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RIVER SURVEY PROJECT

Special Report No.2

Water level gauging stations

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Special Report 2

Water Level Gauging Stations

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Acronyms and abbreviations

AWLR	: Automatic Water Level Recorder
BIWTA	: Bangladesh Inland Water Transport Authority
BWDB	: Bangladesh Water Development Board
DC	: direct current
EC	: European Commission (formerly the Commission of the European Communities)
FAP	: Flood Action Plan
FFWD	: Flood Forecasting and Warning Division (of BWDB)
FPCO	: Flood Plan Coordination Organization (presently merged with WARPO)
GI	: galvanised iron
HRL	: Highest Recorded Level
PDB	: Power Development Board
PWD	: Public Works Department
RSP	: River Survey Project (= FAP24)
SHW	: Standard High Water
SLW	: Standard Low Water
WARPO	: Water Resources Planning Organization
WMO	: World Meteorological Organization

1 Introduction

1.1 The River Survey Project

The River Survey Project (FAP24) was initiated on June 9, 1992, and continued for a period of 4 years. The project was executed by the Flood Plan Coordination Organization (FPCO), presently the Water Resources Planning Organization (WARPO) under the Ministry of Water Resources (formerly the Ministry of Irrigation, Water Development and Flood Protection). The project was funded by the European Commission. The Consultant was DELFT-DHI Joint Venture in association with Hydroland, Approtech, and Osiris. Project supervision was undertaken by a Project Management Unit with participation by WARPO, a Project Adviser, and a Resident Project Adviser.

The project comprised a survey component, a study component and a training component. The objective of the survey component was to establish the availability of accurate field data as a part of the basis for the FAP projects, as well as providing input for other planning, impact evaluation and design activities within the national water resources and river engineering activities.

As part of the survey component of the project, a series of water level gauges were installed along the main rivers. The collected data were used to build reliable time series of water levels and stage-discharge relations for all these gauges. Water level and river slope were monitored for their own purposes, moreover, water level data were required as input for other applications e.g. bathymetry, discharge measurement, rating curves, etc. The data can also be used as input for quality control of associated time series measured by other organizations in Bangladesh. Such quality control was part of the study component of the project, as reported in *RSP Final Report, Annex 3: 'Hydrology'*.

1.2 Background for the RSP water level gauging programme

Gauging of a river stage can be made in different ways. One is to employ a non-recording gauge. The best known non-recording gauge is a staff gauge. This is implemented as a graduated vertical or inclined staff either singly, or in multiple numbers, and visually read by an observer. Data output and quality can be enhanced by addition of a recording gauge, which produces automatic analogue or digital records. The principal distinction of a recording gauge is that it operates autonomously, in that it is not dependent on an observer. In this Report, various types of gauges are discussed and compared.

Gauging of stages are carried out routinely by two government agencies in Bangladesh: Bangladesh Inland Water Transport Authority (BIWTA) and Bangladesh Water Development Board (BWDB). BIWTA operates and maintains about thirty-five (35) recording stations. Most of these are located in the coastal area, and tidal records are available from them. BWDB maintains about twenty-eight (28) recording gauges, which are mostly located in the inland river network. Float or bubble type recording gauges are mostly used at these stations, and analogue data are recorded on paper. However, none of these stations is located at a place which can be effectively utilized by the River Survey Project. Though some BWDB stations are suitably located, such as the one at Hardinge Bridge, a continuous record is often not available. Moreover, it is necessary that digital records are obtained in order to ensure efficient digital data processing. Therefore, the Project planned to install, operate and maintain eleven (11) stations for gauging of river stages. These stations cover locations in the Ganges, Brahmaputra and the Meghna rivers and in their tributaries/distributaries (Figure 1) conforming to the discharge gauging sites or bathymetric sites of RSP (RSP, 1993) (please refer to Figure 2 and Table 1).

Although the measurements as such are relatively simple, it requires quite some organization to assure sufficient data return and data quality from a water level gauging network. The keywords for such a measuring network are ***accuracy, reliability, continuity and sustainability.*** These quality issues depend on such items as planning, technical realization, maintenance, verification, and operational management of the system. The dynamic behaviour of the rivers makes it difficult to keep the automatic stations operational and enforces frequent staff gauge shifts.

1.3 The present Report

The present Report is part of the series of RSP Special Reports, which contains monographs on selected key topics within the survey and study components of the project. Reference is made to *RSP Final Report Annex 1: 'Surveys'* and *Annex 2: 'Sustainable survey techniques'* for a general presentation of the survey programme, of the experience gained, and of induced suggestions and recommendations. Also, in *RSP Final Report Annex 1,* a listing of the actual data collection is made and is compared with the Bill of Quantities. Applications of the water level data are presented in *RSP Final Report, Annex 3: 'Hydrology'.*

The Report describes the construction and installation of the Automatic Water Level Recorders (AWLRs) of RSP, provides guidelines for their operation and maintenance, and evaluates their performance in Bangladesh. The Report also deals with the evolution of ideas and platform designs during the project. A thorough discussion is made on the relevant recording and non-recording gauges with respect to their advantages and disadvantages on Bangladesh context.

Based on the experience obtained by RSP, the Report is framed to assist the major agencies in Bangladesh, such as BWDB and BIWTA, in their efforts to automatize their water level recording.

The Report was first submitted as *RSP Survey Report 6* in November 1995. It was re-submitted in a final draft version as RSP Special Report 2 in July 1996, with incorporation of comprehensive comments and good advice received from the Project Adviser and from WARPO.

The figures are found at the end of the report.

2 Water level gauging

2.1 Non-recording gauges

A non-recording gauge (WMO, 1980) can be of the following types:

- Staff gauge; and
- wire-weight gauge.

Different countries have adopted different types, based on availability, and operation and maintenance considerations. Graduated staff gauges placed vertically are mostly used in Bangladesh; they can be read with a precision of 1 cm. Graduations are made on a wooden plank, which is fixed in the water near the bank with the help of bamboo/wooden poles. Use of staff gauges is based on the advantages that they are cheap to make and that they can be deployed easily at limited cost of installation and maintenance. Its principle is simple and easily understood by people lacking technical education. Moreover, a well trained gauge reader can operate the staff gauge in a flexible way, adapting to changing water level, erosion and sedimentation.

The disadvantage is its dependence on the gauge reader. Often it is difficult to identify a reliable and capable gauge reader. The reliability of the results strongly depends on the human factor. Data may get lost due to human failure (illness and negligence) and get corrupted by human errors (misreading, bad time-keeping, shift errors and non-recording). For verification purposes, multiple staff gauges can be operated at the same station. Besides, a secondary station can, at an extra cost, be set up nearby to be operated by an independent gauge reader. The distance to such secondary station should be small enough to ensure correlation between the readings, and large enough to avoid cooperation between the gauge readers.

2.2 Various recording gauges

The following discussion is devoted to various recording gauges. A recording gauge station consists of five basic components:

- A sensor, which senses the water level;
- a data recorder which collects and records the level data;
- a time keeping component to allow the data to be connected with time. Recordings are either on paper or in electronic memory (digital);
- a power supply to operate the system. This can be a mechanical device, e.g. for a paper recorder, or electrical power from batteries; and
- a supporting structure to hold the instrument and associated parts.

Recording gauges are usually named according to their sensors. The usual types are:

- Float-well type;
- bubble type;
- pressure cell type; and
- acoustic type.

2.2.1 Float–well gauge

In a float–well type, the water stage is sensed by a float in a stilling well. The float sensor consists of a tape or a cable passing over a pulley. The sensor floats in a stilling well and is attached to one end of the cable, and a counter-weight is attached to the other end. The float follows the rise and fall of the water level and drives the pulley which is connected to a level recorder. The float measures basically the water level relative to a fixed platform. The water level in the well must, of course, be equal to that in the river. Therefore, the connection between the well and the river, through well perforations or an intake pipe, may not get clogged by plant growth or settling of sediments. No velocity head errors should be present, requiring a well-designed stilling-well perforation pattern or an intake pipe nozzle. These aspects put even more limiting requirements to the site selection than for the staff gauge station. Also, the stilling-well tube must be vertical, stiff and stable, making the system rather costly. For the operation of the mechanical model, no electronic instruments are required. This might be an advantage as personnel with proper knowledge and experience in electronics may be difficult to find. A disadvantage is the vulnerability of mechanical instruments, in particular to wear and corrosion.

2.2.2 Pressure sensor

The submerged pressure sensor, mounted at a fixed level, converts pressure to a proportional electrical signal. The pressure at any depth is the addition of the barometric air-pressure acting on the water surface and of the hydrostatic water pressure, which is proportional to the immersion depth and to the specific weight of the water. Depending on the angle of the incoming flow the sensor may, to a certain extent, be subject to the velocity head-effects. At 1 m/s, the velocity head can be about 0.05 m, and at 2 m/s about 0.20 m.

As the pressure sensor has no moving parts, and wave-induced pressure fluctuations can be filtered by electronics or software, there is no need to install it in a stilling-well.

A pressure sensor is virtually a no-flow system: The deflection of the membrane is extremely small. This has the advantage that the sensor, if buried due to unexpected sedimentation, will still yield accurate results, provided that the ground water flow-induced pressure gradients are small. Of course, the sensor membrane must be protected by a filter to avoid grain forces in addition to the water pressure. In a tube or stilling-well the sensors readings can be affected by burial because the filling/flushing of the tube requires displacement of a certain amount of water.

Vented gauge-type sensors directly compensate for barometric pressure variations. The reference pressure is supplied through an air-vent tube in the sensor cable. Extension of this type of sensor cable is complicated because also the air-vent tube has to be extended without leakage or blocking. To avoid condensation in the air-vent tube or in the sensor, the air entering the tube must be dry, which is achieved by applying a silica-gel desiccant cartridge. Additionally, the access from the atmosphere to the air-vent tube is provided with a PTFE (teflon) filter pellet which allows air to pass but blocks humidity.

Alternatively, simpler (and cheaper) absolute type pressure sensors can be used instead. A second pressure sensor must be incorporated in each system then. This affects accuracy, cost and power requirements, but makes the sensor cable simpler. One central barometric pressure reading can be made for a whole network. In that case, the air pressure compensation is carried out afterwards, in the office, and a direct validation check upon retrieval in the field becomes more difficult.

For data collection, the pressure sensor is connected to a data logger. This logger can be equipped with a removable data memory or a communication interface for data retrieval. Worldwide application of many different data loggers in combination with a pressure sensor has proven the reliability of such equipment. Installation of the system requires a structural element to attach the sensor to, a guidance for the sensor cable, and a structure to which the electronics and power supply case can be fitted.

2.2.3 Bubble gauge

A gas purge system or bubble gauge, which may be regarded as a pressure sensing system, transmits the pressure head of water to a pressure sensor, usually at the surface. A gas, nitrogen or dry compressed air, is supplied through a tube, and bubbles freely into the stream through an orifice at a fixed elevation in the stream. The gas pressure in the tube is equal to the piezometric head on the bubble orifice at any stage height. The system has been used effectively in large alluvial rivers such as the Niger River in Africa (Peters, 1996). More details can be found in a WMO Report (1980).

In this respect, a new development by the Ott company of Germany may be mentioned. Ott has started the production of a low cost and precise electronic bubble gauge with built-in air-supply.

2.2.4 Acoustic sensor

A recent development is the use of low power acoustic sensors for, among others, hydrological field applications.

The acoustic sensor virtually makes a contact-less measurement, it measures the turnaround time of an acoustic wave to the water surface and back to the sensor. Multiplication of the turnaround time by the speed of sound gives the distance of travel, which is subsequently divided by 2 to get the range.

In formula,

$$d = \frac{t}{2}c$$

where:

d	=	distance between the sensor and the water surface
t	=	travel time of the acoustic energy
c	=	velocity of sound in air

The switch-over from transmitting to receiving the sound wave takes some time, which limits the minimum range to about 0.6 m, according to the specification. At long sound paths, the reflected signal is fairly weak, making the measurement susceptible to electrical interference.

One advantage over most other systems is that no parts are immersed into the water, and that water density variations have no influence. Another advantage is the accessibility of the sensor as no parts have to be immersed. However, due to a dependency on the speed of sound in air, and inherent sensor properties, the basic accuracy is somewhat limited.

Under extreme conditions, rainfall may cause data loss due to reflections from multiple rain drops. The recording can be affected by surface waves to an extent that depends on the distance to the water surface (the footprint of the acoustic beam increases with distance), the wave length, and the wave height.

2.2.5 Radar sensor

A transducer which in many respects is comparable to the acoustic sensor is the radar range sensor. The range to the water surface is measured by the travel time of a RADAR pulse. Operational range can be more than 50 m at accuracies in the order of 0.01 m or even better. Originally these sensors were developed for applications such as industrial tank gauging. However, investment and operational costs prohibited routine field application. The sensors are still quite expensive but most likely cost will drop to an acceptable level.

2.3 Accuracy aspects

Basically, the level of the water surface is to be measured, undisturbed by obstructions, and in a representative stretch of the river. Ideally, static tubes are applied, in order to avoid contamination by velocity head effects. Such effects might, for instance, occur if the water level is measured close in front of an obstruction like a bridge pier, or if a pressure sensor is exposed to high current speeds.

Position
Water level data have to be defined in time and space, a requirement common to all measuring systems. In this respect, the error impact is application dependent, e.g. for river slope measurement water level should be known more accurately than for discharge measurement. In general errors in the station's coordinates, the horizontal position errors, can be kept well within requirements.

Datum
Water levels are presented relative to a Datum, under RSP the PWD Datum is used. It requires quite an effort to maintain vertical error levels within the specified targets, i.e. at a magnitude of several cm. This in particular during rough conditions, during monsoon or under wind stress. Severe erosion around the supporting structure, no matter if it supports a staff gauge or a recording instrument, may result in sinking and/or tilting of the structure and as a consequence erroneous readings. In particular the staff gauge structures, which are small and do not penetrate deep into the river bed, are vulnerable to erosion effects.

Reference level
For reference purposes a staff gauge has to be used and, as mentioned, it is difficult to maintain staff gauge accuracy in waves. As a consequence staff gauge reading errors may also bias the data originat-

ing from auto-gauges. Also the results acquired by electronic instruments suffer, to some extent from waves, high flow rates etc.

Time
Given the accuracy of electronic time keeping devices in watches and data collection equipment, definition in time at sufficient accuracy should not be a problem. In tidal areas, where water level virtually continuously changes at a measurable rate, time keeping must be to the minute, more upstream demands might be less severe. However, for monitoring of surges and long waves, which frequently can be observed, a precise time keeping is required. Staff gauge readers have to be informed about these demands which may conflict with social obligations or other personal matters.

Some relevant environmental characteristics of Bangladesh rivers which affect accuracy can be briefly touched as follows. The density of the river water varies, amongst others, with temperature, salinity and sediment load. The temperature varies from 26 to 30 °C over the year. No significant salinity influence is expected to occur within the area covered by the project. The sediment load can also affect the density.

The applied water level sensors, viz.: staff gauge, pressure sensor and acoustic sensor, not only differ in physical principle but also in their hydraulic properties and the specific operational depth. In next sections instrument specific errors are mentioned.

Staff Gauge
As the staff gauge pierces the water surface it may be affected by high currents and waves. E.g. at high flow velocities a level drop of about 0.05 m was observed along a staff gauge, which may result into, though minor, reading error. Under wave conditions it is difficult to make an accurate reading. However, accuracy can be improved by averaging a number of readings taken during several minutes. If done properly, estimated error is about 5% of wave-height.

Pressure sensor
The pressure sensor is submerged and is, as a consequence, affected by flow and density. The velocity head varies with flow velocity (u) by $u^2/2g$. The acceleration of gravity is represented by g. In order to avoid velocity induced bias on the readings the sensor is preferably installed out of the main stream, that is at some protected place and/or relatively close to the bottom. The sensor's alignment, relative to flow direction is essential for the head to be measured. Static head + velocity head are measured with the plane of the sensing element perpendicular to the flow direction, whereas only the static head is measured with the plane parallel to flow direction. The latter e.g. with the sensor pointing down, hanging on its signal/suspension cable. The RSP pressure sensors were mounted in a vertical tube with the water inlet at the bottom end, and, as a consequence only static head is measured. However, due to secondary effects the reading remains slightly affected by flow.

The pressure reading varies linearly with the average density above the pressure sensor. Temperature and salinity vary within small ranges: their effects on the pressure reading are relatively small. At high sediment concentrations pressure readings may over-estimate the water level. At an immersion depth of 5 m and an averaged **density** change by 2000 ppm the indicated depth will be too high by 0.01 m. Under such conditions the secondary flow effects will likely be larger.

Barometric air-pressure may also affect the results. However, the applied pressure sensor has an inherent barometric air-pressure compensation via a vent channel to the pressure sensor's reference-air inlet.

Acoustic sensor
In air, the speed of sound varies strongly with temperature. Therefore, range and temperature must be measured simultaneously. The temperature sensor is mounted inside a radiation shield to avoid effects caused by solar radiation and radiation loss at night. Stratification of the air mass between the sensor and the water surface, and inaccuracies in the temperature measurements, have some degrading effect on the accuracy of the water level measurement. This effect is smaller during the flood season, as measured ranges are shortest then. The temperature-induced error is about 1.7 mm/°C per meter of range. Over-estimation of the temperature yields an under-estimation of the water level.

The measurement as such is not affected by flow conditions. However, as the sensors are suspended, upstream, from piers of a number of major railway bridges the flow induced level rise upstream of the pier is likely to be detected by the sensor. Under such conditions the reading gives static head plus, though partly, the velocity head.

2.4 Set-up of a river stage network

BWDB has, in the course of time, established a network of water level gauges along the main rivers in Bangladesh. Another (much smaller) network of gauges was installed by RSP in the project area.

The purposes of this RSP network are connected to water management in a broad sense, including irrigation, flood protection and navigation. More specifically, these water level measurements can be used for:

- Stage-discharge relations to study the drainage pattern of the main rivers in Bangladesh;
- assessment of water resources supported by discharge measurements;
- short-term flood forecasting;
- design of river training works using a statistical analysis of peak levels;
- reduction of bathymetric survey data;
- special purposes, such as estimation of hydraulic gradients, and hydraulic and morphologic modelling; and
- monitoring of river stages to determine the least available depth for inland navigation.

A network of water level gauges can be characterized by the spatial distribution of the gauges along the rivers. The density of the gauge network depends on the objectives. For detailed studies and for special purposes, a dense network is required. For water resources estimates of a country, gauging sites are usually located at the boundary locations. The density of gauges in the network depends on the purposes and often also on historical developments. Detailed and special studies require sometimes a dense local network of temporary water level gauges. If the purposes change in the course of time the network might have to be optimized again and subsequently adapted by establishing new stations and/or abandoning of one or more of the existing water level stations.

