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MINISTRY OF AGRICULTURE & FORES

IRRIGATION DEPARTMENT

IRRAWADDY DELTA

HYDROLOGICAL INVESTIGATIONS AND DELTA SURVEY

VOLUME 1 - METHODS

SIR WILLIAM HALCROW & PARTNERS

JANUARY 1982

MINISTRY OF AGRICULTURE & FORESTS (BURMA)

IRRIGATION DEPARTMENT

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1 INTRODUCTION

1.1 General

In the period November 1977 to March 1981 Sir William Halcrow and Partners advised and assisted the Irrigation Department (ID) of the Ministry of Agriculture and Forests in an investigation into the hydrology of the Irrawaddy Delta. The Terms of Reference (TOR) of the Investigation, together with a note on how they were realized, are given in Appendix A. The programme of activities completed in this period is shown in Figure 1.1.

1.2 Objectives of Study

The objectives of data collection as defined in the TOR may be summarised as follows to:

(a) Establish hydrological design parameters for Paddy drainage projects.

(b) Determine availability of fresh water in lower delta channels.

(c) Assess effect of short term projects on hydraulic regime of delta.

(d) Assess effect of widespread embanking on hydraulic regime of delta.

The last three objectives are difficult to realize in view of the complex nature of the fluvio-tidal inter-actions in the intricate network of channels in the delta. Accordingly, the Consultants instigated an arrangement whereby the necessary studies could be carried out using the numerical modelling techniques that have become available in recent years.

1.3 Numerical Model Studies

In August 1977, the Irrigation Department made a formal request to the British Overseas Development Administration (ODA) to finance numerical model studies of the delta, to be conducted by the Hydraulics Research Station (HRS) Wallingford, UK. Close liaison was maintained with the Consultants to ensure that the data required for the model was available when needed, and that the studies carried out on the model were directed towards realizing the objectives of the investigation.

The construction, calibration, proving and application of the model are described in a series of reports published by HRS.

1.4 Organization of Investigations

In a planning report dated November 1977 the Consultants detailed the staff, equipment, and the preparatory work, which should have been available or completed at the start of the survey. This included survey work boats, mobility launches, echo sounders, radios, a network of fuel dumps, benchmarks and staff gauges of known levels, and a set of aerial photographs of the delta. Various difficulties over procurement and authorization unfortunately delayed the delivery times of these inputs, and some revision of the programme was required.

In the revised programme, three teams were assigned to measure cross sections, while other teams were sent to measure gauge datum levels, extend the benchmark survey, install automatic water level recorders, and construct and stock fuel dumps, workshop and docking facilities.

These teams were all led by Assistant Engineers (AE) of the ID, and comprised various combinations of Sub Assistant Engineers (SAE), Engineering Surveyors (ES), Assistant Engineering Surveyors (AES), Helpers (H) and Labourers (L) The AE grades were graduates from RIT or RASU*, some with foreign training. SAE grades generally had diplomas from Government Technical Institutes. ES's had passed through Technical High School and AES were graduates from RASU without technical experience.

Overall control of the team passed through U Ohn Myint, the Counterpart Assistant Executive Engineer (AEE) initially assigned to the project. Upon his promotion and transfer to another division, U Zaw Win, AE, one of the team leaders, took over his duties.

The month by month programme of activities was drawn up jointly by the Resident Team Leader (RTL) of Sir William Halcrow and Partners and the Counterpart Engineer. Applications for Kyat expenditure and staff recruitment were passed through Sao Aung Myint, Executive Engineer in charge of Paddy One design and the Project Director, U Saw Hlaing.

The organization of the staffing arrangements is shown as Figure 1.2.

1.5 Data Collection and Analysis

A schedule of the data collected and the analyses performed in Burma is shown in Table 1.1. As far as possible, data required for the mathematical model was pre-processed in Burma and sent in punched card form to UK. The study included the analysis of some 15,000 cross section coordinates, 20,000 short term tidal observations, 400,000 rainfall observations and 400,000 water level observations, all of which were processed on an ICL 19025 operated by the Rangoon University Computer Centre (UCC). The records have been transcribed to magnetic tapes for safe keeping and further analysis and, in view of their bulk, only the results of the analyses are included in the appendices to this report.

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*RIT Rangoon Institute of Technology

RASU Rangoon Arts and Science University

1.6 Layout of Report

The chapters which follow in this, Volume I contain a description of the methods used to collect and archive the observations

Volume II contains a summary of the observations made, some of them in the form of listings from the computer records which are held at UCC. Annexes to Volume II contains drawings of 665 cross sections of the rivers, 16 cross section of the islands of the delta, and 6 coastal tide records.

Volume III contains the analysis of the records which were not included in the mathematical model. The model reports themselves represent the analysis of the bulk of the observations.

An annex to Volume III contains details of the computer programmes developed on the project

2 BENCHMARK SURVEY

2.1 Planning

In the planning report prepared by the Consultants in November 1977, the requirement for a series of first and second order benchmarks to be established along the lines of the main delta rivers was set out.

The planning and execution of the survey was carried out by the Burma Survey Department, Geodetic and Research Division, and the fieldwork was undertaken by 8 survey teams in the 1977/1978 season.

The results were available in time for the start of hydrometric surveys starting in November 1978.

2.2 Survey Details

The area was surveyed in two stages, with additions made by Irrawaddy Delta Survey teams after November 1978, as shown in Figure 2.1. The main circuit Rangoon - Henzada - Bassein - Rangoon was first established, the subsidiary circuits added to give fairly good coverage of the main river channels of the upper and middle delta. The time allowed for the 1978 survey did not permit an extension into the lower delta, with its extensive mangrove swamps.

The work was carried out by 4 construction teams, whose duties were to fix or construct benchmarks in appropriate locations, each followed up after an interval of two to three days by a level carrying party.

The construction teams, each of 10 men under the supervision of a Survey Officer, built

328	Pipe	BMs -	Consisting of 5ft length of 2" water pipe driven 4ft into the ground and surrounded by a 2ft square concrete plinth.
96	Brick	BMs -	Consisting of 8" iron bolts inserted into brick or concrete surface of buildings, bridges, etc
19	Inscribed	BMs -	Consisting of circles with central dots inscribed on existing permanent and firm concrete floors.
17	Embedded	BMs -	Consisting of a concrete plinth 3ft square founded 2ft below ground level, and fenced off.

The survey teams, each of four surveyors and 18 chainmen, levelled a distance of 2088 kilometres with several major river crossings. The closing error on the main circuit of 764km was 19.025cm, which compares with 11cm expected in first order levelling, and 23cm in second order levelling. These standards were maintained in the secondary circuits.

A total of 1000 man-months of fieldwork, and 90 man-months of office work was needed to complete the work.

2.3 Benchmark Levels

The Tables in Volume II present the accepted benchmark values, and the type and location of each. The levels are referred to the AMHERST MEAN SEA LEVEL.

3 STAFF GAUGE NETWORK

3.1 Planned Network

The network for the investigations was set out in the planning report by the Consultants dated November 1977.

This network was based on the requirement for gauges to be installed at approximately 25km intervals along the main channels, with automatic water level recorders at four points on the main rivers entering the Delta, and at a coastal location. In addition, gauges would be required for 29 day observations on the coast.

The Consultants therefore selected 70 gauges from the existing networks run by seven administrative centres. To these, a further 23 new gauges were added, and the sites for the automatic water level recorders were identified.

It was hoped that all these gauges would be installed and levelled and the housings made ready for the automatic recorders in the event, four of the five stilling wells were completed, and many gauges installed. It was not possible however, to undertake the levelling work that year.

3.2 Existing Gauges

Gauges in the delta are operated by the Irrigation Divisions of Henzada, Maubin, Dredger, and Hydrology, and by the Paddy Project Offices, all of the Irrigation Department. In addition, some gauges are operated by the Port Authority and the Department of Meteorology and Hydrology.

Apart from a very few permanent installations, the gauges consist of tide boards some 15ft long, marked off in feet and inscribed with Burmese characters. These are fixed to mangrove or timber poles in the river, and levelled into a permanent gauge site benchmark (GSBM) normally situated above flood level, and often near the gauge reader's hut.

Inevitably, these gauges take many knocks from the various boats passing in the river, and the gauge datums (ZOG) change frequently. Observers are not well equipped to refix them at the original level, and the resetting of the gauges is a common source of errors.

The use of more sturdy installations would help reduce this problem but in the saline areas there exists the problem of toredo marine worms which destroy timber piles within a year. Construction in steel or concrete would be expensive and often self defeating, as the post becomes a convenient mooring point for larger craft. The permanent installation in Rangoon, for example suffers repeated damage.

The solution adopted by the Irrawaddy Delta Survey team on the gauges operated by them was to install on the bank a little below high tide level a peg with a known level corresponding to an integer number of feet on the gauge. The gauge reader is then able to verify that the reading on the gauge is correct when the tide level is at the peg. The peg, being close to the bank, is reasonably well protected.

3.3 Existing Observations

Most of the organizations responsible for staff gauge observations have been collecting five readings per day, these being at 6am, 12 noon, 6pm, and daylight HW and LW. The Paddy One Project collects hourly observations from 6am to 6pm.

The former observations are published in a series of hydrological year books by the Hydrology Division of the Irrigation Department. The latter observations are analysed by the Paddy Project to produce estimates of mean monthly tide curves at springs, average, and neap conditions at various sites.

The accuracy of the estimation of the HW and LW directly, as is done by the majority of organizations, depends largely on the ability of the gauge reader to predict the time at which they will occur. It is unfortunately apparent from the records that the observer merely guesses at the daily retardation, the guesses usually being 30 mins, 45 mins or 60 mins, and reads the water level at that time. This leads to some obvious anomalies in the record, where the phase difference between two adjacent stations apparently changes every day.

As an example, the records at Sagyin (1) and Zibyuseik (2), 16 miles apart on the same river, for January 5th to January 9th 1976 may be compared.

Day	5	6	7	8	9	
HW (1)	1300	1400	1500	1600	1600	hrs
HW (2)	1400	1430	1500	1630	1600	hrs
Difference	-1	-0.30	0	-0.30	0	hrs

In the analysis carried out by HRS in April 1978, an attempt was made to interpret readings over two 5 day periods from 40 stations. Even after extensive averaging, the results from 11 stations had to be rejected because the predicted times of HW and LW were more than two hours from an estimate provided by adjacent gauges. If the time is wrong, then of course, the level is likely to be incorrect as well, although this is more difficult to check.

The hourly data collect by the Paddy One Project provides a much better estimate of height and time of high and low water. When the data is plotted errors can usually be detected without difficulty, and it becomes possible to estimate times and levels of high and low water withing ±20 mins and ±2cm. However, this method suffers from the problem of the diurnal inequality of the tides. Figure 3.1 shows the record from Elephant Point over the period 29th November to 3rd December 1978. It may be seen that the daylight hours estimation of maximum HW is 16.8ft. In fact, the maximum HW was 18.5ft, 1.7ft higher than the daylight estimate. The situation is reversed at the following spring tide, when the daytime reading is 16.3ft and the night time 14.8ft. Because of the inequality of successive spring tides the higher of these two spring high tides will be the maximum level only 50% of the time. Elephant Point is an extreme example, but in drainage and irrigation design in the delta, difference of 0.1 - 0.2ft are very important.

3.4 IDS Observations

In June/August 1979 it was therefore proposed to the various divisions of Irrawaddy Delta that a system of continuous observations on the spring and neap periods should be introduced. Under this arrangements, readings would be taken at hourly intervals from 6am on a selected day, and continued for 37 hours onwards to 6pm the following day. The days were selected from the predicted tides at Elephant Point so that the two neap and two spring tide periods each month would be covered. In addition daily 6am readings would be collected. The 37 hour period assures that the same phase of tide is covered for all the gauges, since in addition to the 25 hr tidal period, there is a 12hr phase lag access the delta.

The advantages of the system are fourfold.

(a) Better coverage is given of the critical phases of the tide.

(b) The gauge reader is not obliged to stay continuously at his post throughout the mouth. Since the pay of an observer is low, he needs to have time to supplement his income.

(c) Errors are easily shown up when the data is plotted.

(d) The volume of data is kept to a minimum. This is important for the ongoing analysis of the readings.

The 7 point system (6, 12, 6, HW, LW, Time HW, Time LW) generates 7x30 = 210 readings/month
The 13 point system (6am to 6pm) generates

13 x 30 = 390 readings/month

The 37 hr system generates

37 x 4.1 = 152
plus 30 x 1 = 30

These advantages justify the extra expenditure in providing torches and clocks to the gauge readers, as well as extra payments for night time readings.

3.5 Revised Network

In addition to the gauges required for the IDS work, the Paddy 1 design office installed a further 60 gauges at possible culvert sites in the polder areas. In the interests of economy, it was decided to control these gauges together with the IDS gauges under a single team.

For water level observations in the inland areas liable to flooding, a further set of gauges was installed in May/June 1980, these being placed in the east-west transits which had been made of the upper and middle delta islands.

The final network of gauges is tabulated in Table 3.1 and the locations of the gauges are shown in Volume II, and in Fig 3.2. (River gauges only).

These gauges are grouped into geographical units coded I - 1 to 9 centred on fuel dumps in the delta where Engineering Surveyors are stationed to assist in gauge supervision. Administrative control is through the various organizations (Coded J = 1 to 7) mentioned above. The gauges installed by the IDS are divided into river gauges (Code J = 1) and inland gauges (Code J = 6). Within these groupings, the stations are given a two figure number KK so that the four figure code IJKK identifies each station.

3.6 Progress of Fieldwork

In November 1978, a set of gauges for the 29 day $\frac{1}{2}$ hourly observations was installed at 6 coastal stations, and levelled to their gauge site Benchmarks (GSBM). Absolute levels of only one of these stations (Elephant Point) was known, the others generally being too inaccessible to establish levels, although in fact some were later levelled into the network. Observations were made in November/December 1978.

From December 1978 to June 1979, a start was made on levelling in the gauges installed by the IDS team. The survey traces are shown in Fig 2.1 of the report as the IDS extensions. The levelling was done using the two staffs method to minimize the errors, and major river crossings were avoided where possible.

In the period February to June 1979 after studies of possible alternatives, the town of Zalun was chosen as a suitable location for the fifth automatic stage recorder, and a stilling well was installed there.

In April/May 1979, in response to an urgent request from HRS, a further set of 29 day observations was obtained at 9 stations in the middle and lower delta.

It became apparent by the end of the first monsoon that many of the levels published for gauges operated by other divisions were inaccurate, and would have to be checked. This work was therefore undertaken and the GSBM's and ZOG's as knownare shown in Volume II.

An important part of the fieldwork was the regular inspection and maintenance of the gauges, the checking of the ZOG's, and the collection and verification of the observations. This work was carried out for the 89 gauges directly under IDS control by a team of 4 SAE, 11ES, and 2 Helpers, operating under the leadership of 1 AE who also generally supervised the logging of the observations when they arrived in Rangoon.

