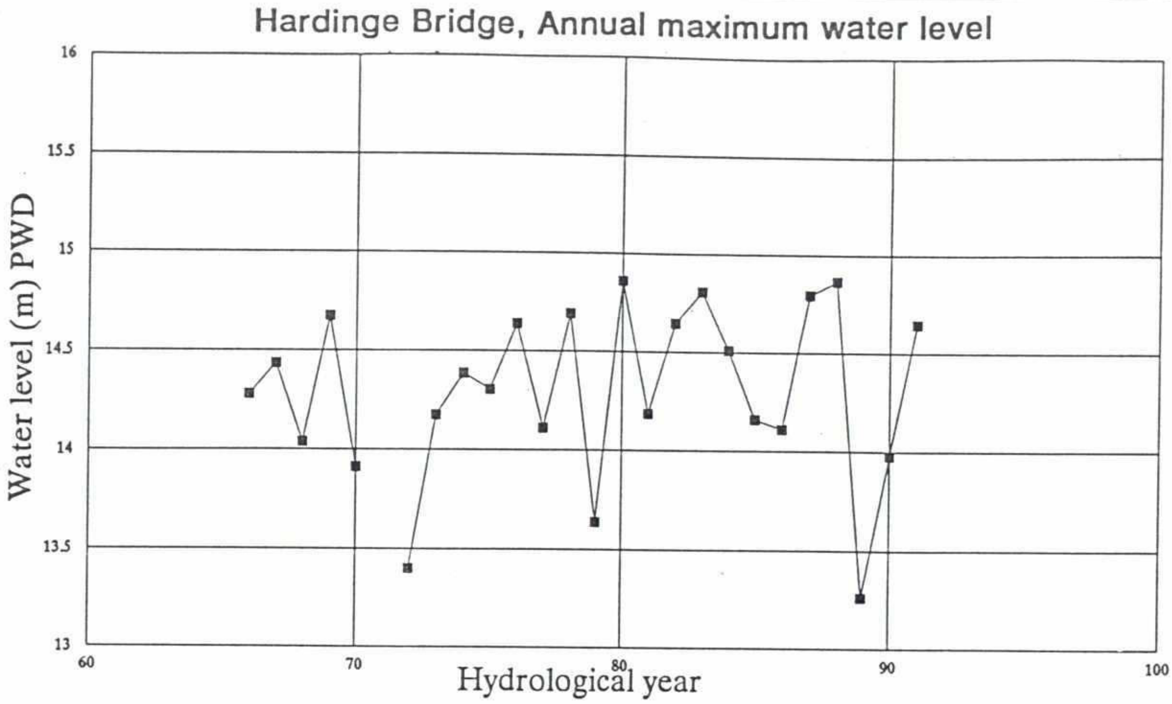
o Volume based on FAP24 rating curves
o Flood season=May 1-Nov 30;data are missing in 71,81 and 82



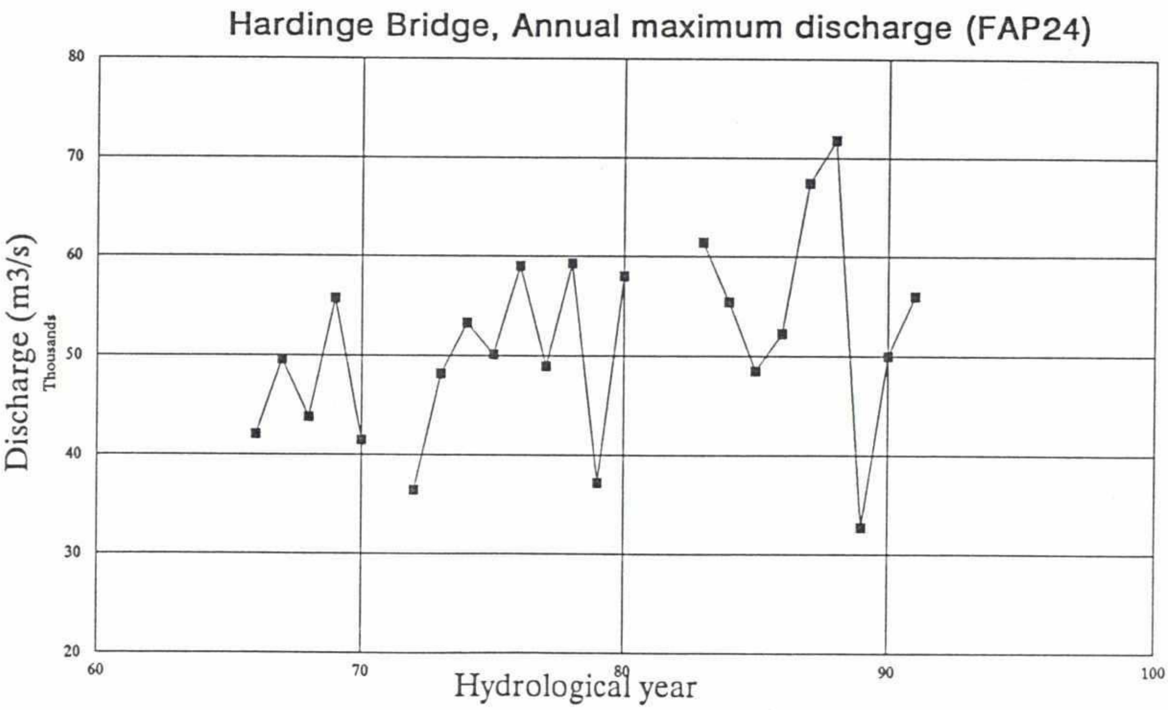
o Volume based on BWDB data
o Flood season=May 1-Nov 30

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Hardinge Bridge. Comparison of BWDB and FAP 24 estimates of flwo volumes.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.21
Scale:	Init:		

224

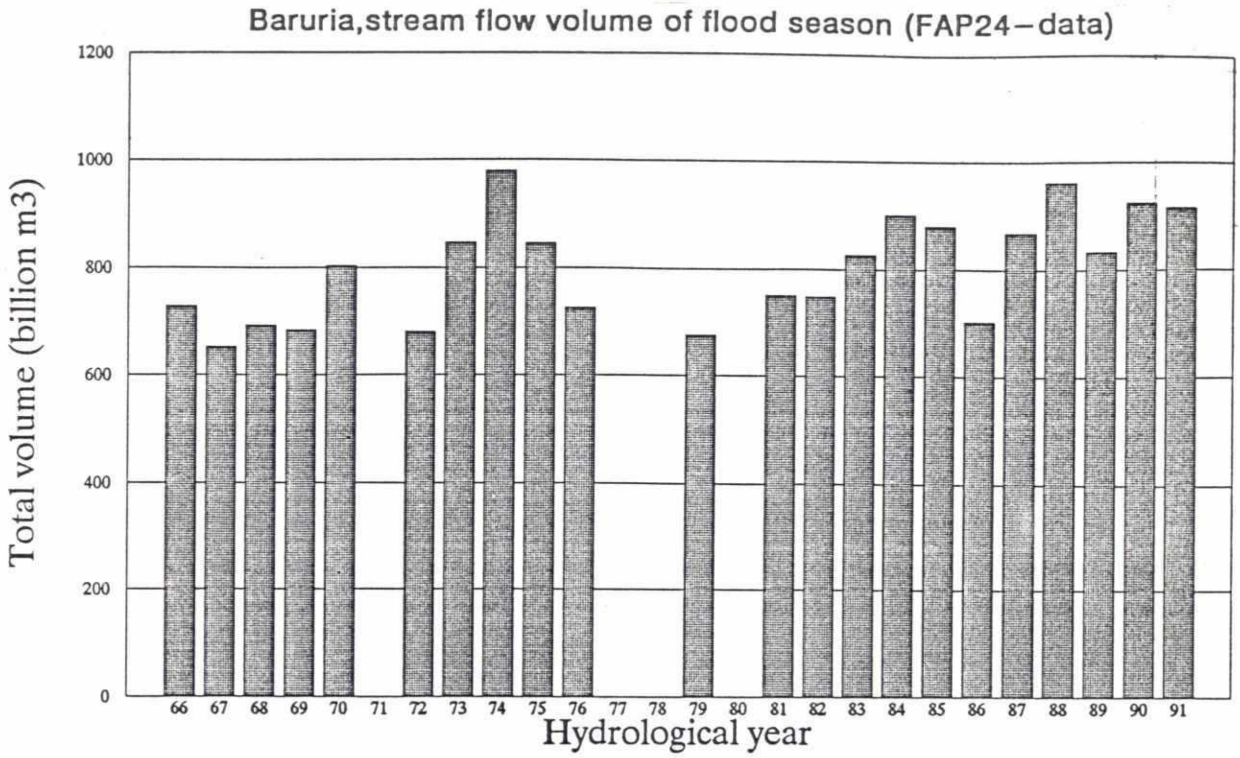


o Based on mean daily water level data, data is missing in 71

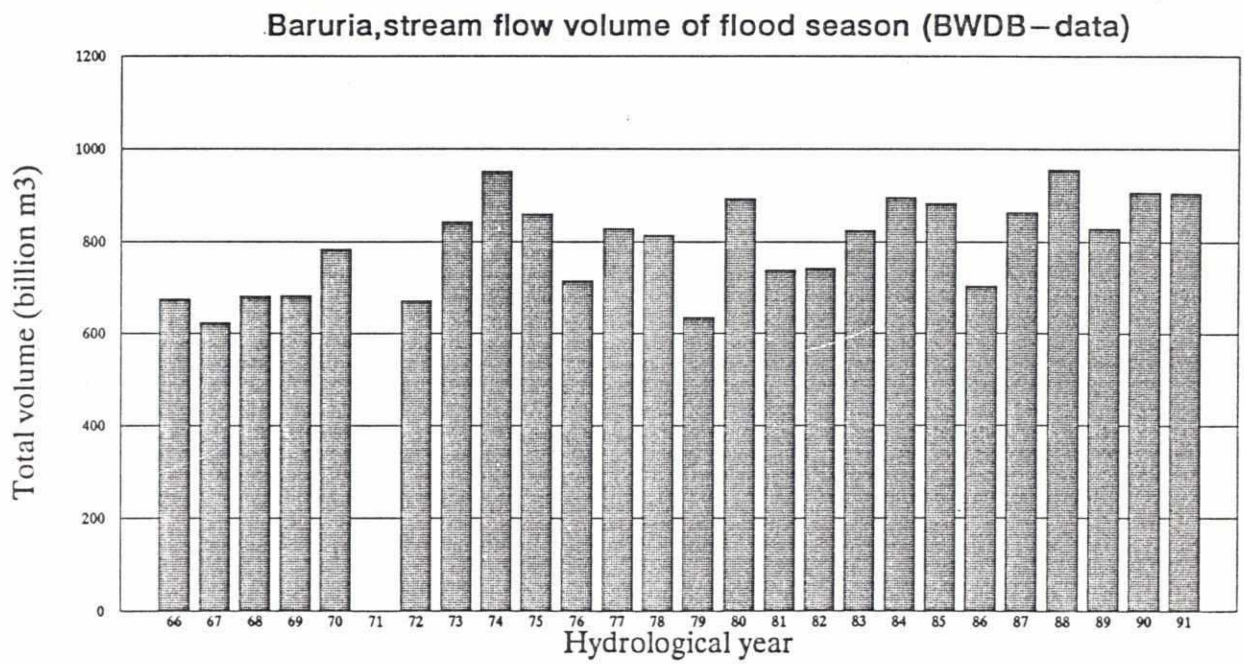


o Based on FAP24 rating curves
o data are missing in 71,81 and 82

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Hardinge Bridge. Annual maximum water-levels and discharges.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.22
Scale:	Init:		

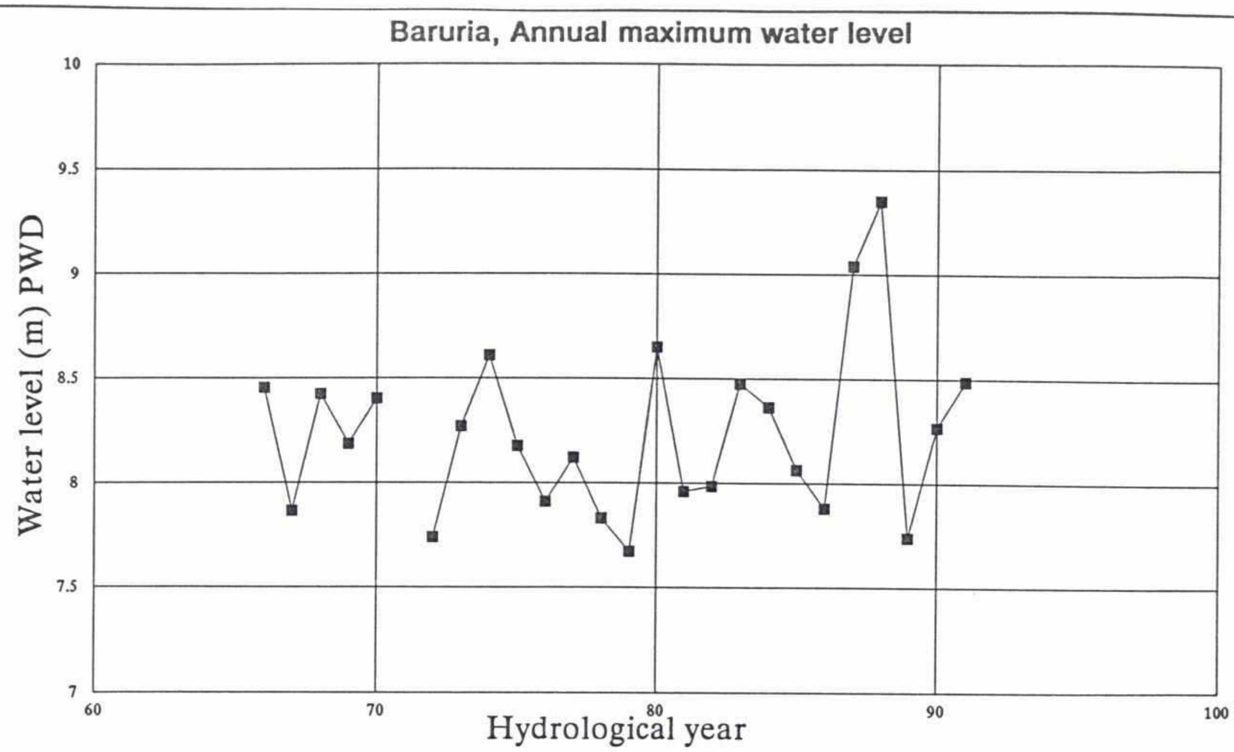


o Volume based on FAP24 rating curves
o Flood season=May 1-Nov 30; data are missing in 71,77,78 and 80

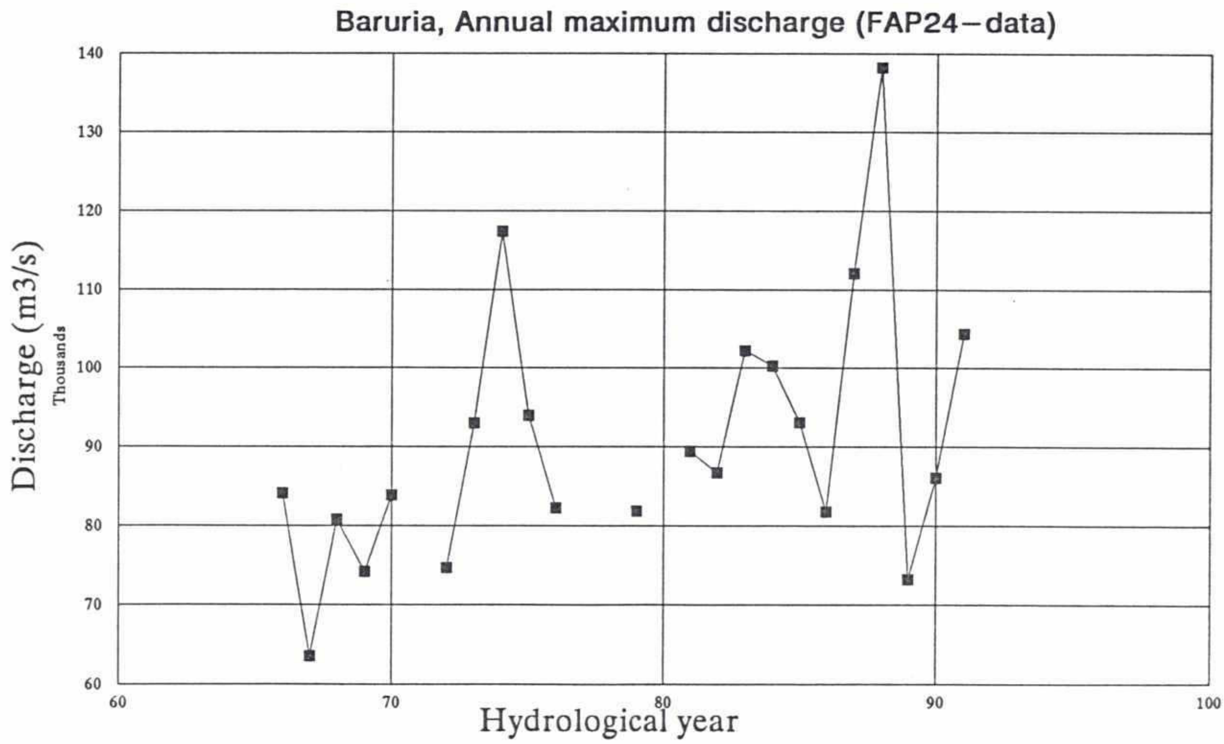


o Volume based on BWDB data
o Flood season=May 1-Nov 30

FAP 24 DELFT-DHI RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland		Baruria. Comparison of BWDB and FAP 24 estimates of flow volumes.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.23
Scale:	Init:		



o Based on mean daily waterlevel data, data is missing in 71



o Based on FAP24 rating curves
o Data are missing in 71,77,78 and 80

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Baruria. Annual maximum water-levels and discharges.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.24
Scale:	Init:		

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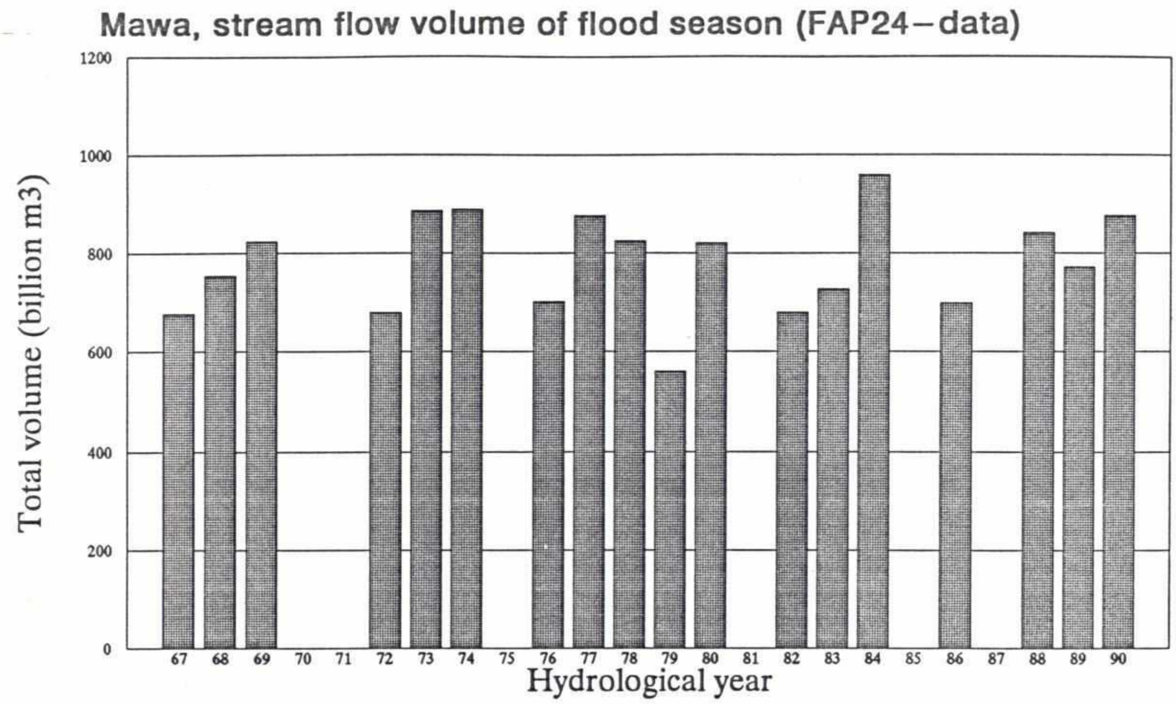
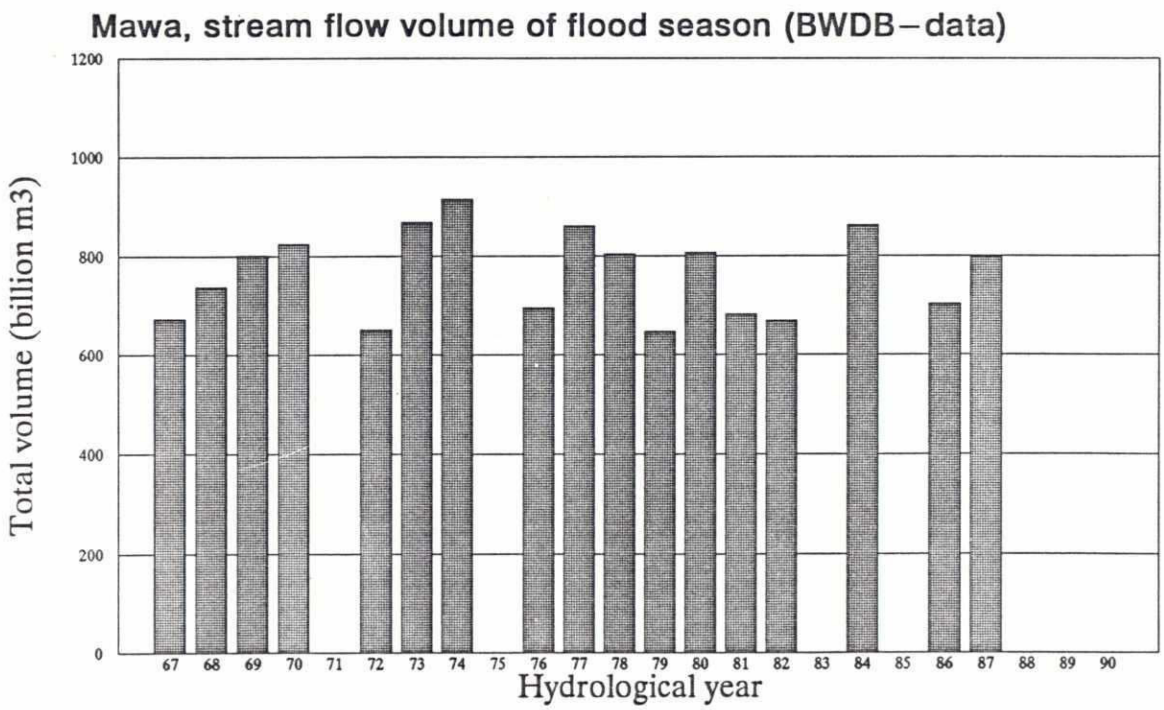
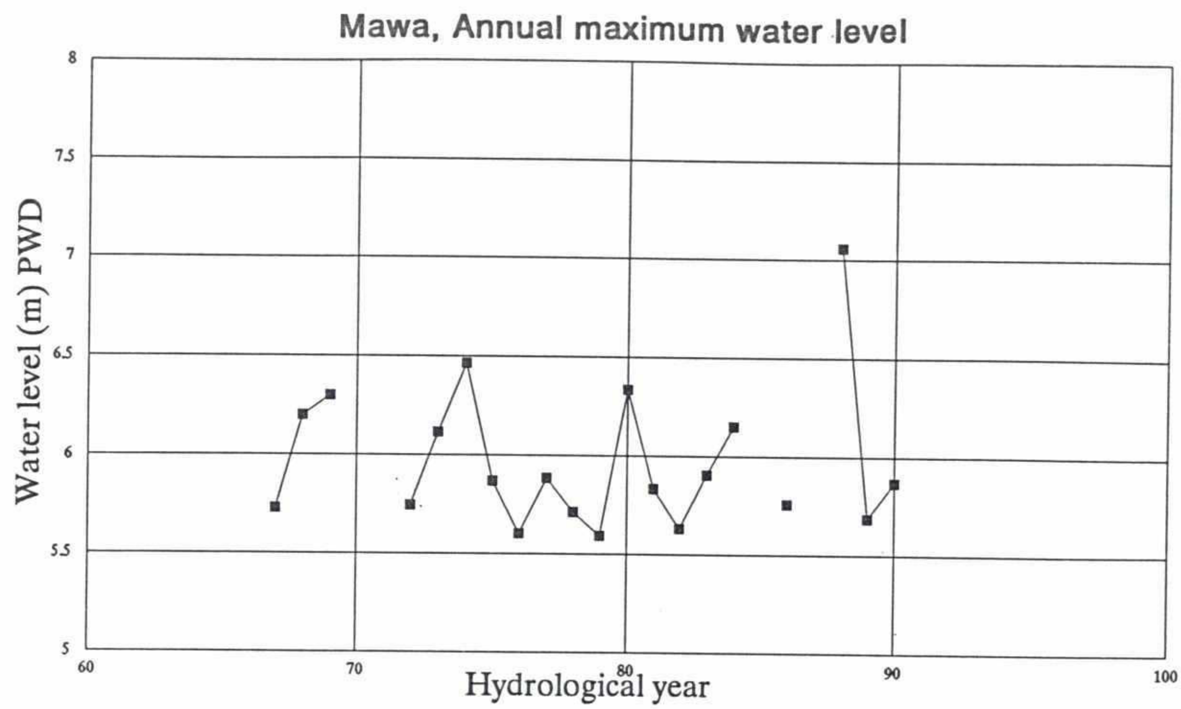


o Volume based on FAP24 rating curves
o Flood season=May 1–Nov 30; data are missing in 70,71,75,81,85 and 87