The frequency of measurements in the established network depends on the particular objectives and natural variability of water level. For example, in a tidal station, the measurements should at least be hourly. In non-tidal stations, the recording interval can be more, but should represent the variability well. For recording gauges, obtaining water level at a desired frequency is out a problem.

The optimization is mainly a process of balancing requirements on the one hand and cost and effort (resources) on the other hand. A number of aspects are indicated in Table 1. The sequence of appearance is not relevant. Two budgets must be available, one for investment and training, the other for operation and maintenance. It is quite possible that the budgets do not allow procurement and operation of two types of instrument at each station. Hence, at stations where typical AWLR characteristics are not required only staff gauges may be deployed.

Requirements	**Cost & effort**
spatial distribution	investment
temporal spacing	maintenance
accuracy	training
reliability	operation
level of automation	sustainability
timeliness of data	site visits

Table 1: Principal aspects of stage measurements network optimization

Main stations have been established to assess the discharges which flow into the country. These main stations along the main rivers are important for the national water management strategy.
Along the main tributaries of these rivers water level stations were established to estimate the discharges. At confluences of the main rivers, water level stations are important for the navigational purposes and to study backwater effects on either river. Relation curves between the main stations show if water level stations in between of those main stations are desirable. For water balance studies a water level station at the downstream tidal boundary of the project area of RSP is established. Further details on the spatial distribution of water level gauges within the network is found in (RSP, Annexure 3 Hydrology). Also worth studying, among others, are the numerous ISO-Standards covering most relevant aspects of river-stage measurements.

In general terms, the gauging sites were established at the boundaries of the project area (Jamuna, Ganges, Padma, Upper Meghna) at intermediate stations (Jamuna, Old Brahmaputra, Dhaleswari), close to important confluences and at some secondary rivers (Gorai, Arial Khan). At the Jamuna project boundary two stations were established, at left and right bank (Figure 2).

Given the significance of river stage data for understanding the hydraulic and morphological behaviour of a river, it was decided to give the water level monitoring system considerable priority. The chosen set-up consists of AWLRs and dual staff gauges, which are read visually. For reference purposes, local bench marks connected to a national datum are maintained. At an additional number of stations, only staff gauges are applied, in particular for slope measurement.

Considering the advantages and disadvantages of the different AWLR types, and based on experience in Bangladesh, the pressure cell and acoustic type AWLRs were selected for the RSP stations. For instrument types, a data-logger is used for level-recording. It comes mounted in a polyester box enclosure, together with two battery packs and interfacing electronics on a printed circuit board (pcb) (DELFT HYDRAULICS, 1992a).

2.5 RSP gauging

In dynamic and instable rivers, very few sites are fit for installation of a permanent gauging instrument. Only at river crossings, such as railway and roadway bridges, permanent stations are feasible. The selected strategy was to install acoustic sensors where bridges were available at the survey sites and pressure sensors at the other, less stable sites. The pressure sensor and associated electronics were mounted on platforms on top of space frames, constructed from steel pipes. For electronic data collection AWLR type instruments were deployed. Each AWLR site was supplemented by two staff gauges, this for back-up and data validation purposes.

RSP established a network of 11 gauging stations in Bangladesh (Figure 2 and Table 2). They were installed at discharge measurement transects, and at bathymetric survey sites.

Eleven AWLR sites were indicated tentatively in the Contract (Bill of Quantities, Table 4.1.b and 5.1.b). Table 2 shows these sites. Based on these indications, the exact locations have been selected.

Reading of the river stage by AWLRs is done at a 30 min interval. The staff gauges are read at 3 hours' intervals, starting at 06 h and ending at 18 h. Hence, 5 readings are recorded daily, during daylight only.

A brief description is given below on the different sensors selected by RSP.

Station Number	River System	River	Station	Sensor
01	Brahmaputra-Jamuna	Jamuna	Bahadurabad and Gabgachi	Pressure/ Acoustic
02		Jamuna	Sirajganj/Bhuyanpur	Pressure
03		Jamuna	Teota (Aricha)	Pressure
04		Old Brahmaputra	Mymensingh	Acoustic
05		Dhaleswari	Tilly	Pressure
06	Ganges	Ganges	Hardinge Bridge	Acoustic
07		Gorai	Kushtia R.B.	Acoustic
08	Padma	Padma	Baruria	Pressure
09		Padma	Mawa	Pressure
10		Arial Khan	Offtake	Pressure
11	Upper Meghna	Upper Meghna	Bhairab Bazar R.B.	Acoustic

Table 2: RSP AWLR gauge sites

Pressure sensors

A pressure transducer is used in a pressure cell gauge. In this gauge, developed by Delft Hydraulics (1992a), an Ott-Heel pressure transducer is used, which measures against atmospheric pressure. A polyamide tube, integrated in the connection cable, conveys the air pressure to the transducer.

The pressure transducer may be mounted at a fixed elevation in two ways, either fixed to a structure, or lowered in a tube. In either case, the transducer should be pointing vertically downwards with the cable running upwards.

Acoustic sensor

Installation of the acoustic sensor requires a support for the sensor which gives it an unobstructed 'view' to the water surface. In particular at low water, when the distance to the water surface can be as large as 10 m, the sensor should be protruding at least 2 m beyond any structural element. Bridges and space frames of power masts are convenient structures to host the acoustic water level measuring system. The associated electrical cable and electronics have to be protected against over-voltage, such as caused by nearby lightning strikes. The electronics and the logger software are largely the same as for the pressure sensor system, which is an advantage from a logistic and operational point of view.

The connected data logger converts the measured range to a value representing water level. To this end, an artificial reference level is assumed at 10 m below the sensor's zero mark. The measured range value is subtracted from 10.0 m. This makes acoustic sensor readings comparable with the pressure sensor readings.

The UDG01, developed by Campbell Scientific Canada Corp. (1992), is an ultrasonic sensor with a measuring range from 0.6 to 10 m and an accuracy within 1 cm. The sound beam spreads to an angle of 20° from the sensor. This implies that an average water elevation is estimated if there are undulations (such as waves) in the illuminated water surface. The sensor operates on a 12 V DC power and weighs about 1 kg.

The cantilever frame for the acoustic sensor, used at most stations, basically consists of a horizontal extension pipe with a downward running vertical pipe attached at the far end. At the lowest end of the vertical pipe, the acoustic and temperature sensors are mounted. The structure is designed such that the acoustic sensor is at a distance of about 3 m from the bridge pier and at a height of no more than 10 m above the lowest water level during the lean season and well above the highest water level to be expected in the monsoon. Where both specifications cannot be met simultaneously, the instrument is installed at monsoon level. However, where possible, a bi-level support was made, which is operated in a low position during the lean season and in a high position during the monsoon.

Figure 3 shows the mode of operation and flow chart of a recording gauge with pressure cell or acoustic sensor, a data-logger system, and a transmitter.

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3 Gauge site selection

3.1 Basic site selection criteria

Relevant aspects with respect to site selection, which should be considered carefully, are:

Representativity: The main objective of a water level station is to collect stage information, which is often used either to establish stage-discharge rating curves, or to measure water level slopes, or to reduce bathymetric soundings to a reference datum. Therefore, stations should be located close to the discharge transect when a stage-discharge relationship is desired, and preferably at the centre of a bathymetric sounding area when depth reduction is desired.

Availability of a fixed structure: If a stable fixed structure exists near deep water, it is an attractive location. The structure can be for example a bridge pier, a jetty, or the support for a tension line.

River bed stability: From the operational point of view the platforms should be installed at stable river sections. This requirement cannot be met under the prevailing hydraulic and morphological conditions, hence, some risk has to be taken to loose an instrument and valuable data. The predicted river bed stability should meet certain criteria.
- Firstly, the stability of the platform depends on the stability of the river bed on which its foundation is laid. Therefore, the river bed should not experience excessive erosion, and it should not be so soft to allow subsidence of the platform.
- Secondly, the morphological developments should not be such that the river bed migrates away from or towards the platform. In the first case the platform might suffer from severe sedimentation, in the latter case severe erosion might result. In addition, the same developments may cause the sensor to stand in an isolated water.

Intensive flow field: The site should be away from the intensive flow field for two reasons: Firstly, the structural stability should not be threatened by the lateral loads caused by flow velocities. Secondly, when a pressure sensor is installed, the flow velocity generates an extra pressure adding an error to the recorded pressure head.

Accessibility: The accessibility of the site is especially important in view of the operation and maintenance activities.

Safety: The site should be safe against possible theft of equipment, and against impact of vessels caused by anchoring. Hence, it should be located in a safe place away from the navigational fairway. Also, the structure should be protected against loading caused by floating debris.

A thorough site selection procedure for water level stations is a prerequisite. First of all, the site must be representative from the hydrological point of view. In addition, particularly for long-term data collection, the reach of the river at the measuring station must be stable, in order to avoid the risk of loss of data and equipment due to local erosion or sedimentation. For routine data collection, the instrument must be easily accessible during both the monsoon and the lean season. Whatever data collection method is selected, a staff gauge may be required for the mobile bed rivers of Bangladesh. Hence, there must be a village nearby, where a suitable gauge reader can be found. As any reading is to be reduced to some adopted datum, it should be an advantage if a properly established bench mark, connected to the national level system, could be found within a reasonable distance.

The rivers of Bangladesh are unconfined and freely migrating with continuous modification of their banks and chars by erosion and siltation. This implies that any structure built for the purpose can either be vulnerable to erosion or to siltation. The following aspects are important in this regard:

- Free river migration implies that a structure can either be scoured, eroded and collapsed or dried up during the low river stage. Erosion and scour hazards demand that the structure should have a deep and secured foundation. However, construction of such a foundation increases the cost to several times the purchasing cost of an AWLR. Such a costly foundation cannot always be justified. Moreover, the siltation problem may make a structure redundant anyway after some time. In case of free river migration, the life-time of a structure can be quite short, the time-length depending on the choice of the location.

- Because of the high seasonality of the Bangladesh rivers, the low-draft country boats change their navigation routes so as to follow the shortest possible way, often along the bank. This makes structures along the banks vulnerable to collision by vessels. As described below, this actually happened in some cases for RSP structures. The changing nature of the navigation routes makes it tricky to choose a location.

3.2 Selected gauge sites along the river network

The site selection is based on the following operations:

- Desk study of maps, images, etc., were made to see the existing nature of the channel migration and to determine some preliminary locations;

- next, the preliminarily selected sites were investigated by field visits. The local people were consulted on the river migration pattern, flow-pattern, etc.;

- the preliminarily selected sites were evaluated with respect to their representativity for the purpose of data collection, and a site was finally selected.

3.2.1 The Brahmaputra-Jamuna river system

Bahadurabad-Gabgachi on the Jamuna River
Bahadurabad-Fulchari is a RSP discharge transect. However, to choose a suitable location for an AWLR at Bahadurabad is difficult, considering the fact that the Jamuna is known as a braided river with rapid channel migration and sand bar movement, and that there are no fixed structures in the vicinity that can be used to mount the equipment.

From earlier field visits and FAP studies (amongst others by FAP21/22), a number of locations have been preliminarily selected as indicated in Figures 4 and 5. A project team, together with a representative of BWDB, made a reconnaissance visit to Bahadurabad on 24-26 April 1993 to determine the exact

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location of the AWLR. Later, in June, another visit was made, with participation by the Project Adviser. Table 3 shows the advantages and disadvantages of the different locations.

Location	Advantages	Disadvantages
1. Jamuna left bank 500 m up-stream from Bahadurabad ghat	1. Near the discharge transect 2. Relatively stable bankline 3. BWDB staff gauge is installed	An unstable char propagating down-stream
2. Old Brahmaputra River Offtake	1. Data could be useful for offtake studies	1. Far from the discharge transect 2. Relatively unstable area
3. Manos regulator at Balashi ghat	1. Fixed wing walls of the regulator exist 2. Kamarjani BWDB staff gauge is located nearby	1. Far from the discharge transect 2. Despite the existence of the wing wall, the bankline is heavily eroding
4. Fulchari railway ghat	1. At the discharge transect	1. Bankline eroding despite efforts to stabilize it
5. Char Gabgachi	1. At the discharge transect	1. Slightly eroding bankline

Table 3: Advantages and disadvantages of different locations near Bahadurabad

Figures 6 to 9 show photographs of the different sites. Considering the advantages and disadvantages of all the visited sites as presented in Table 3, sites 1 and 5 were chosen for the AWLR installation. Figure 8 shows the site at Gabgachi where a platform is seen erected.

Sirajganj on the Jamuna River

Sirajganj is another RSP discharge measurement transect in the Jamuna River. As in the case of Bahadurabad, it is difficult to find a suitable site. Four sites were investigated by field visits. Their advantages and disadvantages are listed in Table 4.

Location	Advantages	Disadvantages
1. Jamuna Bridge site	- Near to the discharge transect - Low water can be gauged	- Highly eroding bank - Danger of being disturbed by bridge construction activities
2. Dhaleswari Offtake	- Relatively stable area	- Low water can not be gauged - Danger of being disturbed by bridge construction activities
3. Bhuyanpur	- Relatively stable on a secondary channel - Low water can be gauged - No disturbance from the bridge construction activities	- Relatively remote - Monsoon navigation
4. Sirajganj	- Stable bankline - BWDB gauge installed - Low water can be gauged - Construction material mobilization easy	- Very strong current during monsoon - Considerable navigation
5. Sirajganj groyne site	- Stable location - Low water can be gauged - Construction material mobilization easy	- About 500 m upstream from the gauge site

Table 4: Advantages and disadvantages of different locations near Sirajganj

The investigated sites are shown in Figure 10. The considerations indicated to select the Bhuyanpur site. Later, after collapse of the tower at Bhuyanpur, it was relocated near the Sirajganj groyne site. Figure 11 shows the bank protection works at Sirajganj. Figure 12 shows the relocated structure.

Aricha on the Jamuna River

Aricha is a bathymetric site at the Ganges-Jamuna confluence. The advantages and disadvantages of different sites as observed by field visits are follows.

Location	Advantages	Disadvantages
1 Aricha Ferry Ghat	– Good communication – Near to BWDB gauge site – Low water can be gauged	- Heavy navigation - Slightly eroding bankline
2 High tension power line pier	– Stable place – Ideal place to mount a sensor	- PDB did not permit to mount the sensor
3 Teota	– Relatively sheltered and stable place – Good communication	- The present secondary channel may develop to a main channel by cutoff and scour

Table 5: Advantages and disadvantages of different locations near Aricha

Figure 13 shows the investigated sites. Figure 14 shows a high-tension power line tower near Aricha. Based on the above considerations, the Teota site was chosen.

Mymensingh on the Old Brahmaputra River
For this station, the railway bridge pier was chosen as a site. Bangladesh Railway gave permission for the installation of the Gauge at one of the bridge piers. Figure 15 shows the location of the gauge. Figure 16 shows the photographs of the bridge.

Tilly on the Dhaleswari River
For this station three rites were investigated. The relative advantages and disadvantages of them are given in Table 6

Location	Advantages	Disadvantages
1 Taraghat roadway bridge on the Dhaka-Aricha highway	- Stable structure, an AWLR can easily be mounted	- Far downstream from the discharge transect - Downstream of a bifurcation point, so represents one channel only
2 On the left bank point-bar at the discharge transect	- At the discharge transect	- Low water can not be gauged - Difficult to read, watch and main-tain
3 On the right bank at the discharge transect	- At the discharge transect - Easy to read, watch and maintain	- Slightly eroding bankline

Table 6: Advantages and disadvantages of different sites near Tilly

Site 3 was chosen. Figure 17 shows the Dhaleswari River and the AWLR location. Figure 18 shows the sites.

3.2.2 The Ganges river system

Hardinge Bridge on the Ganges River
Hardinge bridge is a convenient site because the bridge piers can be used for mounting a sensor (Figure 19), and the discharge measurement transect is located near to it. A float-well type BWDB auto-gauge is installed on the bridge pier (Figure 20). Bangladesh Railway gave permission to use one of the bridge piers.

Kushtia Railway Bridge on the Gorai River
The discharge transect in the Gorai River is located near the Kushtia Railway Bridge. Kushtia Railway Bridge was chosen (Figure 21) and permission was obtained from the Railway Department. Figure 22 shows the Railway bridge and the piers.

3.2.3 The Padma river system

Baruria on the Padma River

Baruria is a RSP discharge measurement transect. Two sites were preliminarily selected for investigation (Figure 23). Their characteristics are shown in Table 7.

Location	Advantages	Disadvantages
1 Baruria on the Padma River left bank	- Stable cohesive bank - Near the BWDB gauge site - Good Communication	- Thalweg near the bank - High current
2 Daulatdia on the Padma River right bank	- Relatively stable interior location	- Crowded navigation and Ferry harbour - Annual dredging of the navigation fairway

Table 7: Advantages and disadvantages of different locations near Baruria site

Figures 24 and 25 show the photographs of Daulatdia ghat. The Baruria location was selected.

Mawa on the Padma River

The discharge transect is located close to the Mawa ferry ghat. Relative advantages and disadvantages are shown in Table 8.

Location	Advantages	Disadvantages
1. Mawa Ferry Ghat on the Padma River left bank	- Rather stable bank - Near the BWDB gauge site - Good communication - Near to RSP gauging site	- Intense navigation
2. About 500 m upstream from the Mawa Ferry Ghat on the Padma River left bank	- Rather stable bank - At a safe distance from the ferry ghat	- Further upstream from the gauging site

Table 8: Advantages and disadvantages of different locations near the Mawa site

Figures 26 and 27 show the locations. The second location was chosen.

Arial Khan Offtake

Location	Advantages	Disadvantages
1. At the offtake mouth of the Arial Khan River	- Easily accessible	- Eroding right bank of the Padma River - Vulnerable to navigation
2. 5000 m downstream from the mouth	- Stable position - Near to the BWDB gauge	- Away from the discharge transect

Table 9: Advantages and disadvantages of different locations near Arial Khan Offtake

Location 2 was chosen. Figure 28 shows the locations.

3.2.4 The Upper Meghna River

Bhairab-Bazar on the Upper Meghna River

On this site, two locations were investigated (Figure 29). The first one is on the bridge pier of the Bhairab Bazar Railway Bridge, and the other is on the Jute-Mills jetty. The Jute-Mills jetty located just upstream of the Old Brahmaputra River outfall was an ideal location, where a pressure cell or an acoustic sensor could be mounted easily. However, the Jute-Mills Authority did not give permission to install the AWLR. The railway bridge was then chosen, and a permission was obtained for the installation. Figure 30 shows the photographs.