Administrative problems limited the extent to which the IDS team could upgrade the standards at gauges falling under the divisions, some of which work to different datum levels (eg. the old ARDC Datum). At many sites it is left to the gauge reader to reinstall the gauge when it is damaged, or the water level rises above Kegwya because of seasonal variations in river levels, and naturally the errors rapidly accrue.

Where the full cooperation of the divisions was forthcoming, the self checking pegs installed at the IDS gauges were extended by the IDS teams. In this way a total of 54 gauges were upgraded.

3.7 Storage of Observations

Under the revised system, the observations in feet arrived in the IDS office on pre-printed forms covering one month's record. Table 3.2 is an example, designed for easy transcription to either punched cards or later magnetic disc.

The records which come from the IDS gauges arrived within 2 - 3 weeks of the end of the previous month. Those which came from the other divisions took up to 8 months to arrive, but this delay was reduced somewhat after the initial problems were sorted out.

The raw data was plotted by hand, four curves per graph, so that errors could be picked out by a team of four draftswomen. The records were also punched onto card (directly from the Burmese) and sent for filing on digital disc files as described in Volume II.

3.8 Historical Observations

In addition to the observations made by the IDS teams during the period of the study, an attempt was made to collect data from various reports and files on a number of gauges in the delta (Maubin, Shwelaung, Henzada and Seiktha) and at some points upstream (Prome, Bhamo and Mawlaik). The recorded high flood levels each year as available are given in Volume II.

4 TIDAL OBSERVATIONS

4.1 Requirements

The tidal constituents at various locations on the coast were required to specify the boundary conditions of the mathematical model, and in the planning report 6 suitable sites were selected. The observations were made in November/December 1979.

In March 1979 a request was received from HRS for further sets of observations to be taken at 9 locations in the delta against which the pilot model could be proved. This meant some changes to the fieldworks programme, and the observations were taken in April 1980.

A further set of observations was taken at Thingangyi to determine Mean Sea Level for use in the Survey.

Figure 4.1 shows the location of the gauge sites used.

4.2 Observations

The observations were taken on tide boards at ½hr intervals day and night over a 29 day period by teams of 3 men acting in relays, and living in temporary huts erected near the gauge. Normal procedure was to check the zero of gauge against the gauge site benchmark at the start of the observations. Unfortunately, at two inland sites this was not done because the team deposing the observers was in a hurry, and believed that the gauge was properly maintained by the local division. This assumption proved incorrect but it was not possible to establish the datum afterwards. However, the tidal constituents could still be established.

4.3 Verification

The readings were checked for gross errors by summing observations taken at the same time each day and plotting the results. The corrected totals were punched onto card and run through a plotting routine to produce stage - time graphs, which are reproduced in Annex B of Vol. II. The cards were then dispatched to UK for analysis by the Institute of Oceanographic Studies.

4.4 Stage

The 20,880 individual readings are not listed in the report as they are not of great interest once processed. They are available on magnetic tape at the UCC.

5 CROSS SECTION SURVEY

5.1 Planning

Cross sections of 2500km of the delta river channels were required to define the hydraulic properties of the reaches included in the mathematical model.

Cross sections of the islands were required to estimate the depth and duration of flooding in the monsoon season.

Bed samples were collected from each of the river cross sections to assist in determining the hydraulic roughness.

The criteria for locating the river cross sections were set out in the Consultant's report 'Requirements for Cross-Section Survey', dated January 1979. These comprised the following:

(a) The total number of cross sections was to be 600-700, a figure considered to be appropriate to the model requirements and also within the capabilities of the IDS team. An initial selection of 580 was made in the first report, to allow for later additions. These additions have since brought the total to 663

(b) The distribution of the sections gave the greatest importance to main channels, important cross links, and channels near or affecting paddyland development areas. The main channels were identified from Landsat images, while the other channels were chosen in discussion with ID. The channels finally included are shown in Figure 5.1.

(c) The initial upstream boundary was chosen to be at the line of the railway crossing of the Delta ie. Chanthagon, Henzada, and Myogwin, since, for the low flow model, the three rivers at these points are virtually independent. This choice was revised later to allow further development of the high flow model.

(d) Sections were sited in each reach 1km from junctions and typically 5km in between. The sections were located where possible on straight reaches rather than at bends.

(e) The limits of the cross sections were taken at a little beyond the embankments or natural levees where they existed. The island cross sections were used to establish general land levels where flooding may occur.

(f) The reaches and junctions were each numbered independently. No particular order was established since further additions disturbed any network based system. Cross sections were numbered sequentially from one end of the reach to the other. For ease of administration, the Delta was divided up into sub-delta units numbered A to L as shown on the key plan in Annex A to Vol II. The selected locations were marked on a Series of Landsat based maps included in the report.

5.2 Measurement of River Cross Sections

The measurement comprised five stages.

(a) Location of the Sections

Once the teams were in the area indicated in the report the detailed location of the cross section was fixed by consulting aerial photographs, the majority of which became available in February 1979. The exact location was adjusted where necessary if the banks were unsuitable for fixing the necessary base line and targets before being marked up on the photo.

The 1944 set of 1 inch to the mile maps of the delta were used when photos were not available, but these were much less satisfactory for navigation purposes.

(b) Establishment of Datum Level

In the ideal situation, staff gauges with known GSBM's were already established every 25km along the main channels. In this case the ZOG's could be checked for the gauge upstream and downstream of the section, and observers posted with mobility launches at both gauges, to read levels every half hour on the half hour. From 3 sets of simultaneous observations of these gauges and a staff gauge at the section, the water surface level at the section was calculated and a level of the local IBM determined.

In some cases, the level of the TBM could be established directly from some other known BM in the vicinity. In much of the lower delta, u/s or d/s gauges with arbitrary datums had to be used and these were levelled in later either by survey or the use of mean tide levels established from 29 day observations.

Volume II gives details of the datums used in each case.

(c) Measurement of the Wet Profile

The wet profile was measured by setting up a transit line and targets on one bank of the river, crossing to the far bank, then running down the targets with double sextant angle measurements while simultaneously noting depths on an echo sounder. The level of the water surface at the start and end of the traverse was noted by an observer using the temporary staff gauge levelled in as above.

Initially catamarans constructed from two local canoes, with a 3m x 5m decking supported across the two hulls, and a canvas awning over, were used, these being equipped with portable echo sounders. Twin 6 HP diesel irrigation pump engines supported on yokes, and fitted with long out board shafts and twin bladed aluminium propellers, provided propulsion. These boats were satisfactory in the dry season in smaller rivers but unsufficiently seaworthy to be used in estuarial waters or windy conditions.

In June 1979 they were replaced by 8m 120HP diesel survey workboats fitted with built-in survey echo sounders, which permitted faster working and operation throughout the delta.

The targets consisted of 0.6m square plywood panels covered with one of three different coloured plastic reflective films and clamped to bamboo poles, laid on a kite shaped plan as Figure 5.2, the long axis defining the transit line and the short defining axis base lines along the bank. The base lines and their angles to the transit line were measured and the width of the river calculated from each extremity of the base line to provide an on-site check. This was easy enough where there were embankments and open paddy fields; elsewhere, the surveyors had to cut traces through heavy riverine scrub or wade through the deep mud of the tidal flats to avoid the mangrove.

The boats would crab across the current to allow the surveyors time to run down the targets. The second surveyor, measuring the angle left, would initiate a fix by calling 'ready', to be followed by the lead surveyor calling 'ready' to fix - fix' and measuring the angle right. In turn, the second surveyor, the lead surveyor, and the sounder would call out their results to the booker. By the end of the training period, a cycle time of 20 seconds was regularly achieved.

This technique was not possible in wide rivers, as the targets ceased to be visable at about 2kms. In this case, a single base line (AB) was set up using EDM equipment and theodolites fixed at each end, one of which (A) was also on the transit line. The boat was talked down the transit (using VHF radios) by the surveyor at A and when on line, A would instruct B to take a fix while the depth was noted on board the boat. This method was successful for the widest rivers of up to 10kms across, even when the banks were extensively covered with mangrove.

(d) Measurement of Dry Profile

Once the wet section was measured, the surveyors, one on each bank, would extend the transit line over the bank for a few hundred metres where possible. On one side the TBM level could be used and, on narrow rivers, the level carried across. On wide rivers, the water surface itself was used to carry levels across, the mean of three measurements being used for this purpose.

(e) Checking of Measurements

In order to ensure that the results obtained were reasonable, the teams were issued with calculators preprogrammed to solve the 3 point fix problem. While the surveyors were extending the dry profile the team leader would enter in the angles left and right, and get the transit distance and departure. If the departure was excessive, the profile would be re-measured The river width would also be checked from both base lines to ensure accuracy. These precautions took little time, since the main effort was in travel to and locating the section, setting up the targets, setting down observers, etc, while the time spent on the cross section itself was relatively short. The cross section measurements were documented in the field on a proforma reproduced in Appendix E.

5.3 Verification and Presentation of Results

The cross section report forms were normally received in the office in batches at the end of each mission. These were then booked in, checked to see if the calculations were correct and passed out to draftsmen for plotting on squared paper at one of three scales, depending on the total width of the section.

The sections were checked to see if they looked reasonable and any discontinuities discussed with the team leaders, When satisfactory, they were stylized into a limited number of x,y coordinates connected by straight lines. The original and the stylized section were then traced, and the resulting cross sections are shown in Annex A to Volume II.

Sets of punched cards were prepared for each section, list ing the x,y coordinates. These were fed into a programme which plotted the coordinates as closely as possible at the same scale as the original on a lineprinter (the location slightly inexact because of the integer nature of line/row output).

The lineprinter output was checked against the tracings to see if the coordinates had been correctly plotted and if satisfactory, the card listings, lineprinter outputs, prints of cross sections, and location plan for each batch of sections were sent off to the Consultant's Head Office.

Artificial embankments were shown by giving coordinate points at the top and bottom of the embankment the same x coordinate. Naturally steep banks were always shown with different x coordinates.

A tabulation of the accepted coordinates is given in Volume II.

5.4 Bed Sampling

In November 1979, bed grab samplers were received by the project, and teams were sent out to take samples from each of the cross sections.

The samples were taken at approximately 1/6, 3/6 and 5/6 of the distance across the section, and kept in plastic bags until they could be analysed.

Some difficulties were experienced with the grab, which tended to stay in the open position in a strong current because the drag on the cable was sufficient to prevent the catch releasing even when the grab touched bottom. The problem was solved by attaching a heavy sinker weight just above the grab, which effectively countered the effect of the drag.

The sediment laboratory equipment was not delivered until June 1980 by the project. In order to provide some initial estimates of the bed roughness, a series of preliminary tests was carried out on the samples using a set of four sieves to assist in classifying the material into silt and fine, medium and coarse sands and intermediate values. The results of these tests were substantially confirmed by a fuller examination, undertaken after the laboratory equipment arrived.

The results of the examination are shown in Figure 5.3, and the tabulated results.

5.5 Island Cross Section Survey

The contour interval on the existing maps of the delta is 50ft, which is far too coarse for the needs of the investigations. Since only limited surveys could be carried out, a series of East-West Transverses of the Delta were made by the survey team, as shown in Figure 5.4.

These cross sections were made on a compass bearing only, with tacheometric measurement of distance. High accuracy was not specified, in view of the limited time available, and in any case was not required for the model. Closing errors were relatively small but there was evidence of some cumulative errors on distance. Nevertheless, the sections are considered accurate enough for the model.

These sections were plotted and stylized in the same way as the river cross sections. The results are shown in Annex B to Volume II.

6 SALINITY STUDY

6.1 Application

The location of the saline front, coupled with a knowledge of the longitudinal salinity profile and the residual freshwater flow into the river, can be used to calculate the rate of longitudinal dispersion of salt in the river estuary. By repeating the analysis with reduced freshwater flows, the variation of its position according to different rates of abstraction can be determined.

6.2 Measurement

The survey was directed towards determining the point of maximum penetration of the front season by season. This occurs at the time of current reversal soon after High Tide on the spring tide, and accordingly measurements were made at or near this time.

A map was drawn up indicating 10 river channels up which profiles were taken, with sections indicated at 5km intervals, numbered consecutively from the mouth. Two boats were used in the survey, each starting 2 days before spring tide and taking measurement each day for five days, one day per river. The boats took 3 measurements of salinity (surface, mid-depth and bottom) at each section; then proceeded upstream at the rate of 3 sections per hour. With a foreknowledge of the approximate location of the front, and of the time of high water, they started approximately 45kms downstream of the expected location 3 hours before expected high water, so timing their arrival at the front at close to high water. Gauge readers at the gauge nearest the expected position of the front took readings throughout the day to ensure that the time of high tide was known.

The errors made in estimating the position of the saline front before or after high water. This was not serious, however, as a correction could be made using the channel velocities predicted by the model.

The locations of the front in January and April are shwon on a small scale map, Figure 6.1. Volume II shows the locations month by month at a larger scale, and a tabulation of the observations.

In the second dry season the method was refined to take simultaneous observations of the salinity at the river mouth. Lack of equipment prevented this being done everywhere, but it proved possible to make some estimate of sea salinities along the full length of the delta coast.

In addition, some monitoring of salinity at the day time high tide was done at certain river mouths to provide an indication of the variation with the phase of the fornightly tide (spring/neap cycle). Table 6.1 summarizes the number of observations made.

7 DISCHARGE AND SEDIMENT MEASUREMENTS

7.1 Requirements

Discharge measurements were required in order to estimate the total inflow into the delta and its distribution in the main river channels in the system.

In particular, the distribution of the flows at the apex of the delta was of major importance, since for the mathematical model the two first effluent rivers of the Irrawaddy, the Ngawun and the Hlaing were treated as having separate inflows, taken as a proportion of the Irrawaddy flow. The appropriate proportion was deduced from the observations.

7.2 Location of Sites

Sites for four fixed gauging stations were identified in the apex of the delta at Seiktha, Myogwin, Chanthagon and Zalun and stilling wells were installed at each location.
Seiktha was chosen as being the lowest point on the Irrawaddy with a stable gauge (vide England's report on the 1939 Flood). Zalun was chosen after some deliberation because of the unstable nature of the Irrawaddy between Henzada and Yandoon, and it is unlikely that the rating curve derived will be useable much beyond the end of the project. Chanthagon and Myogwin were chosen for ease of access, both sites being at the railway crossing of the rivers.

The remaining locations were as shown in Figure 7.1 chosen as being key junctions from which estimates of the storage in the middle delta could be calculated. Where possible, they were sited above the tidal limit but the high tidal range in the eastern delta meant that the stations in this area are tidally influenced even though no reversal takes place.

7.3 Field Measurements

Observations were made at regular intervals throughout the monsoon period at all stations and throughout the year at the four fixed stations. The moving boar method was used on the Irrawaddy at Yandoon, since the high velocities and depths made convertional measurements very difficult. On non-tidal rivers,measurements were made at 8-12 verticals on the transit, two points per vertical. On tidal rivers, in addition to these observations, velocity measurements were made throughout the tidal cycle at a single location to provide a basis for corrections to the other measurements.

At all junctions apart from the one at Yandoon, discharge measurements were taken at all three branches so that a check could be made on the sum of the flows. At Yandoon, it was not possible to measure discharge downstream of the junction.