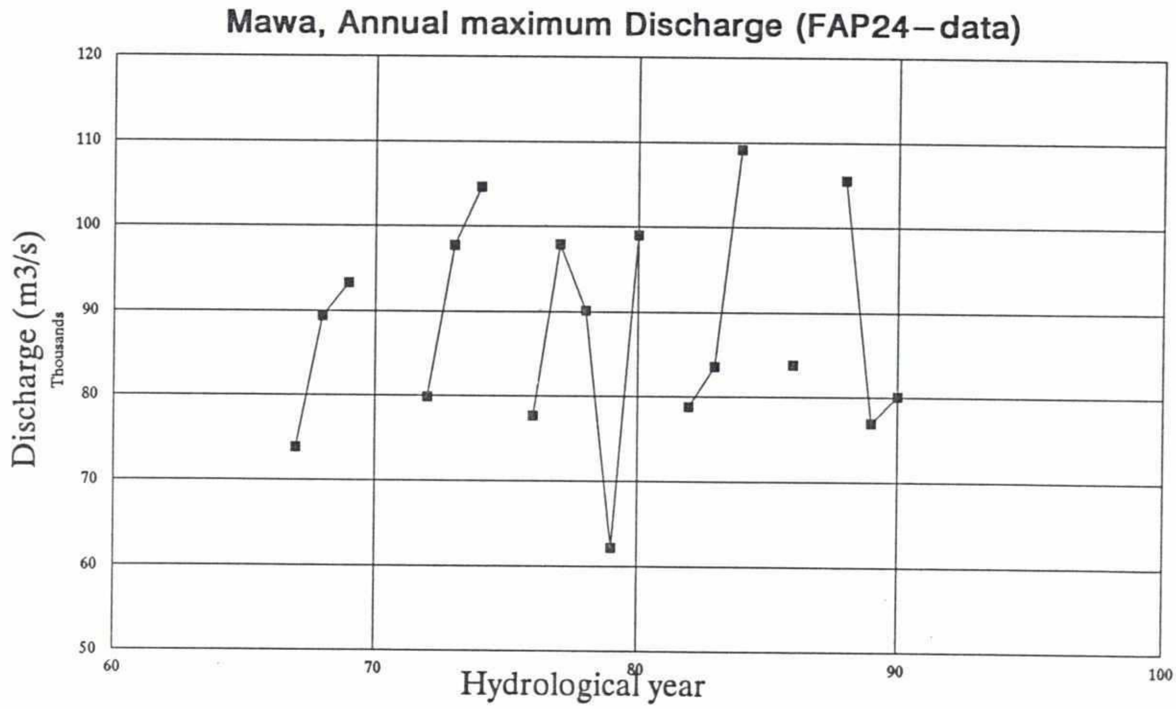


o Volume based on BWDB data
o Flood season=May 1–Nov 30; data are missing in 71,75,83,85, and 88–90

FAP 24 RIVER SURVEY PROJECT DELFT-DHI Delft Hydraulics Danish Hydraulic Institute in association with Osiris Approtech/Hydroland		Mawa. Comparison of BWDB and FAP 24 estimates of flow volumes.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.25
Scale:	Init:		

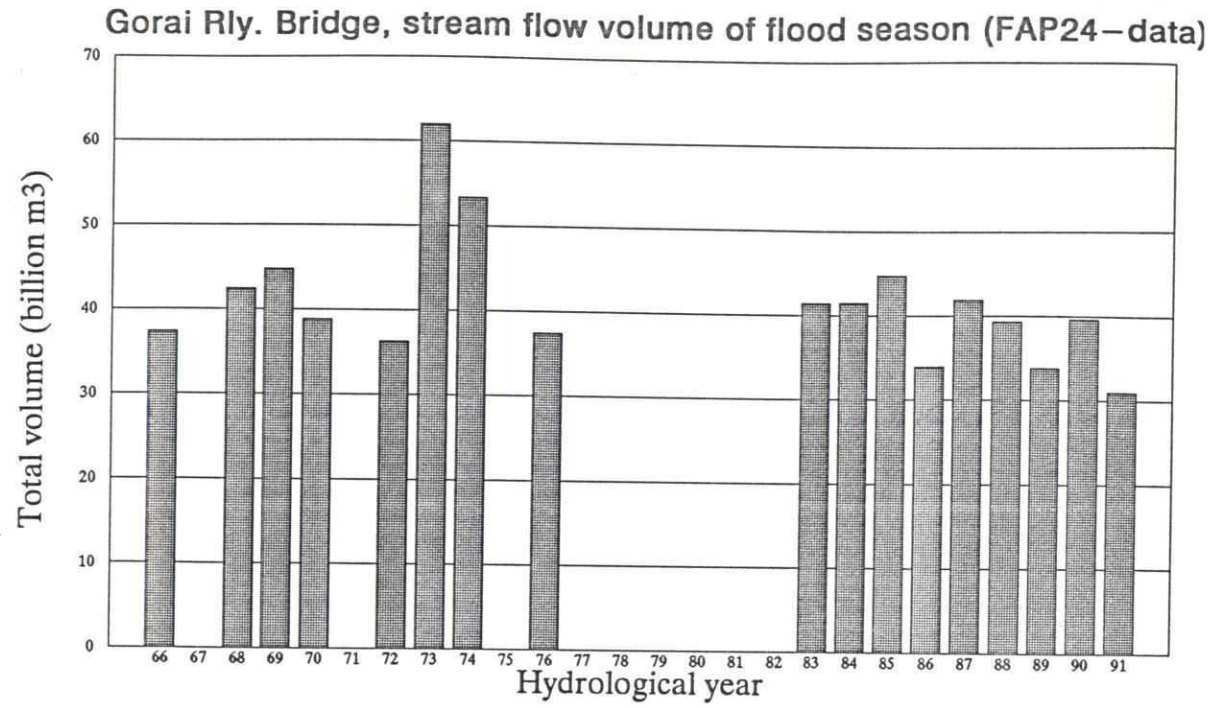


o Data is missing in 71

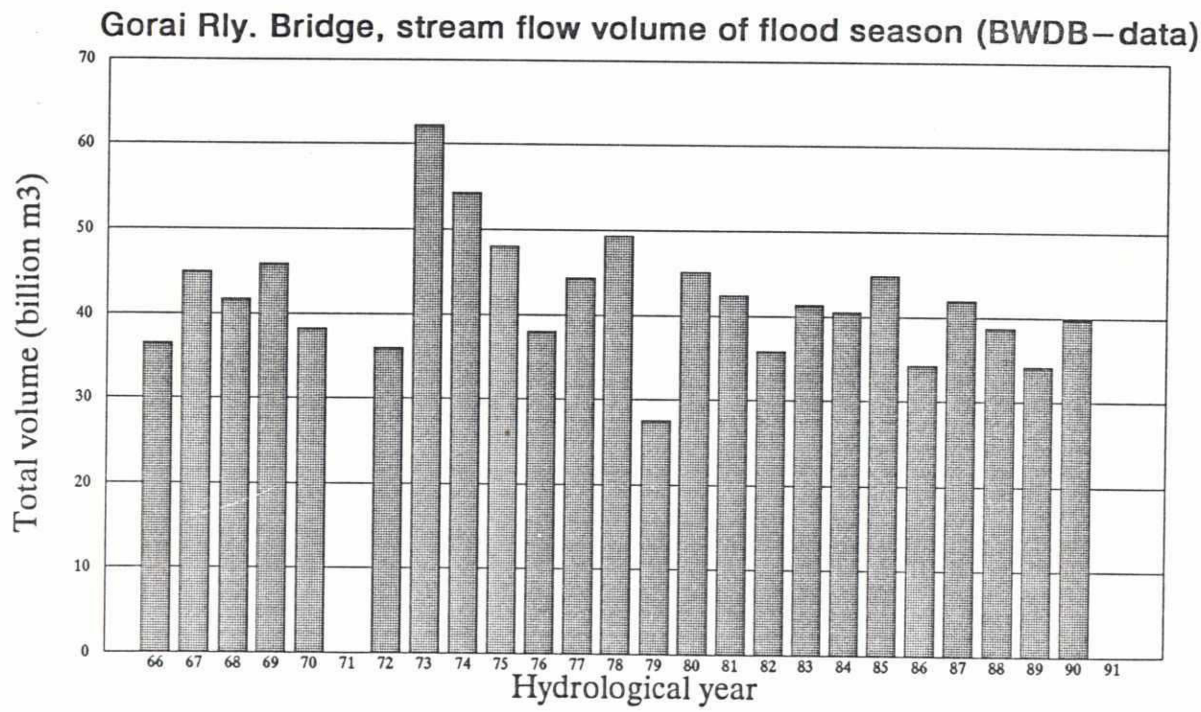


o Based on FAP24 rating curves
o Data are missing in 70,71,75,81,85 and 87

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Mawa. Annual maximum water-levels and discharges.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.26
Scale:	Init:		

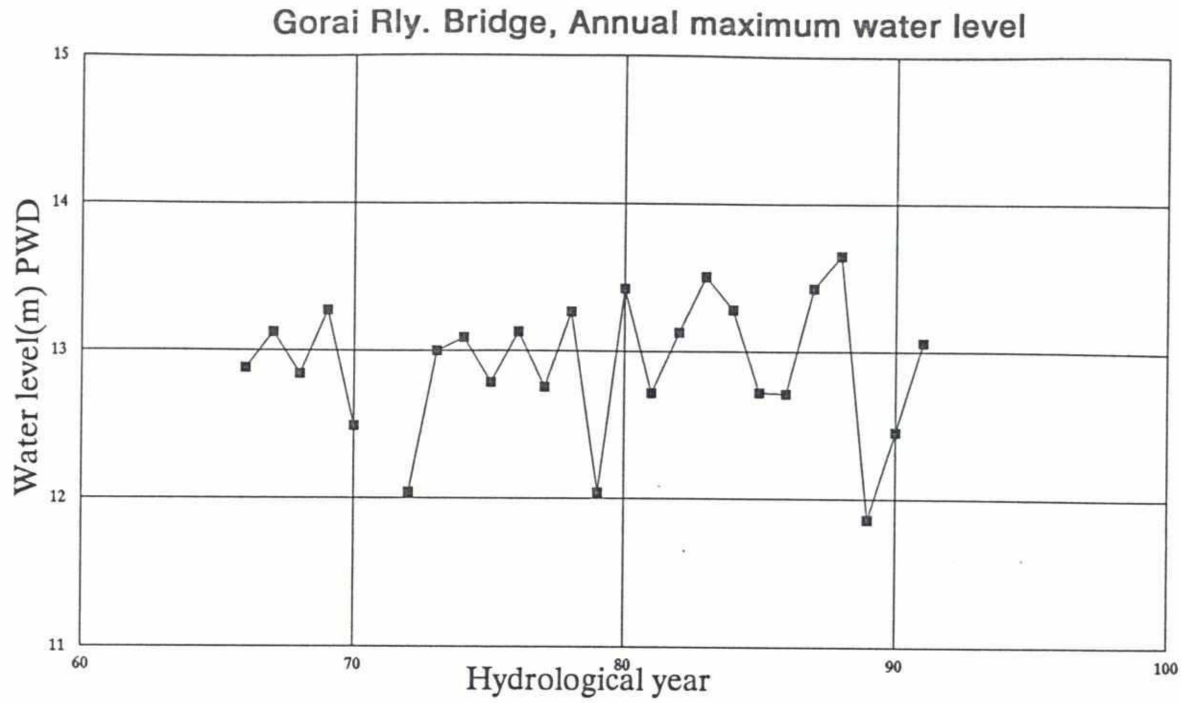


o Volume based on FAP24 rating curves
o Flood season=May 1–Nov 30; data are missing in 67,71,75, and 77–82

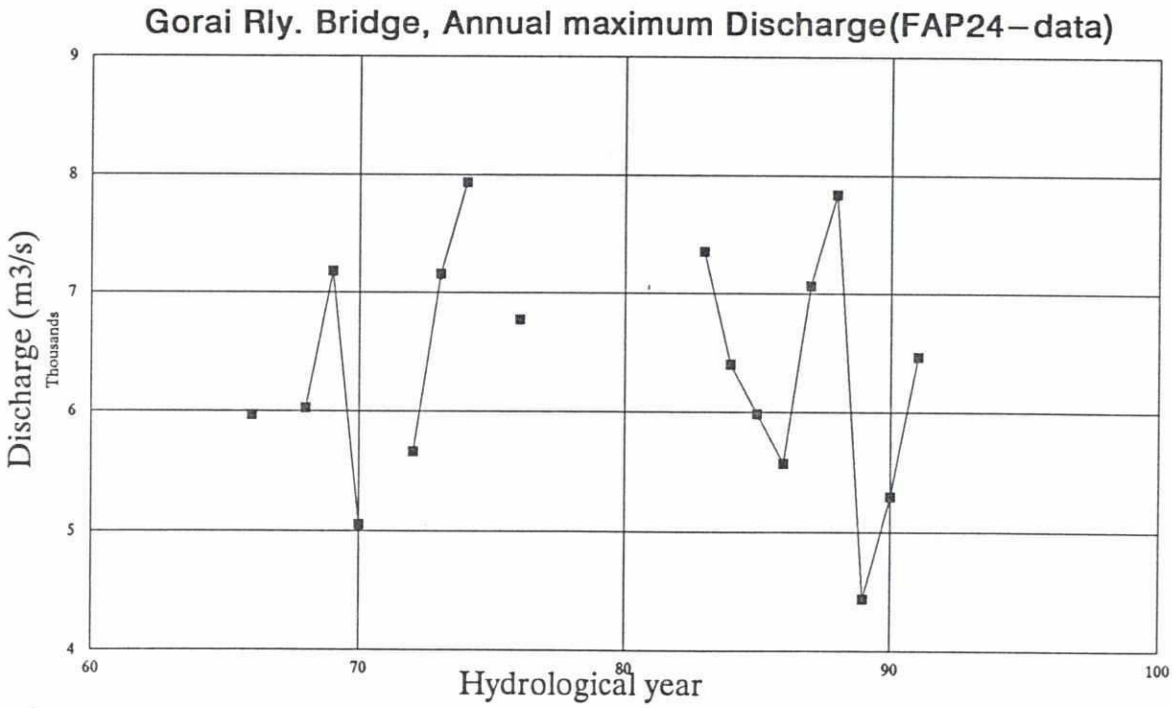


o Volume based on BWDB data
o Flood season=May 1–Nov 30; data are missing in 71 and 91

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics Danish Hydraulic Institute in association with Osiris Approtech Hydroland DELFT-DHI		Gorai Railway Bridge. Comparison of BWDB and FAP 24 estimates of flow volumes.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.27
Scale:	Init:		

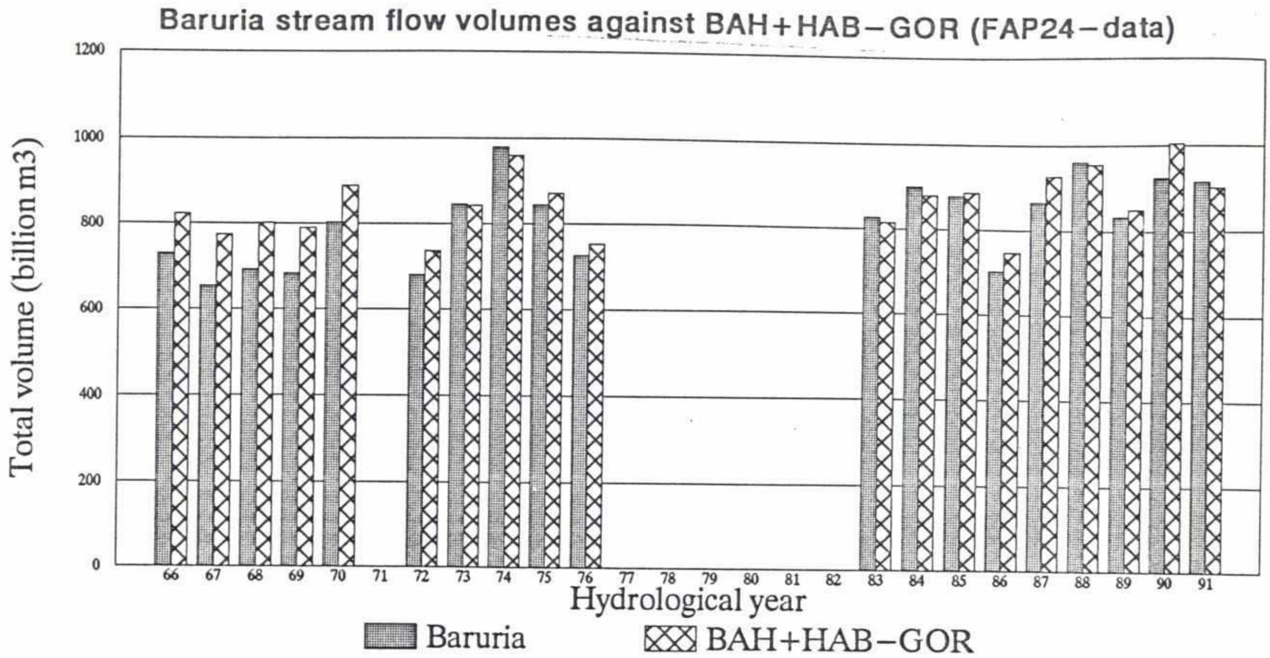


o Data is missing in 71

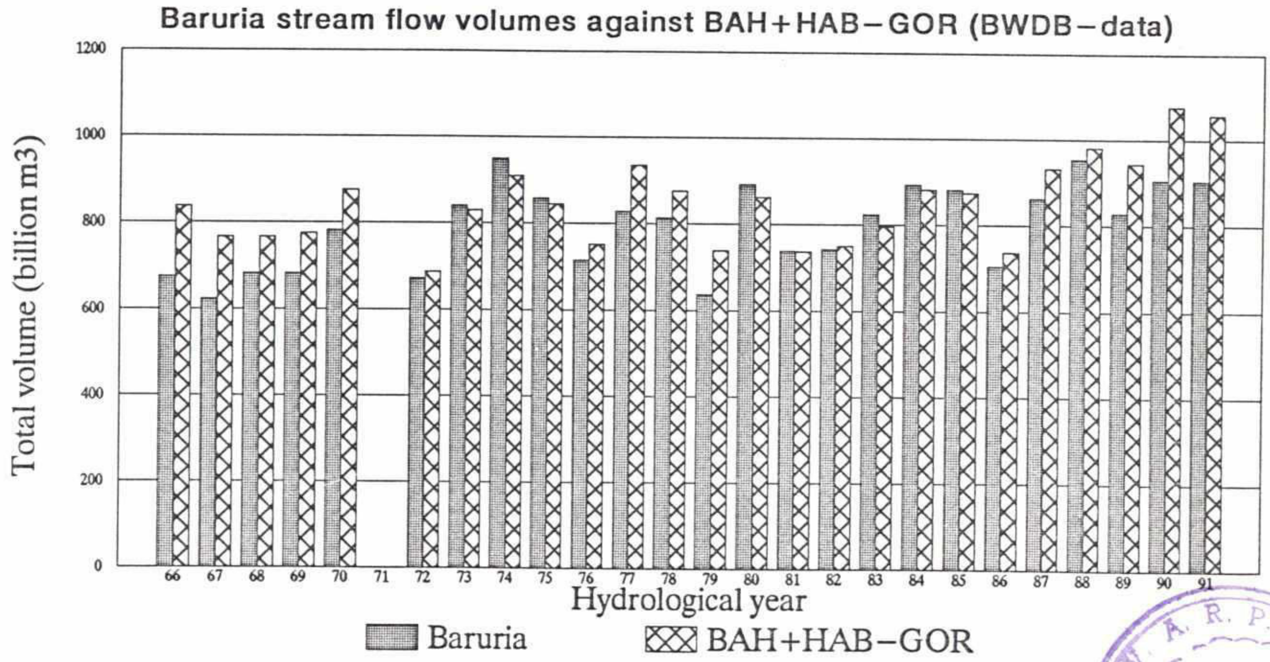


o Based on FAP24 rating curves
o Dàta are missing in 67,71,75, and 77–82

FAP 24 DELFT-DHI — RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland		Gorai Railway Bridge. Annual maximum water-levels and discharges.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.28
Scale:	Init:		



o Volume based on FAP24 rating curves
o Flood season=May 1−Nov 30



o Volume based on BWDB data
o Flood season=May 1−Nov 30

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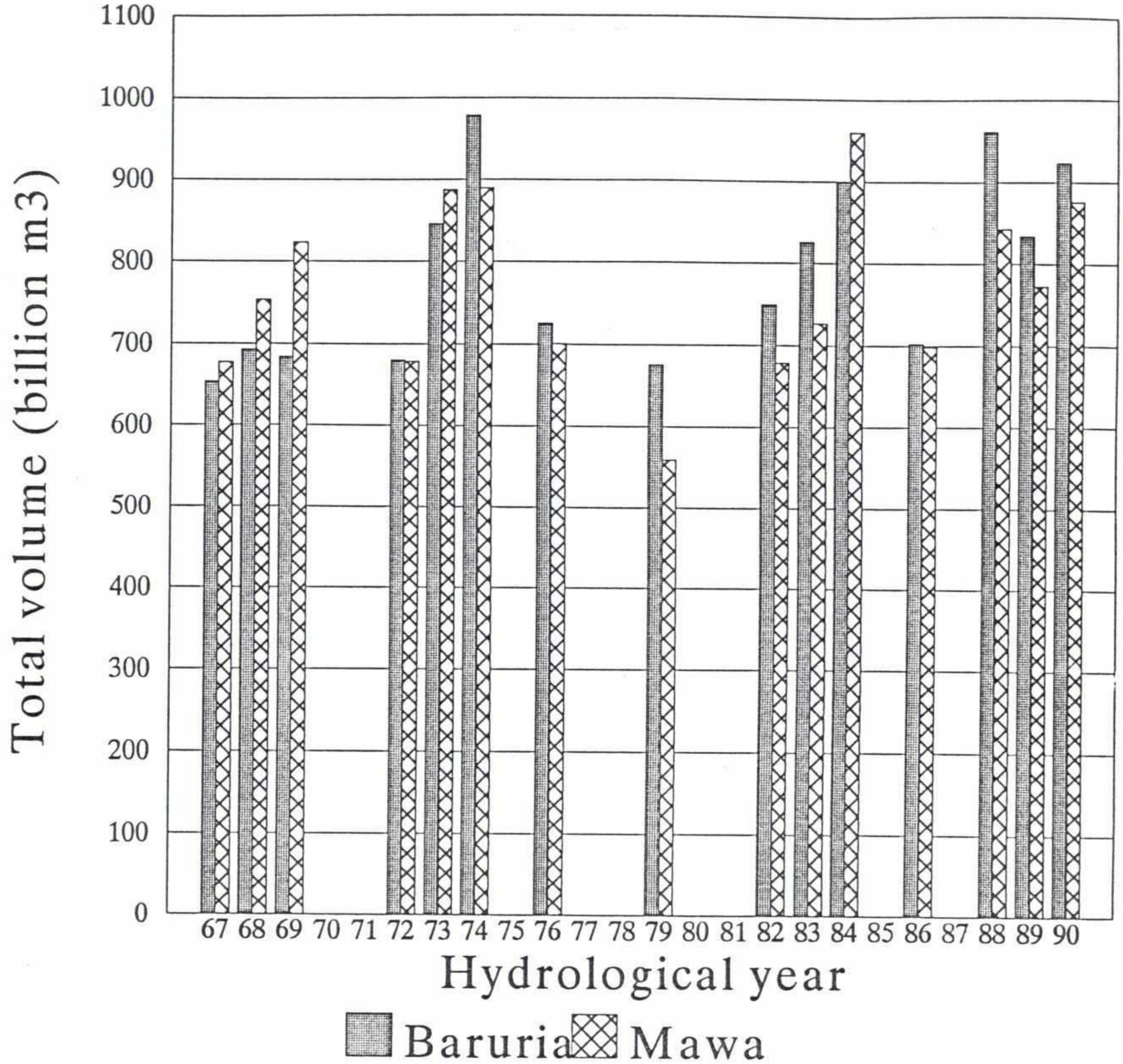
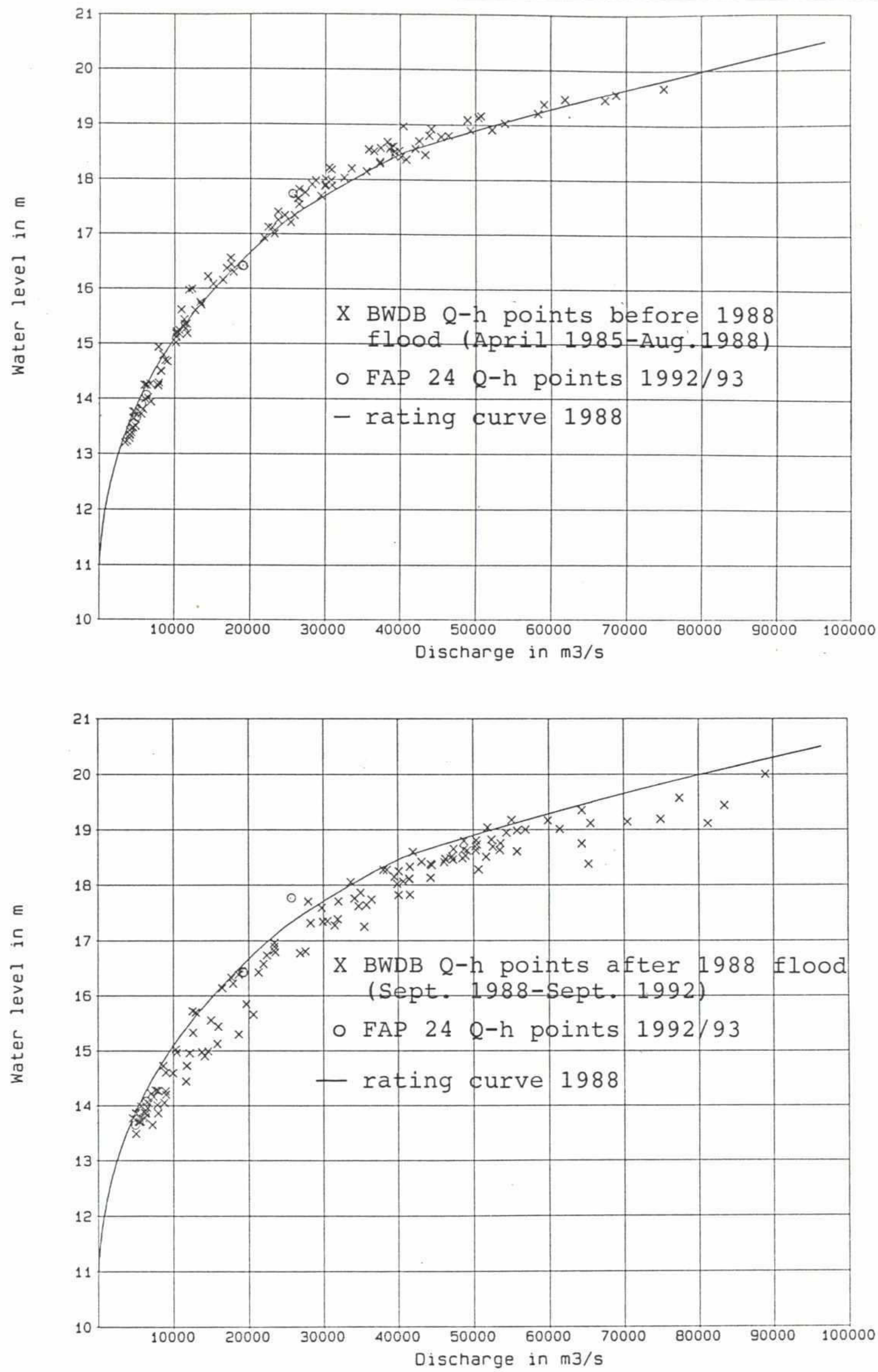
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics Danish Hydraulic Institute in association with Osiris Approtech Hydroland DELFT−DHI		Comparison of flow volumes of Baruria with total volumes of Bahadurabad + Hardinge Bridge - Gorai Railway Bridge.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.29
Scale:	Init:		