4 AWLR platforms

As discussed earlier, at most locations it was difficult to find a suitable safe site where a platform can be placed safely in the morphologically unstable rivers. Based on the earlier experience with platform design, a design concept finally evolved.

In principle, the design is the same for all the platforms. Figure 31 shows the design of a typical platform at Bahadurabad. Some station specific water levels and deck/sensor levels are presented in Table 10.

Station	SLW (m)	SHW (m)	HRL (m)	Deck/sensor (m)
Bahadurabad	12.00	20,6	20.60	21,0
Bhuyanpur (Sirajganj data)	6.00	12,9	15.10	15,6
Teota	2.31	10,14	11.00	11,15
Tilly	2.10	9,9	10.40	11
Baruria	2.60	9,8	10.30	10,8
Mawa	0.90	7,3	7.60	8,1
Arial Khan	0.09	7,4	8.00	7,9
Gabgachi (Bahadurabad data)	12.00	20.6	20.6	17.6

SLW: Standard Low Water at 95% exceedence frequency
SHW: Standard High Water at 5% exceedence frequency
HRL: Highest Recorded Level
Deck: Deck level of the AWLR platform

Table 10: Deck/elevation and other water level data of different station according to NEDECO (1967); Interconsult (1991) and FFWD (1993)

The platforms consist of three basic units:

(1) The tower itself founded into the ground;
(2) the sensor fixing arrangements; and
(3) the data-logger housing.

The tower consists of the following basic elements:

- A triangular frame with three 100 mm GI pipe legs driven 10-20 m into the ground;
- about 7 angular frames equally spaced and braced to the GI pipe legs;
- cross-bracing angles;
- a ladder; and

- a platform on the top with railing.

The sensor fixing arrangements consist of the following:

- A 76 mm GI pipe attached to one of the legs; and
- a 70 mm PVC placed inside the GI pipe.
- The pressure sensor is attached to the PVC pipe.

Figure 36 shows the fixing arrangements.

The data-logger housing consists of the following:

- A cubical box 1x1x1 m;
- a perforated bottom plate;
- heat insulation inside the box containing the cock sheet and air-gap;
- a steel frame for data logger installation;
- ventilation pipes;
- solid brass rod to prevent lightning damage; and
- antenna fixation arrangement.

At locations where railway bridges could be used, individual designs were made for each bridge pier according to its configuration. Figures 32, 33, 34 and 35 show fixing arrangements for acoustic sensors for different bridge piers.

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5 Construction and installation

A short description of the AWLR stations is given here. The location coordinates at summarized in Table 11.

Bahadurabad on the Jamuna River, left channel
The present station is located on the left bank of the Jamuna River at about 700 m upstream of Bahadurabad ghat, where a pressure-type AWLR was installed. The sensor dried up at this location, and was moved to a temporary structure on 21 November 1994.

Jamuna River, right channel at Gabgachi
At Gabgachi, a triangular frame was adopted for support of both the sensors and the data-logger. There is hardly any flow of water at this location.

The pressure cell sensor is housed in a 3" pipe connected at one of the triangular frame legs. Further, an acoustic sensor is fixed to the structure.

Bhuyanpur on the Jamuna River
This station is located on the left bank of the Jamuna River near the Jamuna Bridge site and Bhuyanpur Ferry Ghat, opposite of Sirajganj. Construction of a platform and the subsequent installation of a pressure cell type AWLR were complete by 29 May 1994. On 2 September 1994 the platform collapsed due to heavy scour and erosion.

Teota on the Padma River
This station is located at Teota on the left bank of the Padma River, about 2 km upstream of Aricha Ferry Ghat. Construction of a platform and subsequent installation of a pressure cell type AWLR were complete by 13 May 1994. The sensor dried up in November 1994.

Hardinge Bridge on the Ganges River
An acoustic type AWLR was installed on Hardinge Bridge on 21 July 1994.

Baruria on the Padma River
This station is located on the left bank of the Padma River at about 6 km downstream from Aricha. Construction of a platform and subsequent installation of a pressure cell type AWLR were complete by 28 May 1994. On 25 July 1994 the platform collapsed after collision with a cargo boat.

Mawa on the Padma River
This station is located on the left bank of the Padma River, about 500 upstream from the Mawa Ferry ghat. Construction of a platform and subsequent installation of a pressure cell type AWLR were complete by 10 May 1994. On June .. 1995 the station collapsed after a collision with a country boat.

Mymensingh Railway Bridge on the Old Brahmaputra River
An acoustic type AWLR was installed on the Mymensingh Railway Bridge on 29 June 1994.

Tilly on the Dhaleswari River
This station is located on the right bank of the Dhaleswari River at about 10 km upstream from Taraghat Bridge on the Dhaka-Aricha Highway. On 31 July 1994 the platform collapsed after collision with a cargo boat.

Gorai Railway Bridge on the Gorai River
An acoustic type AWLR was installed on the Gorai Railway Bridge on 22 July 1994.

Arial Khan Off-take on the Arial Khan River
This station is located on the right bank of the Arial Khan River at Koshabhaya, which is 3 km downstream from the off-take.

Bhairab Bazar Railway Bridge on the Upper Meghna River
An acoustic type AWLR was installed on the Bhairab Bazar Railway Bridge on 25 August 1994.

Table 11 on the next page gives details about the staff gauge and AWLR stations. Some stations were shifted during operational use to anticipate local changes of the river bank.

At all listed AWLR stations the 1/2-hourly AWLR-recordings were supplemented by 3-hourly (06h..18h) manual staff gauge observations.

Station	River	Appr. location	Easting	Northing
1 Kabilpur 1)	Jamuna, at Bahadurabad, right channel	7.5 km upstream of Fulchari	461260	792960
1 Shanki Bhangha		1 km upstream of Fulchari	458562	786874
1 Gobindi		2.3 km downstream of Fulchari	460335	782780
1 Gabgachi 2)		Mid char opposite of Fulchari	462810	782462
1 Bhagir Char		4.5 km downstream of Fulchari	461085	780474
1 North Kathiamari 3)	Jamuna, at Bahadurabad, left channel	10 km upstream of Bahadurabad	466678	789365
1 Char Parul		6.5 km upstream of Bahadurabad	468000	786500
1 North Horindhara 4)		1.5 km upstream of Bahadurabad	471036	782000
1 Bahadurabad 5)		0.7 km upstream of Bahadurabad Ghat	471447	780125
1 Belgacha 6)		3.5 km downstream of Bahadurabad	471021	776497
1 Thantania Para		9 km downstream of Bahadurabad	469549	771143
2 Bhuyanpur/ Sirajganj	Jamuna	Left channel, opposite of Sirajganj. Station moved to Sirajganj 1/4 95	479272 471146	708842 706938
3 Aricha (Teota)		2 km upstream of Aricha Ghat	477457	638242
4 Hardinge Bridge	Ganges	At bridge	401066	661668
5 Baruria	Padma	6 km downstream of Aricha	481094	629992
6 Mawa		Near ferry ghat	525840	595937
7 Mymensingh	Old Brahmaputra	At railway bridge	543466	736114
8 Tilly	Dhaleswhari	10 km upstream of bridge	495655	648180
9 Gorai	Gorai	At railway bridge	416646	641622
10 Arial Khan	Arial Khan	Koshabhaya, 3 km downstream of off-take of Arial Khan	507819	590406
11 Bhairab Bazar	Upper Meghna	At railway bridge	601751	658881
12 Mir Char		20 km downstream of Bhairab Bazar,right bank	593839	645104

1) Shifted from Ratanpur, 463166 E, 794 925 N
2) Shifted to 462905 E, 782564 N
3) Shifted from 467071 E, 789615 N
4) Shifted between the location indicated; 471652 E, 781069 N; 471100 E, 781744 N
5) Shifted from 471049 E, 779439 N
6) Shifted to 470889 E, 776386 N

Table 11: Geographical locations of water level gauges

Station 1 at Gabgachi and the Stations 2..11 are AWLR stations.

6 Operation and maintenance

The data return and the quality of a water level collection network strongly depend on operational procedures. Frequent service visits by dedicated staff are essential. In particular, the staff gauge zero-level should be frequently connected to the local bench mark, that is at each visit and with great care, as this is one of the keys for data quality assurance and validation.

In order to ensure adequate operation and maintenance of the water level gauging stations, guards/gauge readers are employed at each station. Water level data are collected by AWLRs at an interval 30 minutes and read from staff gauges every 3 hours from 06:00 in the morning to 18:00 in the evening. The purpose of staff gauge installation at AWLR stations, and reading of the same during daytime hours, is to maintain a double check on the water level data and for redundancy purposes against data loss due to any mishap such as failure of the platform space frame, collapse due to sudden erosion, theft of data-logger, etc. The daytime guard, therefore, has the additional responsibility of taking staff gauge readings at every 3 hours. This has the inherent advantage that local people become involved in the operation and protection of the station. All stations have one or more gauge readers. These aides have to be properly instructed, trained and guided. Careful annotation procedures as well as proper time keeping, including timely gauge reading, must be frequently reviewed.

Normal operation and maintenance works for the gauge stations include:

1. Data off-loading each month, if possible more frequently;
2. battery voltage check and replacement of battery packs if needed;
3. change of dehumidifier in the ventilation box;
4. occasional maintenance painting of the housing and housing support structure;
5. collection of staff gauge data; and
6. liaison with the gauge reader.

Off-loaded data are handed over to the water level data base manager and subsequently saved in the off-line database system of the RSP office in Dhaka.

6.1 Service procedures

Regular service visits to the stations of the water level data collection network are made for a number of reasons:

- To carry out technical maintenance work;
- to retrieve collected data; and
- for reference purposes, i.e. to establish and update the required references of the readings in level and time.

Service visits are paid regularly. In the lean season, the interval is about a month or less, during the monsoon the intervals are shorter and strongly dependent upon river behaviour. Actually, the stations are visited as often as available manpower, transport facilities and local conditions permit.

At rising and falling water levels, the staff gauges are re-positioned accordingly, anticipating the likely level change. At some AWLR stations, the sensor is moved to another elevation to avoid outranging of the sensor.

Upon arrival at a station, checks are made for damage of instruments, structures, staff gauges and associated objects. Additionally, the local conditions are assessed, in particular for changes which may affect the functioning of the equipment and the accuracy of the collected data. Especially, erosion or sedimentation may require measures to secure the station and maintain data quality. The Service Engineer also evaluates the data and the relevant particulars of the elapsed period and assesses the coming period. Subjects may be the accuracy of the gauge readings, both in time and level, events at the station, measures to be taken, errors to be avoided, etc.

Various maintenance activities have to be carried out. For the functioning of the AWLR, sufficient battery power is to be provided. For the pressure transducers the silica-gel desiccant has to be regularly replaced. The functioning of the sensors must be checked for a number of aspects. The most recent/running reading is checked for plausibility on physical grounds. The number of accepted samples for the averaging process should be equal or approximately equal to the number of samples taken. The apparent sensor zero level, relative to the relevant datum, is compared to the previous value. No significant change is allowed unless there is a distinct reason to it.

For each service visit, a *Service Report* is made, giving the details of the technical status of the station, its functioning, and any particulars of interest regarding data yield, quality, continuity, etc.

6.2 Data validation in the field

The validity of the collected data is assessed in a number of steps. Upon retrieval in the field, the data are visualized in a graphical representation of the readings versus time. Distinct errors such as sensor over-range, recording of error codes, and spikes in the data can then be recognized. This allows the operator to take immediate action on site, if technically possible or to assess likely error causes.

In order to monitor the stability in time of the staff gauges and the AWLR station, the elevations of both staff gauges are connected to a bench mark by levelling. Furthermore, the staff gauges and the AWLR are read simultaneously. The staff gauge reading, translated to water level relative to datum, can be mapped on the AWLR reading. Thus, the zero level of the AWLR sensor can be established. In the field, the calculated reference levels of staff gauges and AWLR are compared with similar values from previous visits. In the event of an apparent difference, adequate measures can be taken immediately.

6.3 Field visits and appraisals

All operational AWLR stations have been visited by the Hydrometrist in April and May, 1995, and are visited regularly by the Network Operator. During these visits, the stations are checked for proper functioning, and procedures and factors that might jeopardize data yield and quality are appraised and modified. Some impressions from the inspection visits may be summarised as follows:

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Data off-loading
No malfunctions were encountered then. Upon off-loading, data are translated from the binary format into ASCII coded tables, which allows for an inspection of the collected samples by browsing through the files. However, this method was not efficient to find inconsistencies in the data such as outliers and jumps in the average level, so a new graphical method has been implemented.

Check of system clock
Errors in the setting of the system clock proved to be no more than 2 minutes and can be adjusted by PC. These relatively small time errors do not jeopardize data quality on the upper river sections. However, in the tide-affected areas, time keeping must have an accuracy of 1 minute for comparison of staff gauge and AWLR data. Main error sources are poorly adjusted operators' watches and/or PC clocks. On some occasions, a hand-held GPS-receiver was available, which allowed for precise setting of the PC-clock and subsequently the logger clock. Before departure from the office, the PC-clock and the Network Operator's watch should be properly adjusted. The staff gauge reader should check his watch daily against time-information broadcast by national radio/TV.

Battery check
Nearly exhausted batteries are replaced by new ones. No problems in this regard have been noticed. During replacement, particular care must be taken to avoid short-circuiting of battery wires against each other or to the electronics.

Check of sensor functioning
The average count of the latest data sampling session as well as the average value are checked for plausibility. On two occasions, at Bhairab Bazar and at Mymensingh, the acoustic sensor was not performing up to standards and was therefore replaced by a spare unit. None of the pressure sensors had a functional problem.

Replacement of silica-gel desiccator
Desiccator was initially replaced upon arrival at the site. During service operations, the enclosure is to be open, which exposes the desiccator to the humid surrounding air. In order to avoid rapid saturation of the desiccator, the procedure has been changed: Replacement is made at the end of the service visit.

Inspection of sensor fittings
The acoustic sensors are mounted onto an extension frame made of 3" metal pipe. In windy weather, the frame may flex with the wind to some degree, although not to an extent that influences the data quality. Except for Bhairab Bazar, the sensors are easily accessible. At Mymensing, caution is required not to be caught by a train. At Bhairab Bazar, a boat is needed to reach the bridge pile that hosts the sensor. Access to the sensors requires disassembly of the pipe frame, which takes some time. The reproducibility of the installation is good. For new stations redesign of the pipe frame might be considered, especially for ease of installation and for better resistance to extreme wind loads.

At most stations, the pressure transducers were lowered into a vertical guidance tube with a partly open bottom and perforations at a number of heights. This yielded good stability and reproducibility of sensor level. In the lean season, at two stations, Arial Khan and Bahadurabad, the water level drops below the bottom of the sensor guidance tube. Therefore, in that season, the pressure sensors are transferred to bamboo poles driven into the river bed. At the onset of the monsoon, the sensors are moved back to their monsoon positions inside the guidance tubes.

Inspection of electronics housing and cables
Even though cables are properly protected and guided, awareness towards potential damage must be maintained. The housings at some stations, such as Mymensing and Gorai, have no space to support the PC during operations, which makes the work difficult and puts the PC at risk of falling. Once, at Hardinge Bridge, the housing was cohabited by a considerable number of cockroaches, which had to be wiped out by a brush. The sensors at Arial Khan and Teota suffer from occasional heavy sedimentation.

Reading of AWLRs and staff gauges
Comparison in the field between AWLR and staff gauge readings can be done as follows: The AWLR is put into calibration mode, hereby speeding the recording rate up to 1 record per minute. In this way, several recordings are made, whereupon the staff gauges are read. At Bhairab Bazar railway bridge, where an acoustic AWLR has been installed, the water level is affected by the tide. There, the AWLR electronics unit could be installed onshore, close to the staff gauges. On the other bridges, it may take up to 5 minutes to cover the distance between AWLR and staff gauges. In Arial Khan and Mawa, stations with a noticeable tidal effect, the staff gauges were installed next to the AWLR tower, which enables timely reading of staff gauges. However, in the monsoon, the AWLRs at these stations will be fully surrounded by water and a country boat is needed to reach the AWLRs. During service visits to such stations, simultaneous reading of staff gauge and AWLR must be executed by two persons, e.g. the service engineer at the AWLR and the gauge reader or the levelling assistant at the staff gauges. Otherwise, the 1 minute's accuracy cannot be maintained.

The local gauge readers are to be made aware of the importance of reading at the proper time. They have therefore to arrive at the staff gauges well before the official reading time. It should be made clear to them that reading errors and deceptive actions are easily detected and put their jobs at risk.

Levelling of staff gauges
To allow for a quick and accurate levelling, temporary bench marks (TBMs) were established at all stations in an early stage of the project and were connected to the national datum. These TBMs were made from an abutment of a railway bridge, a step of a stone staircase, a pipe hammered into the ground, etc.

The levelling of the staff gauges was executed with great care, going from the local temporary bench mark to the staff gauges and back again. Results were immediately calculated and checked for correctness. Also, the apparent elevation of the AWLR sensor was calculated and compared with values of previous visits, if available.

Data collection from the gauge reader
In connection with the data collection, the data of both staff gauges must be screened and compared with each other for differences in water level, as some types of error may be detected by a simple comparison, such as outliers and level jumps. Level drifts and similarly varying differences cannot and must not be corrected without additional information.

7 Data management and validation

The gauge reader keeps a staff gauge log in a station logbook. The staff gauge data are transported on paper, to the data base. Upon arrival in office the data are entered into a PC and subsequently keyed into the water level data base.

The AWLR data are collected in digital, PC accessible format. Upon retrieval these data are recorded in PC-memory, on hard disk. At arrival in office the AWLR data are loaded into the water level data base.

The water level data-base holds only ASCII coded water level data and associated station and time information.

7.1 Storage of field data files

Collected field data are loaded into an office PC. For each station, a sub-directory is available. Only ASCII data are kept, while the Logger Binary Files (LBN's) are retained as a temporary back-up. Water level data are validated on a yearly basis. After acceptance of the validated data, the LBN data may be discarded, while the validated data must be carefully kept and maintained.

7.2 Raw data processing and checking

Validation of the raw data is executed on data as they arrive from the field stations. Raw data are plotted against time, quite similar to the method used in the field. A graphics print-out is made for reporting and for assessment of data integrity. Any irregularities are traced back, if possible, to their cause. To maintain the required quality and rate of data return, specific measures may be necessary, like replacement of sensors, as it has occurred in the past at Bhairab Bazar and Mymensing. The raw data plots are also useful in the subsequent validation process. Findings are fed back to the Network Operator. In particular any irregularities are to be discussed in order to allow him to take adequate measures. The follow-up results in adapted procedures, a fault finding and/or repair mission.