Sediment flux measurements were taken at the same locations as discharge, except that at junctions samples were taken only on the main branch of the river. Samples at the apex of the delta were taken using a 250cc steel sampler with spring loaded steel end caps closed by a messenger. This worked reasonably well although at times the messenger would not drop in the current. Elsewhere, 1 litre samples were pumped up through half inch rubber hose attached to a weighted cable. This arrangement was less satisfactory because of the high drag which caused excessive deflection of the cable even with 100kg sinker weights, and also caused the hose to deform.

Sediment samples were taken at eight points on the vertical logrithmically spaced from the bottom, on each of eight verticals. Velocity was measured at the same point. Samples were filtered through pre weighed filter papers on site to reduce the volumes of water which had to be transported. One team was equipped with a pressure filter, the others using gravity filters which took typically one day to drain.

On return to Rangoon the numbered samples were dried and weighed in the sediment laboratory.

7.4 Calculation

Discharge estimates were made on non-tidal rivers by plotting the mean-in-vertical velocity multiplied by depth against transit distances and graphically integrating the area under the curve. On tidal rivers, the velocity was first corrected by dividing by ratio of the velocity measured simultaneously at the fixed boat to the average velocity over the tidal cycle, also as measured at the fixed boat.

Sediment flux estimates were made by multiplying the velocity by the sediment concentration at each point, plotting against depth and graphically integrating to obtain the unit flux. This was then plotted against transit distance and again graphically integrated to obtain the total flux.

The results are tabulated in Volume II.

8 SURGE SURVEY

8.1 Introduction

Surge conditions are created when a combination of low atmospheric pressures and wind shear forces act on a body of water and cause abnormally high water levels. Depending on the configuration of the encompassing coastlines, these levels may be amplified and result in extensive flooding of low lying areas.

The Bay of Bengal is frequently subject to severe cyclonic storms, some of which cross the Burma coast and, very rarely, the Delta coast. When this occurs, the surge induced can cause extensive flooding and the embankments of polder projects must be designed to resist such eventualities.

Preliminary reports of the most severe conditions remembered, those of May 1975, indicated that the depth of flooding could be in the order of 15 feet, which would require a large investment in extra embankments. A survey was therefore carried out to see if this was indeed the case and to the determine frequency of occurence of such conditions.

The survey indicated that the earlier reports were much exaggerated and that depths of flooding of 2-3ft above ground level were more typical.

The possible effects of surge were studied by using the level duration curves of the 1975 storm as coastal boundary conditions in the mathematical model of the delta. The results of this are discussed in an HRS report.

8.2 Previous Studies

Discussion with the Meteorological Department and various other authorities failed to turn up any previous studies of surge conditions in the delta, or indeed of any other place on the Burma coast. Work has been done on the surges induced by cyclones in Bangladesh but that area is very different in exposure to and frequency of cyclonic storms.

The only written report available is one entitled 'The Storm Surge of the Deltaic Region of Burma during May 1975' published by the Department of Meteorology and Hydrology, dated 31 December 1977. The report is short but of interest and is reproduced below with minor amendments.

"Introduction"

Burma is frequently struck be severe cyclonic storms along the Deltaic and Arakan Coasts during the premonsoon (April-May) and post monsoon periods (Oct-Nov). The area struck by the storms experience not only strong winds, torrential rains and floods but also storm surges, particularly at places where conditions are favourable. During the last decade, four severe cyclonic storms struck the Burma Coast (1967 May, Kyaukpyu; 1967 Oct, Akyab; 1968 May, Akyab and 1975 May, Bassein - Gwa). The cost of damage due to this latest storm was estimated as

1.	Loss of Life	...	303 persons
2.	Loss of cattle	...	10191 head
3.	House destroyed	...	246738 numbers (568.3 millions Kyats)
4.	Other buildings destroyed	...	3035 numbers (29.6 millions Kyats)
5.	Ships, boats etc destroyed	...	398 numbers (3.2 million Kyats)
6.	Grains (Paddy)	...	17.5 millions Kyats
7.	Other crops	...	84.4 millions Kyats
8.	State Properties	...	73.5 millions Kyats
	Total crops and structural damage	...	776.5 millions Kyats.

"The Cyclonic Storm of 1975 May"

On 4 May 1975, a tropical cyclonic circulation was first observed in the neighbourhood of the Andaman Sea. It developed into a depression on the next day at 0300 hours, G.M.T. with its centre about 200 miles west of Mergui. The depression then moved north-westwards for the next two days and reached the stage of severe Cyclonic Storm on the 7th morning. The maximum wind speed was then about 80m.p.h. and the storm recurved towards northwest and crossed Burma Coast between Bassein and Gwa at 1630 hrs G.M.T. on the same day. It continued to move inland for ten hours as a land depression and weakened into a low some 100 miles away from the point of landfall. The track of the storm is shown in Figure 8.1 and the main characteristics of storm are shown below.

STORM

Size (radius of maximum wind)	= 30-40 miles
Estimated central pressure	= 970-965 mb
Pressure drop (outer minue central)	= 1010mb - 970 mb = 40mb (45mb)
Maximum wind speed	= 120 mph (53m/s)

TRACK

Forward	= 8 to 13 m.p.h. 3.5 to 5.8 m/s.
Alignment with respect to the coast line at the time of landfall	= 45° to the coast

"The Storm Surge"

Due to the cyclonic storm of May 1975 the deltaic area was affected by a surge which reached about 60 miles inland from the Deltaic shoreline. Information about the surge from local authorities revealed that the highest water level (astronomical tide plus the surge) occurred not along the sea shore but at some 30 miles inland as shown in Figure 8.2.

"Duration of Surge"

The duration of surge over the deltaic region seemed to vary. Near the shoreline, the duration of surge was known to be about 12 hours, and it increased to a maximum during of 72 hours at some 30 miles inland. Again it decreased to 6 hours further inland. The storm surge duration is shown in Figure 8.3.

"Discussion"

The storm surge which affected in the deltaic region in Burma revealed that the general direction of inflow of sea water was along the estuaries of the delta due to the effective onshore winds of the storm".

It can be seen from the maps Figure 8.2 and 8.3 that there are a very limited number of points on which the contours are based. This may explain the confusion which has arisen in drawing the contours of water level which are drawn in an impossible configuration. It also appears as though the surge levels were up to 15ft above ground level, a fact which is not confirmed by the villagers questioned.

A new survey was therefore made, as discussed in the following section.

It should be noted that the widespread damage is as likely to have been caused by high winds and flooding due to rainfall as it is by surge".

8.3 Field Survey of Recent Surge Levels

In view of the anomalies noted in the report on the May 1975 surge, it was decided to send a team to investigate levels of surge occurring during this storm, using the recently established benchmark network as a basis for reducing flood marks to the Amherst datum.

The team made an extensive tour of the lower and middle delta, contacting villagers to ask where flood levels had reached in the 1975 storm and asking how this level compared with other floods in recent memory.

The results of the survey,which was completed in July 1980, are given in Volume II. A small scale map is shown as Figure 8.4.

A number of factors should be borne in mind when interpreting the survey results.

(1) Memories vary 5 years after the event.

(2) Surge propagates with less attenuation up the main channels than in the minor streams.

(3) Local flooding due to the heavy rain associated with the cyclone is not easily distinguished from surge.

(4) Where river levels are low and the surge does not exceed bank full level, it passes unnoticed. Gauge records were examined in such cases but usually the Zero of the gauge was unknown.

(5) Some errors in locating benchmarks appear to have been made.

Although these problems have caused a number of anomalies which remained even after further investigation, there seems to be little evidence of flooding of more than a few feet.

It is clear, however, that the 1975 storm created the worst flooding known in the lower delta. The 1974 flooding was referred to by many villagers in the middle delta but this was associated with a high flood in the Irrawaddy, which burst its embankments in many places.

The high levels noted in the drainage area of the Daga could well have been caused by flooding on this catchment which was crossed by the cyclone. Unfortunately neither of the two rain gauges on this catchment were operative at the time but high 2 day falls were observed at Lemyethna (122mm), Ingabu (200mm), Henzada (75mm), Zalun (98mm), Danubyu (149mm) and Pantanaw (322mm), which indicates that this is a possible explanation.

Recollections of the surge duration were also recorded by the survey team and have mapped out in a very consistent manner, as shown on Figure 8.4. This is surprising, as it cannot be easy to recall such a figure after an interval of 5 years and it tends to confirm that the event was exceptional.

The short duration of surge north of Bassein is not inconsistent with flooding as a result of rainfall in the Daga catchment. The general impression of the survey team was that flooding occurred to a depth of 2-3 feet over an extensive area in the Pyamalaw - Ywe river systems but only in the extreme southwest did villagers flee their homes to escape high flood levels.

9 METEOROLOGICAL OBSERVATIONS

9.1 Planning

At the time of writing the planning report, it was believed that there was an adequate number of rainfall stations in the central delta but that further stations would be required in the hills and on the coast. More extensive meteorological observations were being made at Rangoon, Bassein and Prome and it was considered that a further three stations would give adequate coverage of the delta.

Accordingly, a list of equipment was drawn up for the additional rainfall and meteorological stations.

9.2 Installation

Some consideration delays were experienced in the supply of the equipment, and it was not until April 1980 that it was installed. Observers were sent for training in the use of the equipment to the Department of Meteorology and Hydrology.

Difficulties were encountered in finding suitable locations in the Yomas where rainfall could be measured, as few people live there, and suitable observers could not be found. Accumulator gauges were therefore constructed locally, with cylindrical reservoirs under the gauge. These gauges were visited once a week and the depth of water in the reservoir measured. Water in the reservoir was covered with a layer of oil to prevent evaporation, and the ratio of the gauge area to the reservoir area was known, so that the accummulated rainfall could be calculated.

The gauges were not ideal but served an impression of rainfall in areas where measurements would otherwise be difficult and expensive to obtain.

Certain of the Met. Office gauges in the delta were no longer operating. Where these had a record going back over a number of years, the IDS took them over for the duration of the project in order to provide full coverage.

The location of the various stations is shown in Figure 9.1

9.3 Long Term Rainfall

Long term records were available for the 34 year period 1947 to 1980 at 32 stations within and around the delta. These were used as a basis for the analysis of depth-duration - area - frequency relationships described in volume II of this report. The 400,000 observations of daily rainfall were punched onto card and, after a series of checks, transcribed to magnetic tapes which are held by the University Computer Centre Rangoon.

9.4 Observations

The observations taken are tabulated in condensed form in Volume II. The daily rainfall observations are not included, as these are much more useful in their digital form on tape. Instructions on the use of a programme designed to allow interrogation of the tape to obtain any subset of data are included in the Annex to Volume III.

TABLES

TABLE 1.1

Data Collected In Burma

		No of Records
Survey		
1.	Benchmark Levels - 496	496
2.	Staff Gauge Datums - 195	195
Water Levels		
1.	29Day ½ hourly Levels - 17 Locations	23664
2.	6am Daily Levels - 195 Station 600 days	117000
3.	37hr Hourly Levels - 172 Station 86 tides	547000
4.	Historical Annual Levels - 8 Stations	605
5.	Surge Duration and Level -	61
Discharge Measurements		
1.	River Discharge Rating Curves - 5 Locations	59
2.	Distribution at Junctions -	69
3.	Sediment Discharge -	48
Morphology		
1.	River Cross Sections - 665 Sections (Stylized)	665
2.	Island Cross Sections - 840 Kms (Stylized)	15
3.	Bed Samples - 1893	1893
Salinity and Temperature		
1.	Longitudinal Profiles - 14 months	4340
2.	Time Profiles - 4 months	3736
Meteorological		
1.	Historical Daily Rainfall - 1156 Station yrs	421940
2.	Daily Observations at 3 Stations - 12 Observations	13140

TABLE 3.1 GAUGES USED IN SURVEY

I CODE		1	2	3	4	5	6	7	8	9
ES		U OHN LWIN	U KYAW NYUNT	U TUN HLA	U CHIT PWE	U ZAW TUN	U HLA WIN	U SAN THEIN AYE	U SEIN PWE	U MYINT SAN
J CODE	KK CODE	PYAPON	BOGALE	BETUT	THINGANGON	BASSEIN	WAKEMA	YANDOON	HENZADA	RANGOON
1 RIVER IDS	1	PYAPON	AMA	KADIPA	TAUNGGALE		THONGWA	PAYAGON		TWANTE
	2	THAMEINTAWA	EYA	HPONATKHO			KYONKABYINWA	HLEZEIK		DEDAYE
	3	KALAHTEIK	HNGETPYAWCHAUNG	ZEBYUCHAUNG			MEZALI	KYAMAN		THANDEIK
	4			PYINSALU				NETHAMEIN		ANAUKTOE
	5			DANIZEIK				EIKLAHA		WABALAUKTHAUK
	6									TATTHIT
	7									KALEIN
2 PADDY ONE	1	SETTUMYAUNG	KATHAMYIN	KYICHAUNG	KYAGAN		KYONKABYIN			
	2	TAMAN	KATHABAUNG	KAKAYAN	KOWBO		UGYUN			
	3	HTALUN	SETSAN	HPOGWELAY	AUKPYUNWA		WAKEMA			
	4	KOEEINTAN	ASIGALAY	MAUNGNGE	GWECHAUNG		TAWKANUT			
	5	DANON	MYITKYOE	HTONBUGYA	SINTHAE		TAUNGNGU			
	6	AHCHAGYI	THAECHAUNG	KYEINGYAUNG	MAUNGKYWET		KALA			
	7	AHPHAUNG	GANCHAUNG	ALONTAUNG	HPONYOGON					
	8	KONDAINGLAY		WECHAUNG						
	9	TITAN		KAYANKWIN						
	10	BAWDIMA		KALAKWIN						
	11	DEDALU		BEBAUK						
	12	AHPYAUK		SINCHAUNG						
	13	KAKABAING		HPOGWEGYI						
	14	SHWEDON		THINGANGYI*						
	15	KYETPHAMWEZAUNG								
	16	KYONKADUN								
	17	PHALET								
	18	YATPHAYON								
	19	KANIGYI								
	20	AUKKABA								
	21	SITKEDIYEGYAWA								
	22	MYOGON								
	23	HMWEHTON								
	24	AWAGWIN								
	25	HPOGWEYOE								
	26	KYONKAN								
	27	NGAGYIYOE								
	28	ULON								
	29	WACHAUNG								
3 HYDROLOGY	1		BOGALE	KANBE	CHAUNGWA	KANYWA	MYAUNGMYA	WEDAUNG		HPOTOKEWA
	2		KYUNGYI	ALEYEGYAW	HNGETPAUK	DAKAWA	PULU			KYAIKLAT
	3		HPOTILUK	PEIKTAGYI	SAGYIN	KANGYIDAUNG	SAGAMYA			
	4		PYALEIK	HLAINGBON	NGAPUTAW	THABAUNG	PYINYWA			
	5		MOULMEINGYUN	LABUTTA		KYAUNGGON	YANMANAING			
	6		AUNGHLAING	KYAGAN			GAWTUTAUNG			
	7		TAYUKMYAIK	HPOBYE			PEGON			
	8		KYUNGYI							
	9		WEDAUNG							
	10		MYINGAGON							