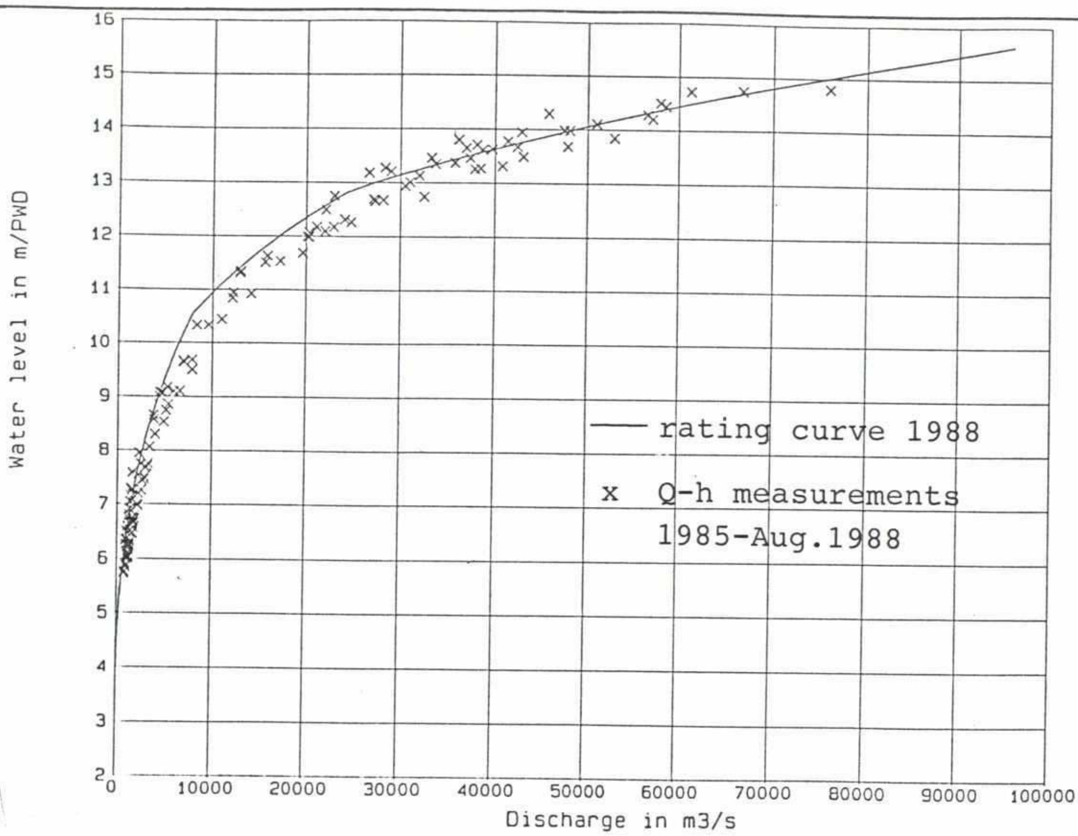
o Volume based on FAP24 rating curves
o Flood season=May 1–Nov 30

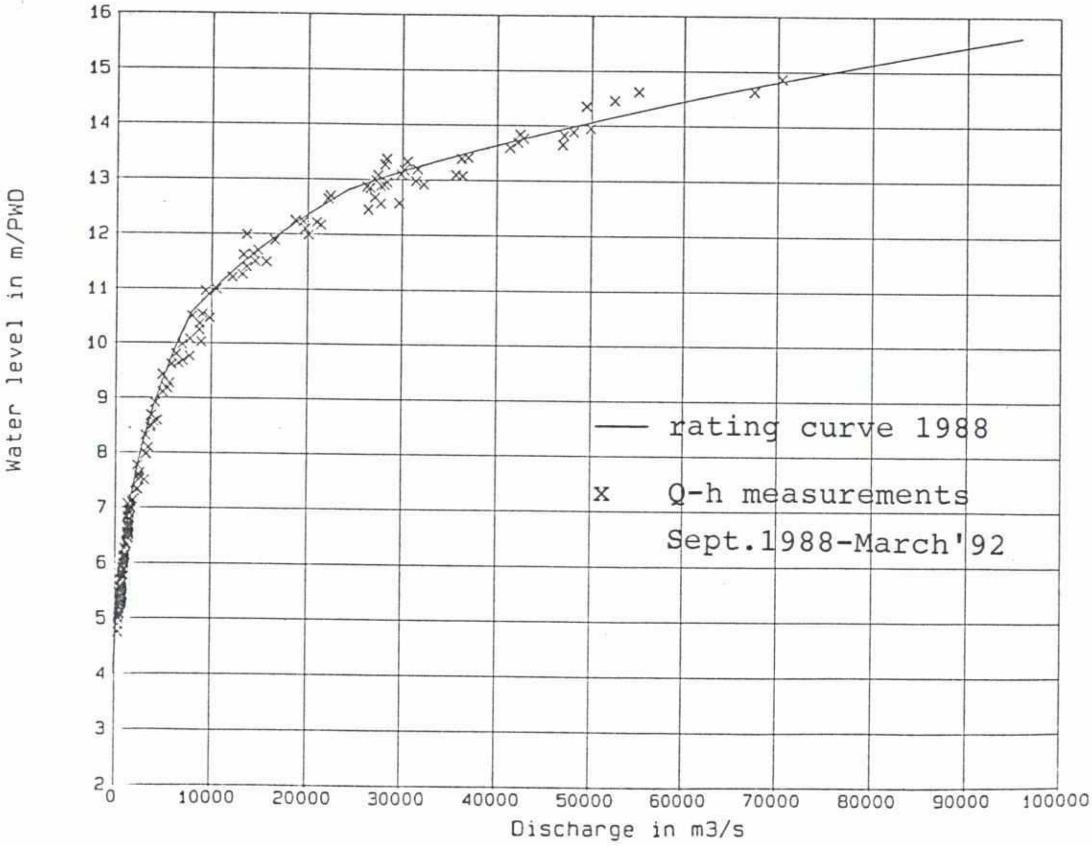
FAP 24 DELFT-DHI RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland		Comparison of stream flow volumes at Baruria and Mawa for the flood season.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.29a
Scale:	Init:		

222



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Bahadurabad. Comparison of Q-h measurements before and after 1988 flood.	
File:	Date:	Hydrological Study Phase 1	Fig. 5.30
Scale:	Init:		





FAP 24 RIVER SURVEY PROJECT Delft Hydraulics Danish Hydraulic Institute in association with Osiris Approtech Hydroland DELFT-DHI	Hardinge Bridge. Comparison of Q-h measurements before and after August 1988 flood.

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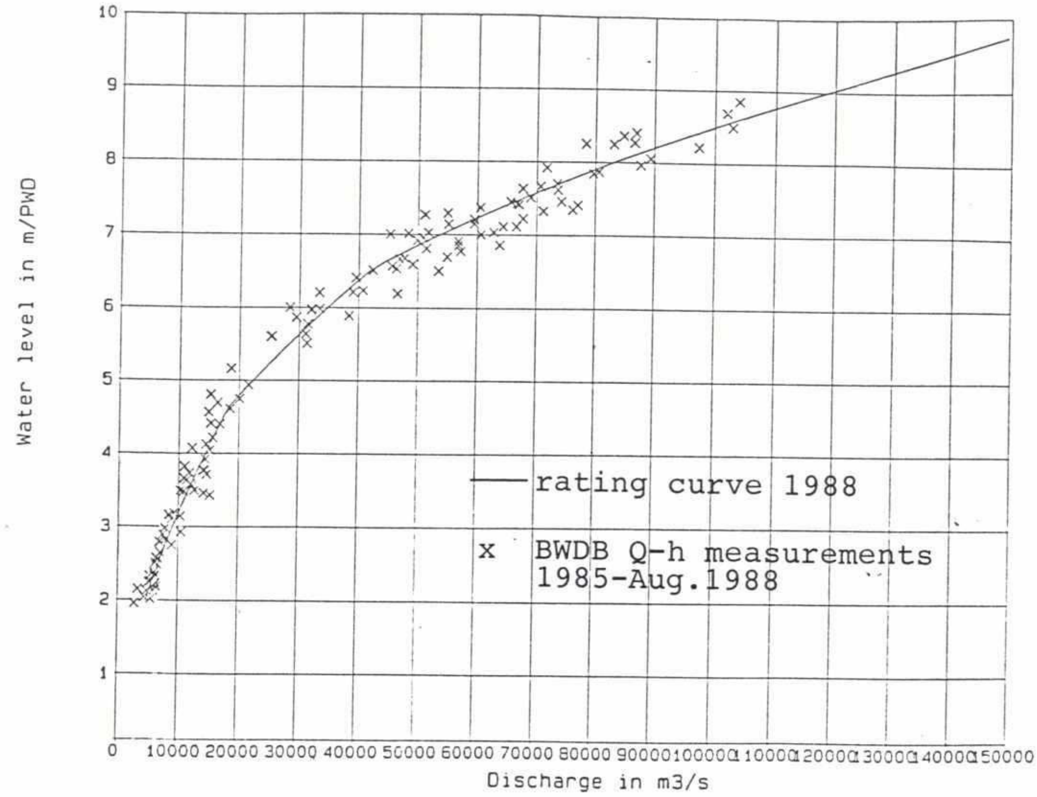

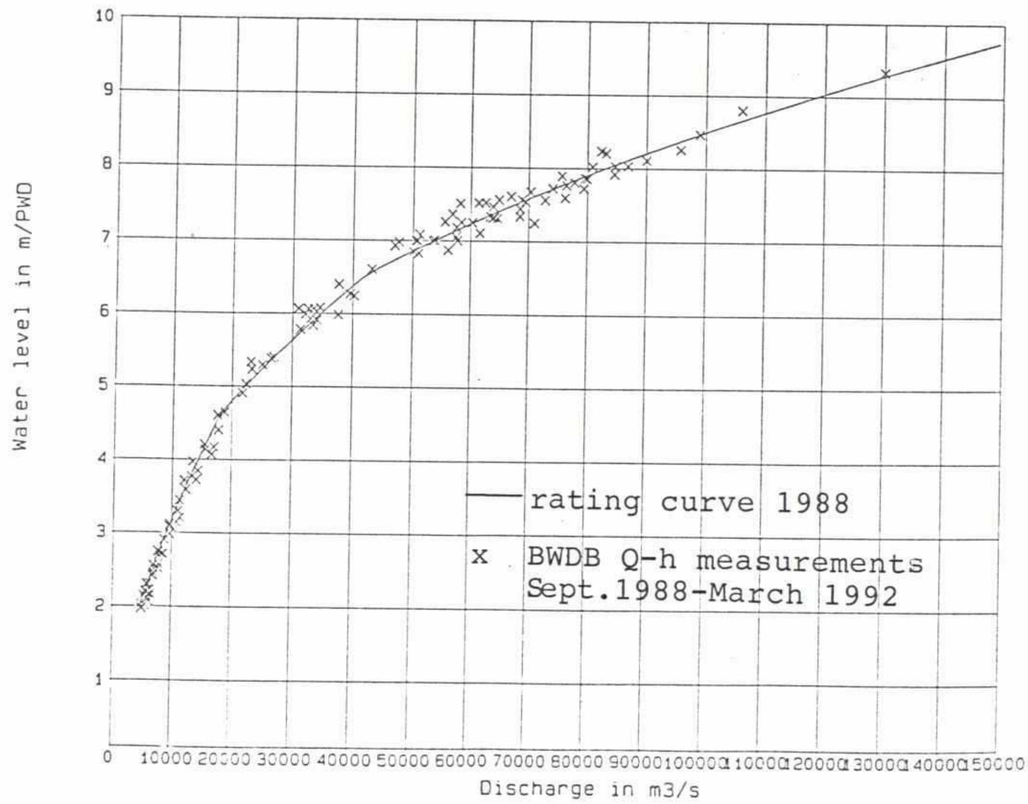

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Baruria. Comparison of Q-h measurements before and after 1988 flood.	
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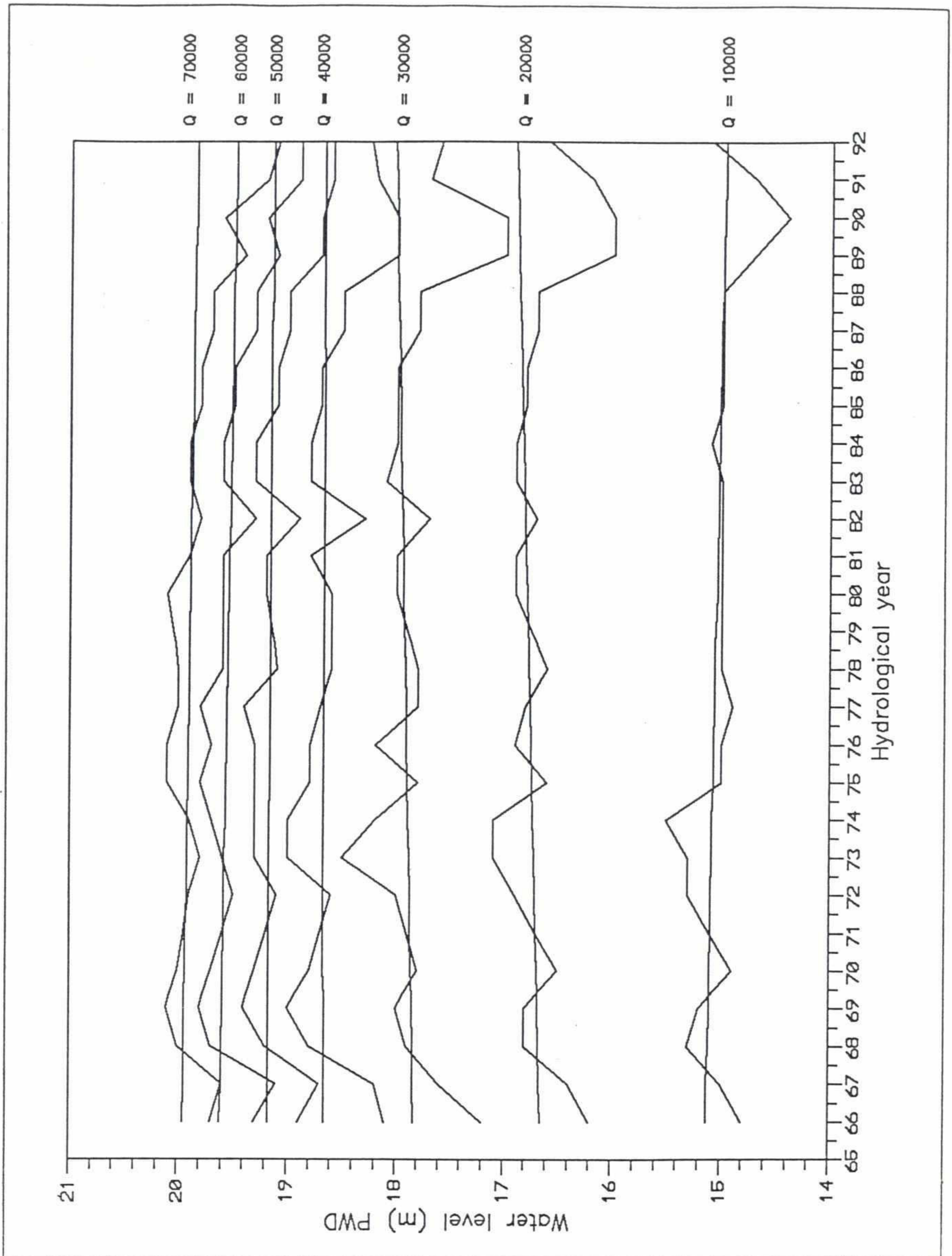
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Bahadurabad. Specific gauge analysis 1966-92	
File:	Date:	Hydrological Study Phase 1	Fig. 5.33
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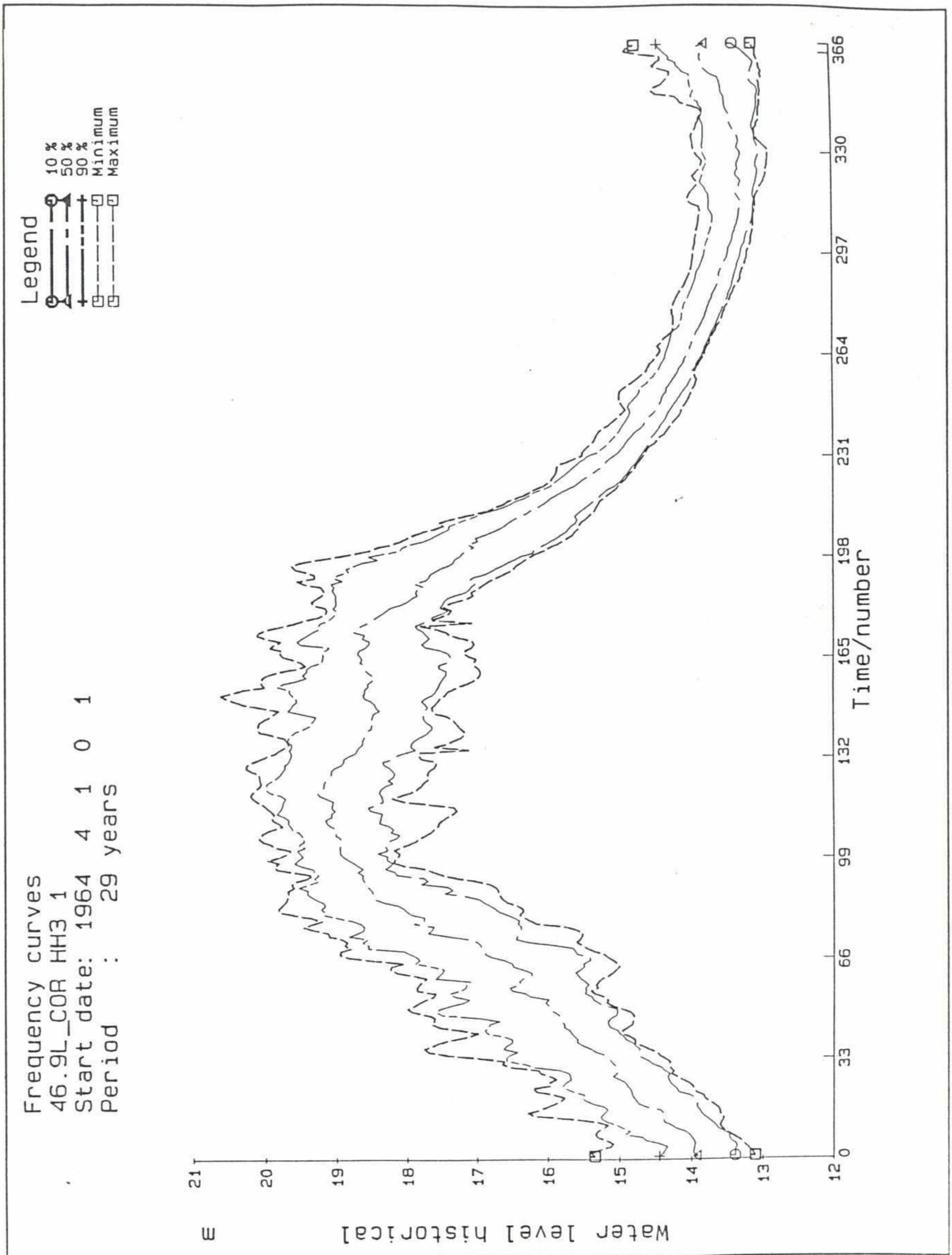

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Bahadurabad. Frequency curves for water-levels.	
File:	Date:	Hydrological Study Phase 1	Fig. 6.1
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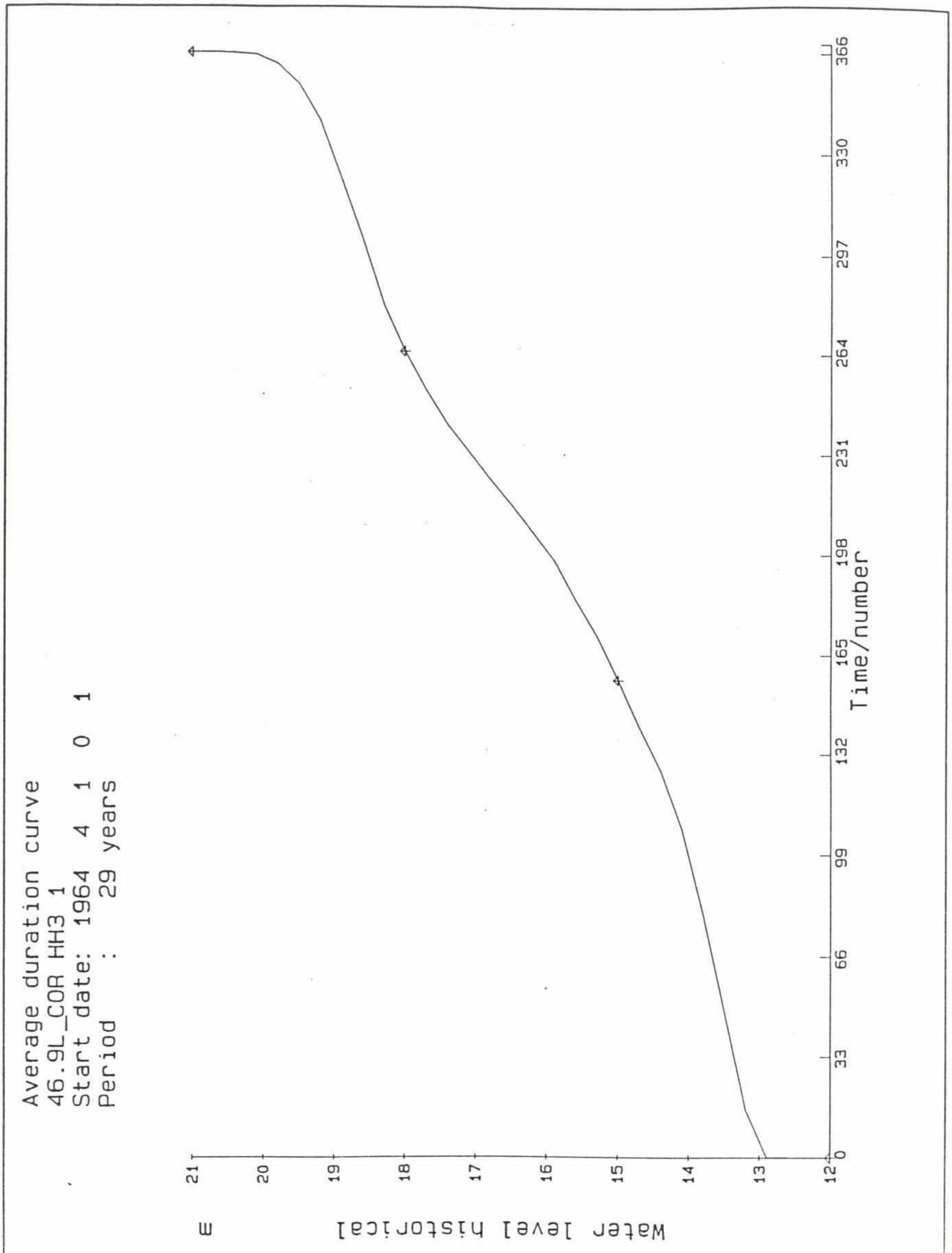

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI	Bahadurabad. Duration curve for water-levels.