7.3 In-office data validation

From each station, readings are available from two sources: AWLRs and staff gauges. These records are to a great extent independent. The common factor is their connection to the local bench mark. It is of great importance that this connection is made with professional precision and care.

The validation process is formalized in strict procedures which are implemented in software. In general terms, the process is executed as follows: Staff gauge and AWLR data are retrieved from their dedicated files. From a third file, the reference file, reference levels of staff gauge and AWLR are read, as well as the pre-set margin of acceptance of the differences between staff gauge and AWLR readings. Based upon various criteria, to be explained below, the valid water level is, under application of the selection criteria, selected from the AWLR and staff gauge data. Output is generated and recorded in various output files.

The selection criteria are arranged in various classes, viz.:

- physical limits;
- time window; and
- difference.

The procedures related to these criteria are described hereafter.

Physical limits
Firstly, the data have to be within a certain range, which reflects certain physical limitations. For the AWLR, the limits are -0.50 and +10.50 m, for the staff gauge 0.0 and 2.0 m. The associated reference levels, which are set in the reference file, must also fall within fixed limits. The operator may set a reference level to error code in order to prohibit use of the associated data.

Time window
Subsequently, provided that readings pass the physical limits test, they are subjected to a time test. During processing, the program advances through the data files. At each processing step, the processing time is increased to the time associated with the next valid sample in either the AWLR or the staff gauge file, or in both in case of coinciding sample times. The sample time stamp must fall within a window of -1.5 and +1.5 minutes around the processing time. In other words, only data for which the time stamp differs less than 1.5 minute from the current data processing time are accepted for further use. Due to the mechanism of advancing through the files, always at least one sample coincides with the processing time.

```
                  +
                ||  reading
                ||  limits
                ||
                ||
 -------------->++<---------------
                ||        time ->
                ||
                ||
                ||
                  -
```

A sample must fall within the time and reading limits.

Difference

In case that samples of both data sources pass the physical and time tests, they are subjected to the difference test. If the difference falls within the margin as set in the reference file, the AWLR level is regarded as valid, otherwise the staff gauge level is adopted. If both AWLR and staff gauge level passes the test, the AWLR level will be used.

The priority can be summarized in tabular form as follows:

AWLR	staff gauge	valid
ok	ok	AWLR
-	ok	staff gauge
ok	-	AWLR
-	-	none

Table 12: Data acceptance priorities

The data collection interval of the AWLR is 30 minutes, while that of the staff gauge is 180 minutes. Hence, only 1 out of 6 AWLR samples can be tested according to the time criterion as described before, which could result in a waste of data. To overcome this problem, a linear interpolation procedure is applied to the staff gauge data, provided that these data passed the time and range tests. For each AWLR sample time, the AWLR level is compared with the associated interpolated staff gauge level. If the difference falls within the margin that has been set in the reference file, then that AWLR value is regarded as valid. To ensure that only data which meet both physical and time requirements are maintained, the interpolated staff gauge data are not retained.

Figures 37 and 38 show some examples of raw data recorded by different sensors and by staff gauge. Several validation runs are executed on the data. Some validation examples are given in Figures 39 to 44. In the first run, the data are processed under the assumption that all samples and reference levels are correct. The AWLR data are kept as they are, while erroneous samples are simply neglected during processing. As explained before, staff gauge samples may be corrupted by typing and other errors. In particular, outliers can be distinguished from the change (differentiated data) plots. That is because a single outlier is a discontinuity in the data and consequently gives a relatively large derivative just before and just after the erroneous reading. A step function, usually a result of an error in connection with a staff gauge levelling after a shift, can also be distinguished by the derivative.

Many data errors can be visualised by plotting the collected time series. Sporadic reading errors are quite conspicuous as they do not correlate with the surrounding readings. This in particular during the dry season in the upper river stretches. In tidal areas only larger can be spotted in this graphic way. Data errors which exceed the 'noise band' can be spotted. As a rule of thumb, errors smaller than two times the standard deviation are likely to pass undetected. In this respect the standard deviation is a 'local' value in which only a small number of surrounding values is included. Clearly not all sudden level changes are due to measuring errors.

Drifting errors, or gradual changes, develop beyond the time span of good correlation and must, as a consequence, be detected by other means. In practice, data from independent sources are compared with each other. While comparing readings, errors can only be detected when the data sources exhibit a dissimilar error behaviour. To achieve this, the data collection could be of a different nature, e.g. one human and the other instrumental. In case of detected differences, an assessment of the error cause (or causes) is to be made. If it is plausible that only one of the data series is corrupt, then the other is used for further processing. However, it is quite possible that additional data are required to establish the data quality. Therefore, regular and accurate levelling from the local bench mark, although laborious, is an effective means of data enhancement and verification. The levelling is to be done by qualified and committed personnel.

Some examples of validated water level data are shown in Figures 45 to 57.

7.4 Data management

Data storage is organized in a system of directories and sub-directories. For each data collection station, there is a separate directory with the name of that station as directory name (or an abbreviation of it in case the station name has more than 8 characters). Each station directory has a number of associated sub-directories containing the various data types. The binary raw data are kept in a directory RAW, and the converted ASCII data in a directory WLR. The gauge readings are kept in GAU, and validated data sets reside in directory VAL. Unique data such as the AWLR and staff gauge readings are kept on at least two independent systems for the sake of security. Under no circumstance must these unique data get lost due to negligent data management or failing backup.

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8 Level gauging experiences

Gained experiences are reported and evaluated and conclusions are drawn with respect to sustainability of the applied level gauging methodology for application under Bangladesh conditions.

Generally data collection was executed on a routine basis. The gauging stations were visited as frequently as possible, this to minimize data loss due to malfunctioning of a data collection system, a gauge reader problem etc. For some failures it could still take several weeks before the problem was identified and solved. At numerous occasions data were affected or lost due to a score of causes. All measuring systems had their share of problems. Quite some redundancy was built in: each station operated 2 staff gauges and an AWLR. Thanks to this redundancy the overall data return of validated daily stage data comes close to the optimum.

A description of a number of failures is given hereafter.

8.1 Staff gauge faults

Most staff gauge errors detected under RSP are known and experienced in other networks. As there are few, if any, stable, well established reaches of river in the project area, it was not feasible to establish permanent staff gauge stations. The staff gauges had to be shifted frequently to adapt to changing water level. The supporting structure was constructed of a number of bamboo poles tied together by rope. Provided that the binding is properly done this set up can be very effective.

At numerous occasions the bamboo structure was damaged or destroyed by hitting or colliding country boats. Usually the second staff was not affected as it was operated at a distance. Several staff gauges were lost due to river bed erosion.

Another cause affecting the data return and quality is the human factor. Although most gauge readers were quite dedicated to their tasks and achieved a respectable data return others had a lower performance. The most frequent errors that occurred are described below.

- **timing errors:** timely reading, or in any case a consistent annotation of time of reading is important, in particular while water level varies. In tidal-affected stations various timing errors were detected while comparing the staff gauge data with the AWLR data. Some readers were very professional, they maintained a difference of only a few cm with the AWLR, and so for several weeks. Others exhibited a varying difference of 10 cm or more. This is largely to be contributed to bad time keeping although also waves might have hampered the readings. One particular reader produced very small difference with the AWLR, except for the early morning reading.

  These timing errors can be avoided by explaining to the gauge reader the importance of proper timing and possible errors with their effects.

- **reading errors:** systematic reading errors were not detected. Sporadic reading errors often occur in multiples of 10 cm, usually these are detected by a proper validation procedure.

- **confusing staff gauges:** to make such errors detectable the staff gauges should have different levels, preferably 0.50 m or more apart. Also the horizontal spacing should be in the order of 100 m, this amongst other reasons to prevent the gauge reader to read both gauges at one time.

- **bad gauge shift:** the gauge reader shifts the gauges to a lower or higher elevation in order to adapt to changing water levels. To maintain gauge zero the staff gauges are shifted one after each other, the zero of the shifted gauge is subsequently connected to the other gauge by simultaneous readings. The conditions at gauge shift time usually are rather difficult. During these procedures errors may creep in, e.g. due to reading error upon reading error, subsiding gauges, etc. Therefore the shifted gauges should be connected to the local bench mark by levelling.

8.2 AWLR faults

The AWLR has to be operated through a PC supported user interface. It was learned from practice that half a day of training on the operation of the AWLR is sufficient to get operational. Under RSP a land surveyor and one of his assistants were quite capable to operate the AWLRs. For maintenance purposes some technical knowledge is an advantage, especially in association with the electrical connections involved. Below a number of possible causes of data loss or erroneous data are given.

- **timing errors:** the AWLR's internal clock has to be set to the proper time system, usually local time. The adjustment is done using a (portable) PC. Any error in the PC's clock will be copied to the AWLR. Therefore this it is important to set the PC clock accurately, prior to depart for a mission. If a timing error is introduced then it will stay constant which allows for time recovery assuming that the fault is detected at next service visit. Provided that the AWLR clock is checked every 1..3 months no significant timing errors are to be expected.

- **data logger errors:** no malfunctioning of the data logger or its associated electronics was experienced. This is consistent with experience of gained in other projects with similar equipment.

- **data loss:** data loss was experienced at several occasions. At one time the equipment was found smashed open and with the batteries removed. As a result the instrument stopped functioning and all recorded data were lost. Since 1996 an upgraded logger version is brought to market. In that version recorded data will be retained by an incorporated back-up battery, but the instrument will stop functioning without battery anyway.

  Unfortunately data were also lost due to improper procedures in handling the data. Some files were temporarily stored on floppy disk but not yet loaded in the data base. Due to a mishap, that floppy disk became inaccessible before data were loaded into the data base.

- **missing data:** data were not collected because of collapse of the supporting structure due to erosion or a collision with a country boat; due to the cutting of a cable to an acoustical sensor; due to a defective acoustical sensor.

8.3 Pressure sensor faults

Pressure sensors have deployed for stage and tide measurement for several decades. Modern pressure sensors are robust and quite accurate. Typical instrumental error causes are described hereafter, most were not experienced by the pressure sensors.

- **measuring errors:** no sensor based measuring errors were detected.

- **sensor malfunctioning:** no sensor malfunctioning was detected.

- **sedimentation:** in the post flood season at a few occasions and at separate sites heavy sedimentation took place, rising to more than 1 m above the level of the pressure sensor. It was observed that the sensor readings still could follow the water level changes, however, not accurately, more in a drifting way. Sedimentation is the main error cause for the pressure transducers. It should be closely monitored and anticipated on as soon as the sensor is likely to be covered.

- **flow effects:** no significant flow effects were detected.

The pressure sensors as such proved to be reliable instruments. However, three sensors were lost due to platform collapse.

8.4 Acoustical sensor faults

Field experience with acoustical sensors is limited as compared to the pressure sensor. However, development progresses steadily. Experiences gained under RSP are described in some detail here.

- **measuring errors:** the acoustical sensor proved to be the most susceptible to electrical interference on sensor electronics. In particular at low water, that is at the longest measuring range, the reflected acoustical signal is weakest and has to be amplified substantially. Recently an improvement on this was proposed to the manufacturer by DELFT HYDRAULICS.

- **sensor malfunctioning:** several sensors started malfunctioning, probably due to effects of nearby lightning strikes. For this the sensor requires an improved transient protection. In particular the relatively long cables involved are a hazard for over-voltage.

- **temperature effects:** at low water the measuring range is longest which makes the temperature effects largest. At low wind speeds, less than 1 m/s the ventilation of the temperature sensor's radiation shield is insufficient, furthermore stratification in the air layer closely above the water surface may even increase this effect.

- **heavy rainfall:** it was expected that during heavy rainfall the acoustical sensor might lose track of the water surface. However, no evidence has been found to support this.

- **handling of waves:** it is not entirely clear how the sensor handles signals reflected from wind induced surface (gravity) waves. Some experimental work in a coastal area revealed that the short waves, as they are found in a river environment do not significantly bias the level measurement.

- **velocity head:** upstream of the piers of the railway bridges a considerable velocity head was measured during the main flood events. This by comparing the staff gauge data with the AWLR data. The difference of both data types gives an approximation of the velocity head. At Hardinge bridge the detected head increased to about 0.5 m.

An upgraded version of the acoustical sensor is available now. It has some accuracy and reliability improving advantages, the temperature effect on the speed of sound is of a physical cause and has no solution yet.

(As mentioned earlier in this report the RADAR sensor is in the operational sense quite similar to the acoustical sensor. However, the measuring range is much larger, and there is no significant temperature effect.)

8.5 Errors common to staff gauge and AWLR

Some operational rather basic aspects affect both the staff gauge and the AWLR.

- **connection errors:** connection to a well chosen and properly established local bench mark can be done quite accurately. On steep banks it might be very laborious and requires a skilful levelling team. The weakest point is considered to be the connection to the staff gauges. For best accuracy the averaging method, as mentioned earlier in this report, will improve accuracy over a single staff gauge reading.

- **spatial errors:** often it is hard or impossible to find a nearby spot to shift a gauge to, it may be hundreds of metres up- or down-stream to an adequate spot. A slope related level change will be the result, and the representativity of the readings must be carefully assessed.

Comparing the staff gauge data with the AWLR time series it becomes clear that one of the main error sources is due to gauge shifting and subsequent sloppy connection to the local bench mark.

Obviously, where it comes to connection of the AWLRs to the local bench mark the same errors can be introduced. In this respect both systems behave similarly.

8.6 Error detectability

In Section 7.3, some aspects of error detection are covered.

The applied procedures revealed a great percentage of errors due to level shifts and reading/data entry errors. Such errors could be repaired by careful study of the station reports. Furthermore any significant inconsistency between the data originating form staff gauge and AWLR was uncovered. Sometimes it required a good understanding of the underlying hydraulics and physics to pinpoint the cause of inconsistency.

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9 Evaluation of the sustainability of the adopted AWLRs

Table 13 presents the operational periods of the water level stations. The AWLR stations are Gabgachi and the stations 2..11. At the AWLR stations staff gauges were operated simultaneously. Due to this combined operation data losses were small.

Based on the RSP experience, an evaluation of different gauging options were made, as summarised in Table 14. In this Table, the automatic float-well type gauge used by BWDB and BIWTA was also evaluated, based on information gathered from these two organizations. This was done for the sake of comparison and completeness. The evaluation is made on nine criteria which are: Reliability, platform stability, shifting, environment sensitivity, density of records, susceptibility to interruptions, time keeping, operation and maintenance, and price. A further screening on the sustainability of these options is made in *RSP Special Report 11: 'Optimization of hydraulic measurements'* (RSP, 1996).

	Station	River	Operation period	Station-months	Type
1	Kabilpur	Jamuna, at Bahadurabad, right channel	1/6/94 - 3/2/96	20.1	S
1	Shanki Bhangha		1/6/94 - 3/2/96	20.1	S
1	Gobindi		1/11 92 - 30/4/95	30.0	S
1	Gabgachi		15/7/93 - 31/5/96	33.5	A+P
1	Bhagir Char		1/6/94 - 31/12/95	19.0	S
1	North Kathiamari	Jamuna, at Bahadurabad, left channel	21/6/93 - 12/2/94 01/6/94 - 3/2/96	7.7 20.1	S
1	Char Parul		14/6/93 - 12/2/94	8.0	S
1	North Horindhara		1/6/94 - 4/2/96	18.3	S
1	Bahadurabad		6/6/93 -31/5/96	34.3	P
1	Belgacha		1/6/94 - 4/2/96	20.1	S
1	Thantania Para		16/6/93 - 11/2/94	7.9	S
2	Bhuyanpur/ Sirajganj	Jamuna	29/5/94 - 30/4/95 1/4 95 - 26/5 96	11.0 + 13.9	P
3	Aricha (Teota)		13/5/94 - 23/5/96	24.4	P
4	Hardinge Bridge	Ganges	21/7/94 - 31/5/96	22.3	A
5	Baruria	Padma	28/5/94 - 24/5/96	23.9	P
6	Mawa		10/5/94 - 30/5/96	24.7	P
7	Mymensingh	Old Brahmaputra	29/6/94 - 24/5/96	22.8	A
8	Tilly	Dhaleswhari	28/5/94 - 23/5/96	23.8	P
9	Gorai	Gorai	22/7/94 - 31/5/96	22.3	A
10	Arial Khan	Arial Khan	3/6/94 - 31/5/96	23.9	P
11	Bhairab Bazar	Upper Meghna	24/7/94 - 28/5/96	22.1	A
12	Mir Char		31/5/95 - 28/2/96	9.0	S

A: acoustic AWLR + 2 staff gauges, P: pressure cell AWLR + 2 staff gauges, S: staff gauge

Table 13: Operational periods of water level stations

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WATER-LEVEL GAUGING BY THE RSP – EVALUATION OF OPTIONS

Gauging	Reliability	1) Platform stability	Shifting	Environmental Sensitivity	Density of Records	Susceptibility to Interruptions	Time-keeping	Operation and Maintenance	4) Price (ECU)
Non-recording staff gauge	Not very reliable (dependent on gauge reader)	No platform, but supports are vulnerable to erosion	Can be shifted easily	Can work everywhere	Sparse day-time records	Very susceptible to interruptions	Dependent on gauge-reader watch	Hardly any maintenance except occasional shifting	100
5) Auto-pressure sensor and data-logger	Reliability proven	Vulnerable to platform failure	Platforms cannot be shifted easily	Vulnerable to siltation, humidity and air-vent failure	Desired dense digital records can be obtained	2) usually no interruptions occur	Reliable electronic clock	Needs battery changes and data offloading	4000
5) Auto-acoustic sensor and data-logger	Reliability proven	Vulnerable to platform failure	Platforms cannot be shifted easily	Vulnerable to temperature and humidity	Desired dense digital records can be obtained	2) usually no interruptions occur	Reliable electronic clock	Needs battery changes and data offloading	7000
3) Automatic float-well type	Reliable analogue data	Vulnerable to platform failure	Platforms cannot be shifted easily	Vulnerable to siltation of inlets	Continuous record (digitization necessary)	2) usually no interruptions occur	Reliable clock	Needs battery, paper and pen changes	3000

1) Use of a fixed structure in all cases can avoid the use of a platform
2) Unless there are failures of platforms batteries or electronics, there are no interruptions.
3) This type of is considered because BWDB and BIWTA use them.
4) This estimate does not include platform construction and installation costs; the RSP platform costs about 4000 ECU
5) Data can be transmitted on-line to the survey vessel by installing a transmitter at an additional cost.

Table 14: Evaluation of water level gauging options based on RSP experience

9.1 Staff gauges

The staff gauge is widely used, worldwide, often for reference purposes next to an automatic recording gauge. Relative advantages and disadvantages of it are discussed in Chapter 2. In Chapter 8, field experiences and fault causes were reported.