* Only used for 29 day observations

TABLE 3.1 (Cont'd) GAUGES USED IN SURVEY

I CODE		1	2	3	4	5	6	7	8	9
ES		U OHN LWIN	U KYAW NYUNT	U TUN HLA	U CHIT PWE	U ZAW TUN	U HLA WIN	U SAN THEIN AYE	U SEIN PWE	U MYINT SAN
J CODE	KK CODE	PYAPON	BOGALE	BETUT	THINGANGON	BASSEIN	WAKEMA	YANDOON	HENZADA	RANGOON
4 MAUBIN	1		THONGWASAING				SHWELAUNG	PANTANAW		THAYAWE
	2						KYWEDON	ALAN		LETKOKPIN
	3							YANDOON		MAUBIN
	4							SETKAW		HTANI
	5							DANUBYU		KANAUNG
	6							MEZALI		KATTIYA
5 OTHER	1					BASSEIN	EINME			TWANTEWA
	2									RANGOON
	3									TAWKALU
6 IDS FLOOD	1	THAYETNGU				KYONPYAW	HTIWAPHALAN		KANYWA	WATAW
	2					MYALECHAUNG	INNMA		MAUGON	ALANGYI
	3					NYAUNGWAING	TAGUNDAING(WAKEMA)		YWAGALE	TUCHAUNGGALE
	4					MALARGON	TAGUNDAING(EINME)		AIZAUK	ALEYWA
	5					WETTOE	PADAT		PAUNTESU	THIDAAYE
	6					SUTTHWA	SINTOE		BANTBWEGON	LETKYET
	7					PANTAWYOE	KYONDAINGGYI		NGANI	THAZINYEGYAW
	8					SHANYWA				KAHMU
	9					KHAYUCHAUNG				CHAUNGWA
	10									KYINHPAW
	11									WAYONECHAUNGPYAR
	12									SINCHAUNG
7 HENZADA	1					ZEBYUKWIN			HENZADA	
	2					MAGYILAHA			MYOGWIN	
	3					NGATHAINGCHAUNG			CHANTHAGON	
	4					ZINBYUNGON			MONYO	
	5					LEMYETNA			NGABATCHAUNG	
	6								MYANAUNG	
	7								SEIKTHA	
	8								NYAUNGGYO	

ရေမှတ်စခန်း: နှစ် လ

မှတည်မျက်နှာပြင်
သုညရေမှတ်
ယူနှစ်

၃၆ နာရီအတွင်းရေမှတ်

ကုဒ်	ရေမှတ်စခန်း:	နှစ်	လ	နေ့	N ကဒ်	ယူနှစ်	၆	၇	၈	၉	၁၀	၁၁	၁၂	၁	၂	၃	၄	၅	၆
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၂၀				၂၁	၁	"													

TABLE 3.2

TABLE 6.1

Record of Salinity Measurements

(a) Number of Observations on profile/number of observations at River Mouth (each observation made at surface, mid depth, and bottom of river).

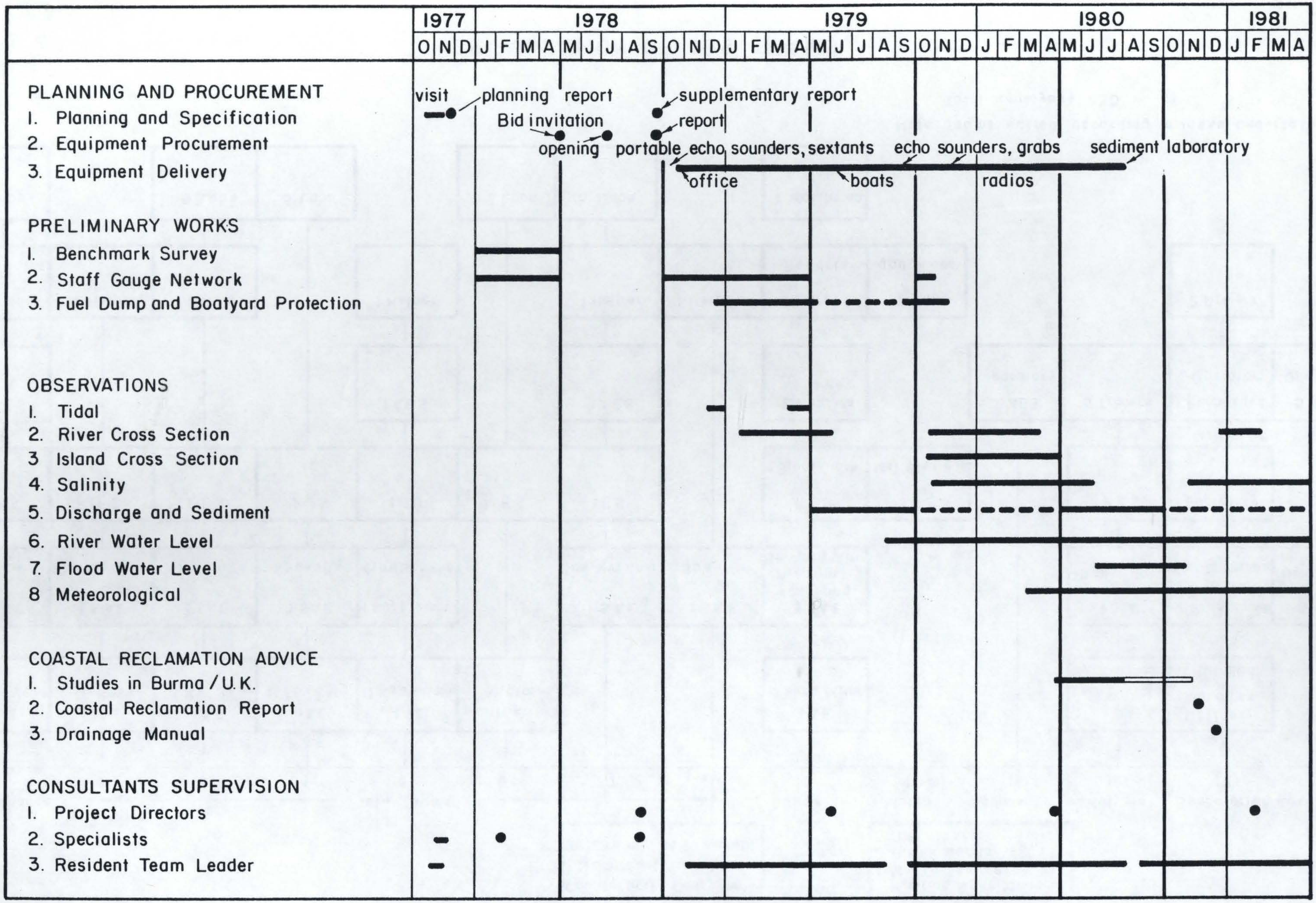
DATE	A	B	C	D	E	F	G	H	I	J
79 NOV 20-24	11/ 0	6/0	5/ 0	10/ 0	10/0	8/ 0	8/ 0	12/ 0	15/ 0	16/ 0
79 DEC 2- 7	6/ 0	4/0	4/ 0	5/ 0	5/0	8/ 0	9/ 0	11/ 0	16/ 0	16/ 0
80 JAN 17-22	6/ 0	6/0	5/ 0	5/ 0	6/0	11/ 0	7/ 0	9/ 0	12/ 0	13/ 0
80 FEB 15-19	8/ 0	4/0	4/ 0	6/ 0	4/0	13/ 0	4/ 0	7/ 0	14/ 0	7/ 0
80 MAR 16-23	9/ 0	10/0	5/ 0	6/ 0	7/0	10/ 0	11/ 0	8/ 0	9/ 0	10/ 0
80 APR 1- 5	8/ 0	10/0	3/ 0	7/ 0	7/0	10/ 0	7/ 0	9/ 0	9/ 0	7/ 0
80 MAY 30- 4	7/ 0	9/0	7/ 0	10/ 0	7/0	10/ 0	7/ 0	10/ 0	9/ 0	8/ 0
80 JUN 29- 2	10/ 0	6/0	5/ 0	11/ 0	8/0	6/ 0	6/ 0	8/ 0	8/ 0	7/ 0
80 JUL 29- 3	8/ 0	4/0	5/ 0	7/ 0	7/0	5/ 0	5/ 0	6/ 0	7/ 0	8/ 0
80 NOV 21-25	10/ 0	4/0	4/ 0	10/ 0	9/0	9/ 0	8/ 0	10/ 0	7/ 0	8/ 0
80 DEC 20-24	7/13	5/0	4/13	7/ 0	10/0	10/12	10/13	9/12	13/14	11/14
81 JAN 21-26	4/11	6/0	5/13	8/13	9/9	4/ 0	4/ 0	7/14	9/ 0	7/16
81 FEB 19-24	6/12	7/0	5/ 9	5/13	7/0	13/13	4/ 0	8/14	7/ 0	6/15
81 MAR 21-25	10/12	4/0	4/ 9	7/13	8/0	15/13	7/ 0	6/14	8/ 0	7/15
81 APR										
81 APR*										
81 MAY										
81 JUN										

* Neap Tide Observations.

(b) Daily High Tide Observations
(5 observations from 1hr before to 1hr after High Tide)

Date	Line
3-18 January 1981	A,E,H
8-18 February 1981	A,E,H
7-20 March 1981	A,E,H

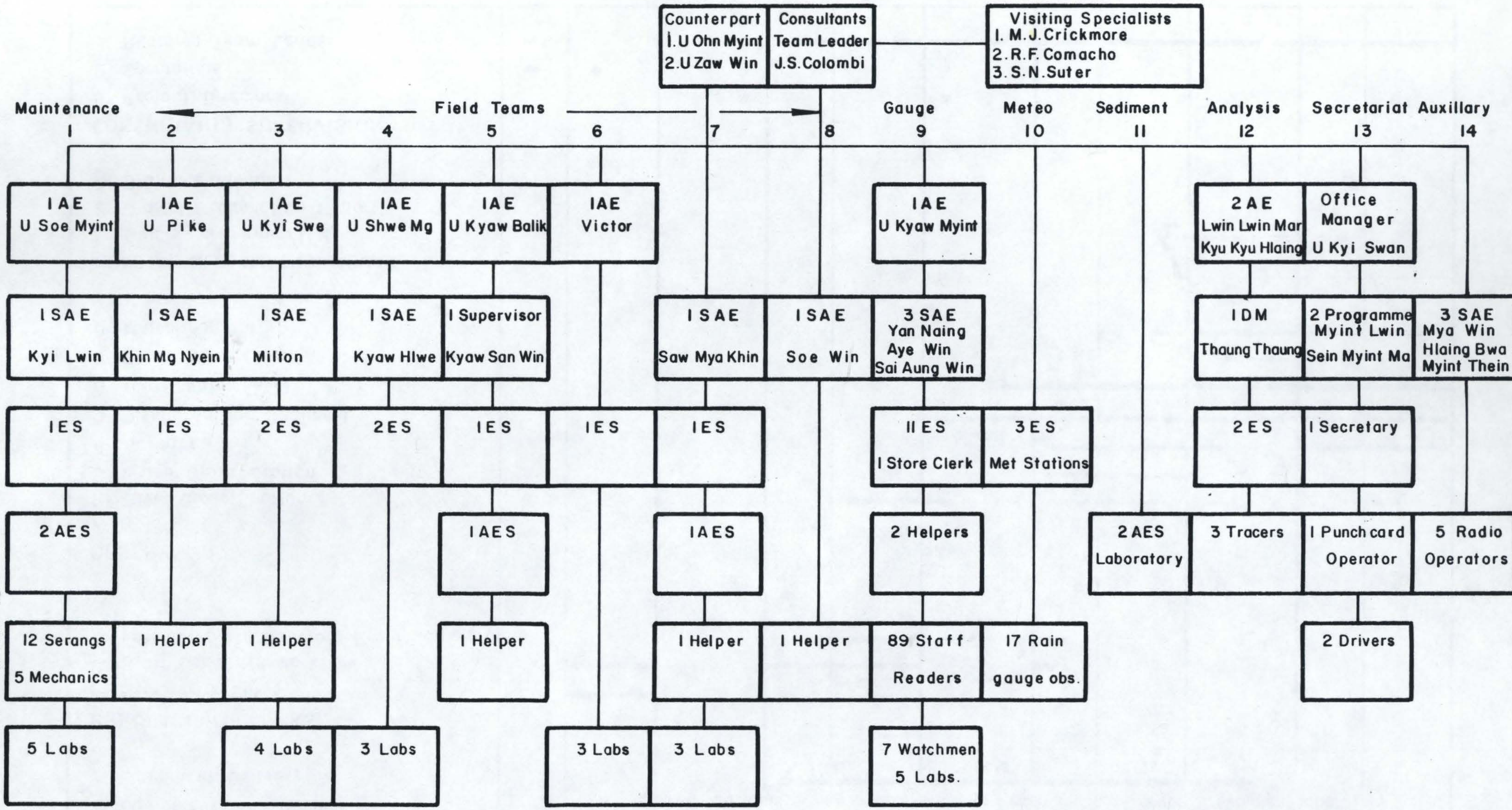
FIGURES



PROGRAMME FOR HYDROLOGICAL INVESTIGATIONS

Figure 1·1

Sir William Halcrow and Partners



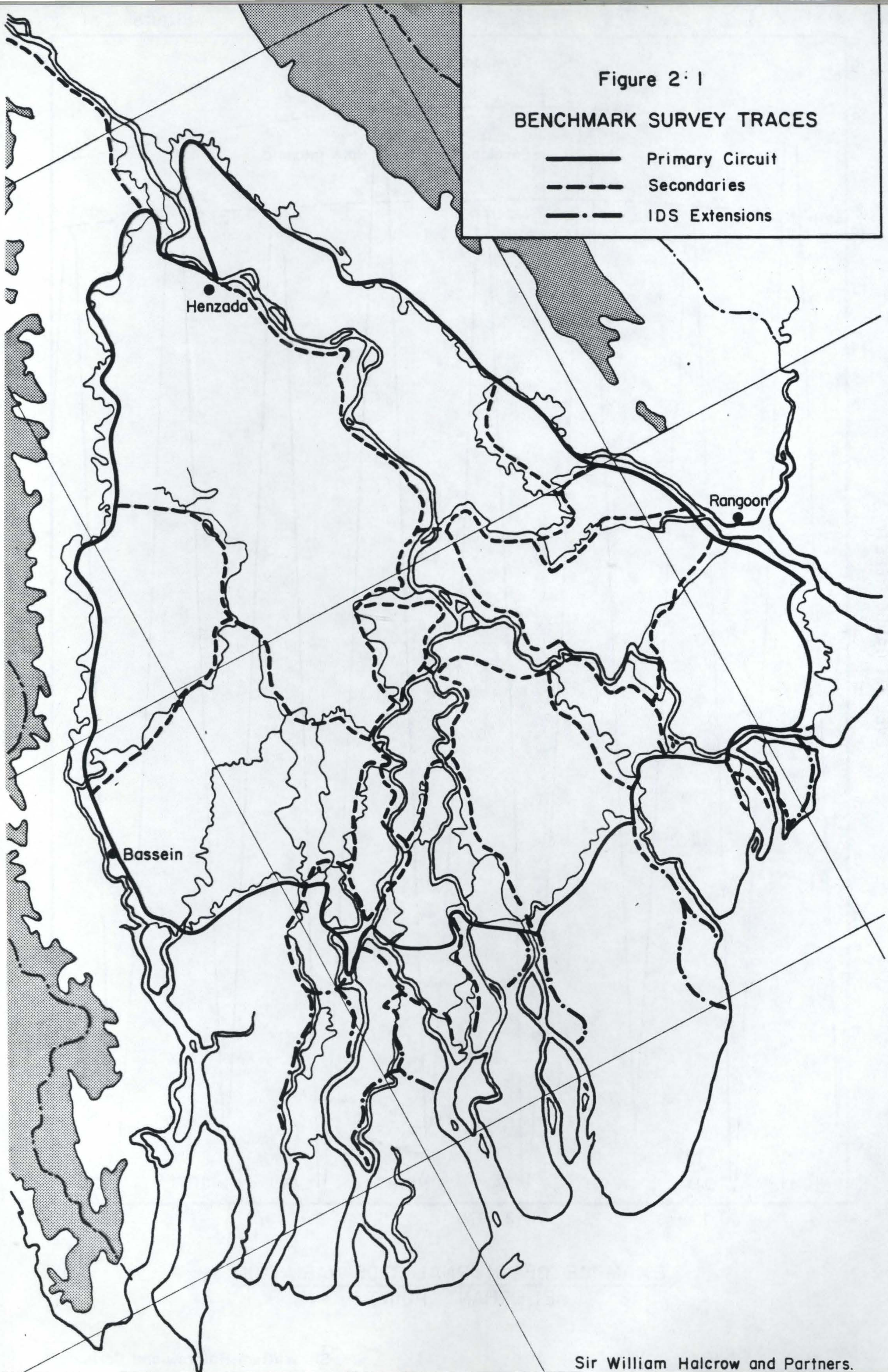
Note. Teams varied according to tasks undertaken