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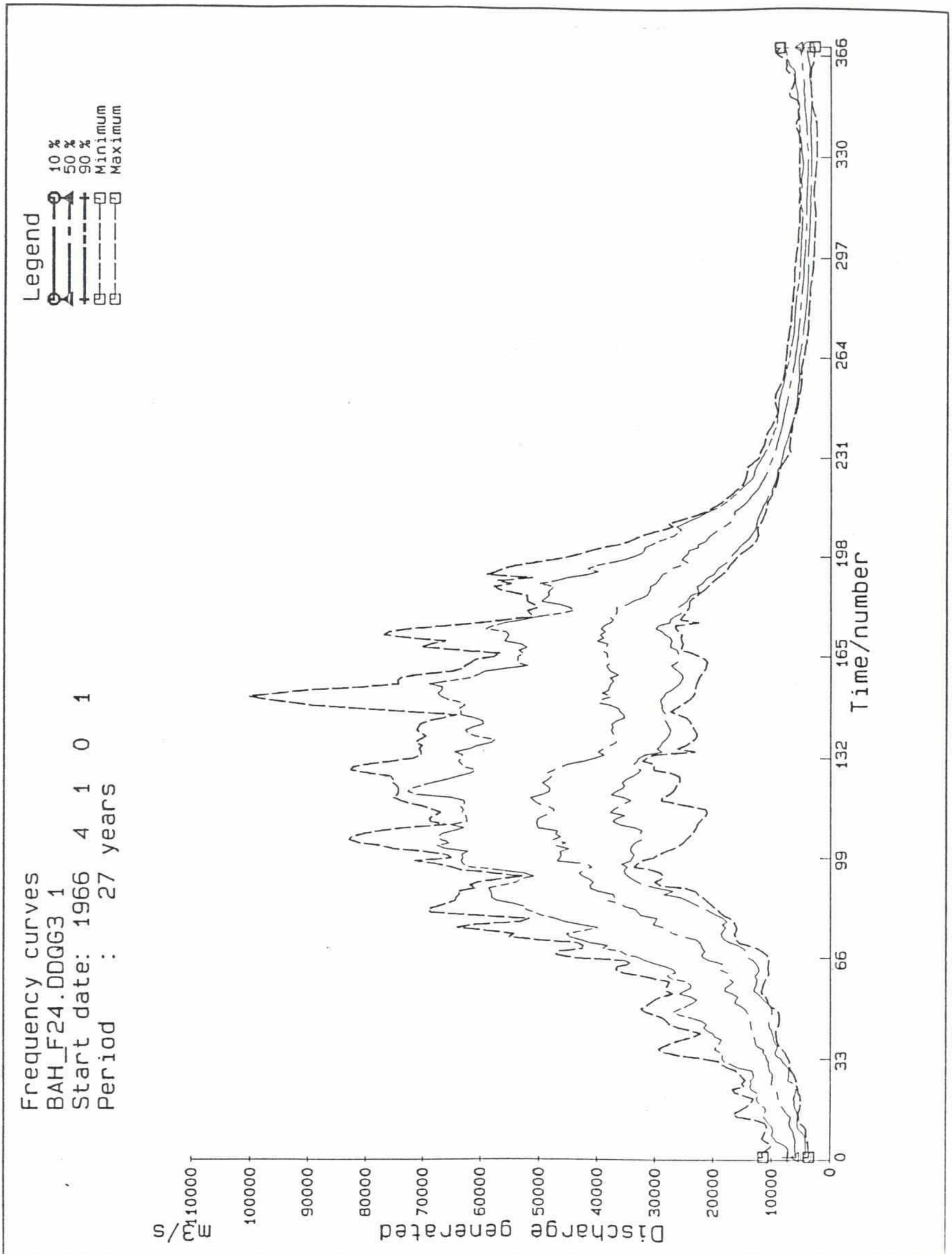
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Bahadurabad. Frequency curves for discharges.	
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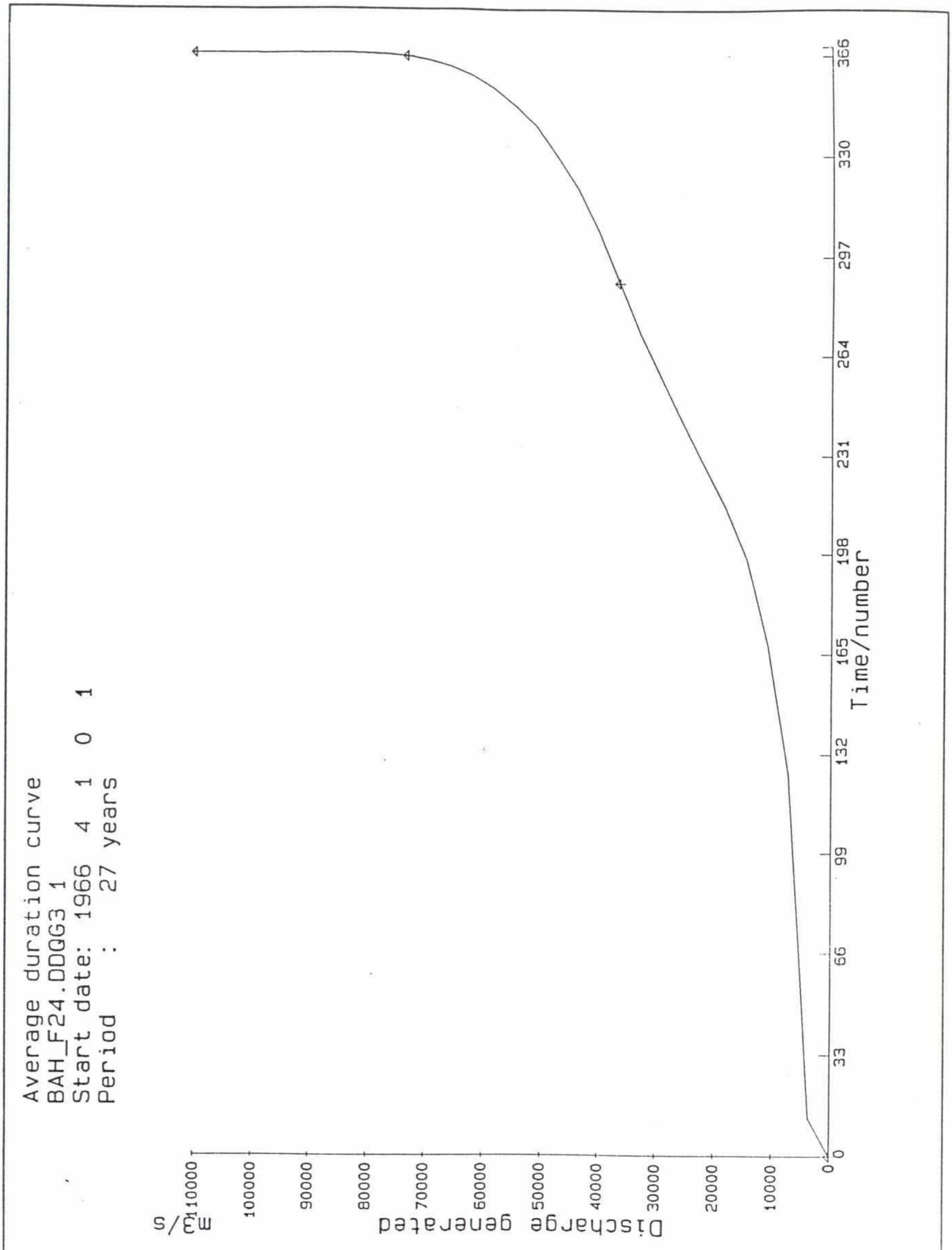

FAP 24 RIVER SURVEY PROJECT DELFT-DHI Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland		Bahadurabad. Duration curve for discharges.	
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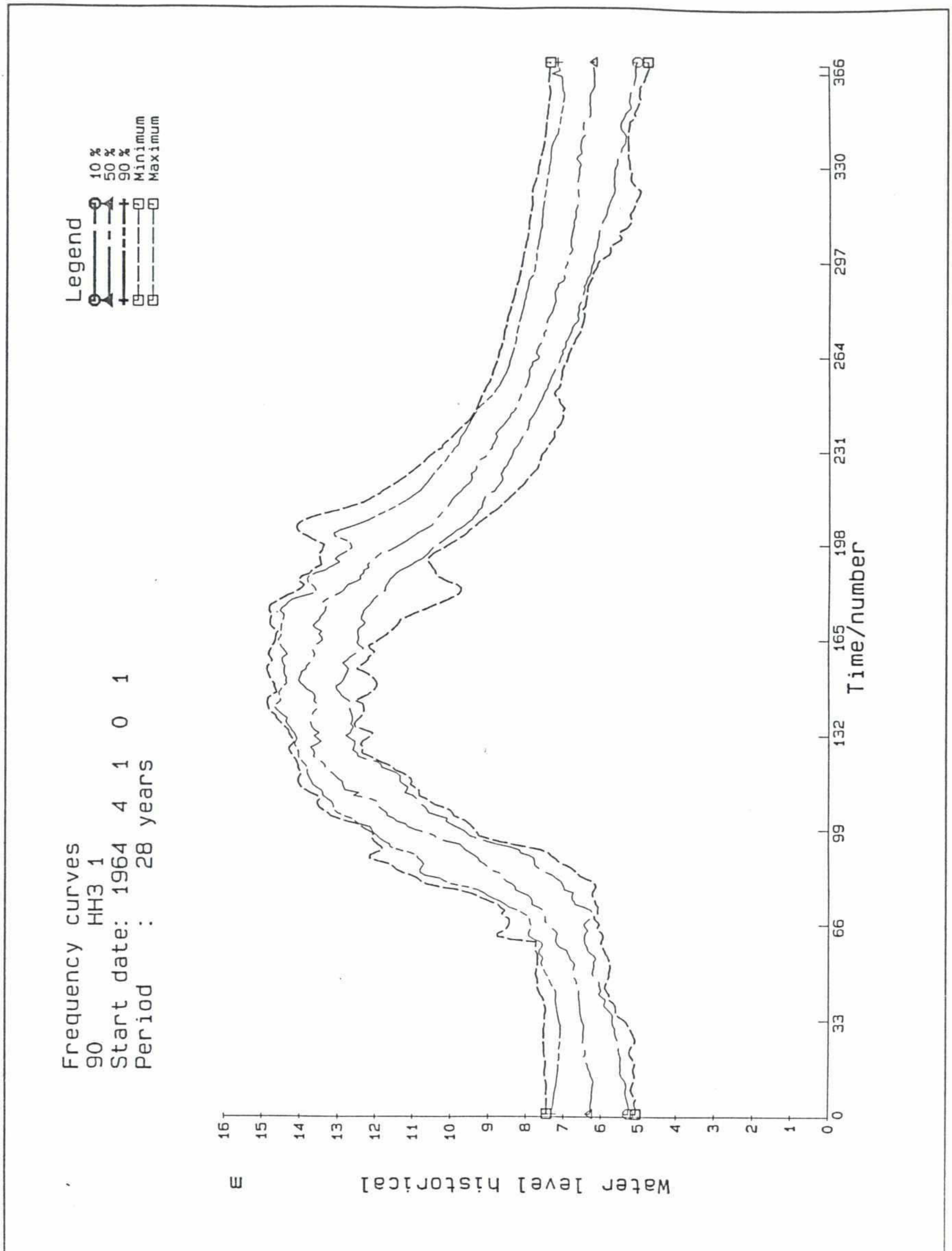
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Hardinge Bridge. Frequency curves for water-levels.	
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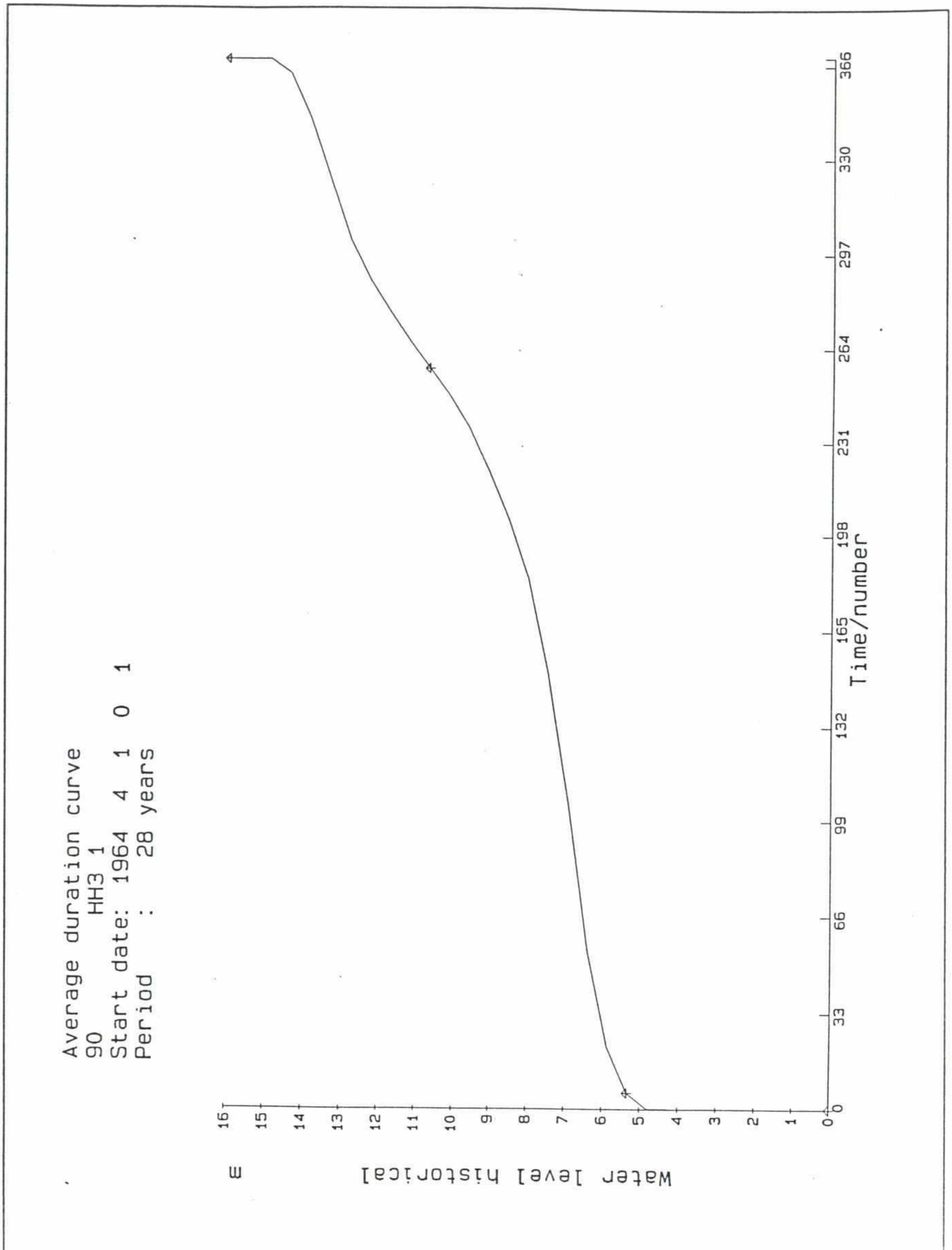

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Hardinge Bridge. Duration curve for water-levels.	
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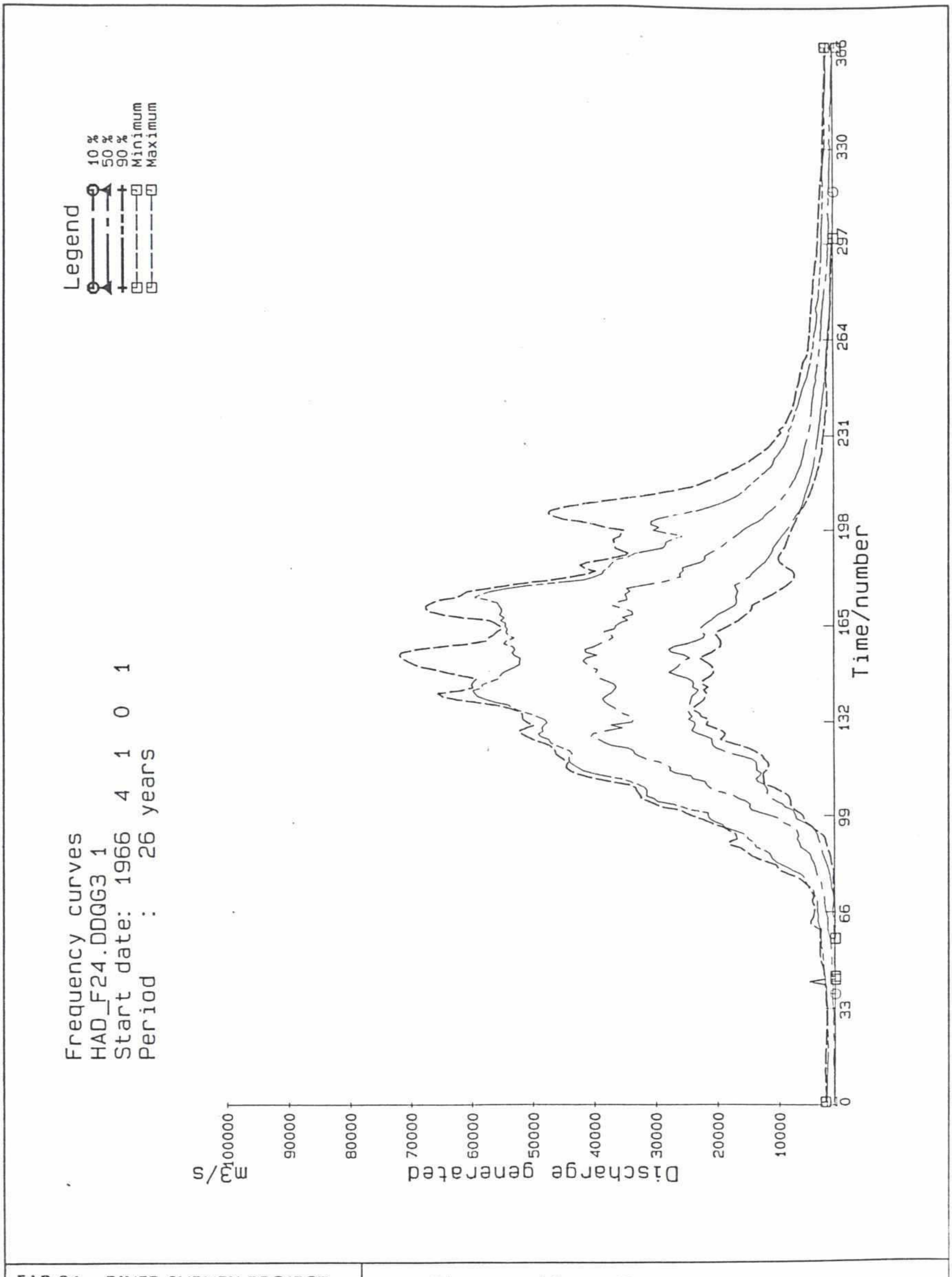
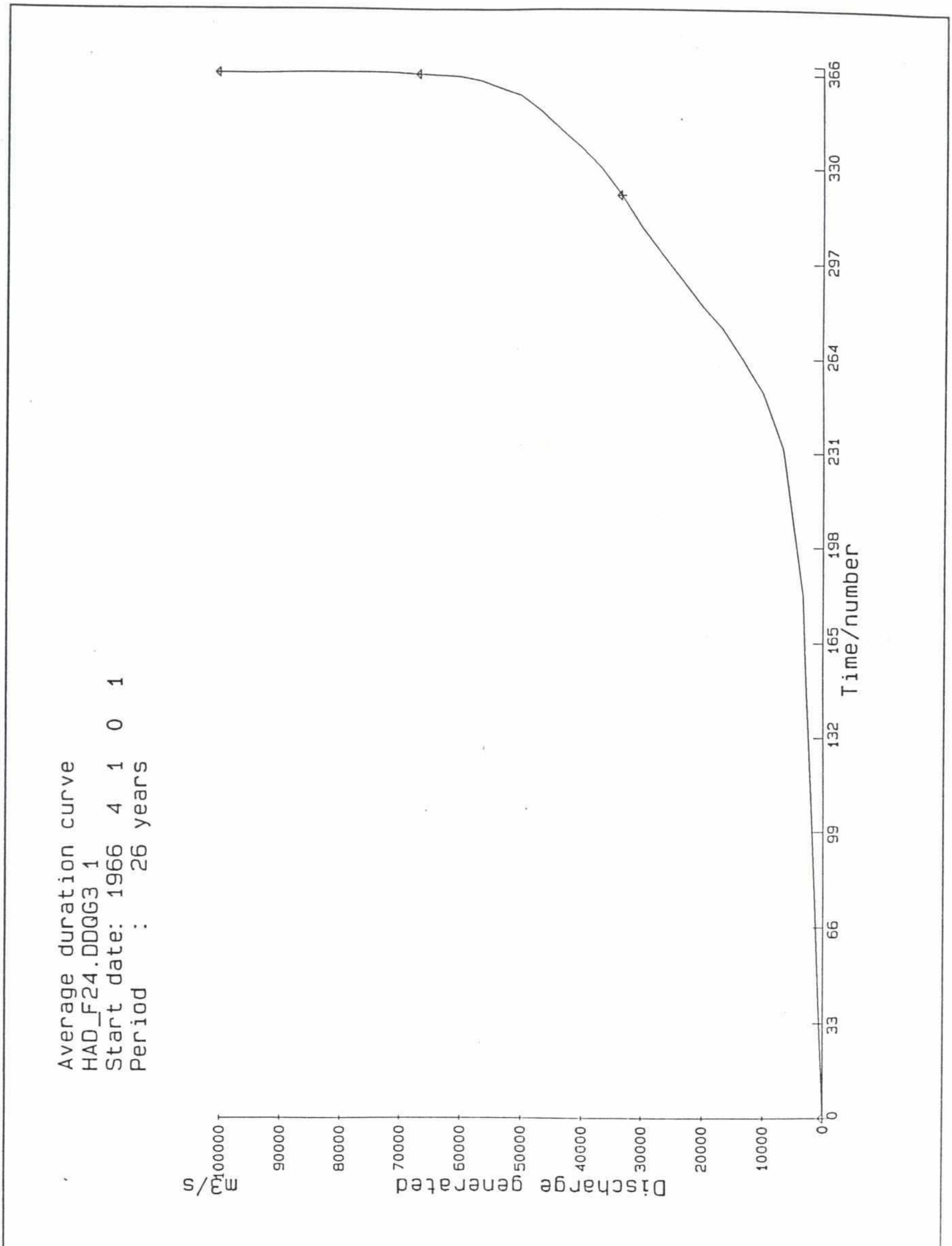
Scale:	**Init:**		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Hardinge Bridge. Frequency curves for discharges.	
File:	Date:	Hydrological Study Phase 1.	Fig. 6.7
Scale:	Init:		