Main points in favour of the staff gauge are:

- The gauge can be cheaply and easily installed without *a priori* investigation or knowledge of the stream course;
- it can be easily shifted;
- it is easy to get a gauge reader; and
- the gauge needs hardly any maintenance.

Main points against the staff gauge:

- The staff gauge is operated by humans and as a consequence human error may filter into the data. To be mentioned are incorrect reading and annotation, shift errors, interruptions and time-keeping errors (dependent on gauge-reader watch); and
- reading during bad weather and/or night time is difficult and not attractive.

The staff gauge will continue to be used as an independent unit and as a support to an automatic gauge.

9.2 AWLR stations

Under RSP a number of AWLR automatic water level recorders were implemented. The data loggers proved to be reliable: no data logger failed due to a defect. Main advantages are:

- Continuous data collection, during day time and night time, in digital, computer accessible format;
- the data collection rate can be adjusted to specific applications and conditions. Applications in tidal areas require a relatively short data collection interval. Also to monitor quick stage changes a short data collection interval is required;
- A software wave attenuation filter can be included, as a consequence no stilling well is required; and
- readings are taken timely and objectively.

RSP systematised the design of the AWLR platforms for the first time in Bangladesh. Designs in other forms were used previously by BIWTA and BWDB, but are not completely documented.

The success of the platform designed by RSP is mixed. Most platforms are still standing, while some have collapsed. The reasons of platform and/or AWLR failure are evaluated to be:

- **navigation hazards:** During high river stage, motorised and sailing country boats follow a navigation route close to the river-bank. These boats are hardly equipped with (adequate) navigational aids. Therefore, the platforms which are most often located near the bank, are vulnerable to vessel impacts, especially during the night. Our experience shows that this is a major factor of failure;

- **morphological development:** Scour or siltation, are important factors. In the short period of observation, primarily between 1994 and 1995, the morphological factor did not play a major role in the collapsing of structures. Only the tower at Bhuyanpur appeared to have collapsed due to scour (Figure 58);
- **construction defects:** Experience shows that construction defects (or a fraudulent construction) can lead to the failure. For example, it was observed that it was difficult to connect two pipes (the full thread should be covered in the joint), which lead to the failure (such as shown in Figure 59). However, in all the cases, the impacts of boats triggered the failure;
- **molestation:** Vandalism and theft caused data loss, no instruments were damaged beyond repair or stolen;
- **inaccurate data handling:** Data were lost due to diskette failure in combination with poor compliance of formal data handling procedures; and
- **maintenance failure:** The AWLR, the sensor and the supporting structure require maintenance, including change of consumables such as batteries.

9.3 Pressure and acoustic sensors

The mode of observations by the two sensors is an improvement as compared with the float-well type system, the main reason being their direct compliance with modern digital computing. With a good operation and maintenance programme, and a trained staff, the sensor performance was found to be satisfactory. Figures 59 to 62 show the comparison of raw data between different sensors, and also the staff gauge. As with earlier examples, the agreement is good between the sensors and the staff gauge.

For best results, the sensors have to be installed according to a well designed scheme, taking the local conditions into account. In particular flow effects and possible sedimentation as well as erosion have to be evaluated prior to installation. The pressure sensor has best accuracy but has to be installed submerged which makes it difficult to access in case of failure or for maintenance purposes. This especially during the monsoon when water levels are elevated. The acoustic sensor has the advantage to be accessible as it is installed above the water surface. Furthermore it measures to the water surface which makes the sensor insusceptible to velocity and sedimentation effects.

However, the location of measurement is to be selected with care, e.g. the flow effects around bridge piers may degrade accuracy. Errors in the measurement of air-temperature result in range errors. This may in particular occur at low water levels and during stratification of the air-mass between water surface and sensor. Investment costs for pressure- and acoustic sensors are comparable. From the operational point of view the acoustic sensors have an advantage.

It is expected that future developments will improve accuracy and reliability of acoustic sensors. Radar sensors give a better performance, both in accuracy and range, at higher investment costs and a much larger power consumption.

9.4 Strategy for the future

Under conditions as prevailing in Bangladesh, at each station, staff gauges should be operated in any case, irrespective of the presence of other systems. Automatic systems are added only if special demands must be met, as the operation of an automatic water level recorder is considerably more costly than of staff gauges only. In tide-affected areas and at other locations where water levels can change rapidly, i.e. were accurate time-keeping is required, automatic recorders should be applied. Also when data have to be collected continuously (for real-time monitoring), or when a high reliability is required, automatic recorders are to be considered.

However, also the reliability of automatic recorders depends on proper maintenance and a well-designed supporting structure at the right place. For operation of automatic water level recorders, properly trained and dedicated staff is required, as well as suitable equipment for servicing and operation. If sensors have to be installed at bridges and other permanent structures, then the acoustic sensor has a preference over the pressure sensor.

As experienced under RSP operation of space frame platforms is possible but at a considerable risk of collapse. Given the dynamic behaviour of the Bangladesh rivers this problem will not be solved cost effectively in the near future. Alternatively, at stations exhibiting a high risk of collision, installation of the pressure sensor at some height above the river bed, with the sensor cable running to the shore, might be considered. Instead of the precise, but costly sensor a bubble gauge tube might be considered. Both alternatives exhibit a higher risk of sensor loss due to sedimentation or severe erosion at the advantage of a lower risk of loss of the electronics unit.

In many applications there is no need for real-time operation. Then a less powerful AWLR, lacking real-time communication facilities, can be considered. As mentioned in Section 2.2.3, recently such units came commercially available at relatively low investment costs. In particular the new Ott bubble gauge is of interest. Another advantage of these units is their small size.

The staff gauging methodology, in particular the adaptation to changing river level by shifting the staff gauges, proved under RSP to be rather effective. This very methodology might be enhanced by adding a low cost AWLR to the staff gauge supporting tripod. Obviously there is the risk of loss of data and the AWLR. This risk can be reduced by installing the electronics unit at a nearby safer place with only the bubble tube immersed, possibly attached to a staff gauge structure. The staff gauge readings and the AWLR recordings are no longer independent of each other which is a disadvantage of the method.

The demands on the gauge reader have to be increased, more training is required and the shifting has to be executed more meticulously. Additionally to that, each shift has to be followed by a levelling session. The tripod staff gauge support may require a redesign for easy handling and stable operation. It is recommended to consider this combined staff gauge-AWLR approach for future deployments and to make a careful design of its implementation and operation.

A future gauging strategy can take the following shape:

- Use staff gauges with thoroughly trained gauge readers at stations where water level changes slowly. Monitor the performance of the readers and give feed back if required;
- implement well designed gauge shifting procedures and frequent levelling to a bench mark;

- for real time operation and at stations exhibiting quick level changes AWLRs can give the required performance;
- yearly refurbishment of AWLRs and the associated supporting structure is preferably executed during periods of low stage. Then the equipment is best accessible and flow velocity is lowest. During a maintenance period staff gauge reading is to be continued;
- AWLR data collection is supplemented or supported by manual staff gauge reading;
- in particular at unstable river sites implementation of low-cost, but accurate, AWLRs on staff gauge tripods might be considered as an alternative for the large AWLR supporting structures;
- frequent field visits, quality checks and data validation should be routine exercise;
- In the office, tight data handling and validation procedures are to be maintained.

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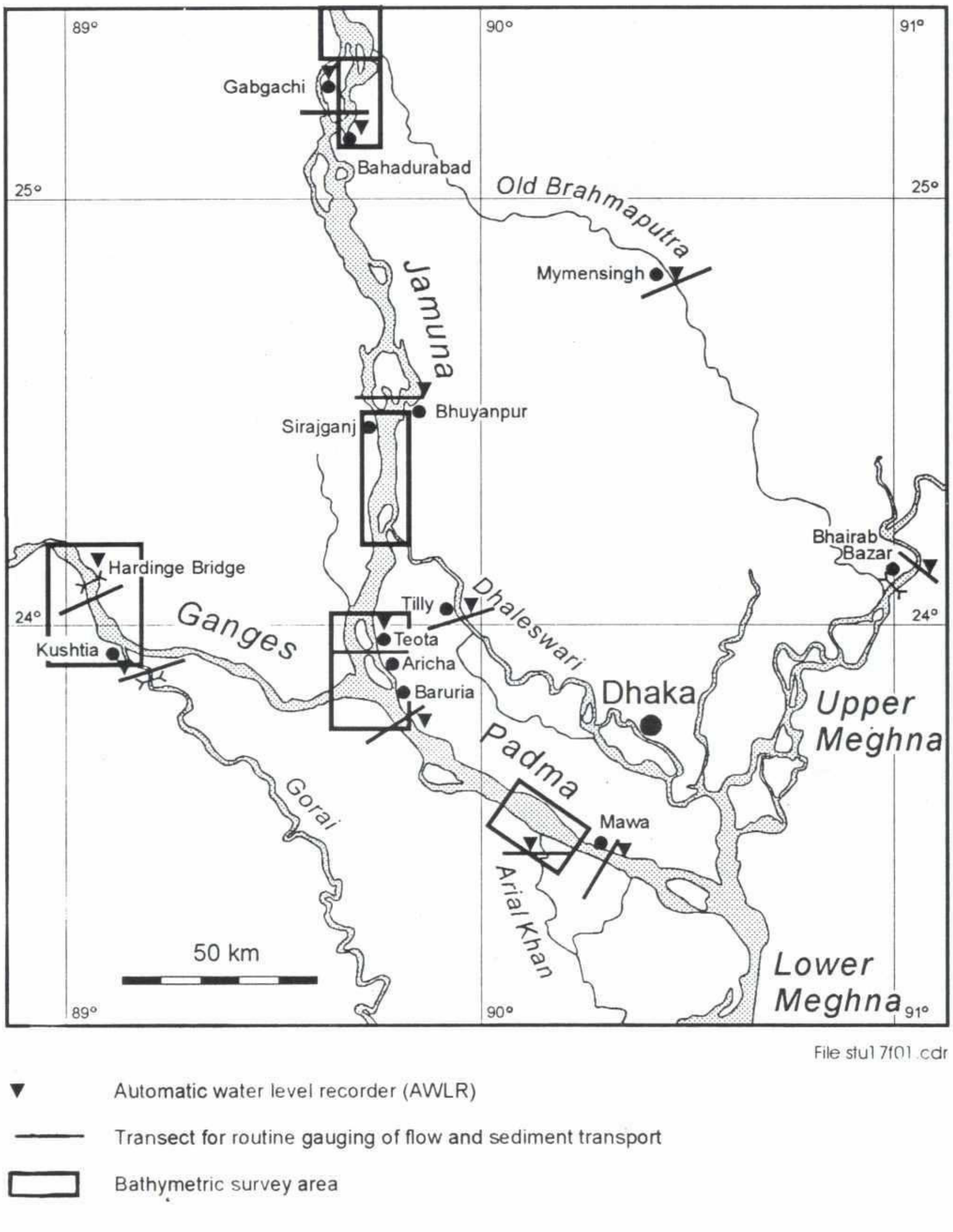


Figure 1: Bangladesh river system with RSP measuring sites

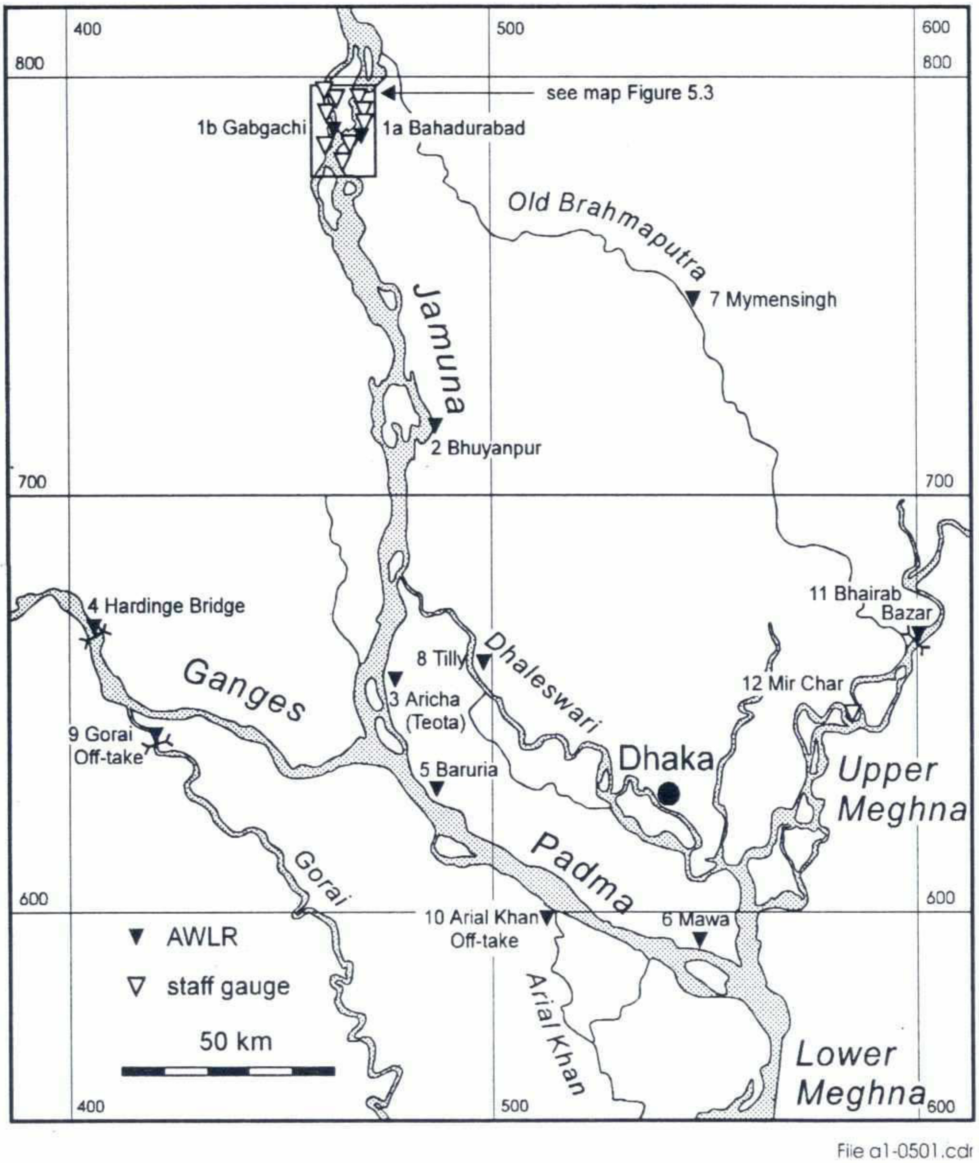


Figure 2: General sites of water level gauges

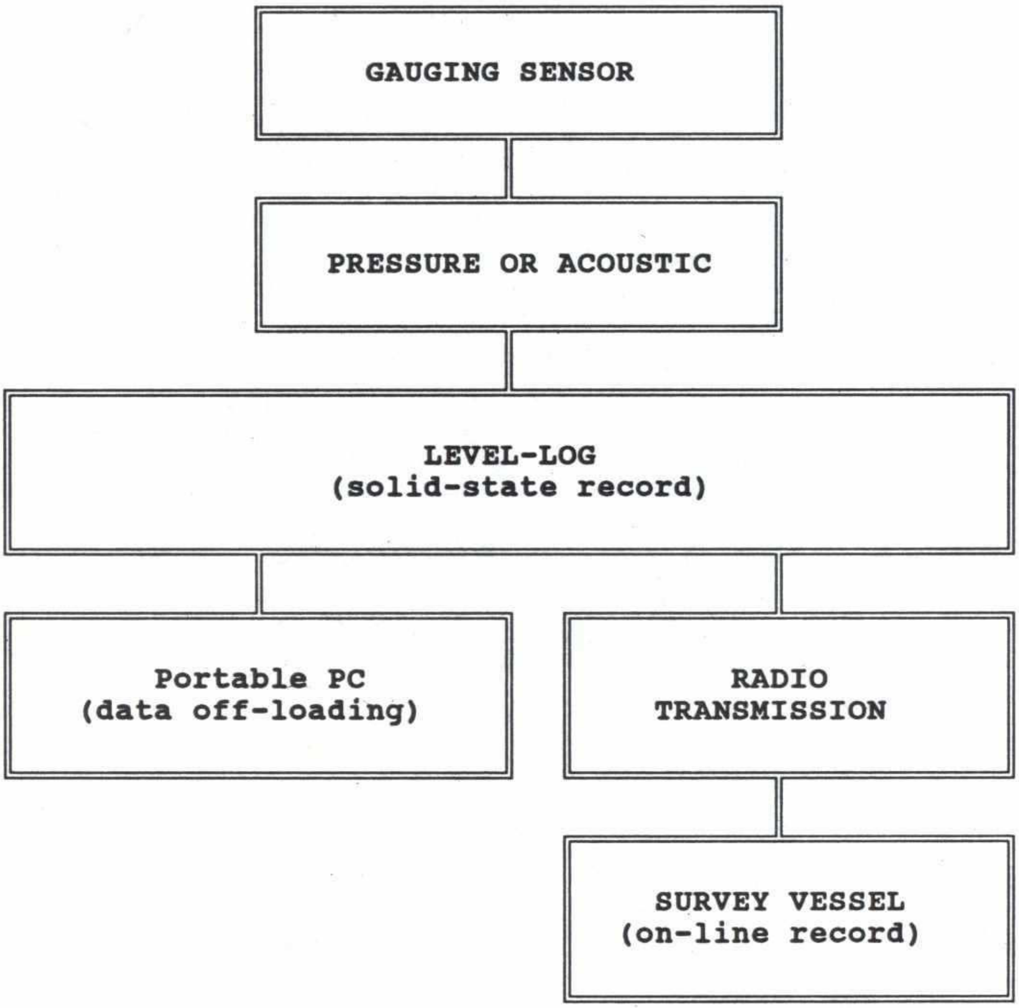


Figure 3: Mode of operation and flow chart of a recording gauge with pressure sensor or acoustic sensor, a data-logger system, and a transmitter