Total employees 230

ORGANIZATION OF IDS TEAMS

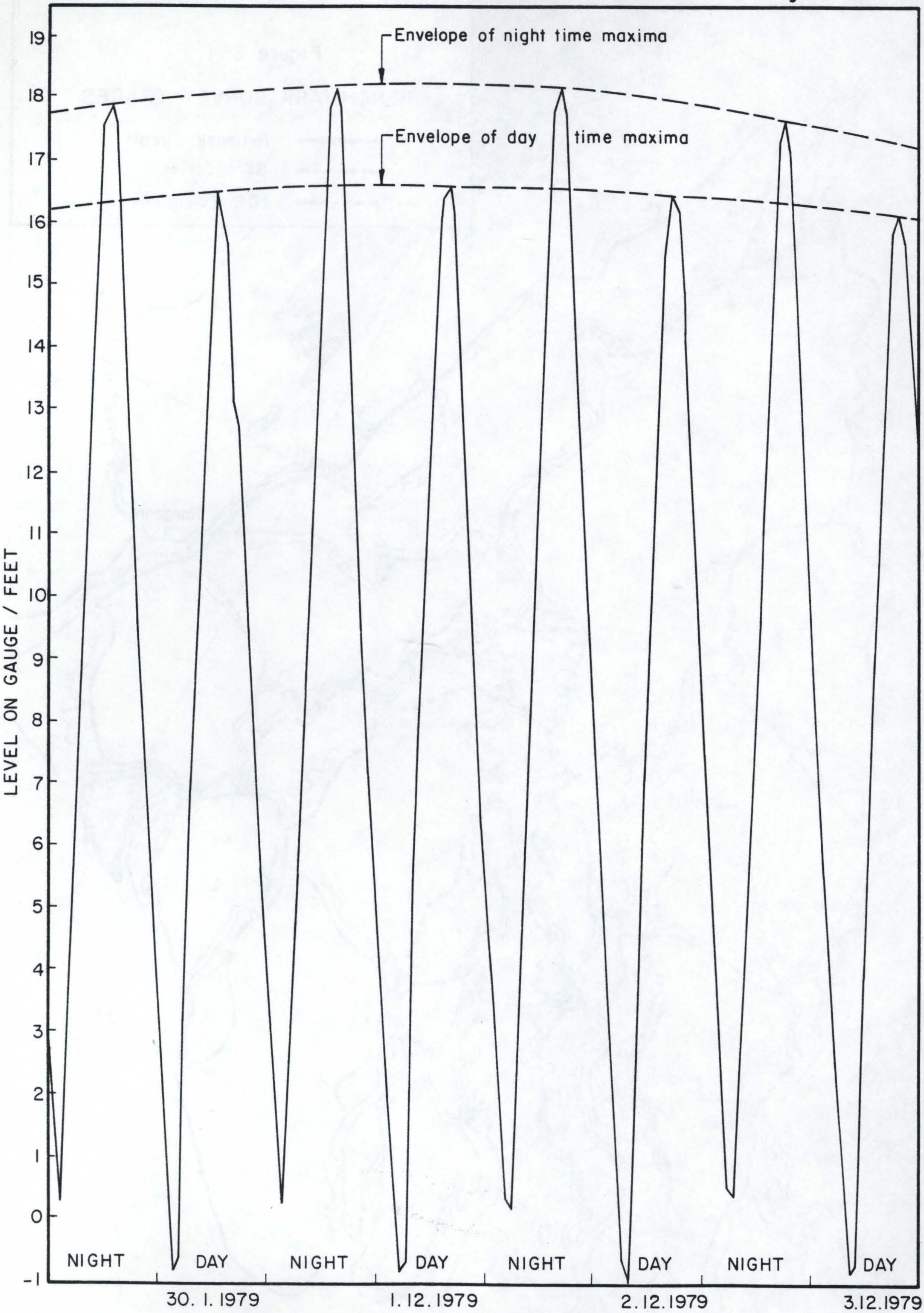
Figure 1.2

Sir William Halcrow and Partners.



Sir William Halcrow and Partners.

Figure 3·1

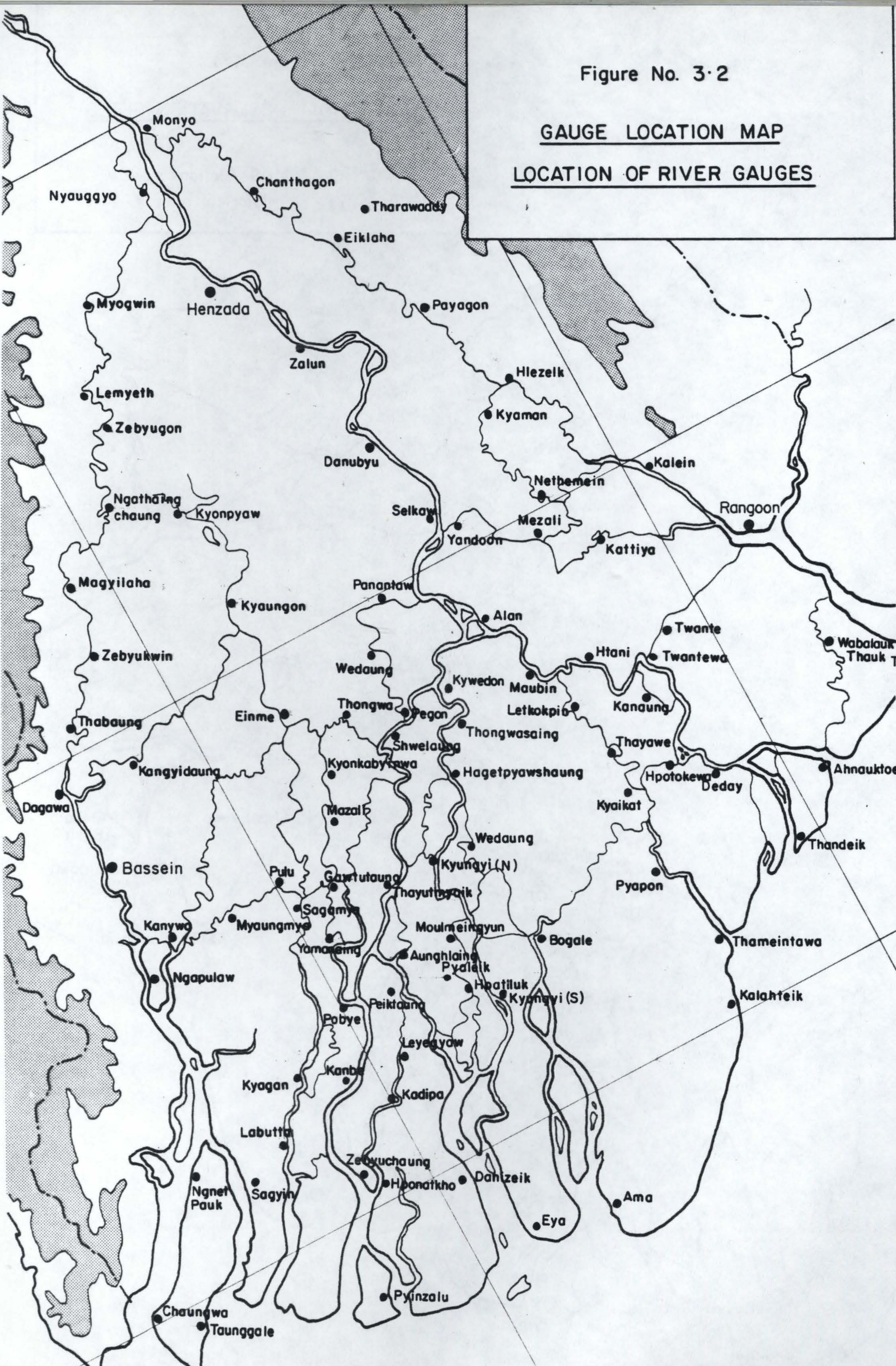


EXAMPLE OF DIURNAL TIDE VARIATION
(ELEPHANT POINT)

Figure No. 3·2

GAUGE LOCATION MAP

LOCATION OF RIVER GAUGES



Sir William Halcrow and Partners.

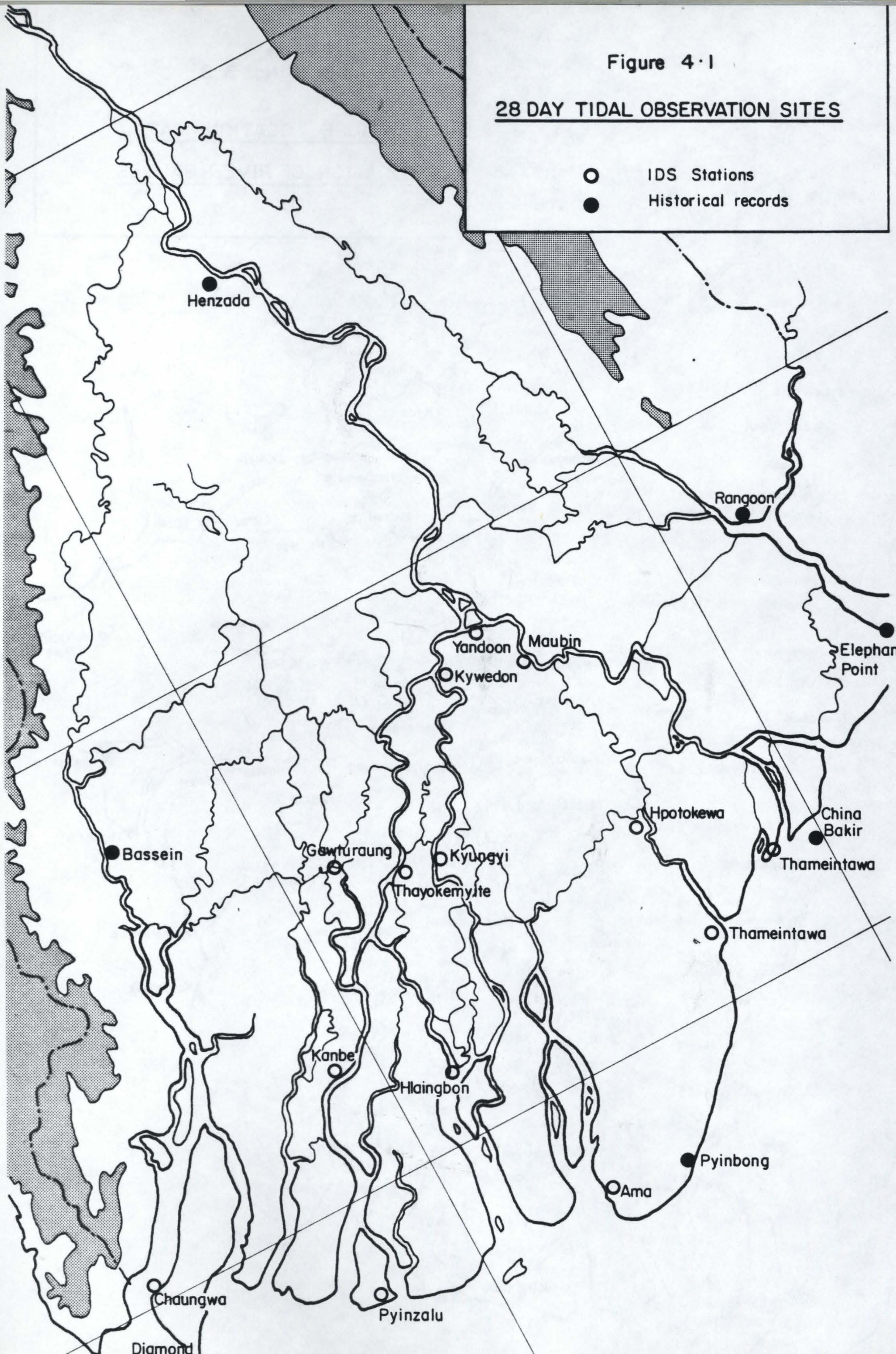


Figure 4·1

28 DAY TIDAL OBSERVATION SITES

Sir William Halcrow and Partners.