FAP 24 DELFT-DHI	**RIVER SURVEY PROJECT** Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland	Hardinge Bridge. Duration curve for discharges.	
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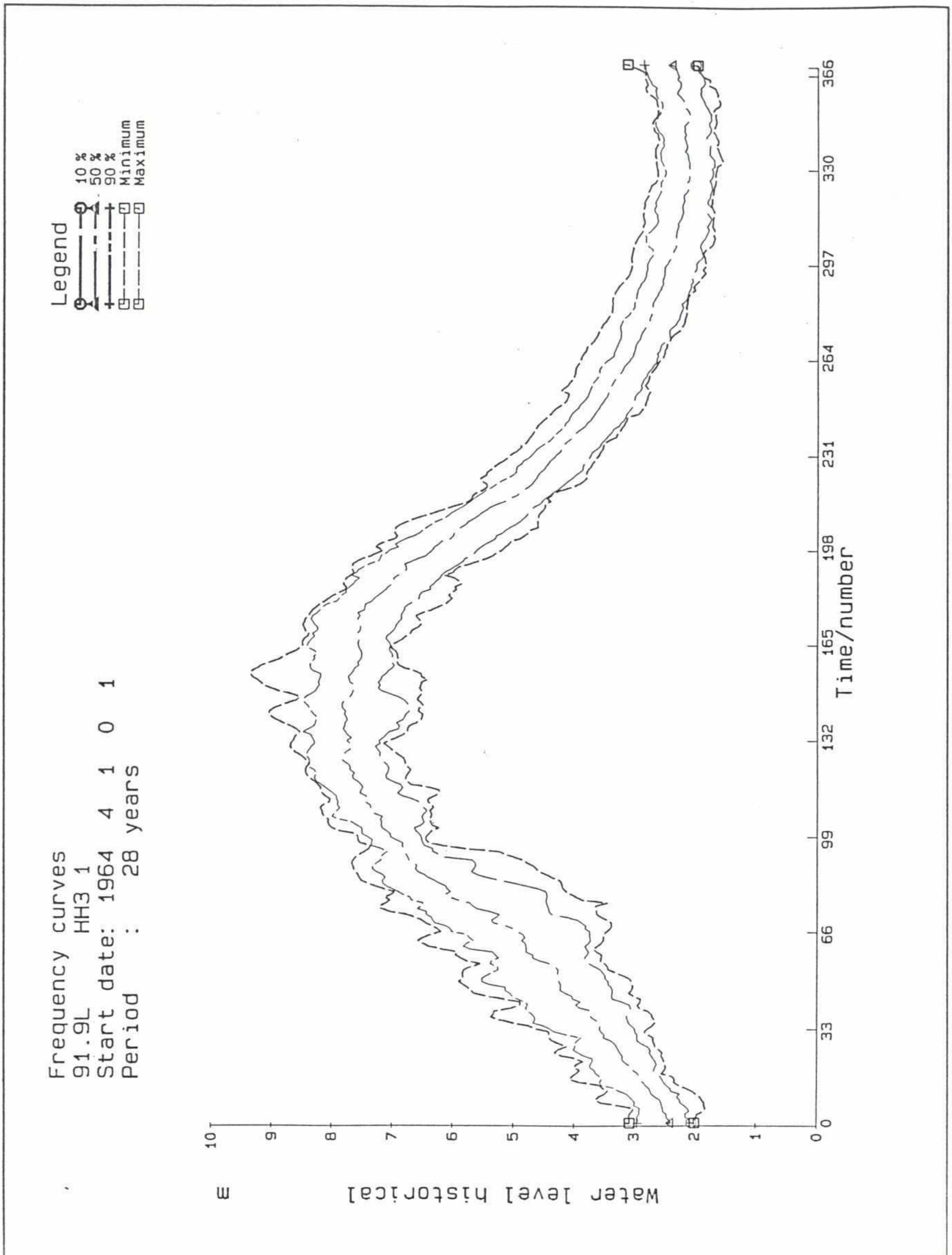
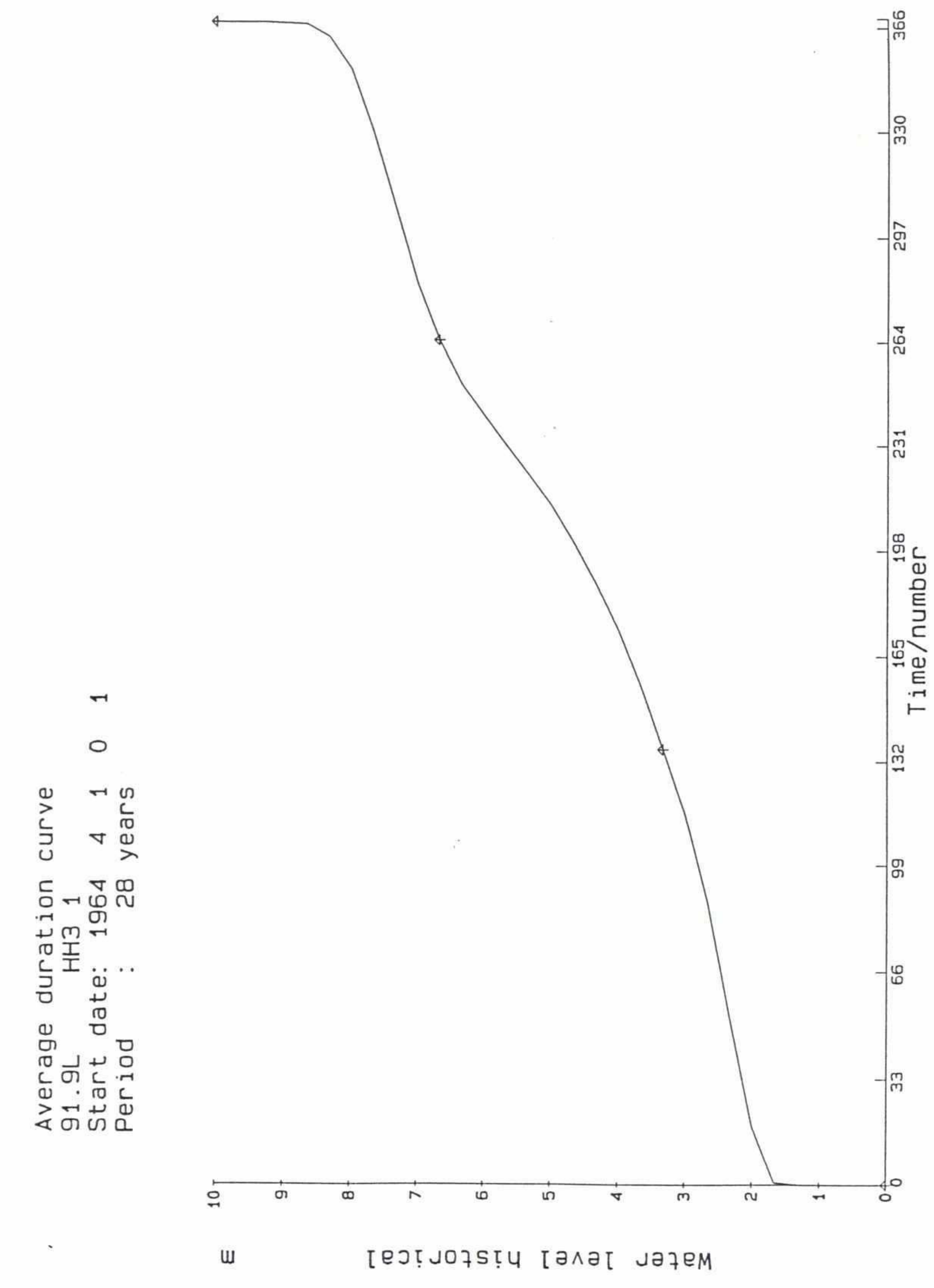
Scale:	**Init:**		



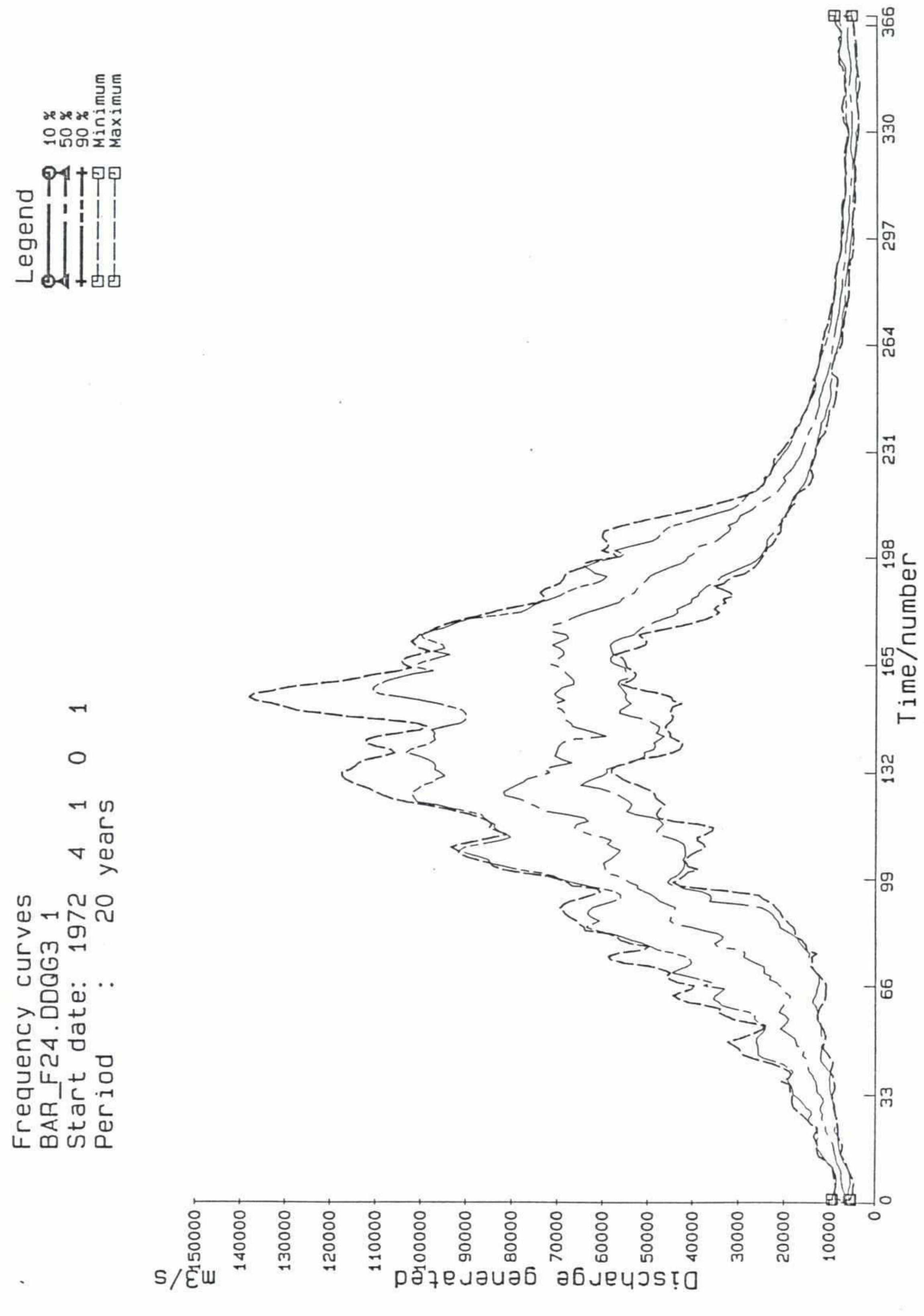
FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Baruria. Frequency curves for water-levels.	
File:	Date:	Hydrological Study Phase 1	Fig. 6.9
Scale:	Init:		

26f

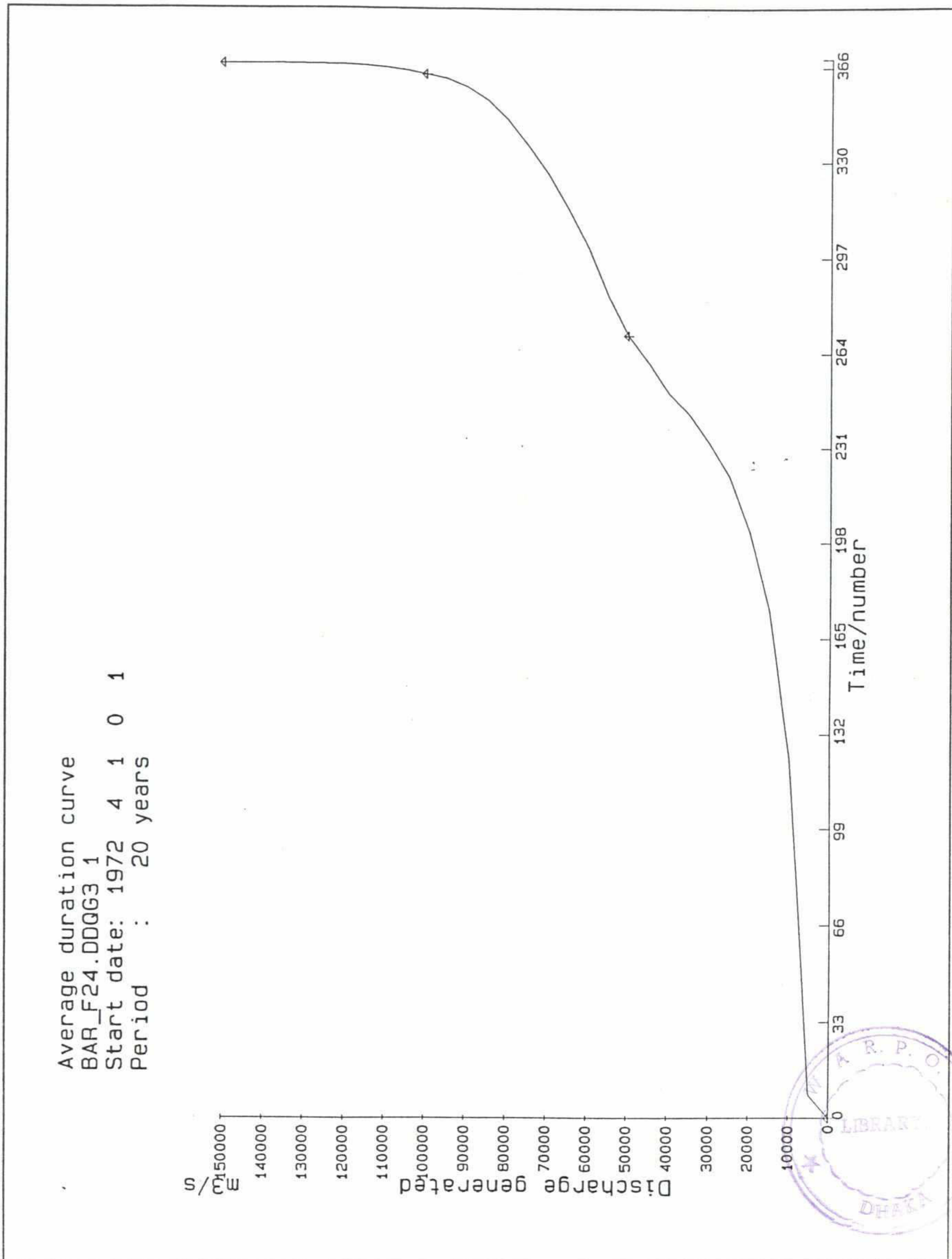


FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI	Baruria. Duration curve for water-levels.

File:	Date:	Hydrological Study Phase 1	Fig. 6.10
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Baruria. Frequency curves for discharges.	
File:	Date:	Hydrological Study Phase 1	Fig. 6.11
Scale:	Init:		



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FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Baruria. Duration curve for discharges.	
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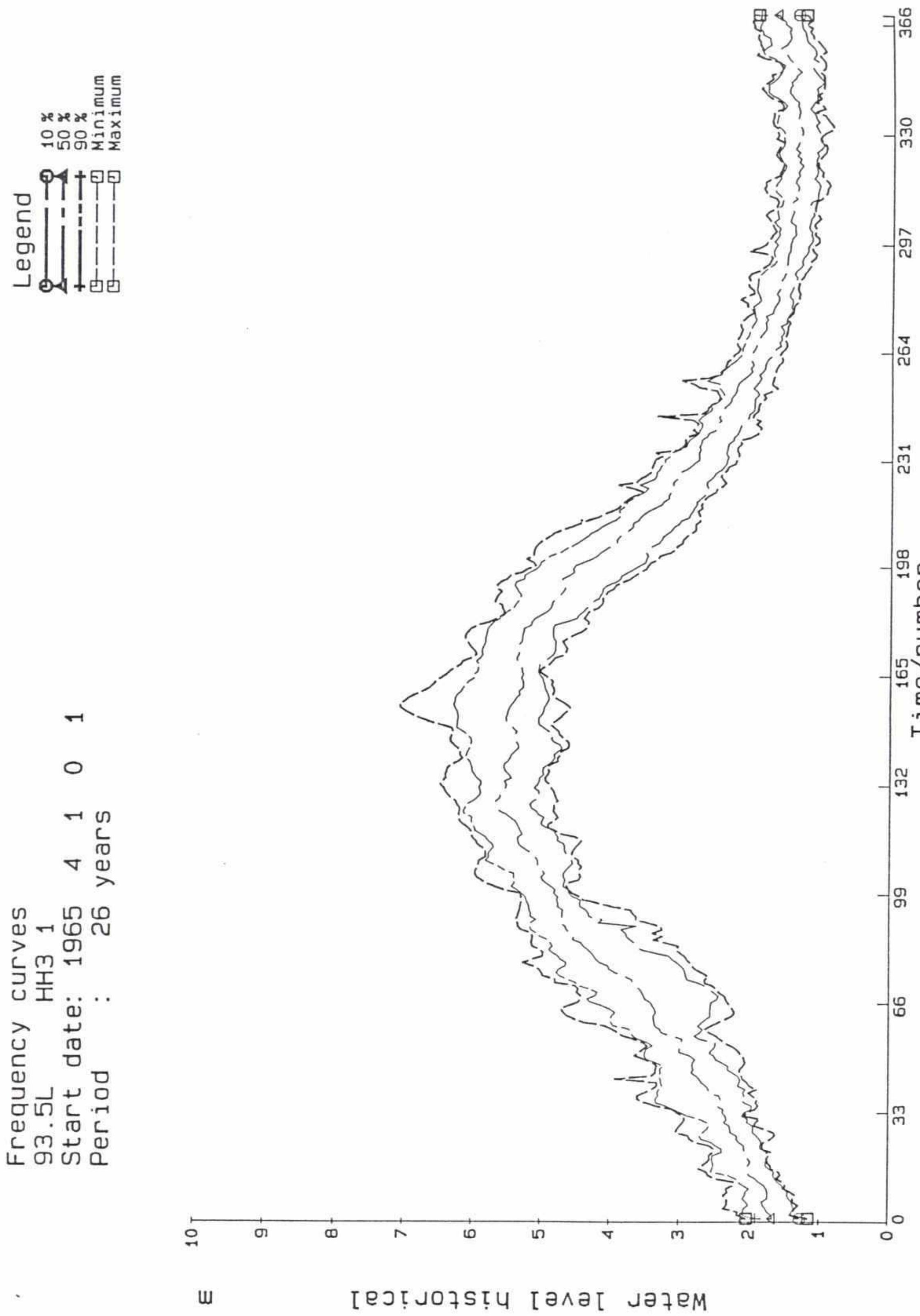
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Mawa. Frequency curves for water-levels.	
File:	Date:	Hydrological Study Phase 1	Fig. 6.13
Scale:	Init:		

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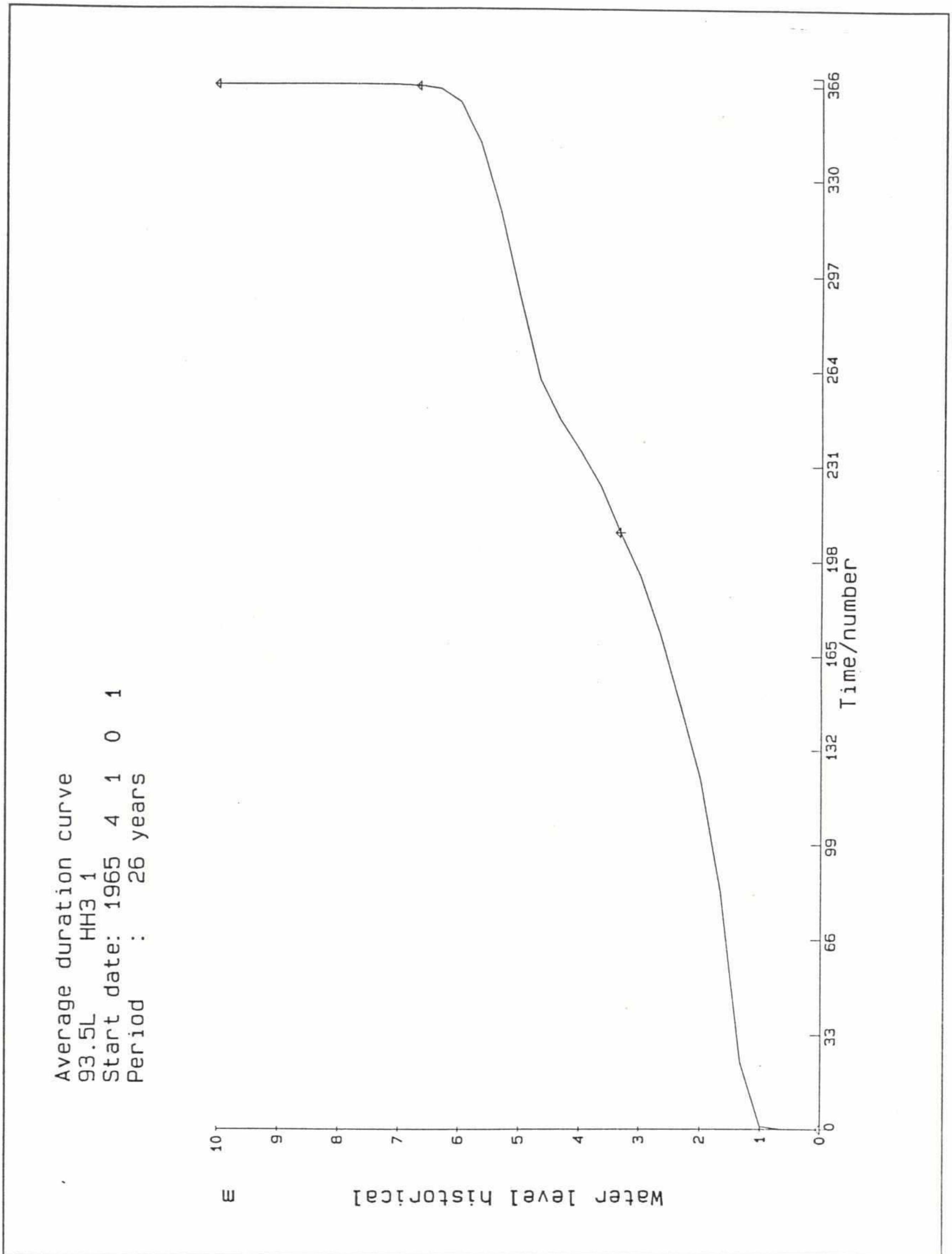

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI	Mawa. Duration curve for water-levels.

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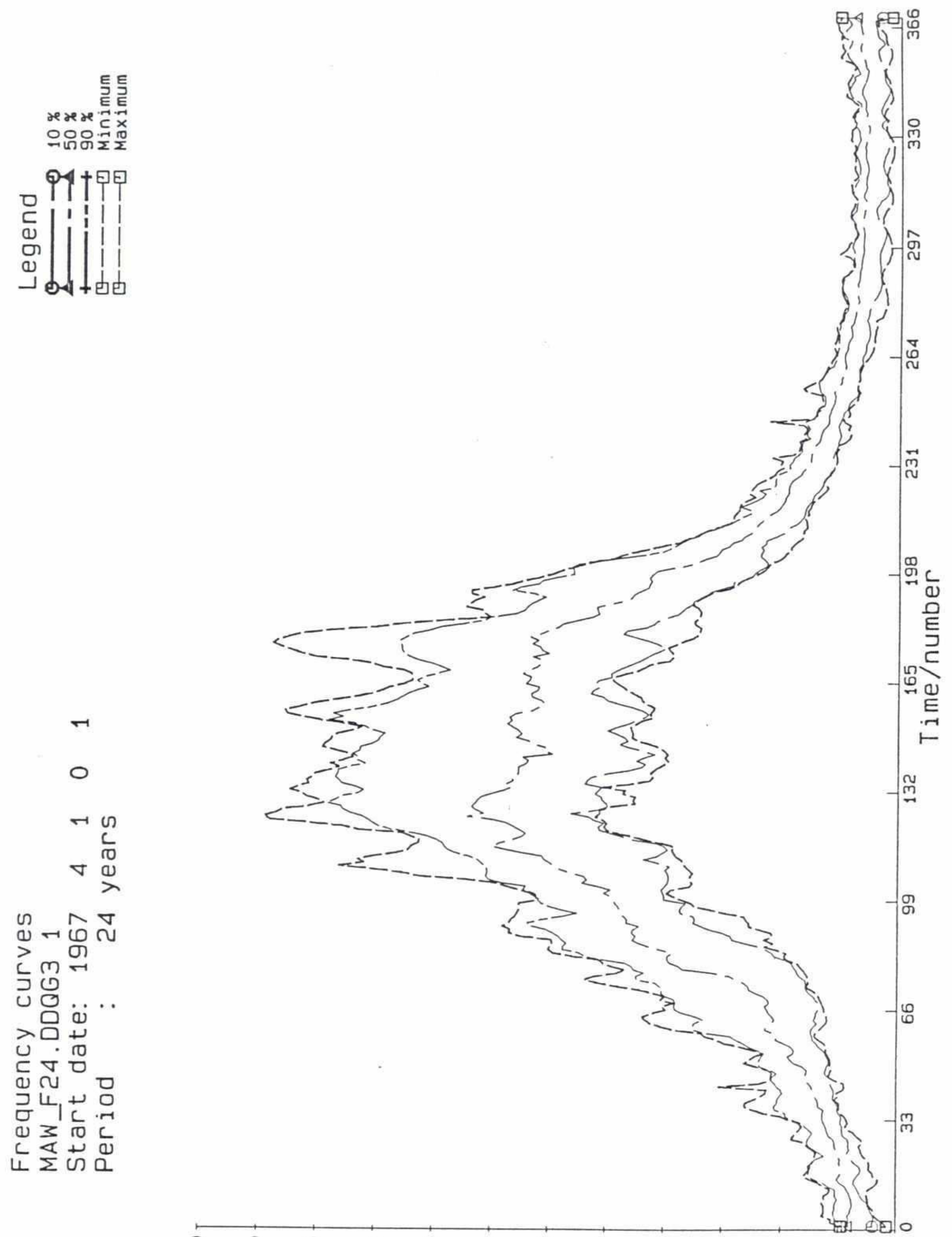
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Mawa. Frequency curves for discharges.	
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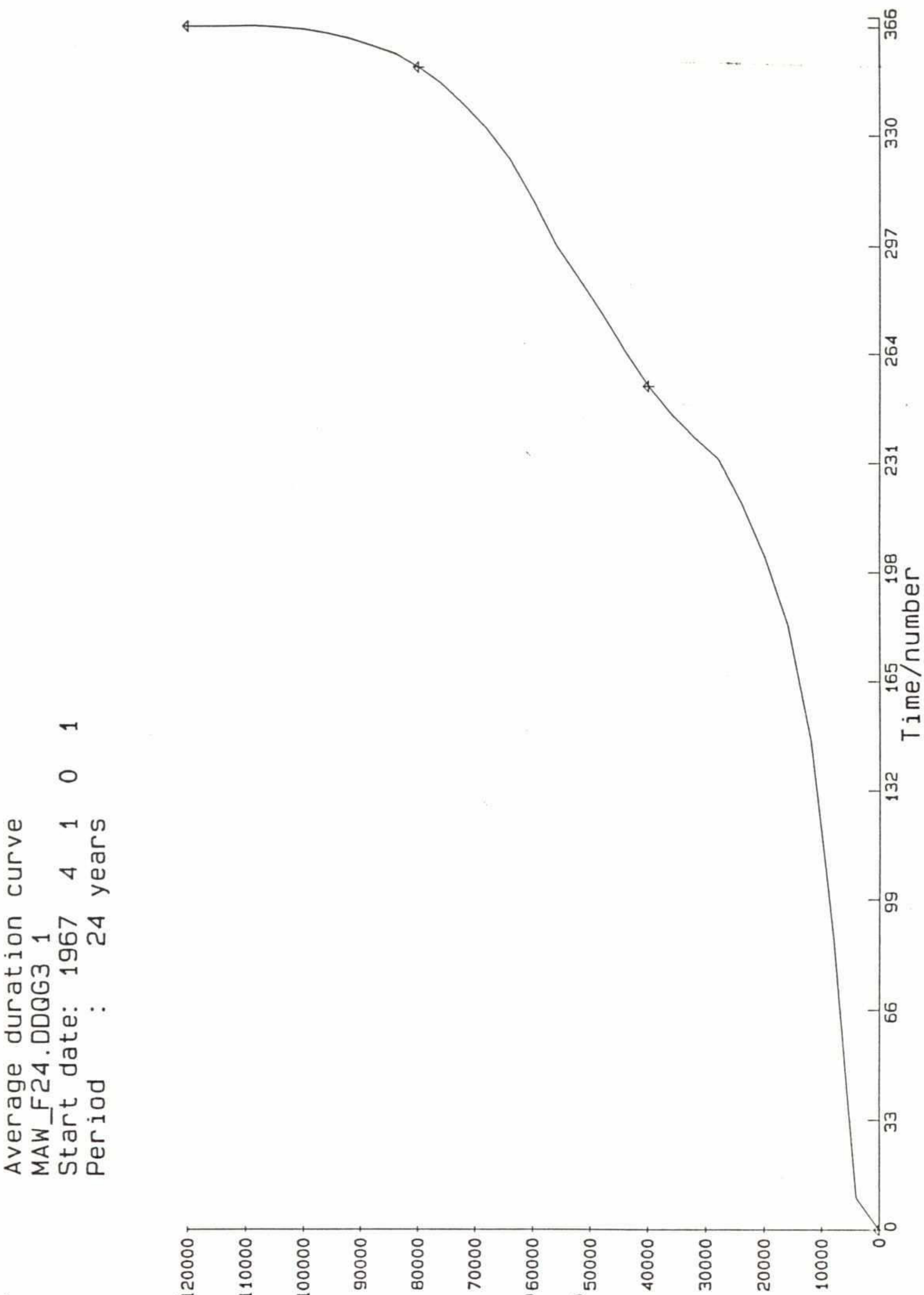