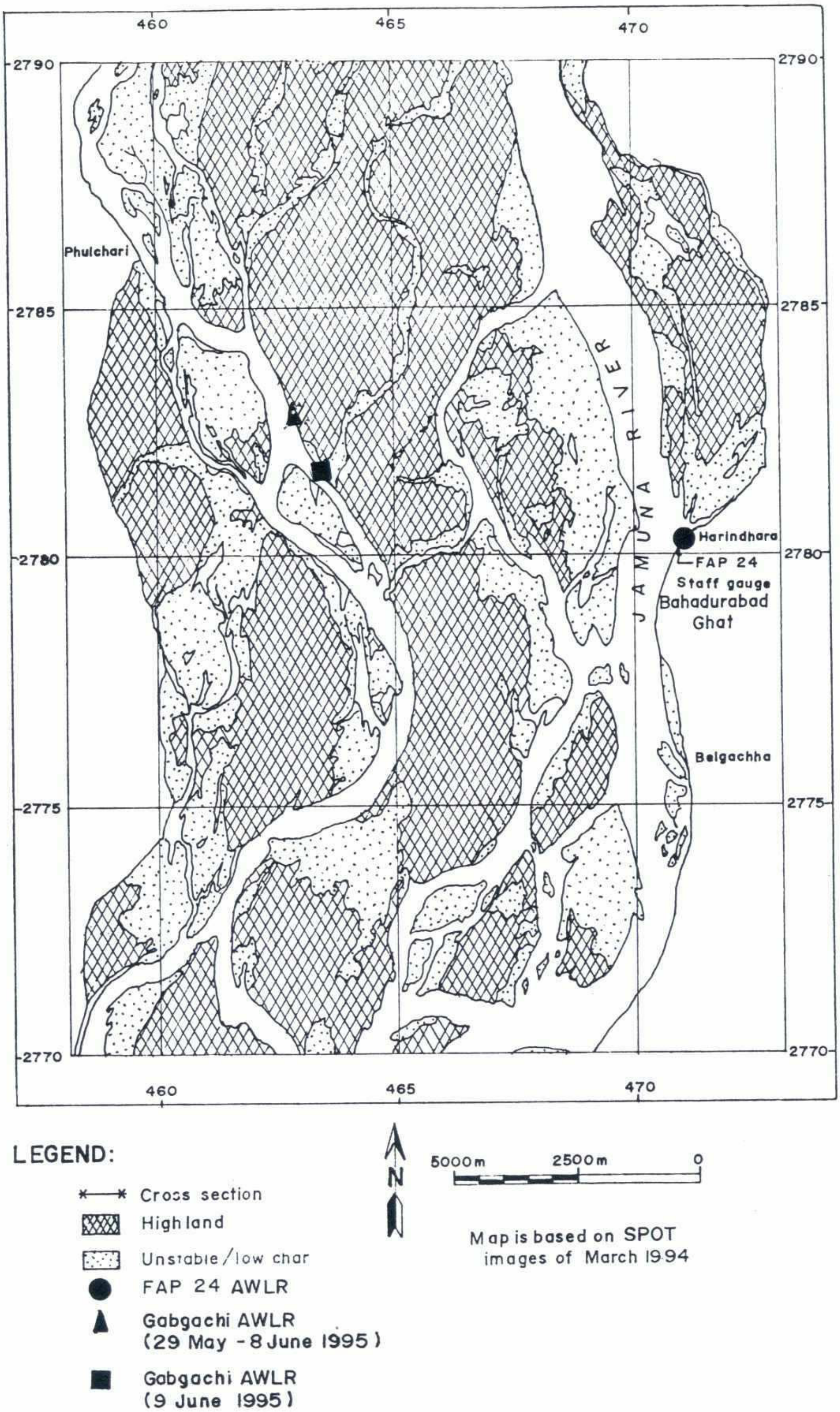


Figure 4: Jamuna River near Bahadurabad water level gauging sites at Bahadurabad and Gabgachi

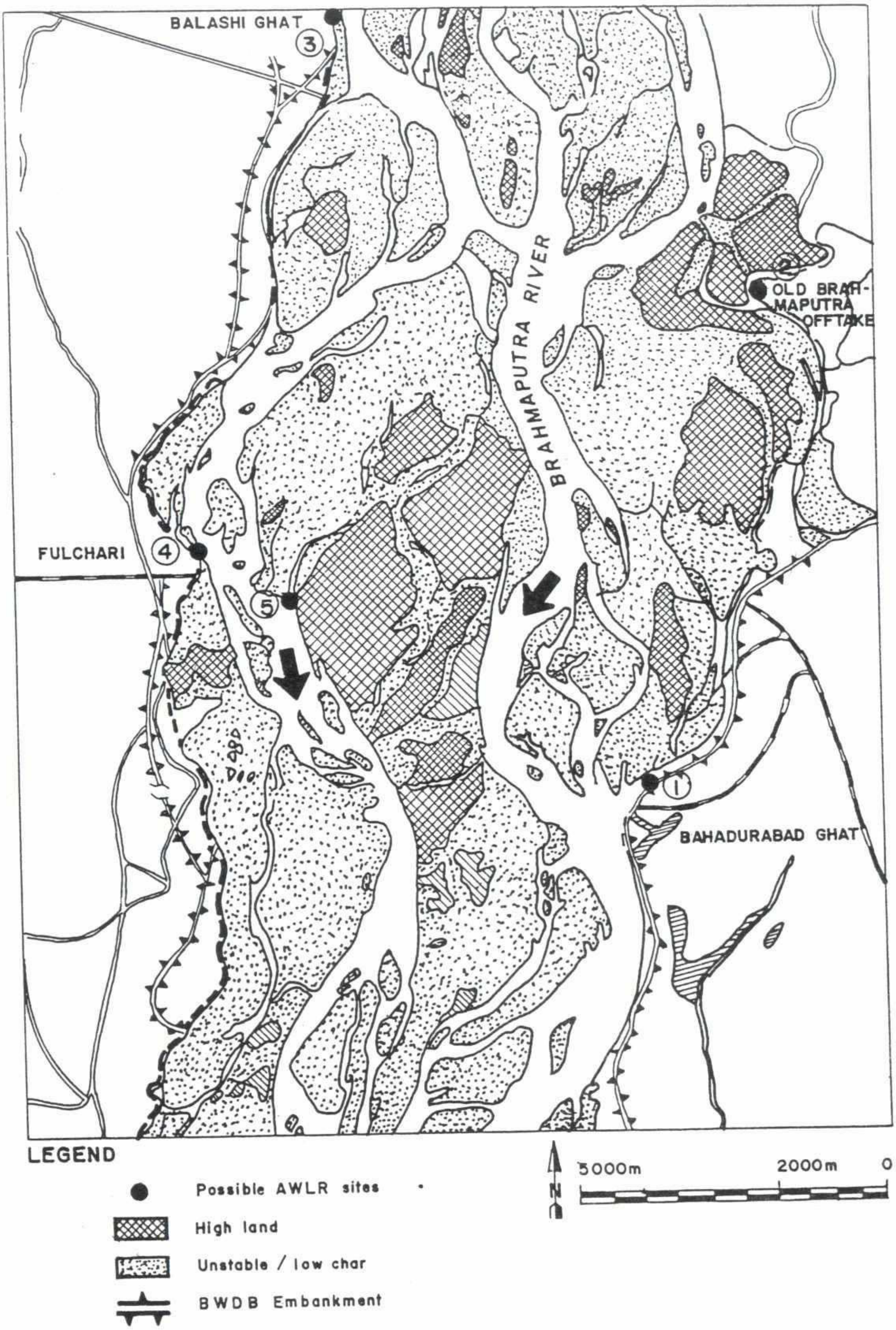
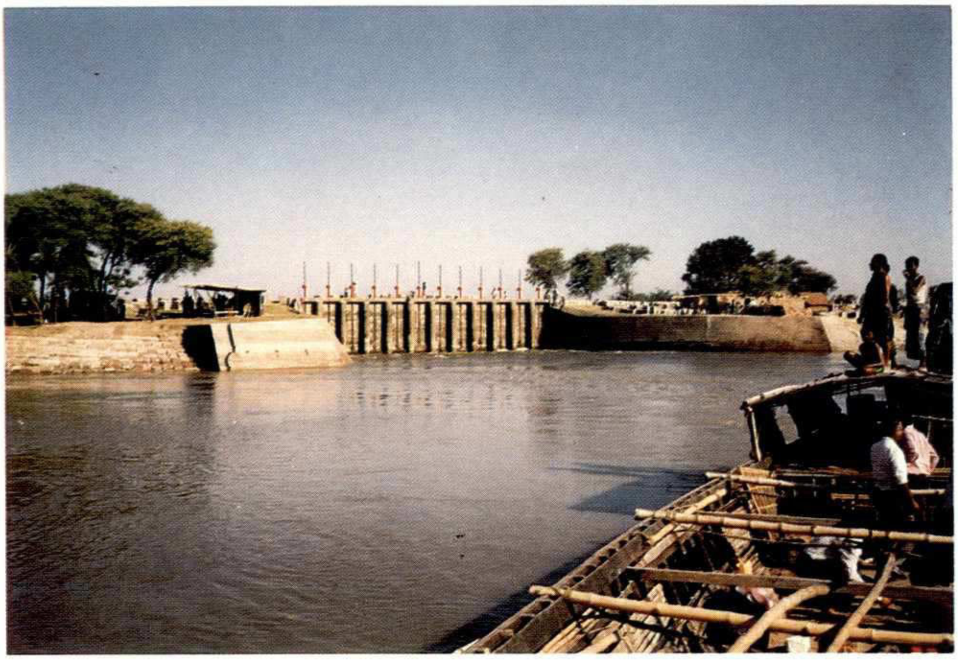


Figure 5: Five possible sites near Bahadurabad–Fulchari discharge transect. 1. near Bahadurabad railway jetty. 2. Offtake of the Old Brahmaputra River. 3. Manos regulator, 4. Fulchari railway ghat. 5. Gabgachi site



a. Manos regulator

b. Wing wall of Manos regulator and Balashi ghat (looking downstream)

Figure 6: Manos regulator photograph at Balashi ghat-a possible site for installation of AWLR

a. Slightly eroding bankline and char

b. BWDB staff gauge and sugar cane field

Figure 7: Photograph of Bahadurabad gauge site

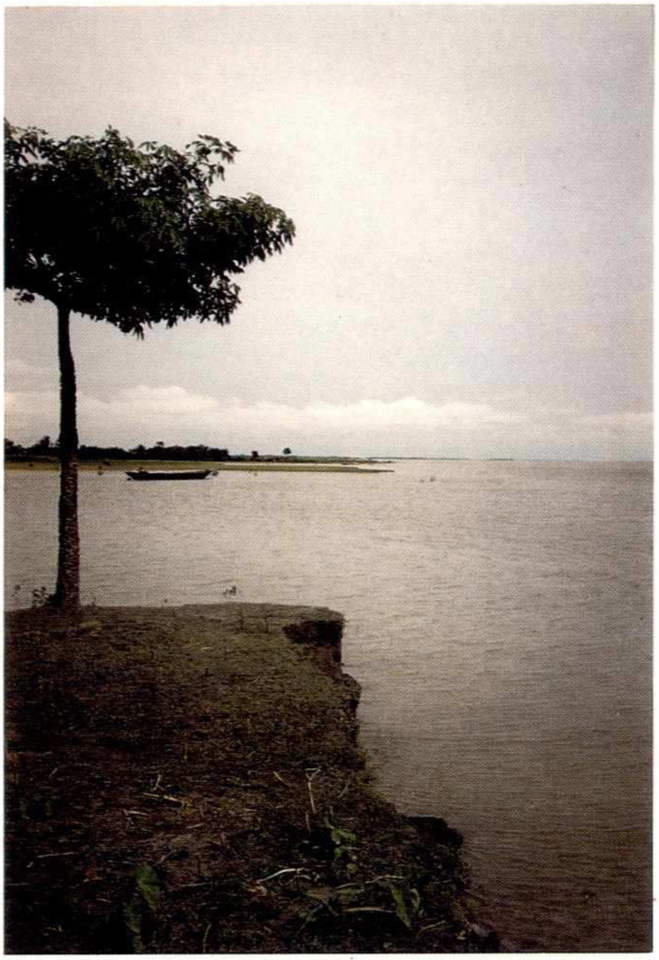


Figure 8: Photograph of Gabgachi gauge site - the slightly eroding bankline and the channel mouth

Figure 9: Photograph of a platform built on a new site at Gabgachi

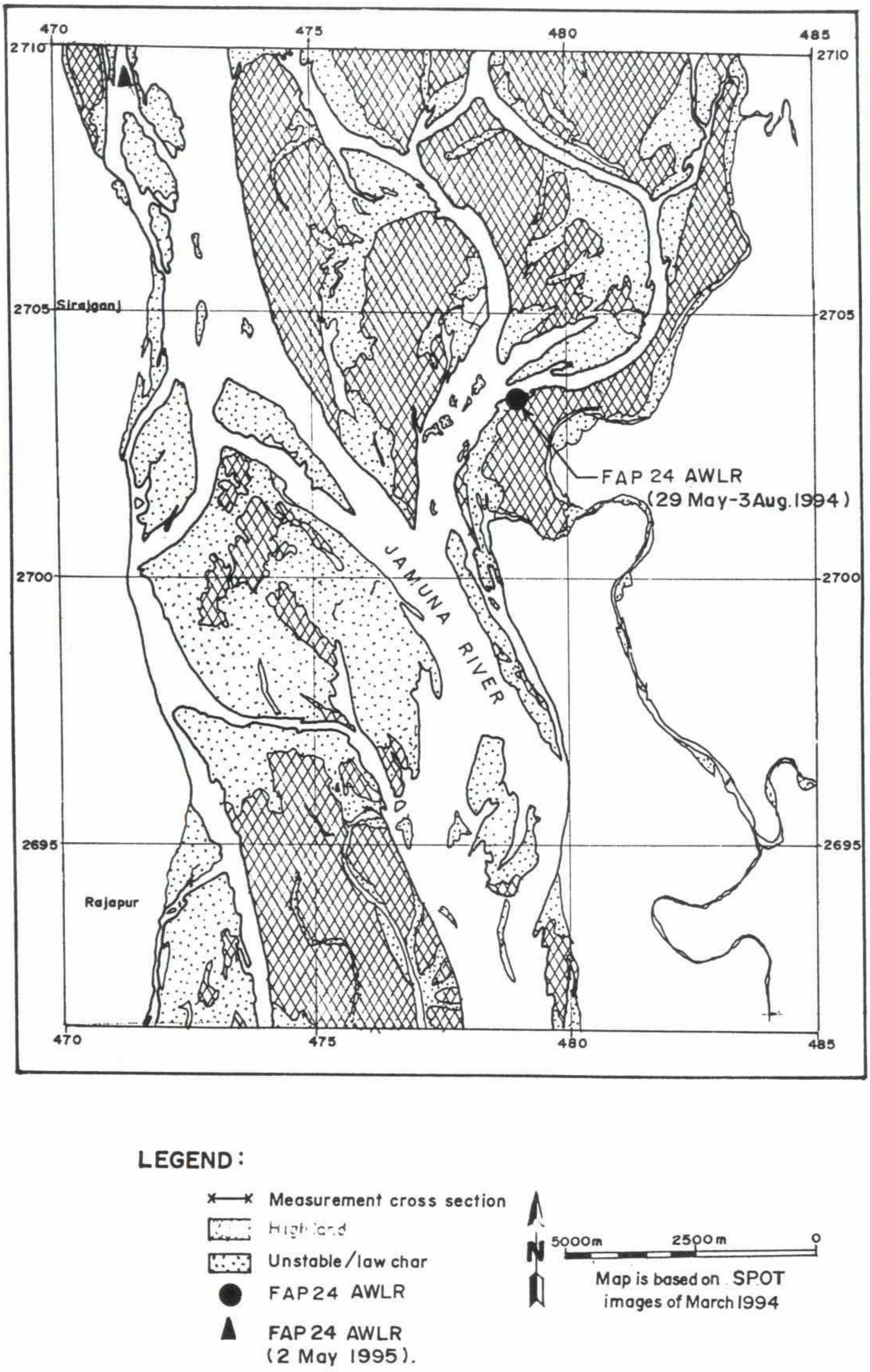


Figure 10: Gauge sites in the Jamuna River at the Sirajganj-Bhuapur location

Figure 11: Bank-protection works at Sirajganj - an apparent stable bank appears suitable to erect a tower but vulnerable to heavy current

Figure 12: Photograph of a platform built at the new Sirajganj gauge site

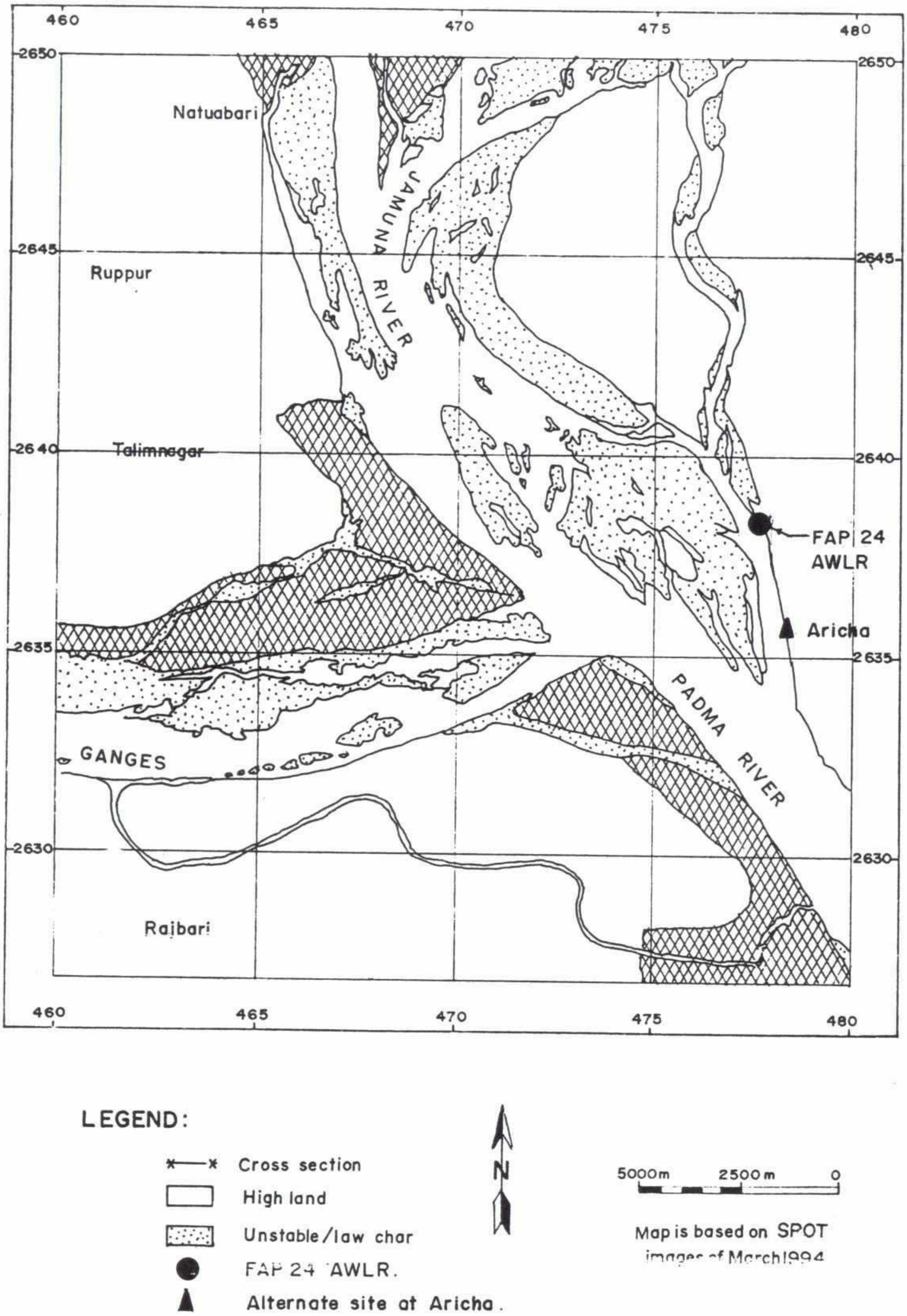


Figure 13: Gauge sites at Aricha-Teota in the Jamuna River

Figure 14: High-tension power line at Aricha - a possible platform to mount an AWLR