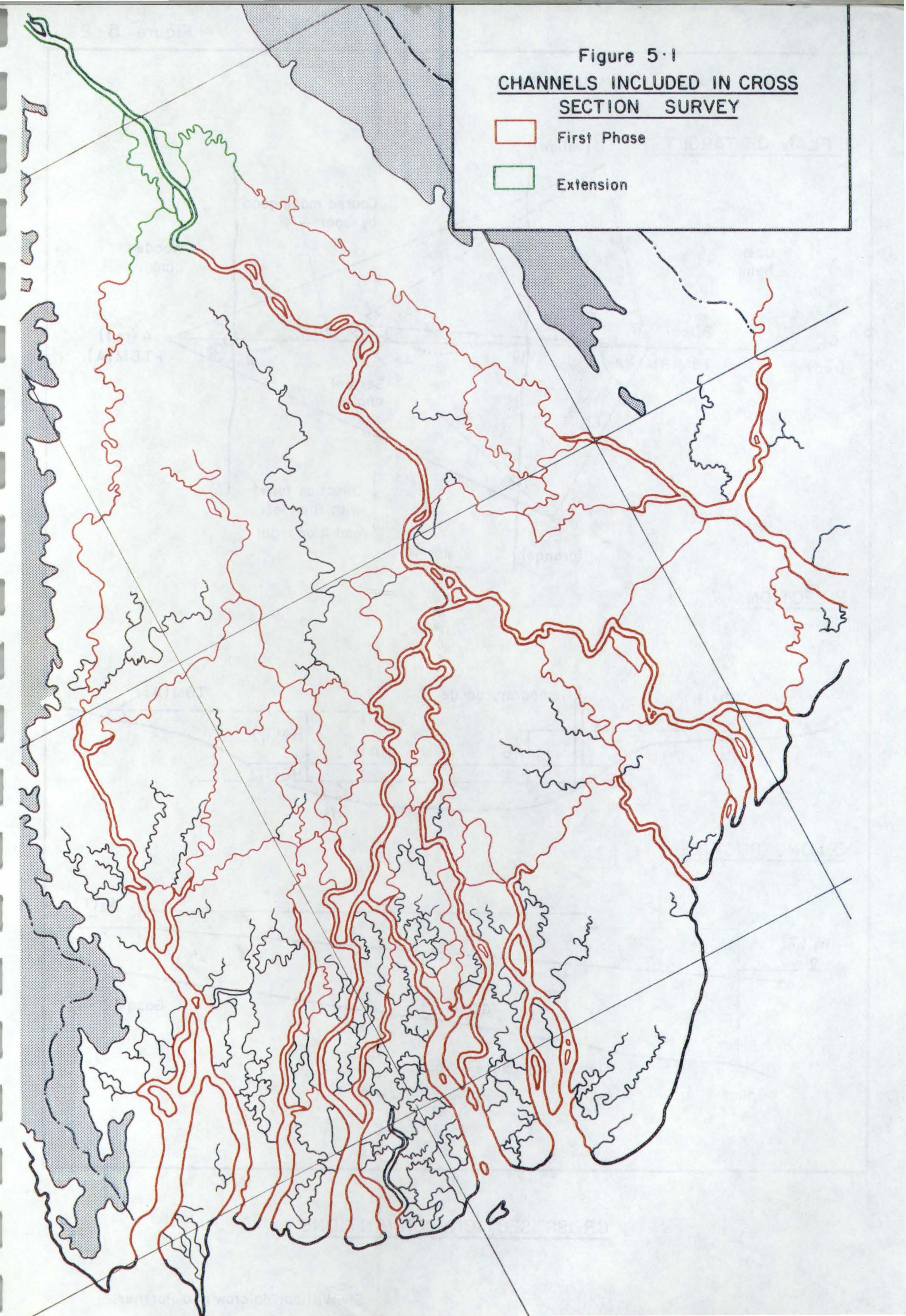
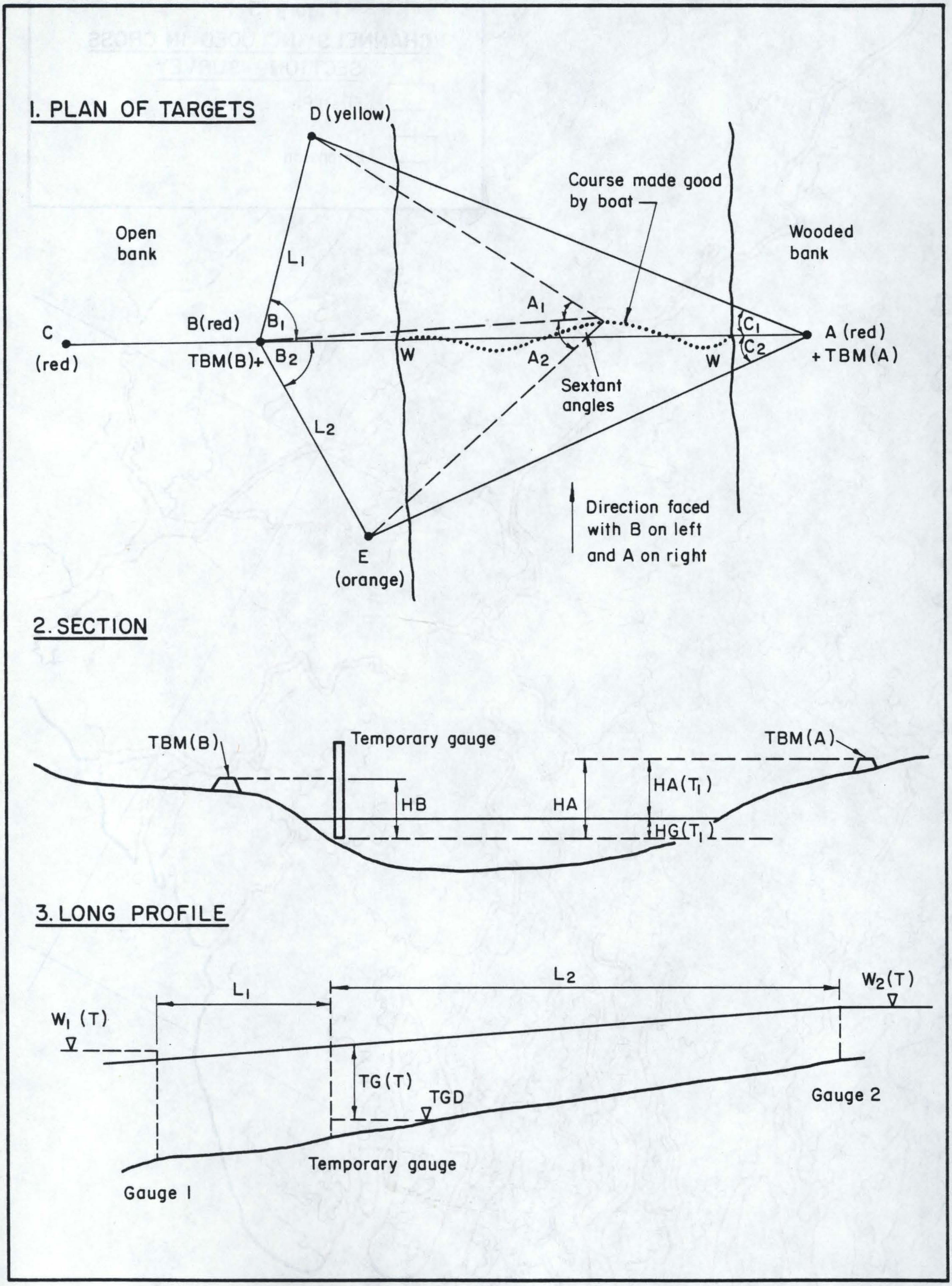


Figure 5·1
CHANNELS INCLUDED IN CROSS SECTION SURVEY



CROSS SECTION CONVENTIONS

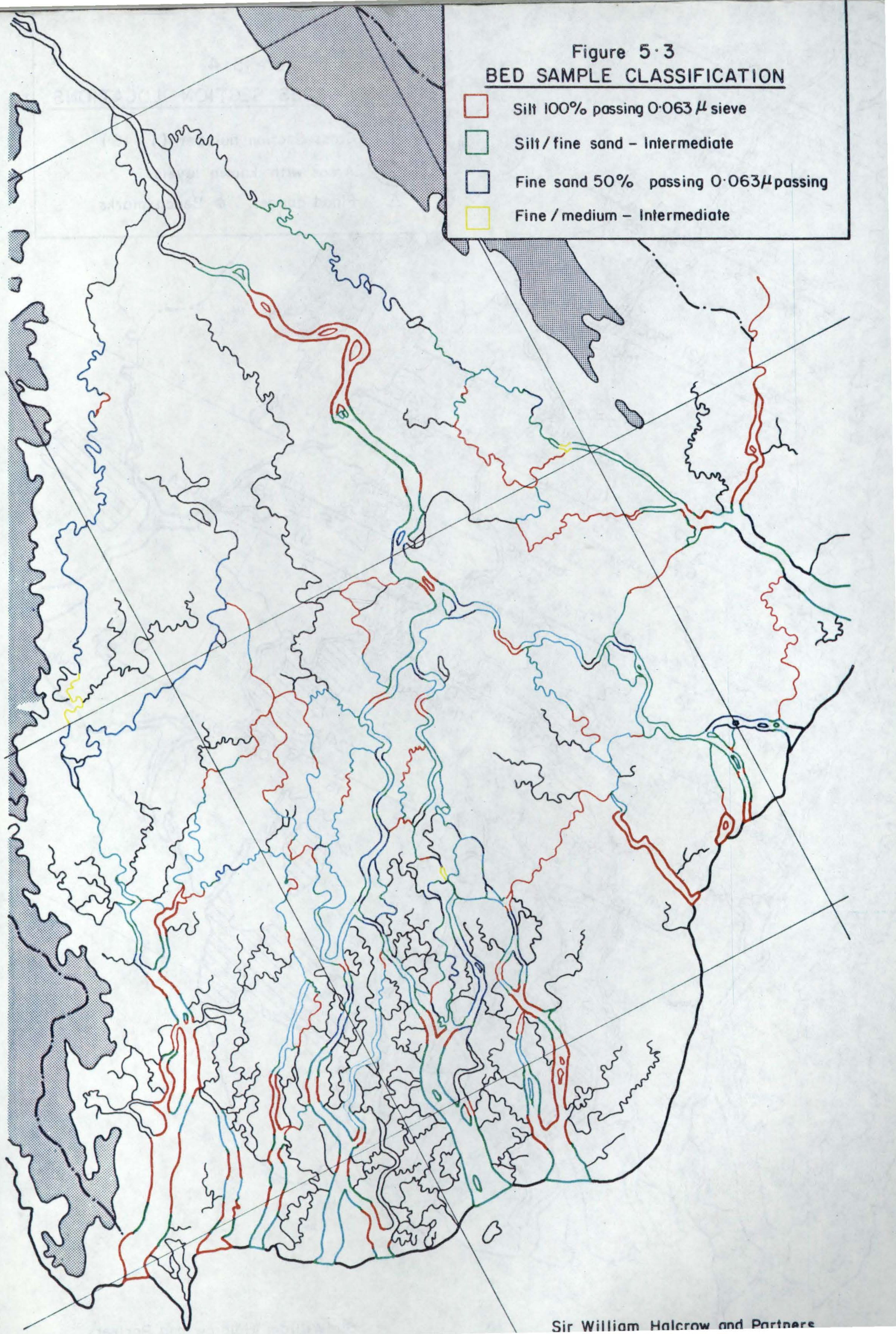


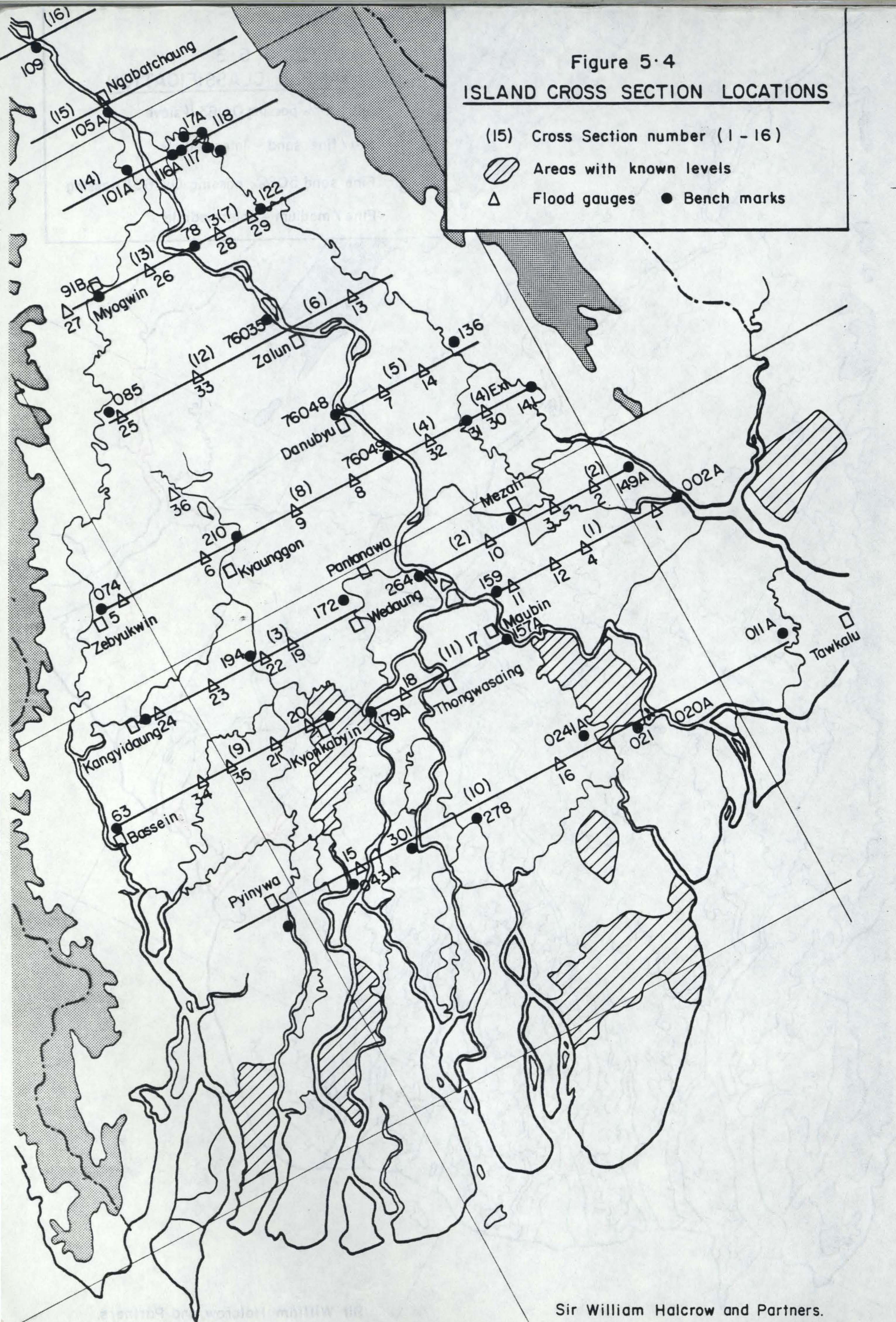
Figure 5·3
BED SAMPLE CLASSIFICATION
Silt 100% passing 0·063 μ sieve
Silt / fine sand - Intermediate
Fine sand 50% passing 0·063μ passing
Fine / medium - Intermediate

Figure 5·4
ISLAND CROSS SECTION LOCATIONS

(15) Cross Section number (1 - 16)