FAP 24 — RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Mawa. Duration curve for discharges.	
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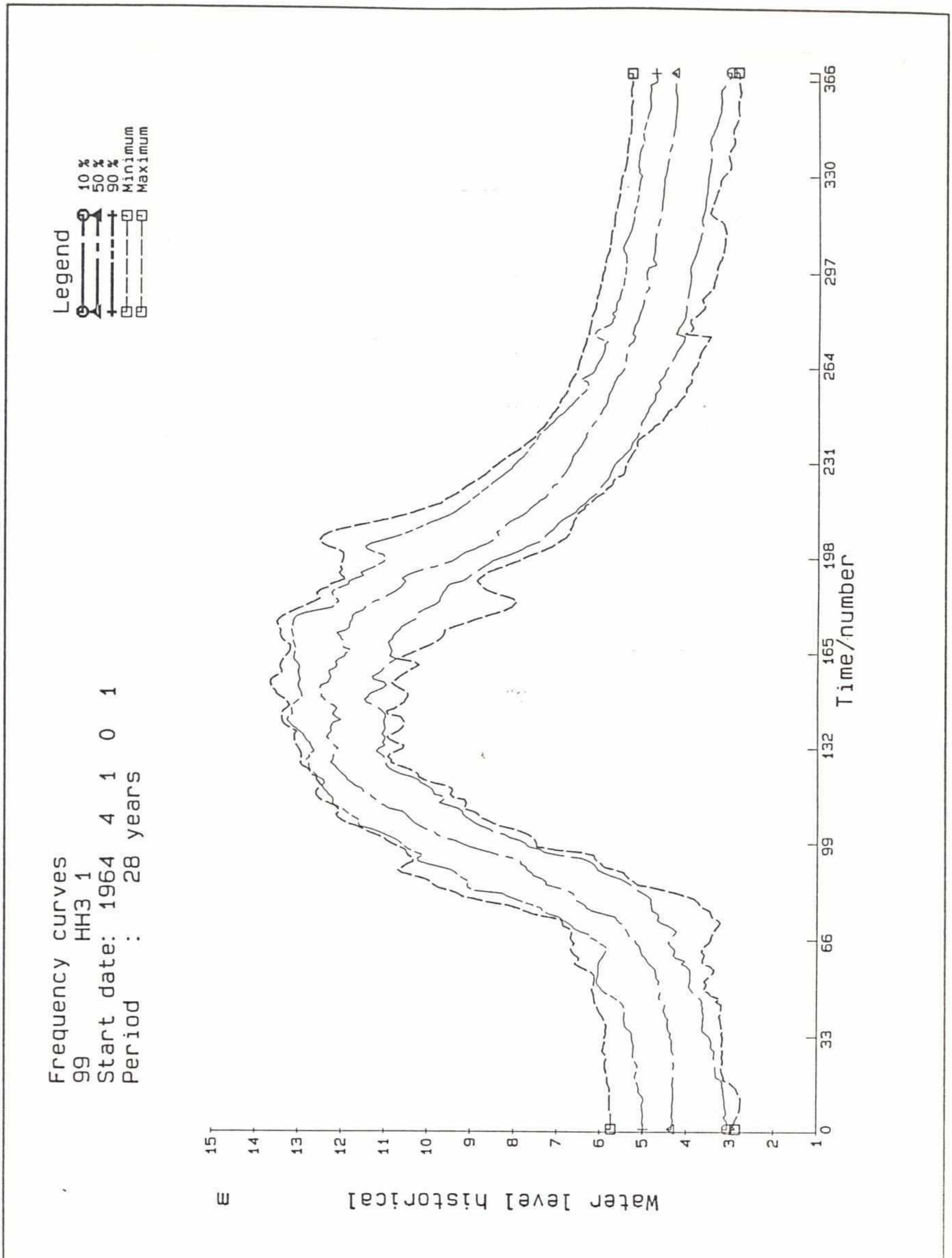
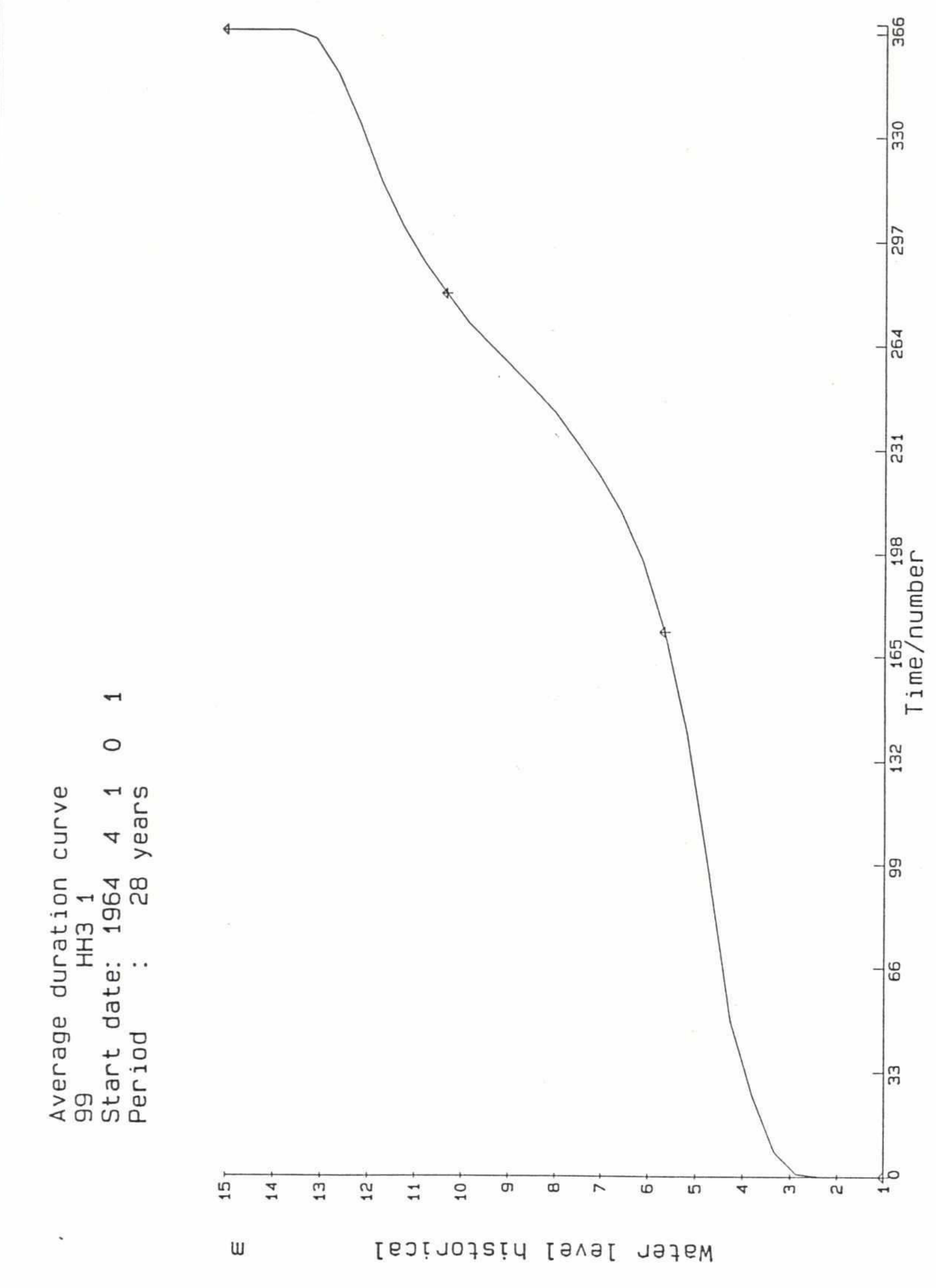


FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Gorai Railway Bridge. Frequency curves for water-levels.	
File:	Date:	Hydrological Study Phase 1	Fig. 6.17
Scale:	Init:		

284



FAP 24 **RIVER SURVEY PROJECT** Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Gorai Railway Bridge. Duration curve for water-levels.	
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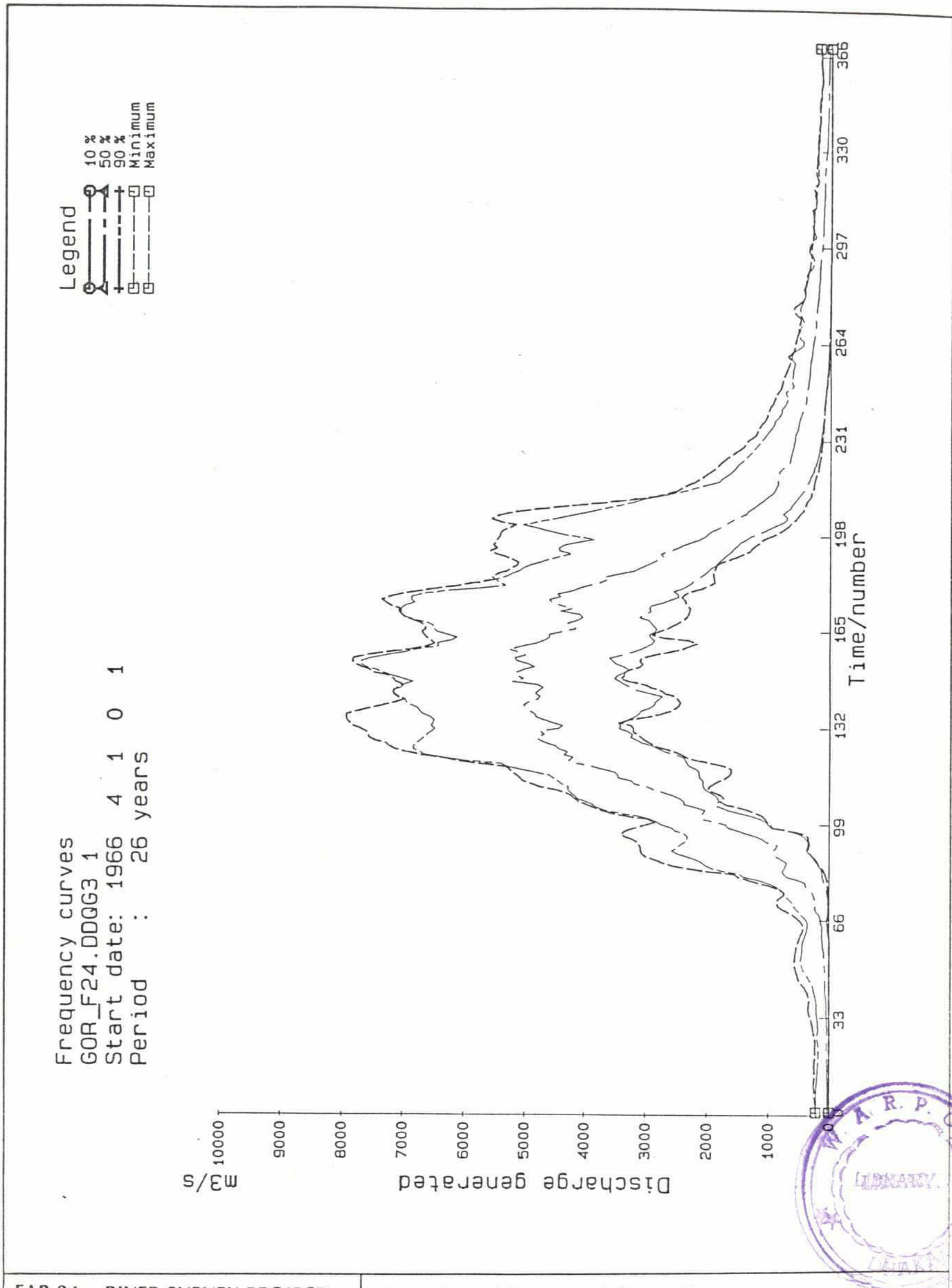

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FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Gorai Railway Bridge. Frequency curves for discharges.	
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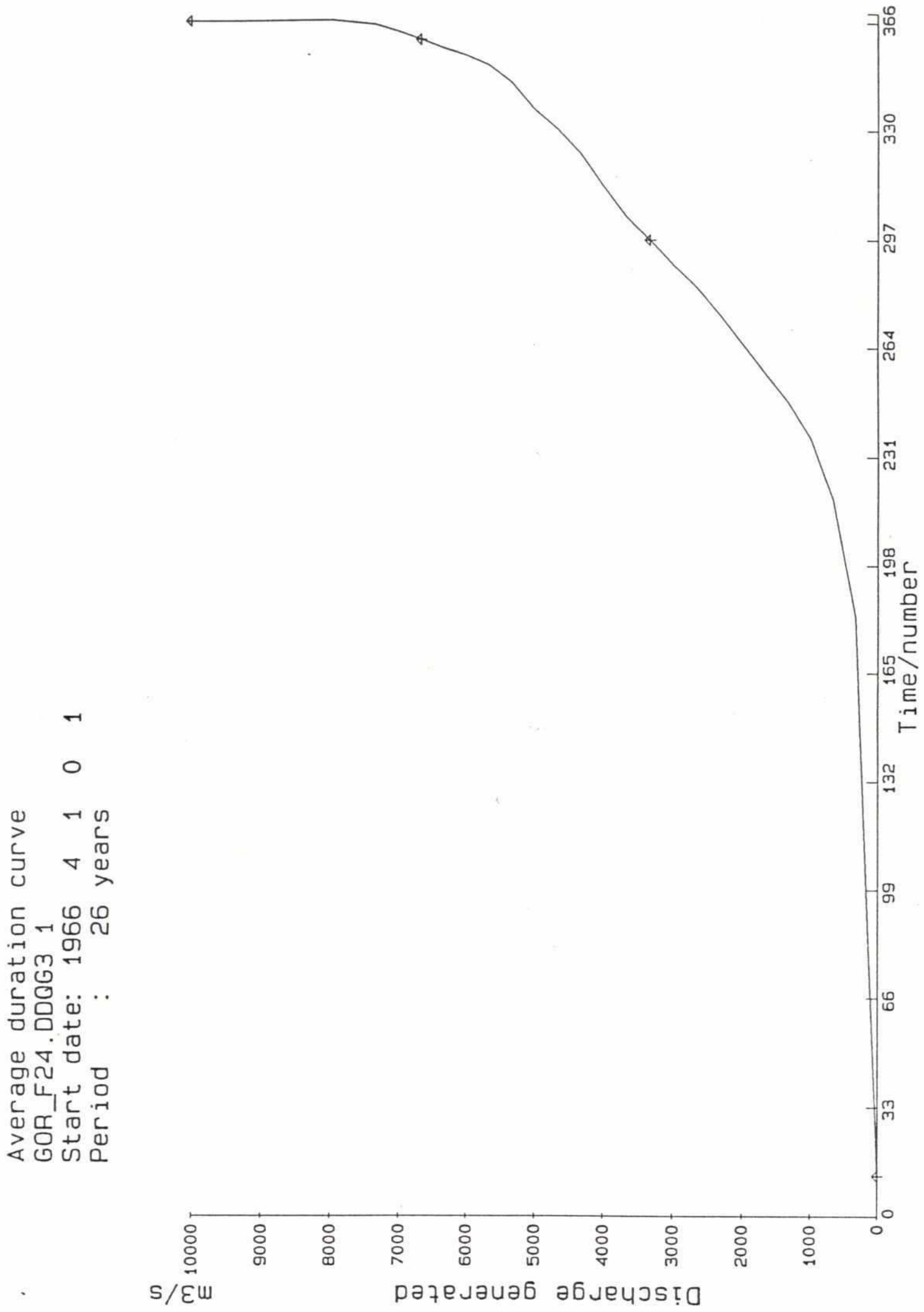

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI	Gorai Railway Bridge. Duration curve for discharges.

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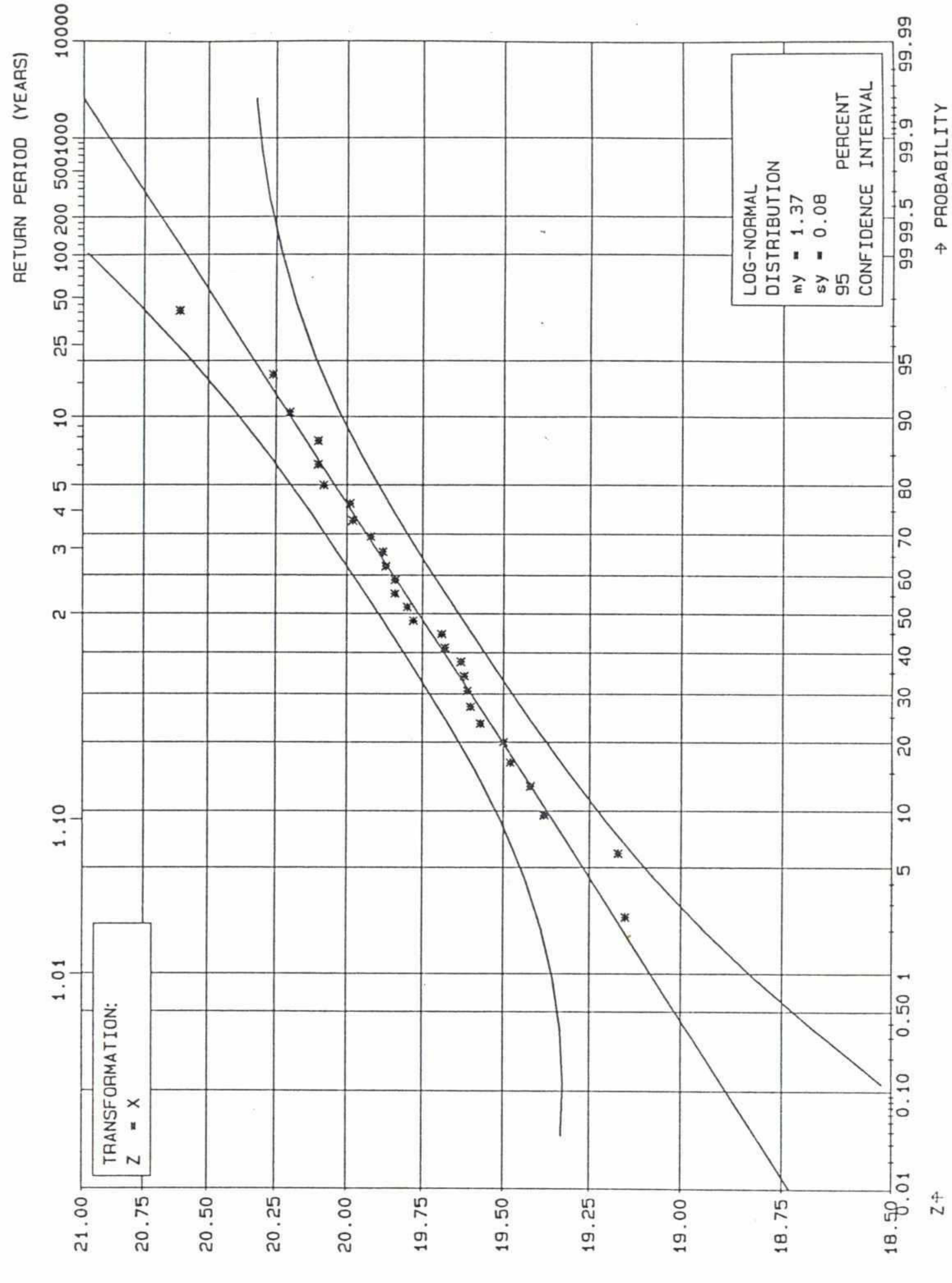

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Bahadurabad. Frequency analysis of peak water-levels, 1964-92	
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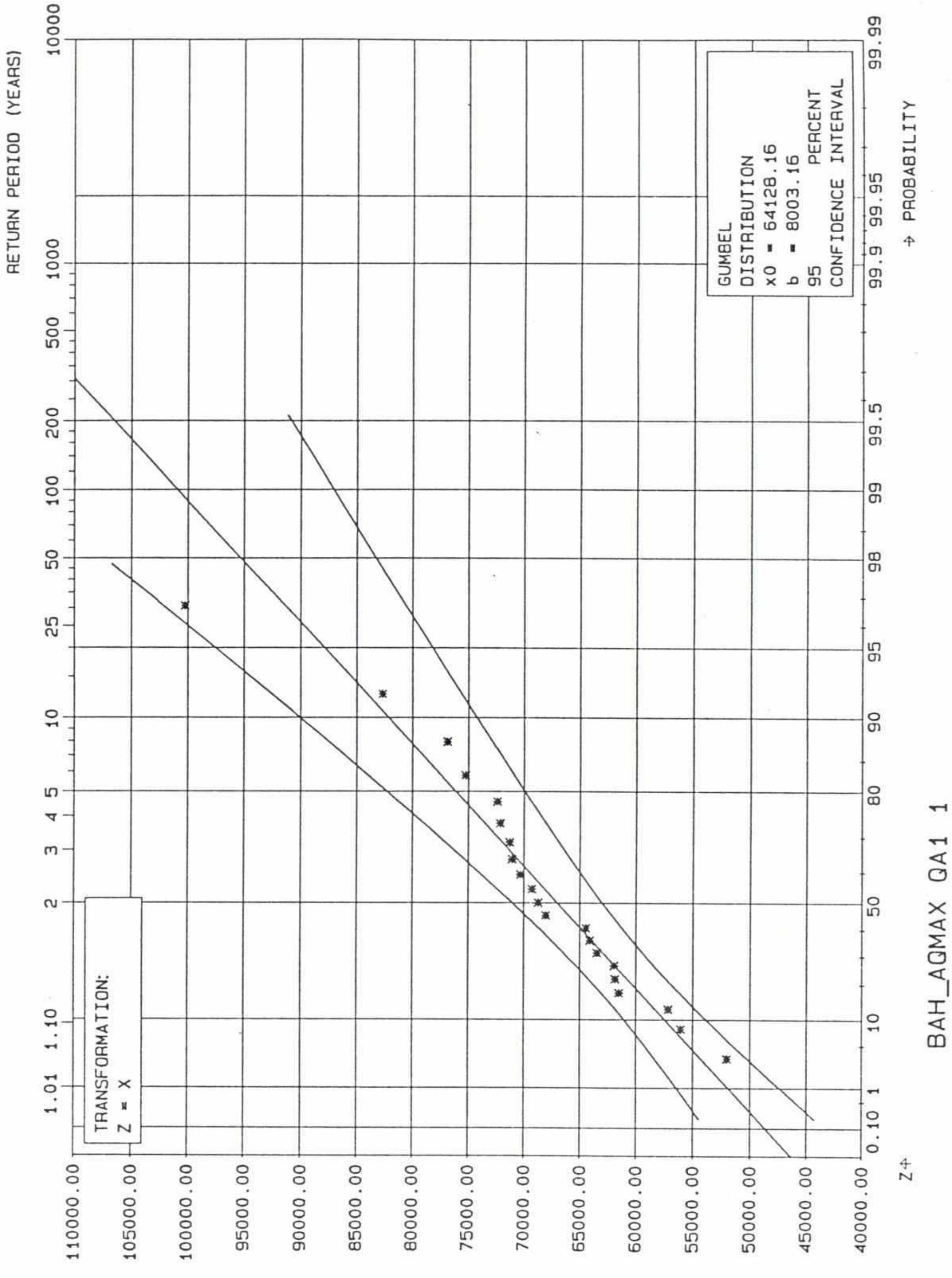