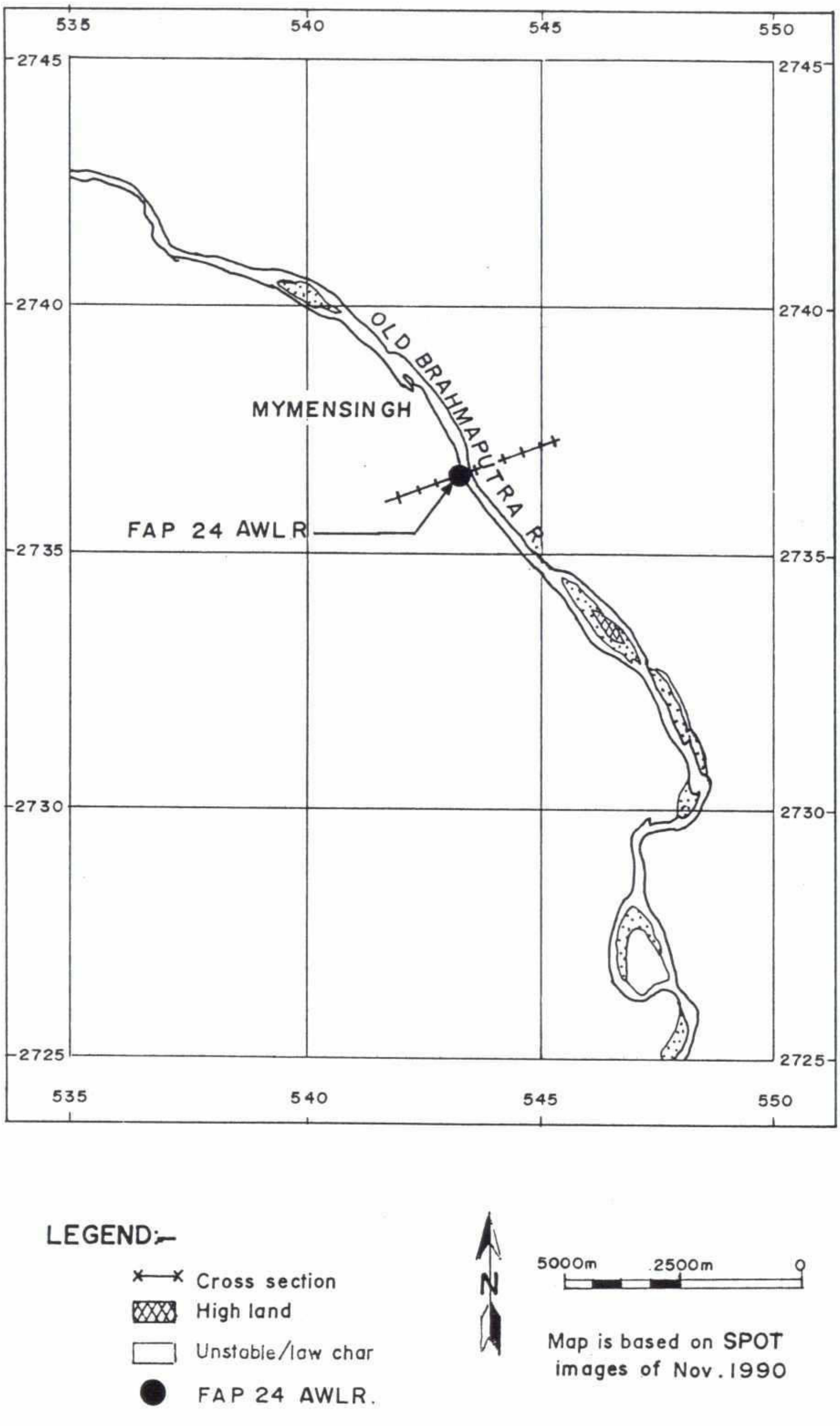
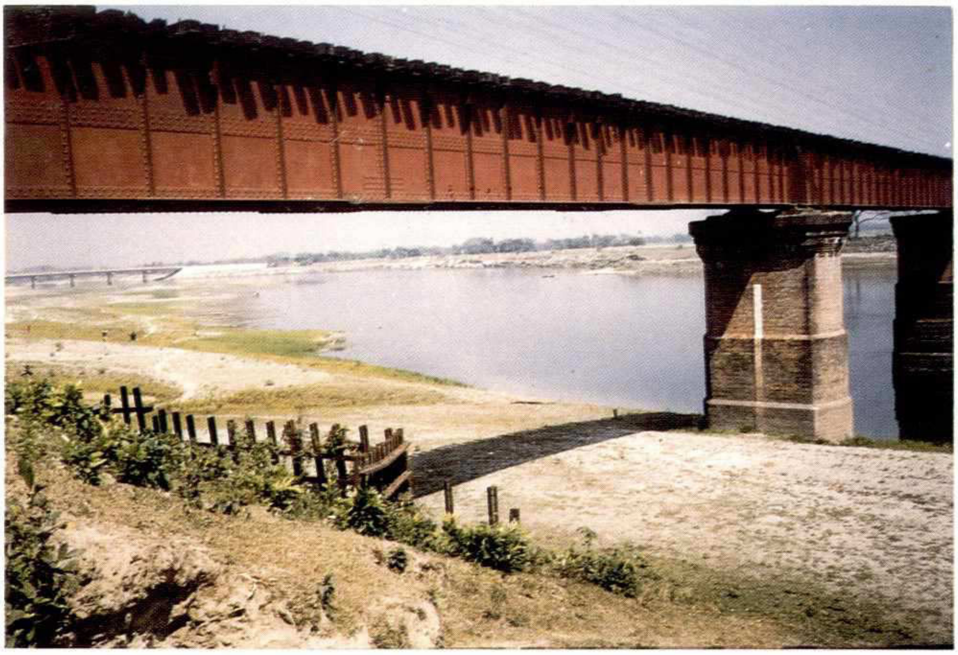
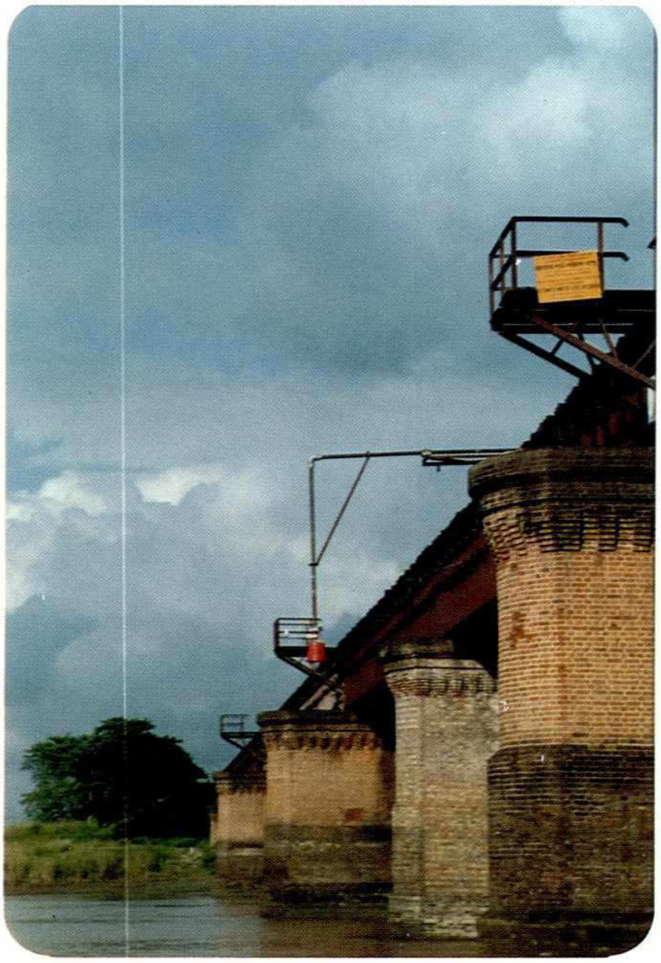


Figure 15: Old Brahmaputra River and Mymensingh railway Bridge



a. The bridge section on the right bank



b. Mounted acoustic type AWLR on one of the piers of Mymensingh Railway Bridge

Figure 16: Photographs of Mymensingh Railway Bridge

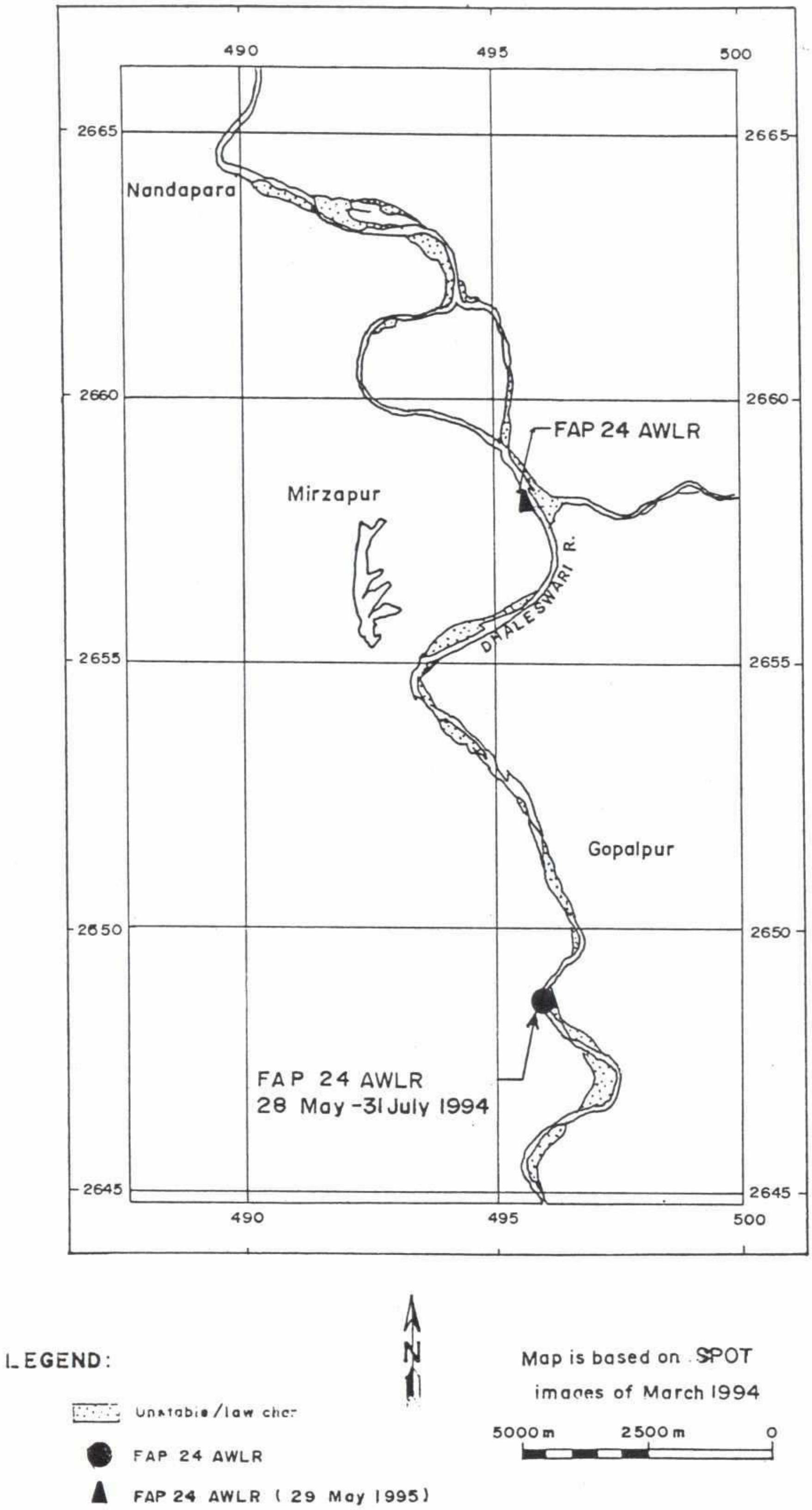


Figure 17: Gauge sites in the Dhaleswari River at Tilly

a. Gauging site 1 showing the BWDB staff gauge

b. Gauging site 2 showing the newly erected platform

Figure 18: Photographs of gauge sites at Tilly

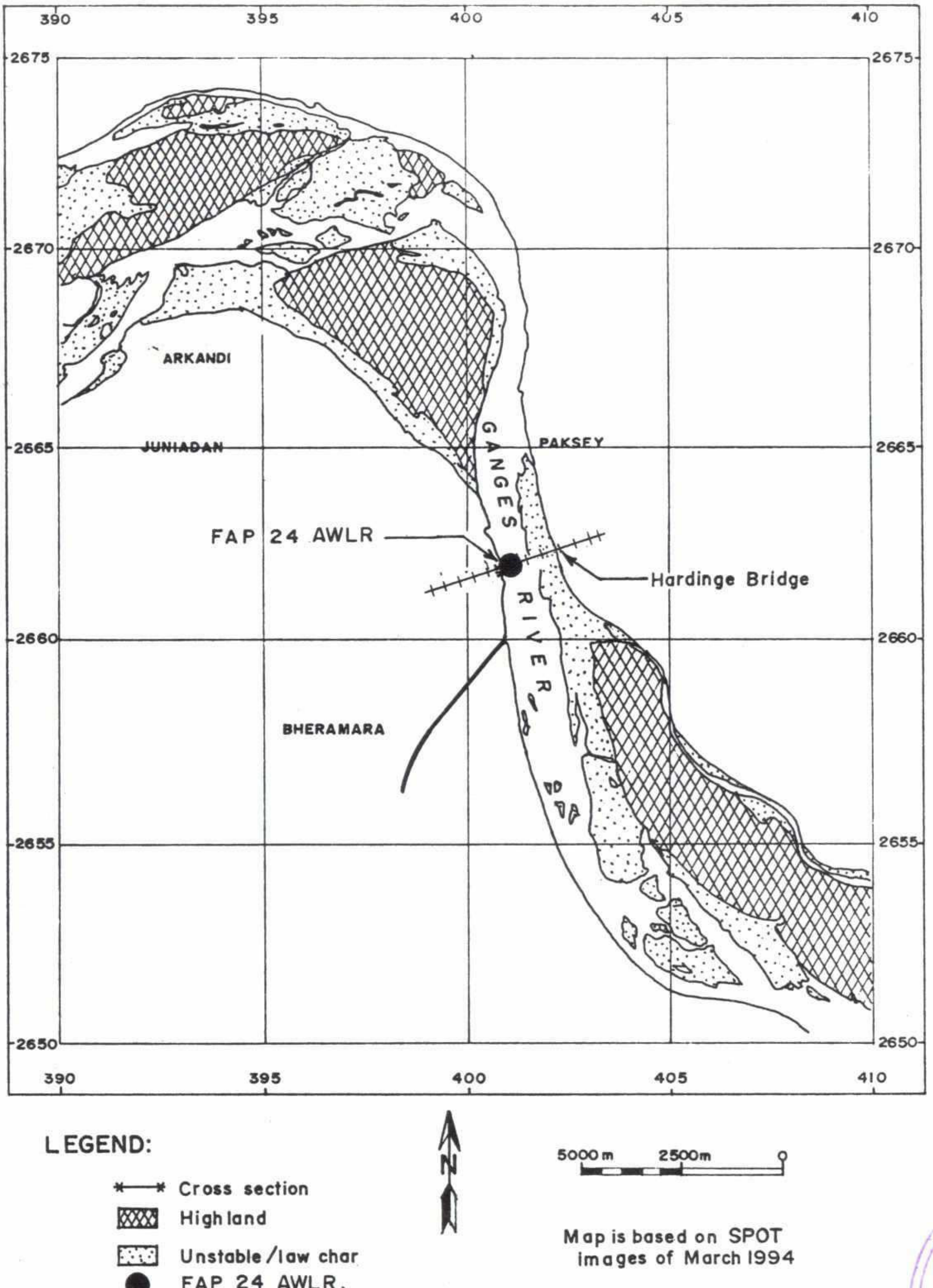
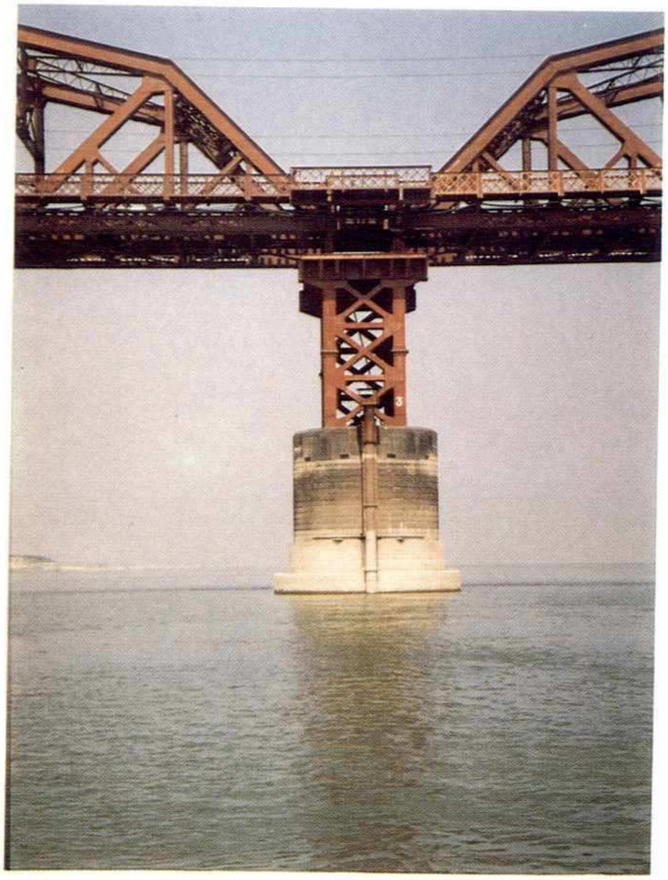
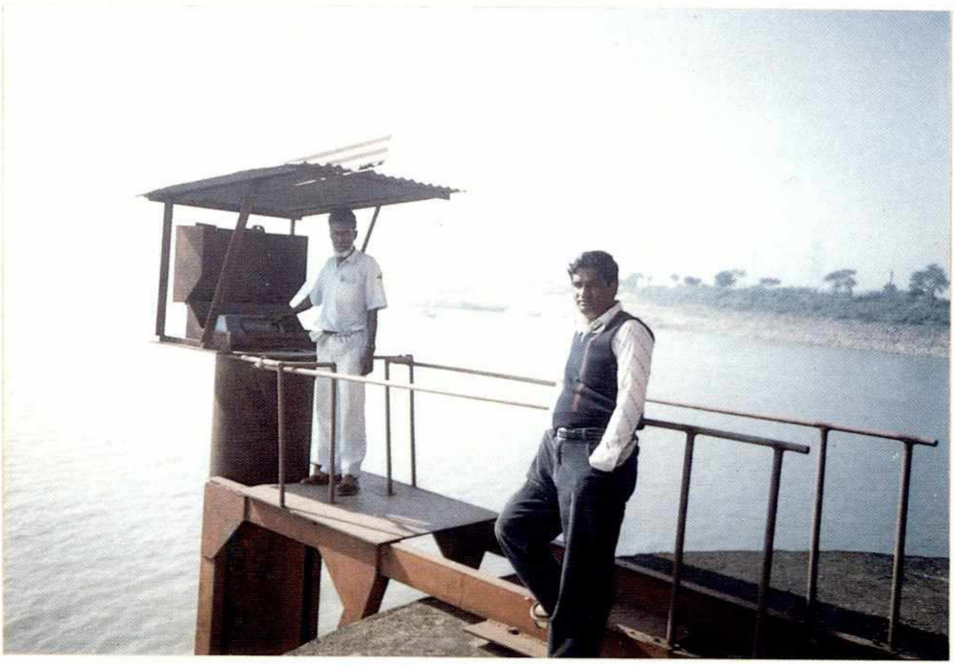