Areas with known levels

Δ Flood gauges ● Bench marks



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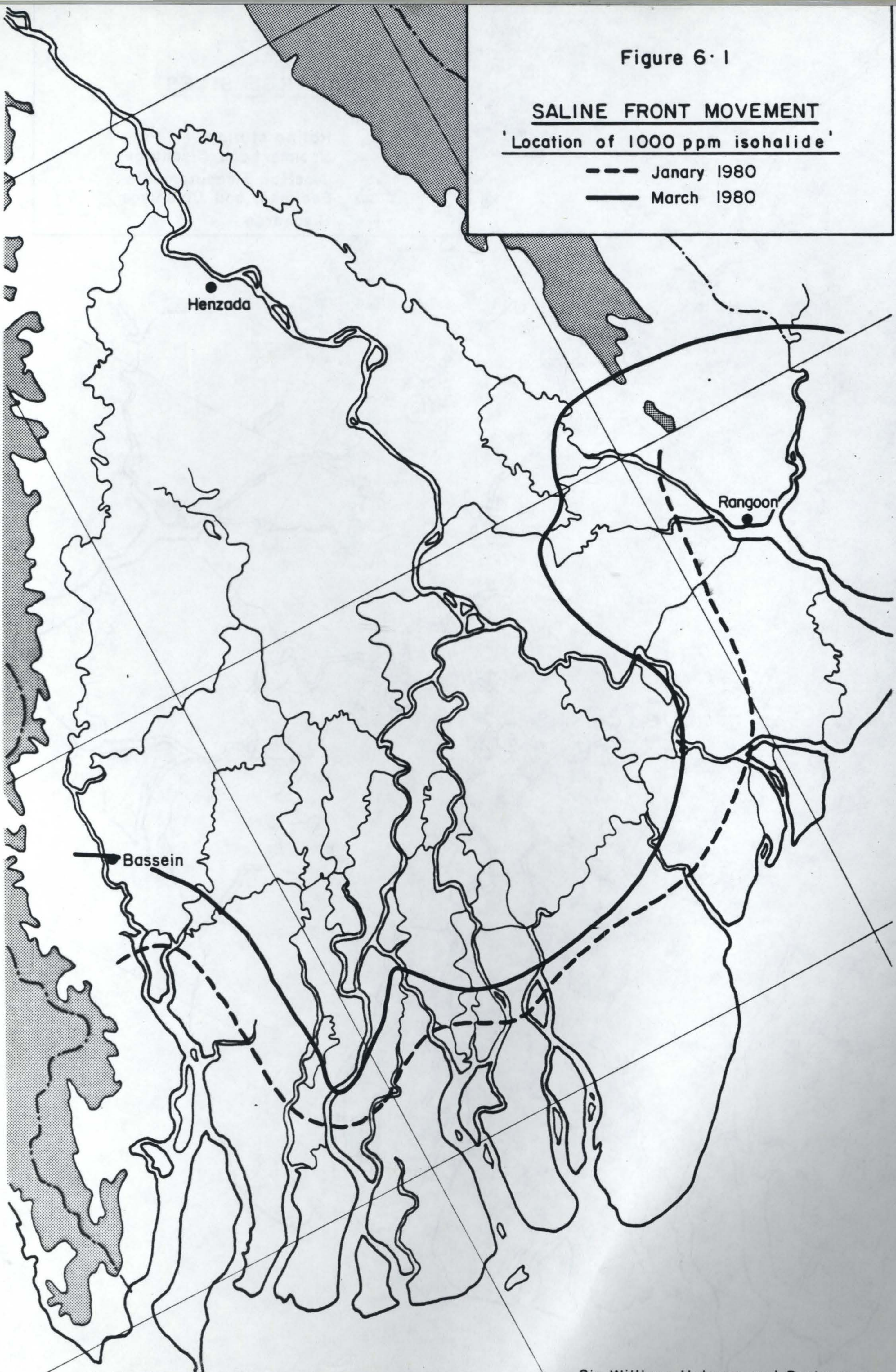

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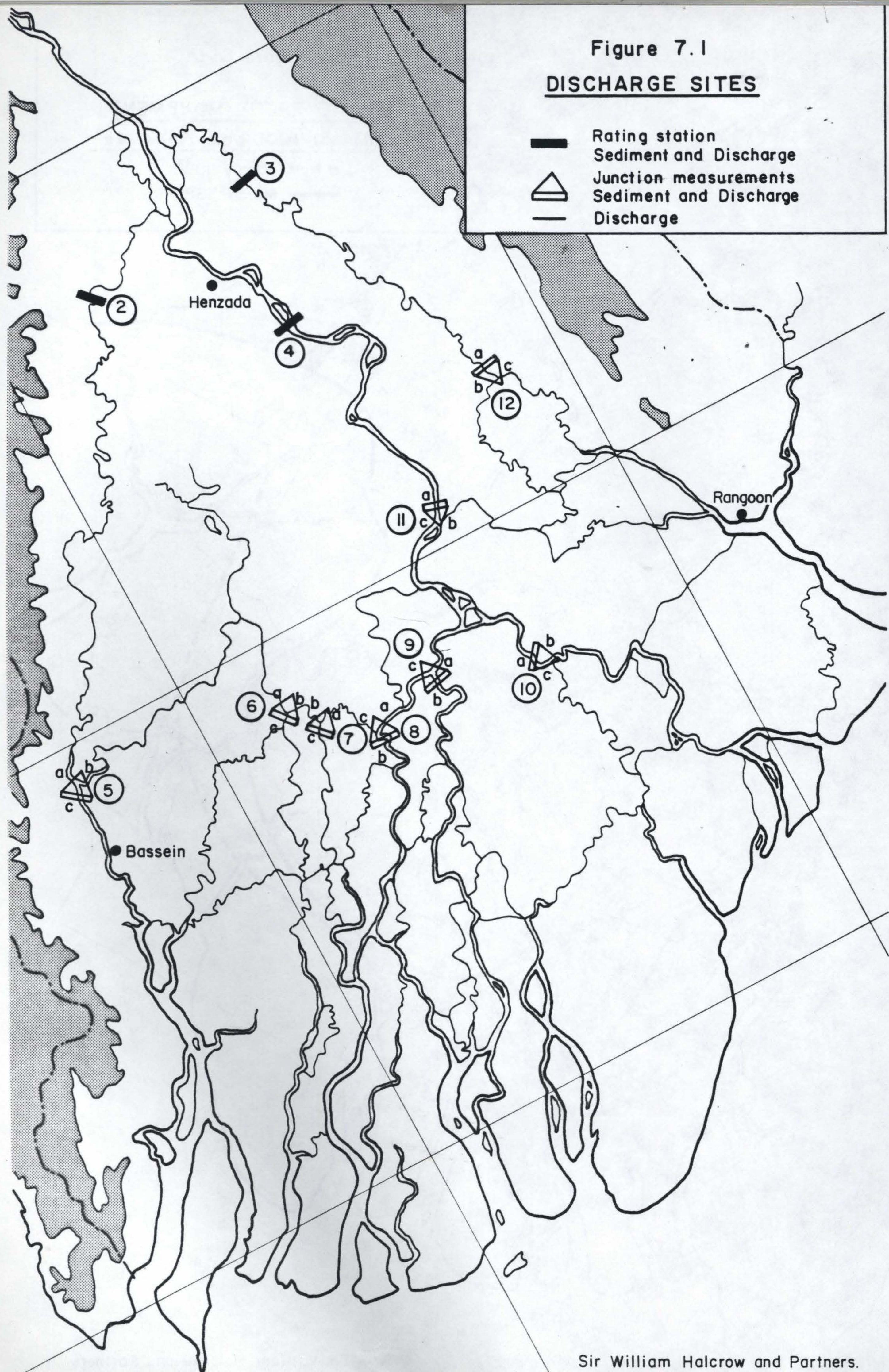

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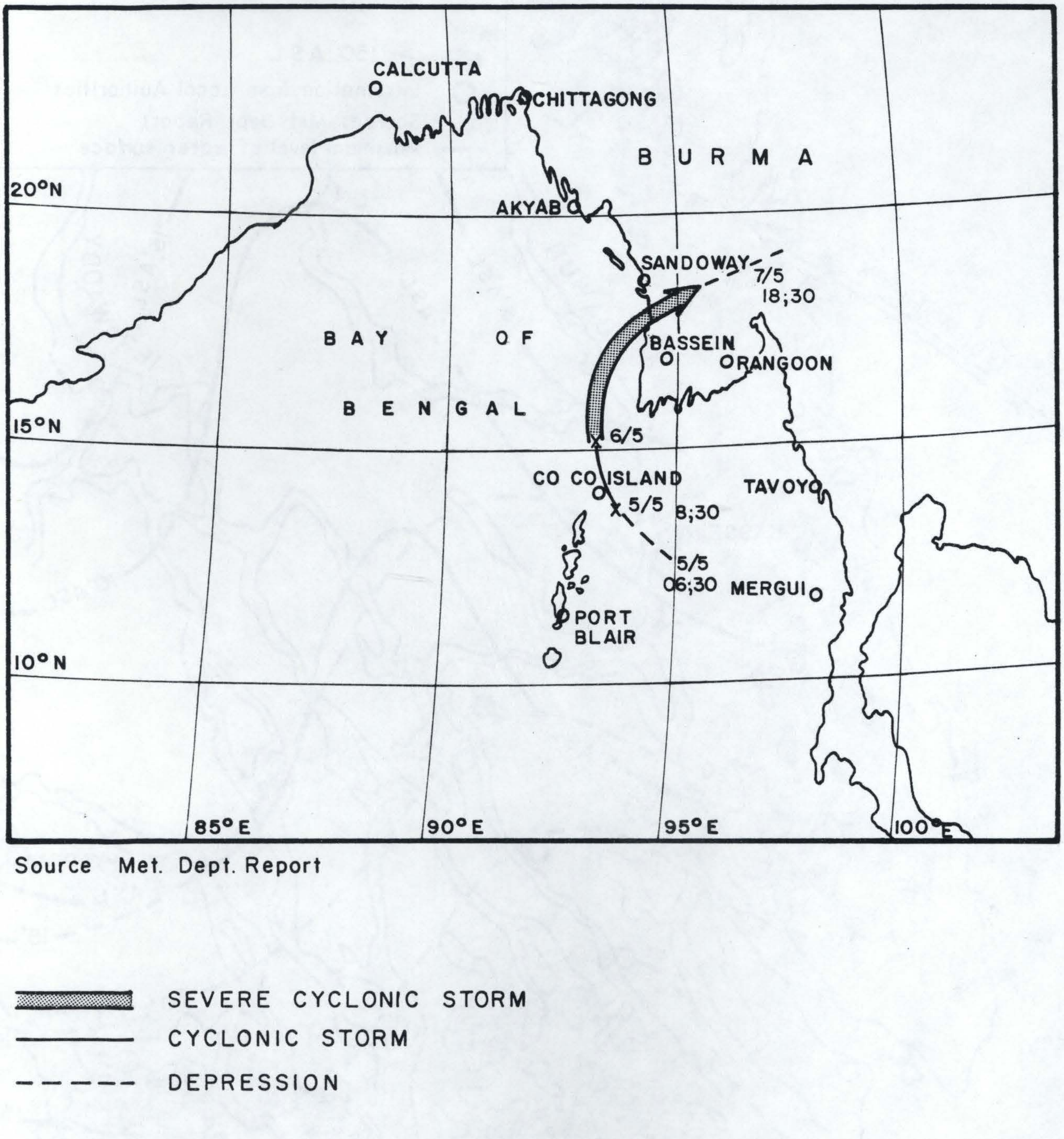