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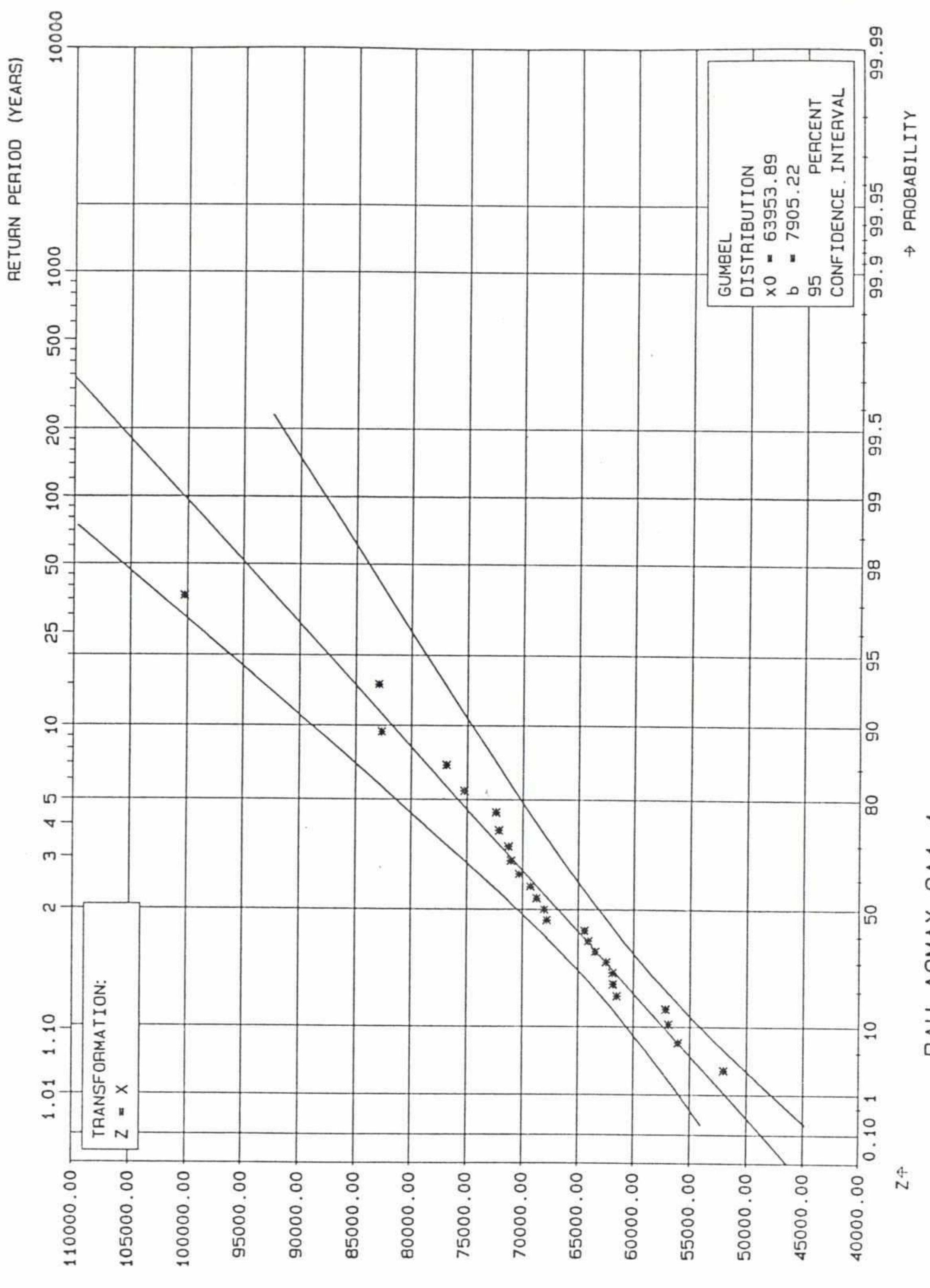

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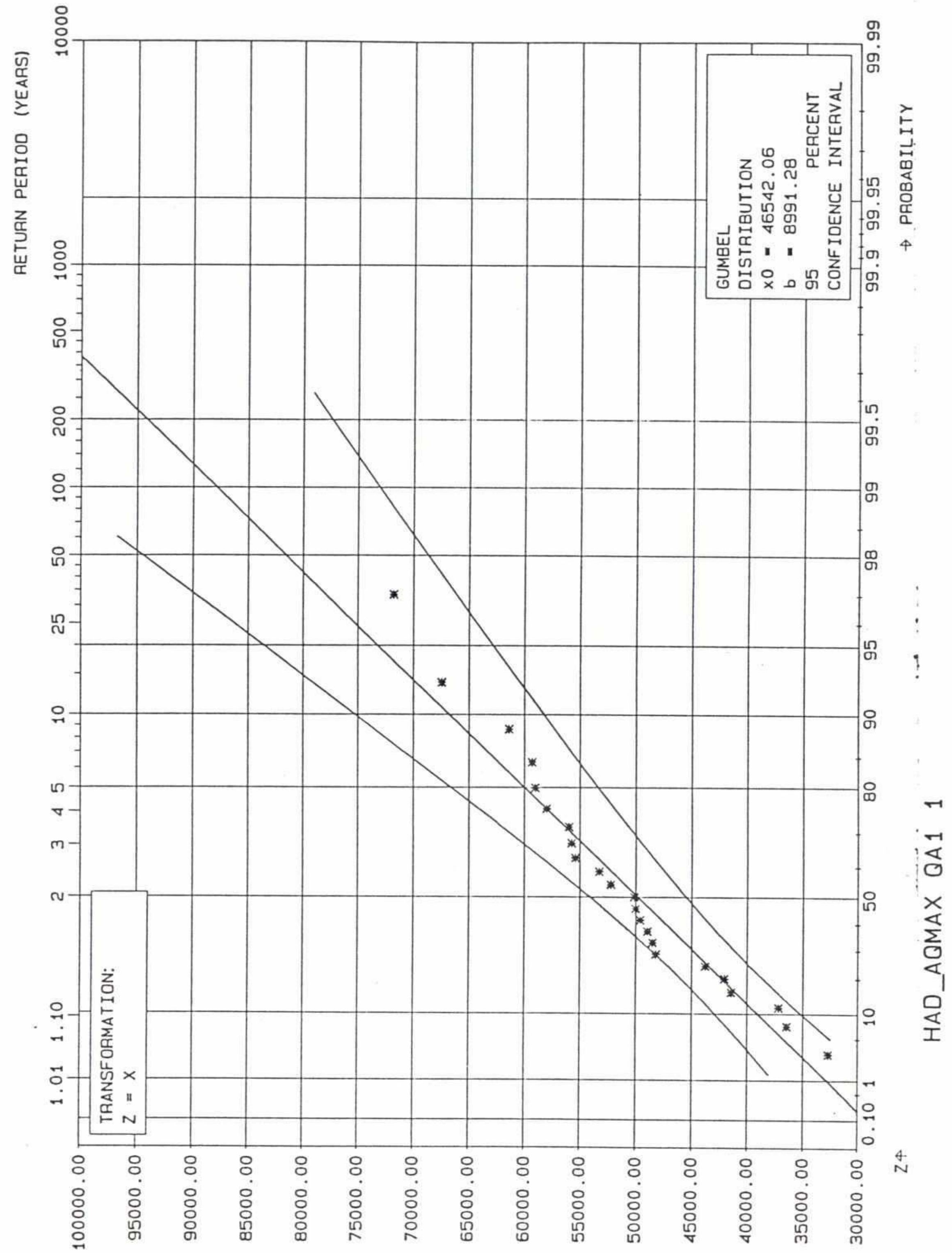

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI	Hardinge Bridge. Frequency analysis of peak discharges, 1966-91 (Gumbel)

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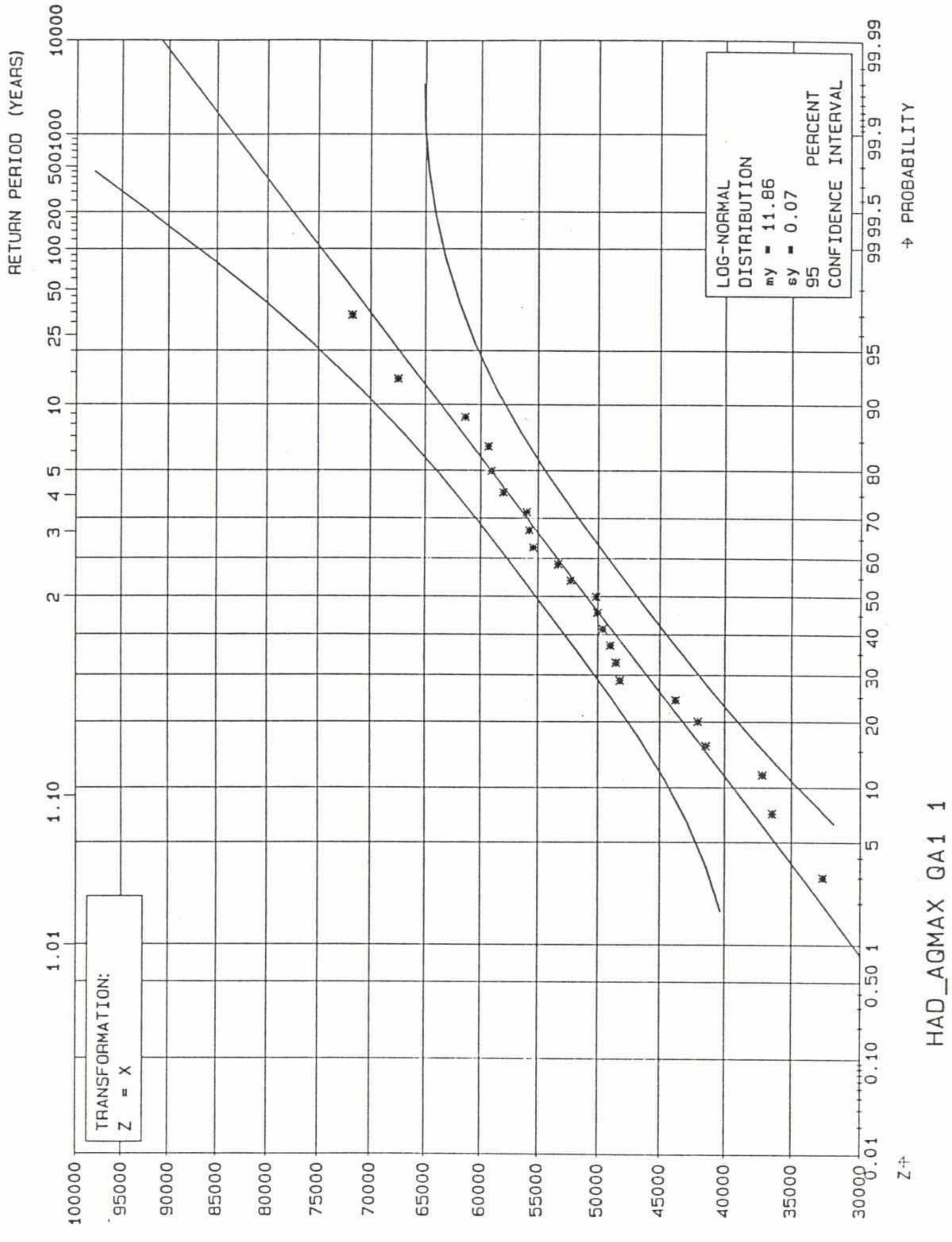

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Hardinge Bridge. Frequency analysis of peak discharges, 1966-91 (Log-Normal)	
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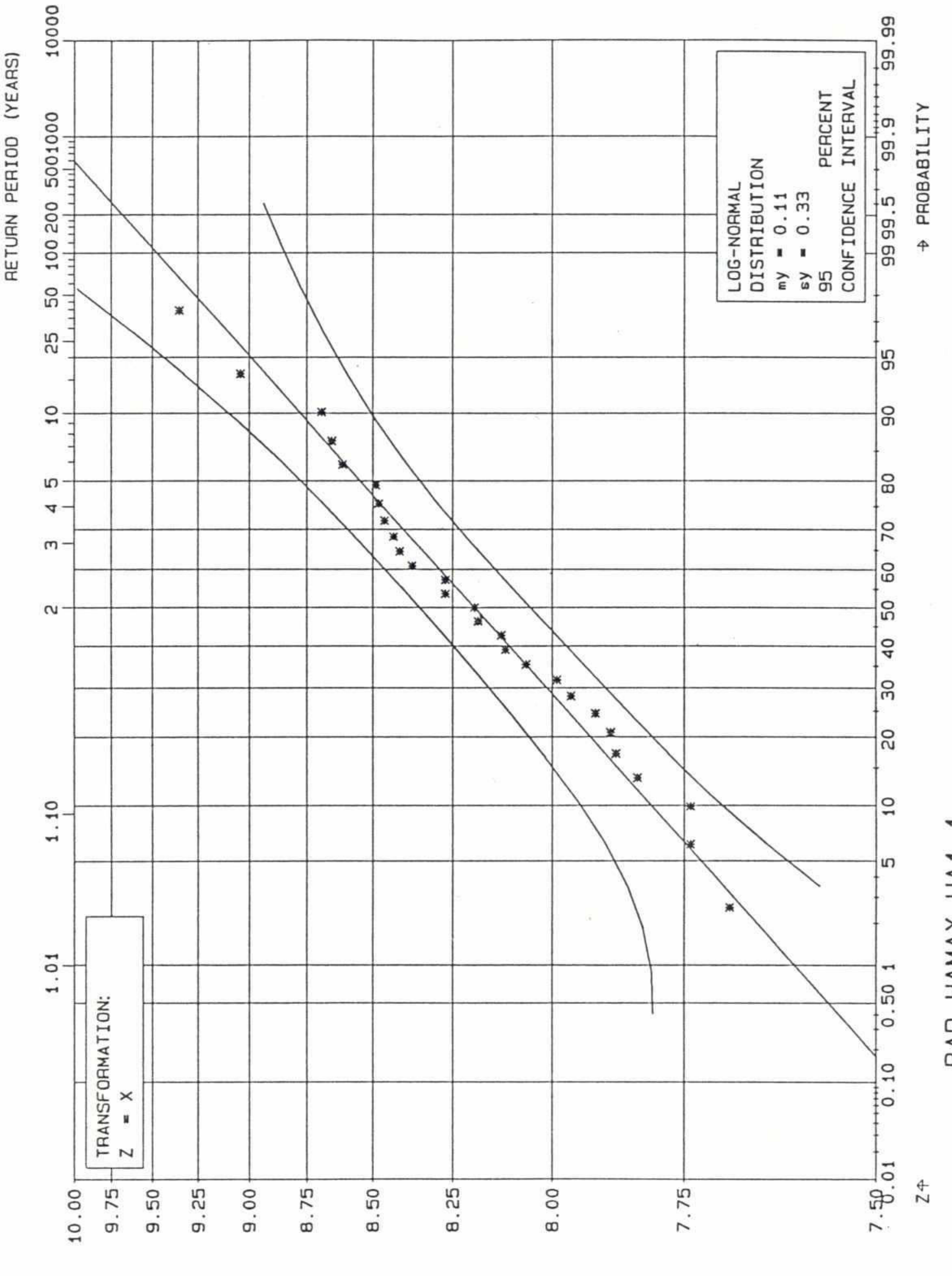
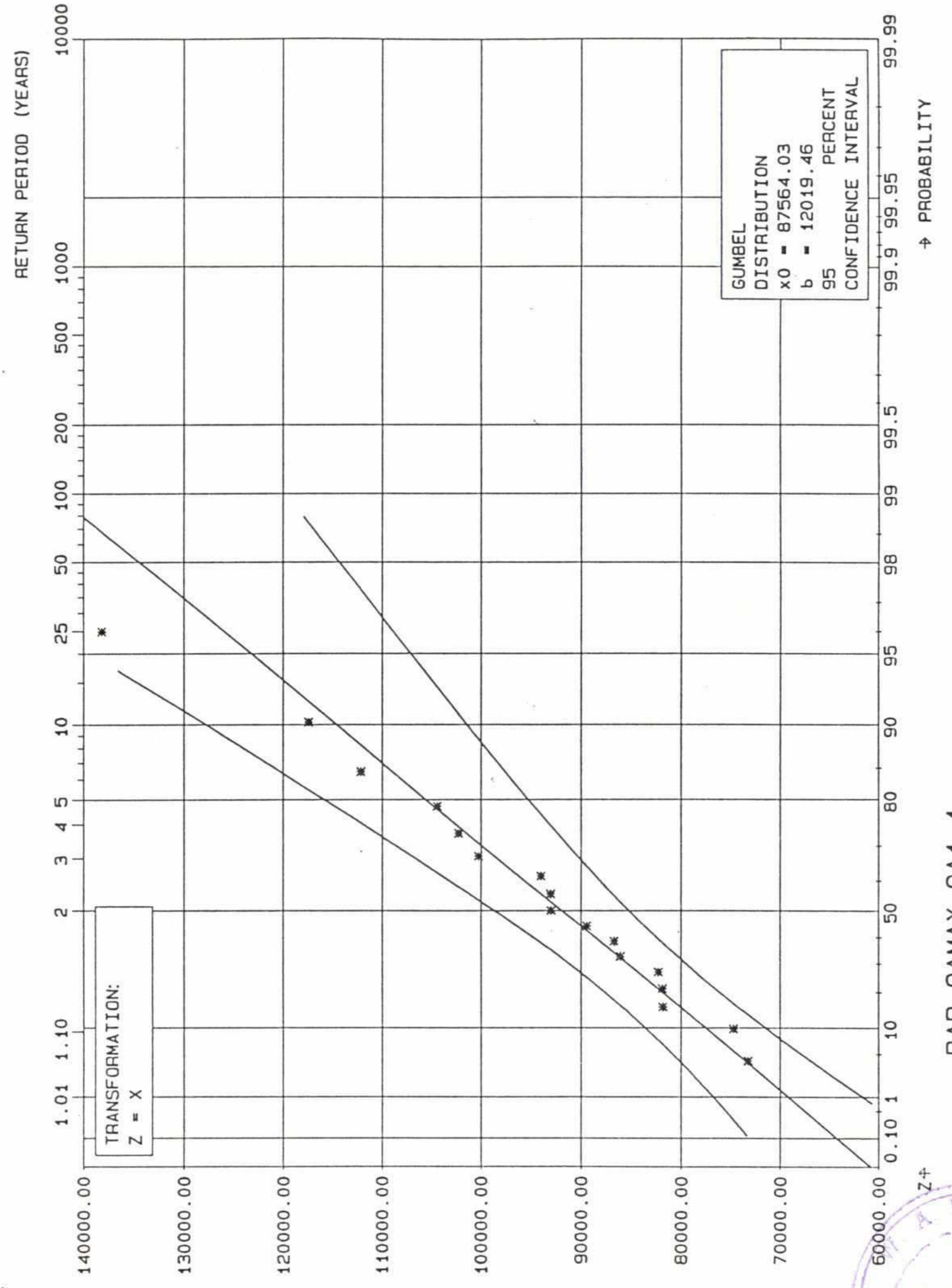


FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI	Baruria. Frequency analysis of peak water-levels, 1964-91

File:	Date:	Hydrological Study Phase 1	Fig. 6.26
Scale:	Init:		



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FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Baruria. Frequency anslysis of peak discharges, 1972-91.	
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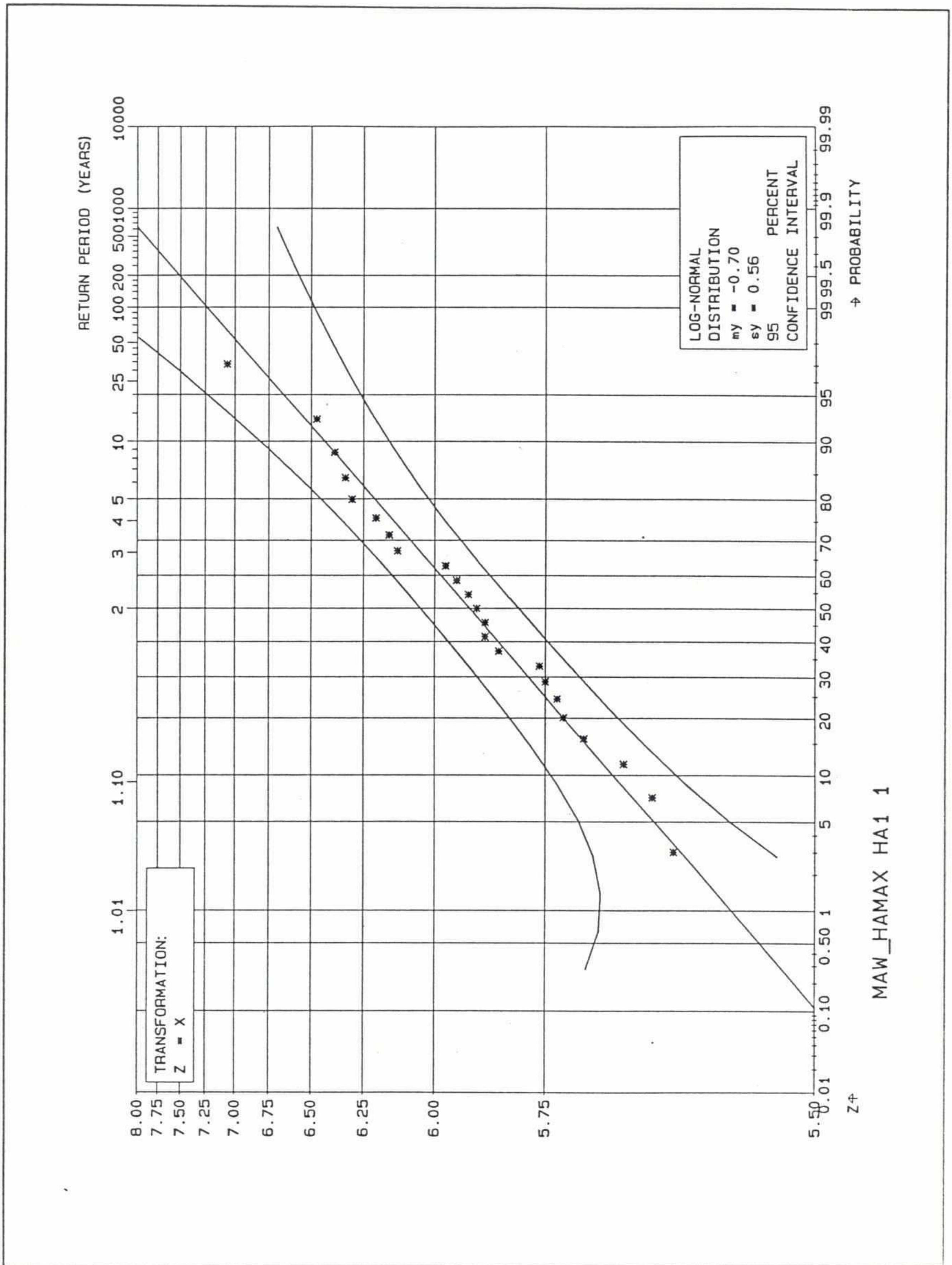

FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Mawa. Frequency analysis of peak water-levels, 1965-90	
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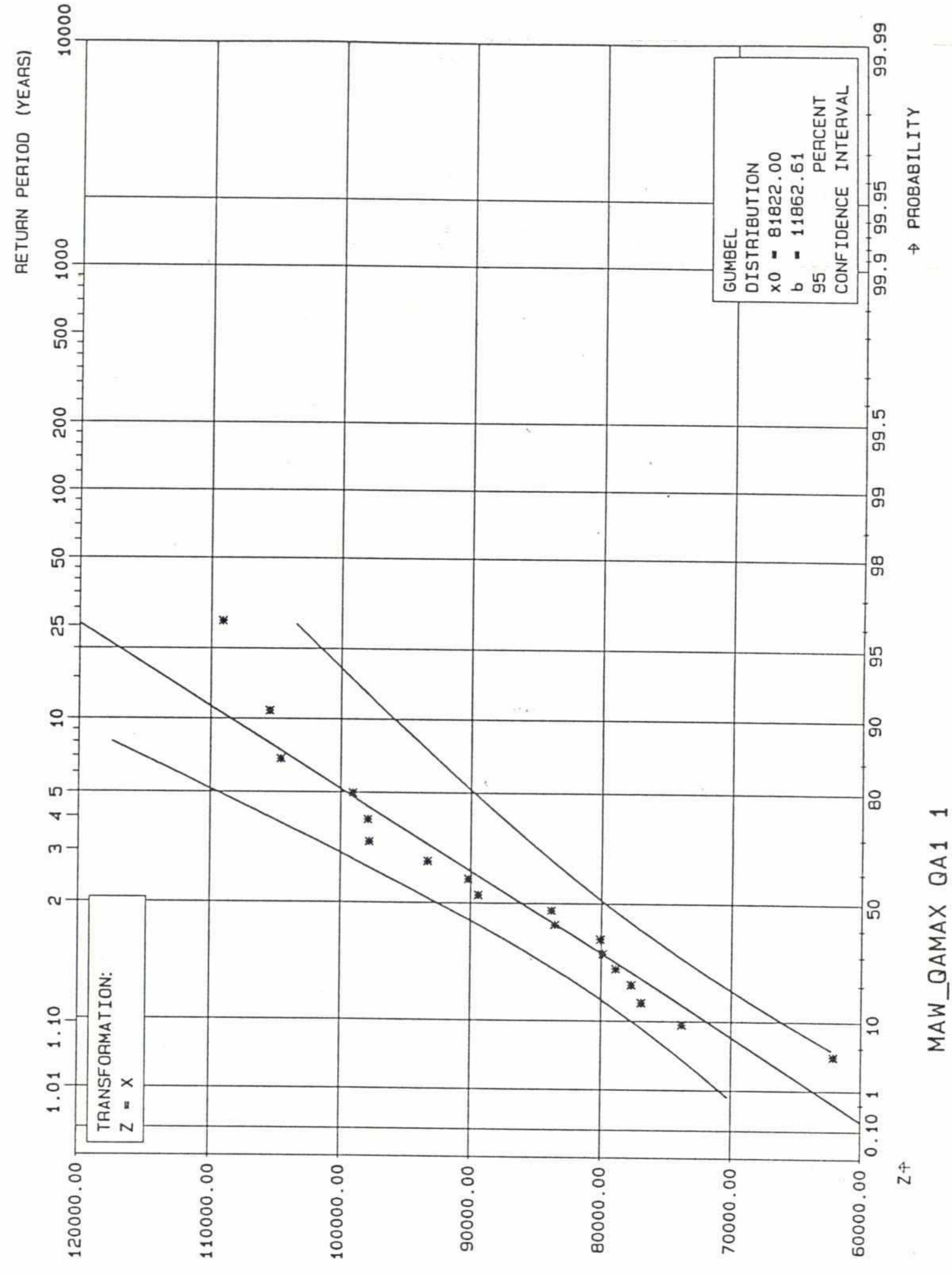
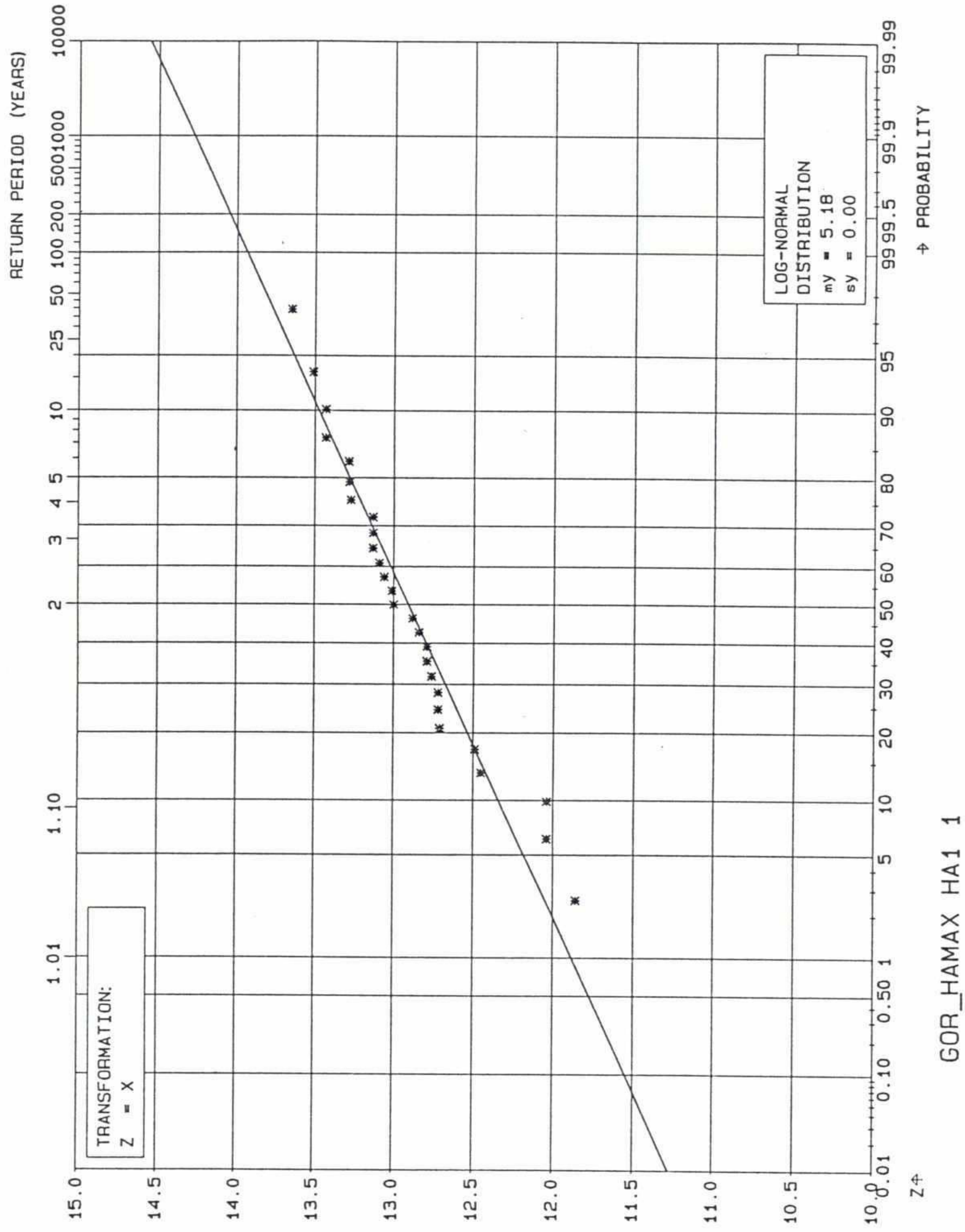


FAP 24 RIVER SURVEY PROJECT DELFT-DHI Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland	Mawa. Frequency analysis of peak discharges, 1967-90.

File:	Date:	Hydrological Study Phase 1	Fig. 6.29
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Gorai Railway Bridge. Frequency analysis of peak water-levels, 1964-91.	
File:	Date:	Hydrological Study Phase 1	Fig. 6.30
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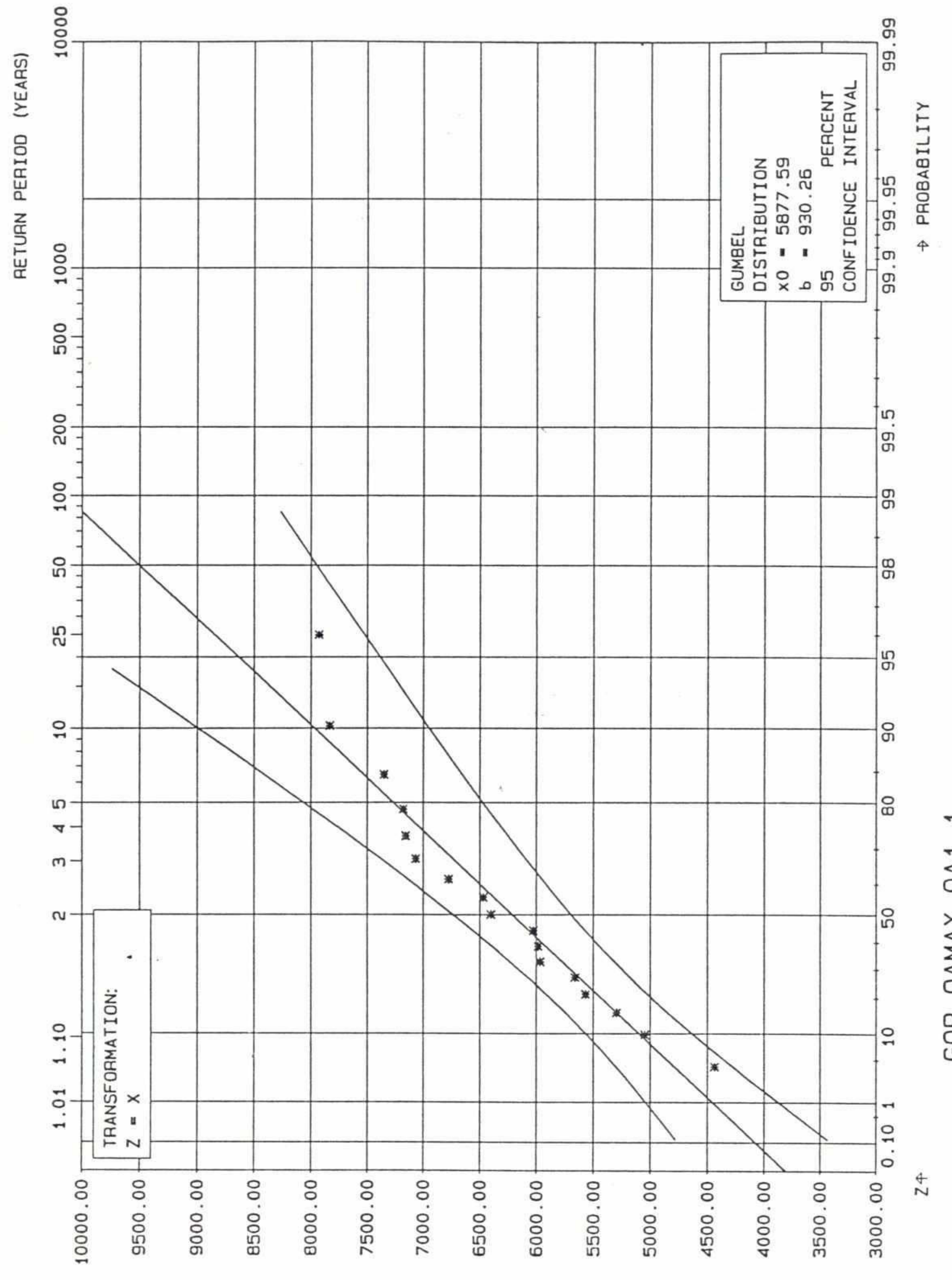
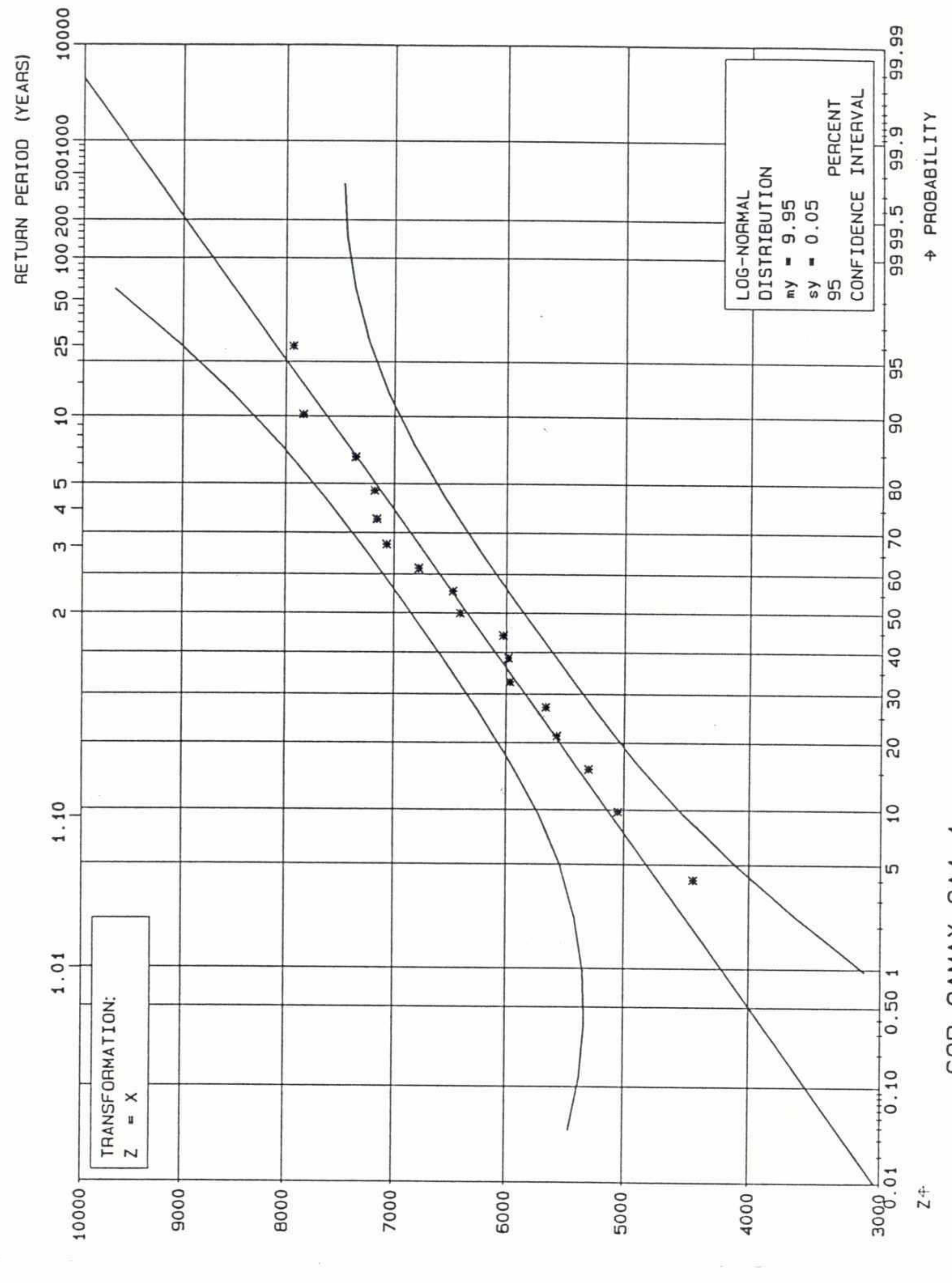


FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Gorai Railway Bridge. Frequency analysis of peak discharges, 1966-91 (Gumbel).	
File:	Date:	Hydrological Study Phase 1	Fig. 6.31
Scale:	Init:		



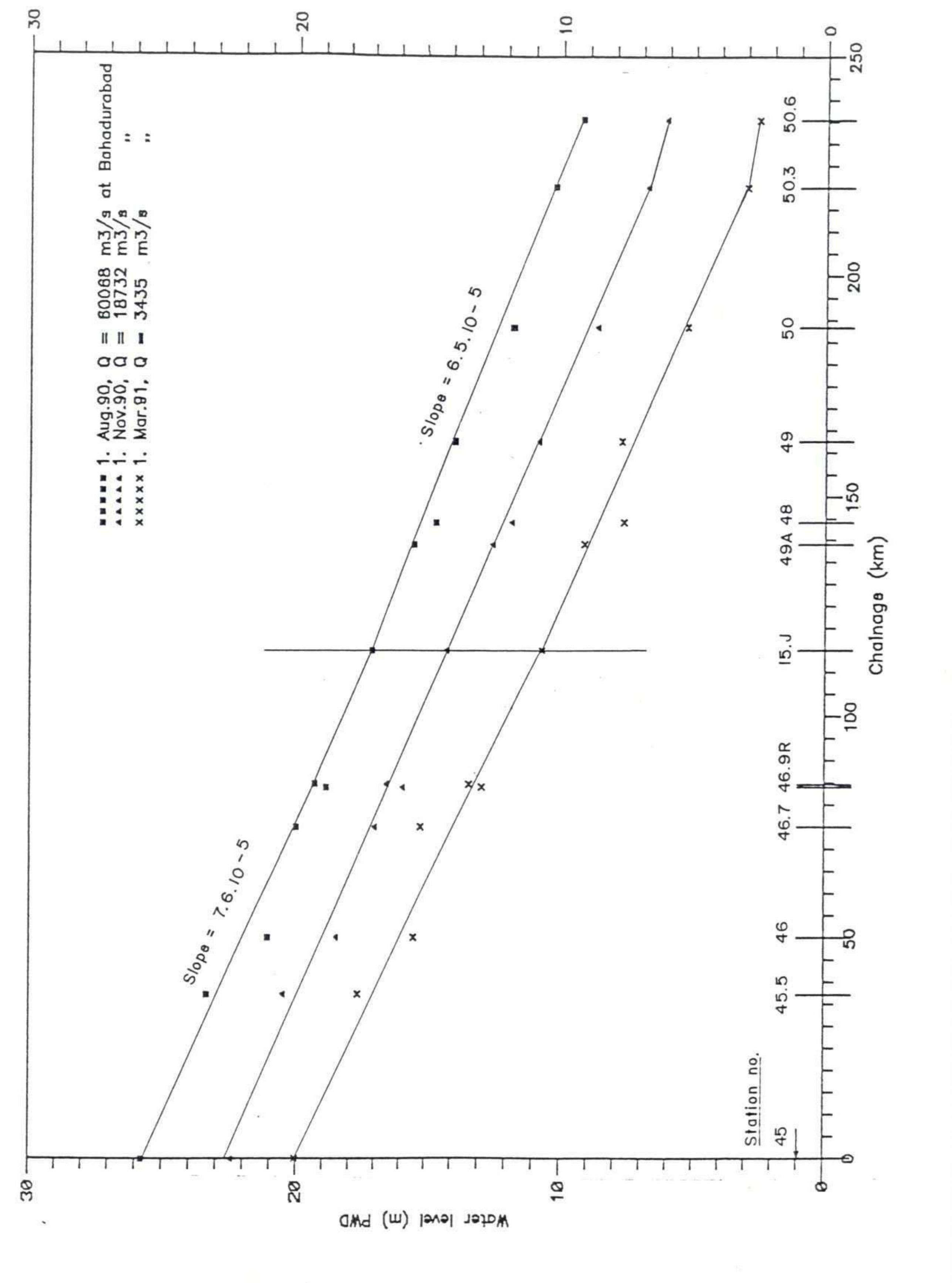
FAP 24 **RIVER SURVEY PROJECT**

DELFT-DHI

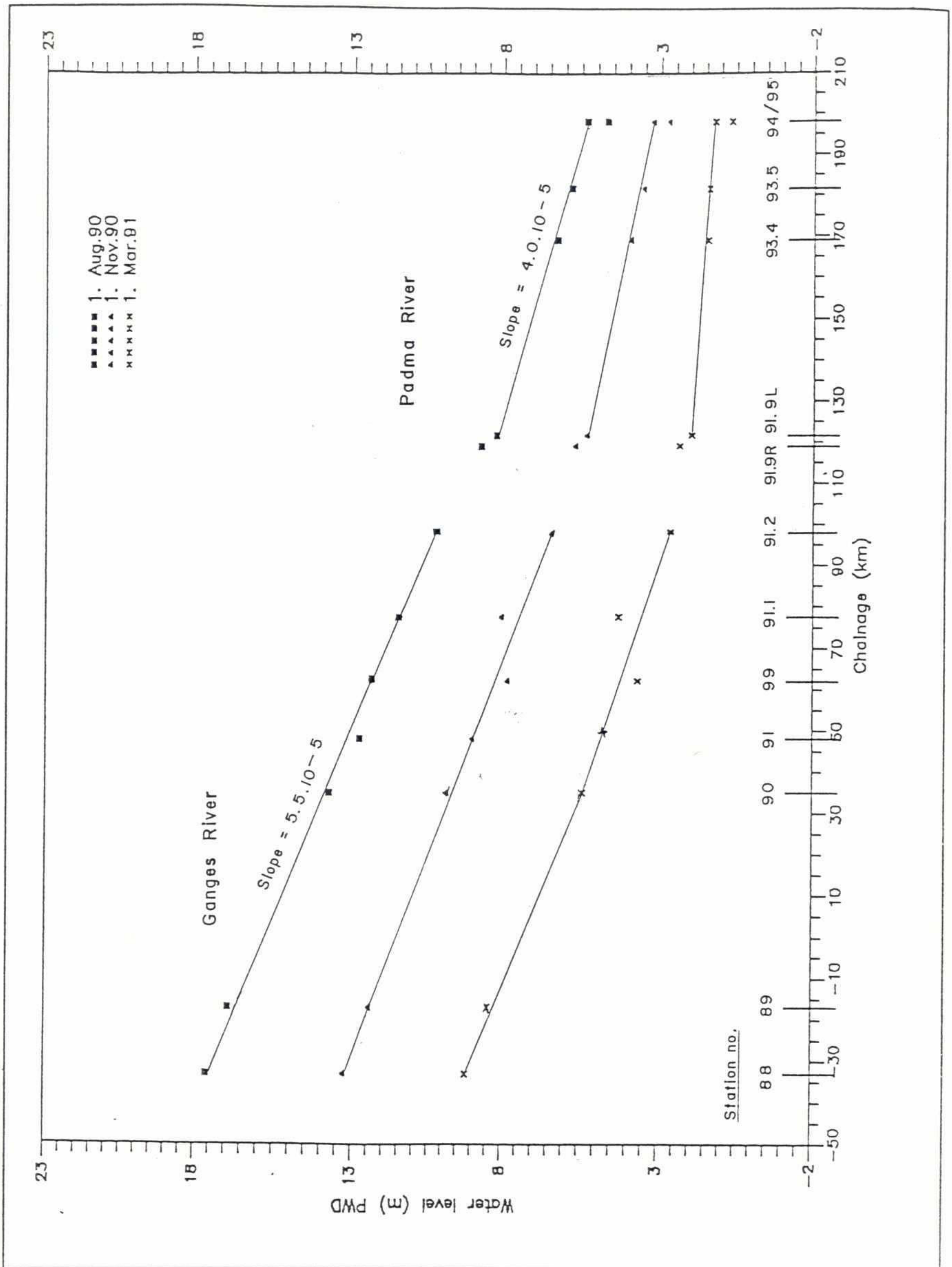
Delft Hydraulics/Danish Hydraulic Institute
in association with Osiris/Approtech/Hydroland

Gorai Railway Bridge. Frequency analysis of peak discharges, 1966-91 (Log-Normal).

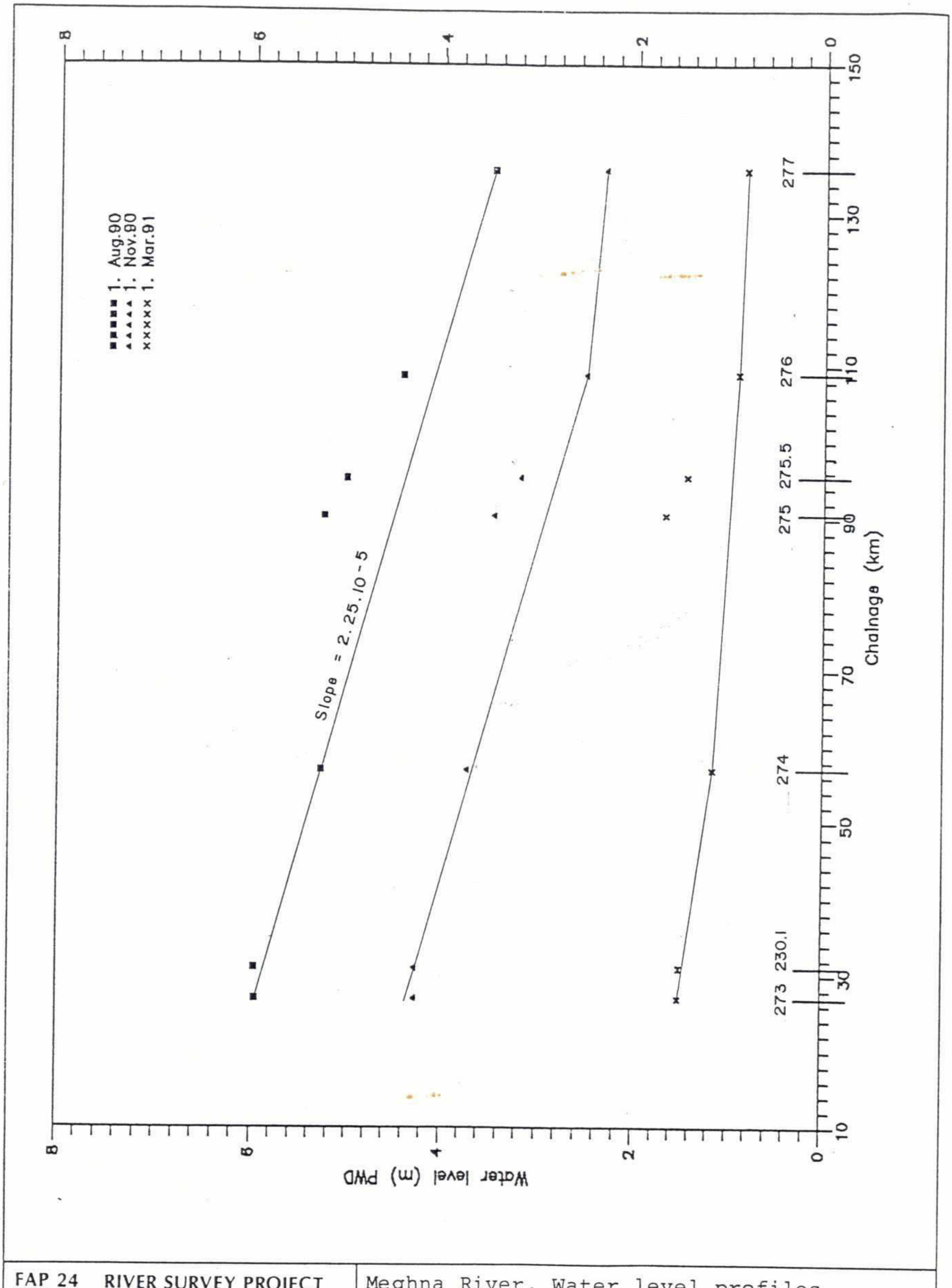
File:	**Date:**	Hydrological Study Phase 1	**Fig.** 6.32
Scale:	**Init:**		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Jamuna River, Water level profiles	
File:	Date:		Fig. 7.1
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Ganges-Padma River, Water level profiles	
File:	Date:		Fig. 7.2
Scale:	Init:		



FAP 24 RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland DELFT-DHI		Meghna River, Water level profiles	
File:	Date:		
Scale:	Init:		Fig. 7.3