Source Met. Dept. Report

TRACK OF 1975 CYCLONE

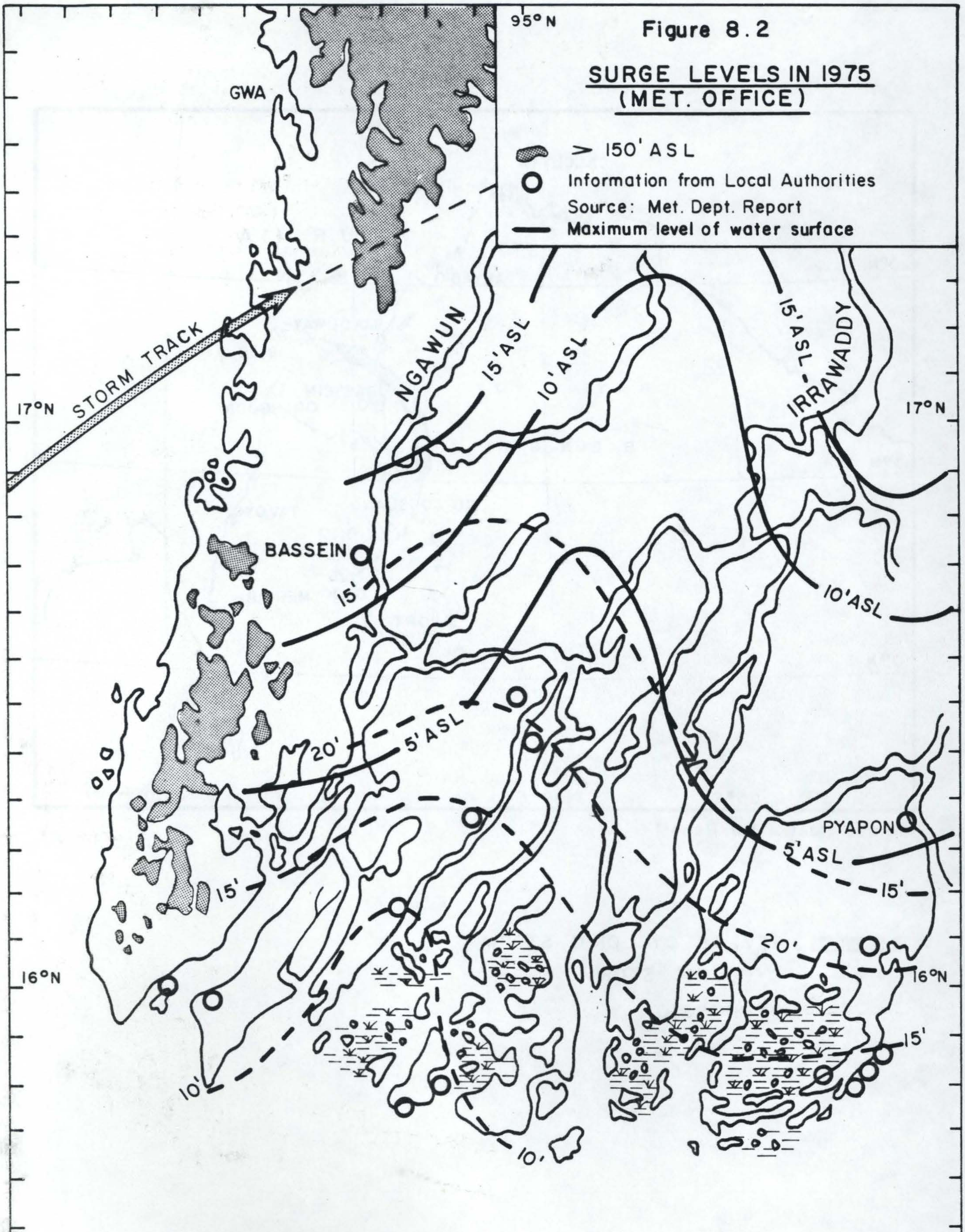
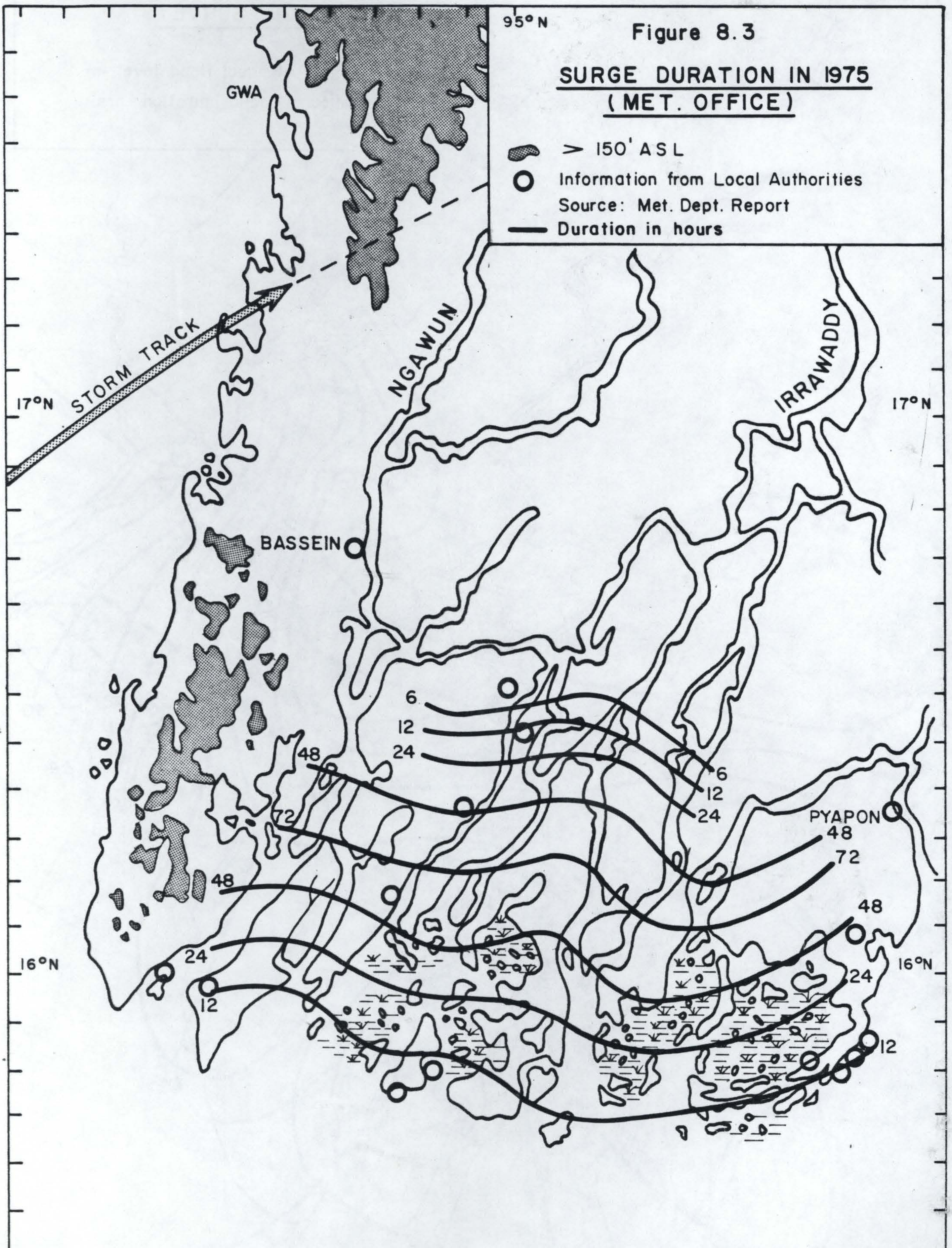


Figure 8.2
SURGE LEVELS IN 1975
(MET. OFFICE)
> 150' ASL
Information from Local Authorities
Source: Met. Dept. Report
Maximum level of water surface
95° N
GWA
STORM TRACK
17°N
NGAWUN
15'ASL
10'ASL
15'ASL
IRRAWADDY
BASSEIN
15'
10'ASL
20'
5'ASL
PYAPON
5'ASL
15'
15'
20'
16°N
15'
10'
10'
ANDAMAN SEA
95°E



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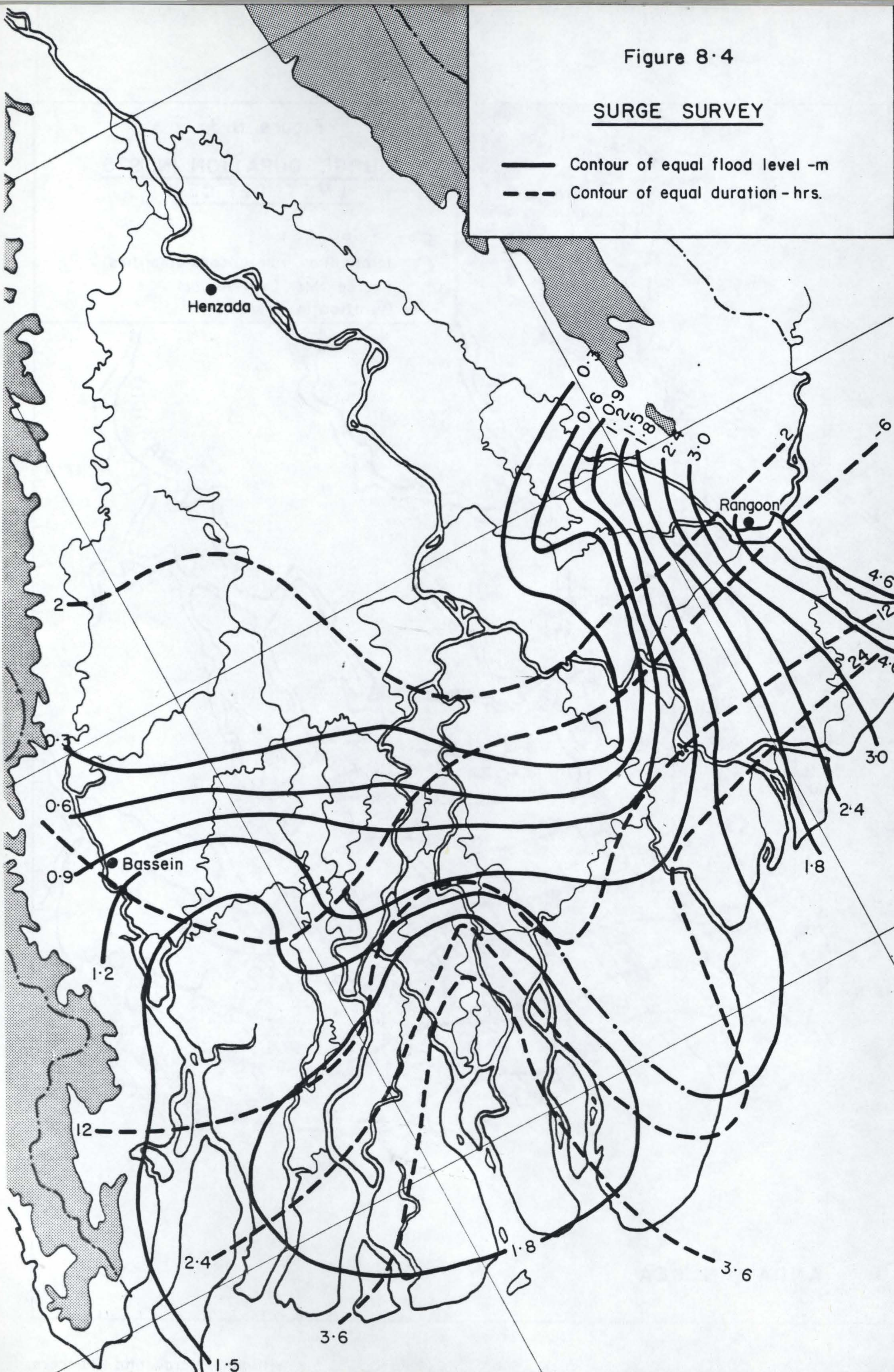

Figure 8·4

SURGE SURVEY

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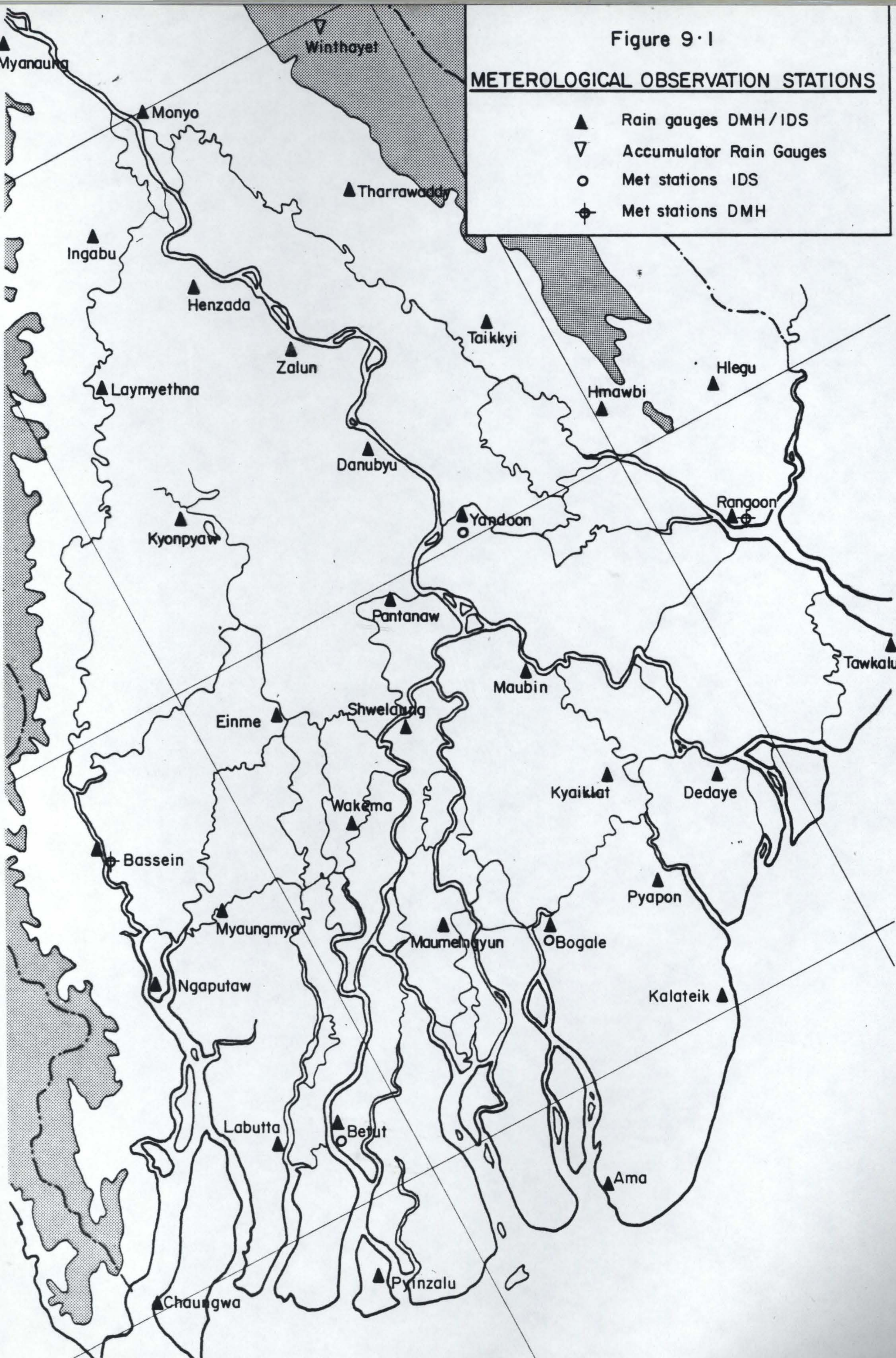
Figure 9·1

METEROLOGICAL OBSERVATION STATIONS



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APPENDIX

APPENDIX (A) TERMS OF REFERENCE OF THE INVESTIGATIONS & SURVEYS

Part (I) HYDROLOGICAL INVESTIGATIONS

1. The consulting firm shall make available the experts in the field of Hydrology, Hydrometry and Coastal Land Reclamation, with provision of administrative support and high level advisory services which they may need to carry out their duties. The firm shall also arrange for training of local hydrologists and technicians that is pertinent to the nature of the hydrologic problems in the Irrawaddy Delta; and in the course of the experts work in Burma the consultants shall provide training for their counter parts.

2. The data collection programme and investigations should be directed towards the following four objectives:

(a) Hydrologic data requirements for technical design of the 185,000 acres Paddyland Development Project (IDA Credit No. 642 BA) and similar short term projects in the future;

(b) Determining the extent of fresh water supplies in lower delta channels for potential dry season small pump irrigation;

(c) Assessing the effects of delta projects on flood levels and hydraulic regime of the delta system;

(d) Assessing the effects of accumulative embanking and ultimately total confinement of flood flows in the entire delta.

3. With respect to establishing the hydrologic instrument network and data collection programme the consultants shall advise and assist the Irrigation Department in the following:

(a) reviewing all available data and studies of the delta system;

(b) locating and scheduling installation of a hydrological recording network throughout the lower and middle delta comprising permanent and shifting stations for the hydrologic data collection programme;

(c) planning and setting up the programme for measuring the following:

- (i) river water levels;
- (ii) discharges;
- (iii) sediment transport;
- (iv) overland water levels and flows;
- (v) salinity in the lower delta and parts of the middle delta channels;
- (vi) basic hydrometeorological parameters;
- (vii) tidal flows;

(d) processing and organizing hydrologic measurements including using computers;

(e) preparing small, explicit mathematical models for analysing tidal and flood records;

(f) estimating frequency and duration of flooding and tidal levels at key locations;

(g) processing and analysing salinity measurements in relation to upland discharge and tidal conditions;

(h) establishing hydrological design criteria for design of drainage and flood protection systems in the tidal and non-tidal zones;

(i) instructing professional and technical staff.

4 Hydrometry:

(a) siting, designing and constructing river level recording stations on channels in the lower and middle delta;

(b) selecting and installing recording stations for supervision of operations in the tidal and non-tidal zones;

(c) installing hydrometeorologic stations;

(d) setting up workshops for hydrological instruments repair and maintenance;

(e) establishing data collection organisations and schedules;

(f) conducting stream flow and sediment measurements, particularly under flood conditions;

(g) analysing stream flow measurements including processing by computers;

(h) conducting salinity measurements;

(i) instructing professional and technical staff.

5 Coastal Land Reclamation:

(a) planning drainage systems;

(b) computing drainage requirements for conveyance systems and tidal sluices;

(c) estimating the effects on internal water supply and drainage of closure of small creeks;

(d) preparing tidal sluice operating procedures for optimal water supply and drainage, taking into account flood levels and variations in river channel salinity;

(e) instructing professional and technical staff.