Figure 19: Gauging site in the Ganges River at Hardinge Bridge



a. Bridge pier showing the BWDB float-well AWLR



b. Pier-top construction of the BWDB AWLR

Figure 20: Photographs showing the Hardinge Bridge

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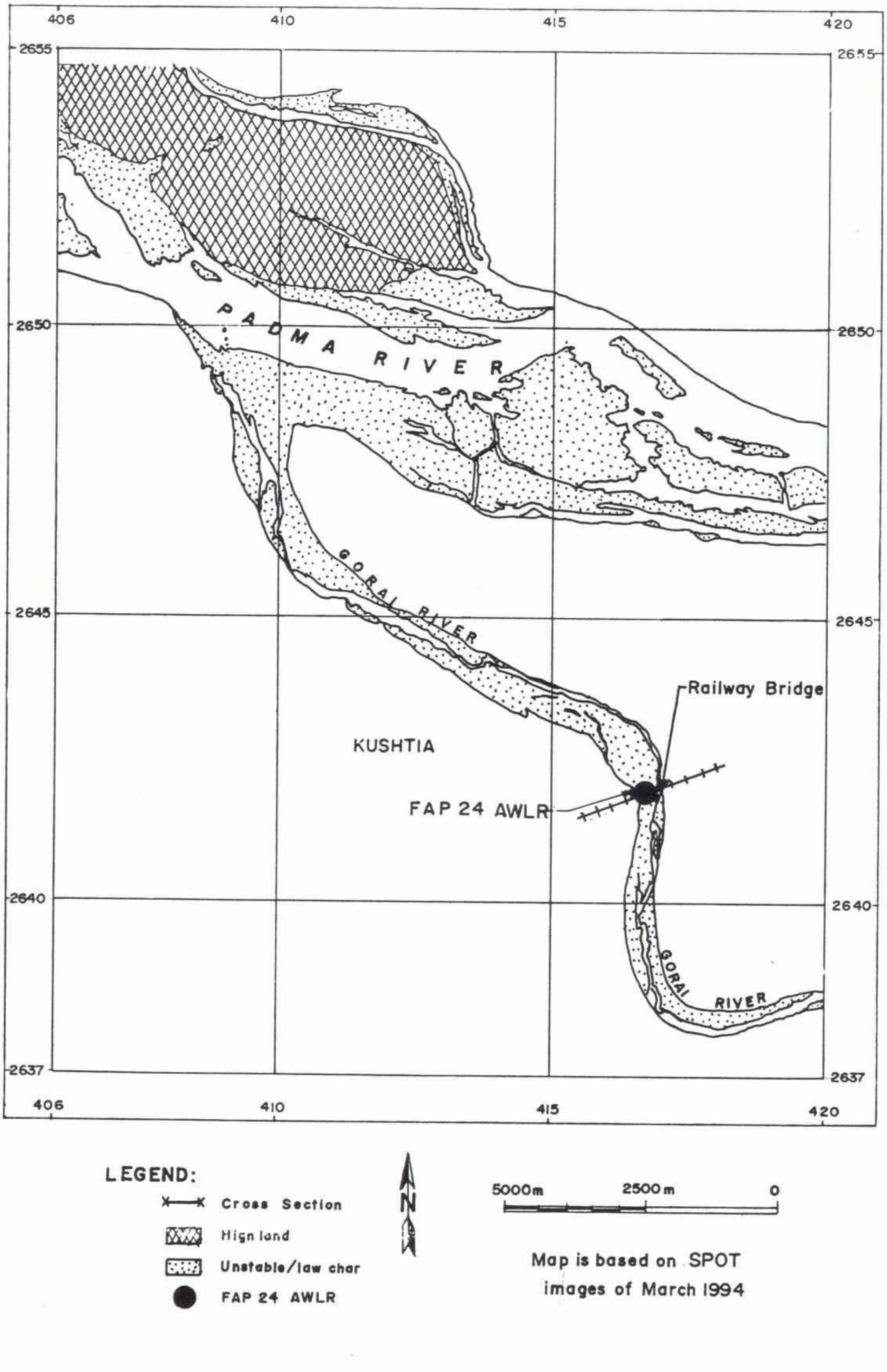

Figure 21: AWLR site in the Gorai River at Kushtia Railway Bridge

96

a. The dried Gorai River and the Railway Bridge

b. The AWLR site in one of the bridge pier

Figure 22: Photographs of Gorai Railway Bridge

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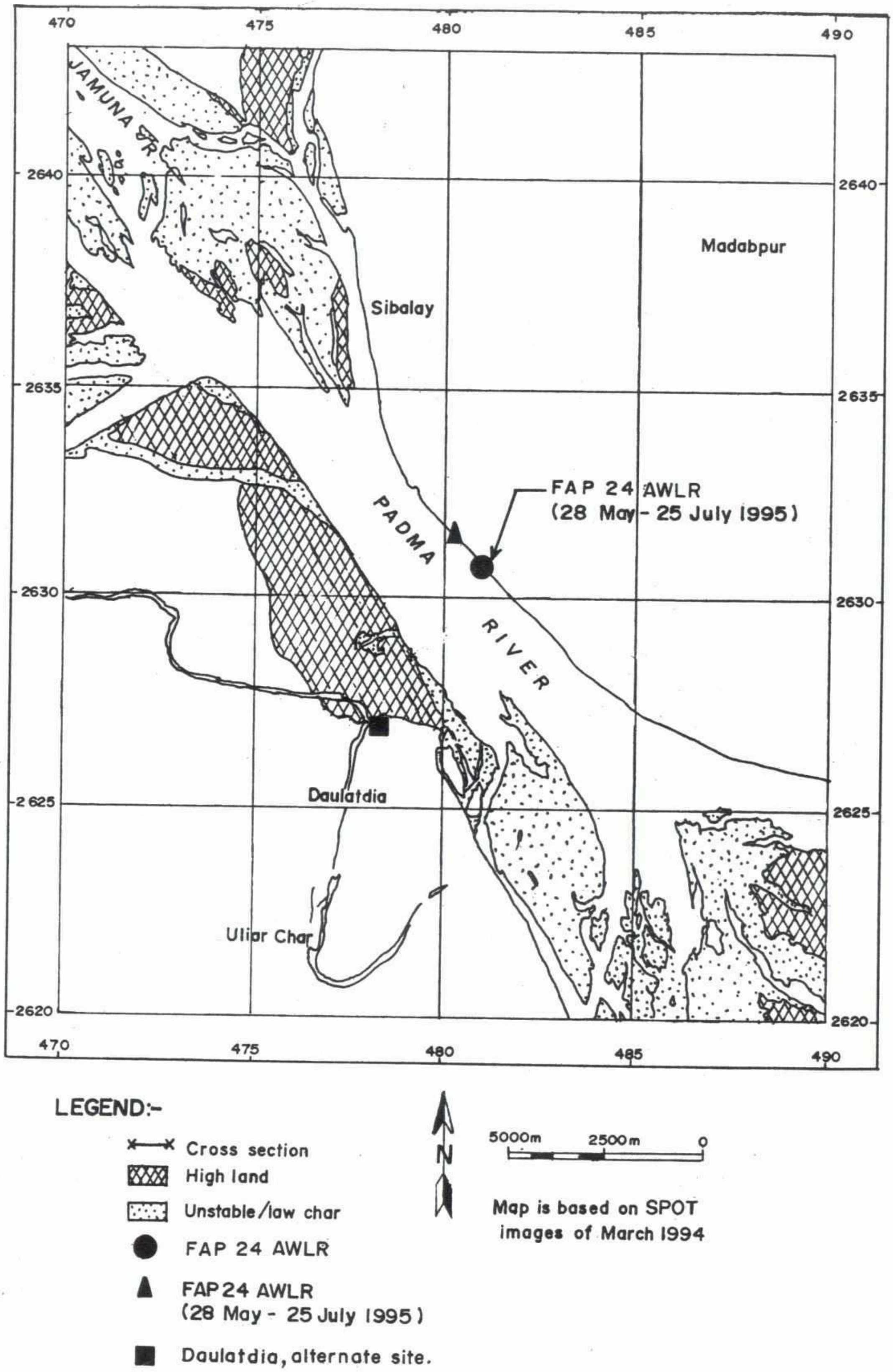


Figure 23: Baruria Gauge sites on the Padma River

a. The harbour and the Ferry terminal at Daulatdia

b. A Ferry plying through a dredged channel

Figure 24: Photographs of Daulatdia sites on Padma River right bank

a. The BWDB gauge near which the earlier gauge was installed

b. The present Baruria Gauge site

Figure 25: Photographs of Baruria gauge sites in the Padma River left bank

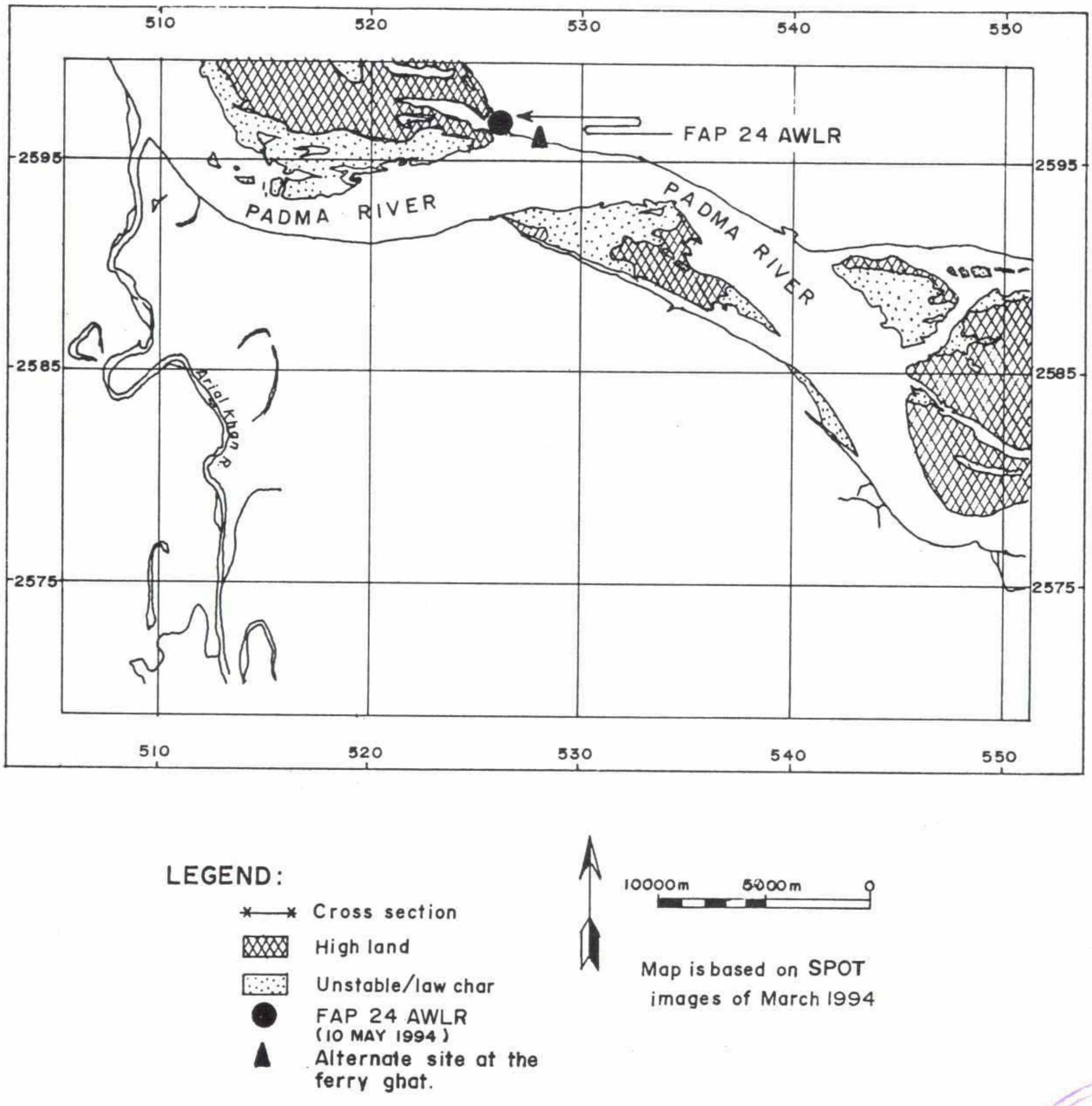


Figure 26: The Mawa gauge sites on the Padma River left bank

Figure 27: The Mawa AWLR is being constructed

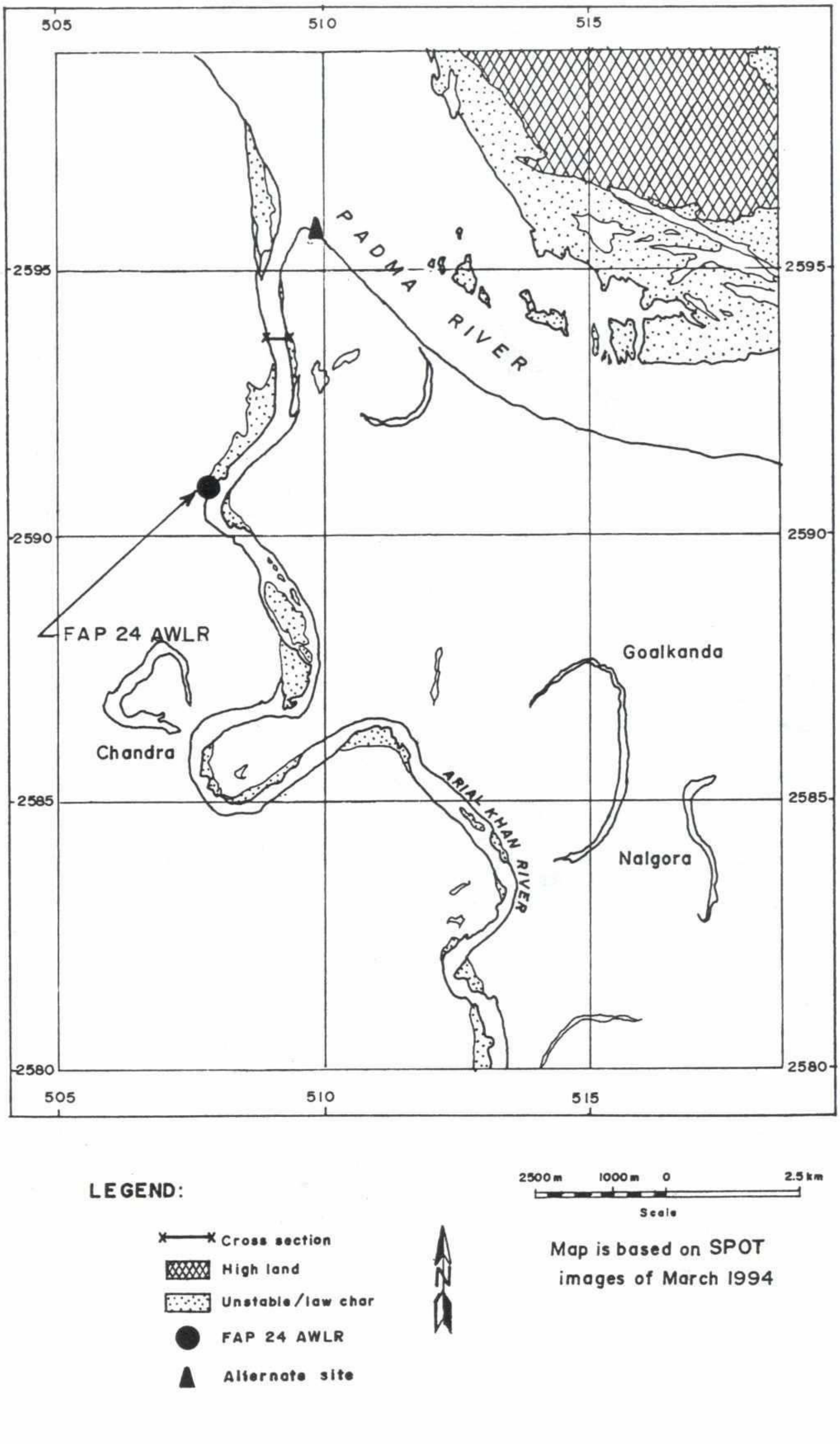


Figure 28: The gauging sites in the Arial Khan River

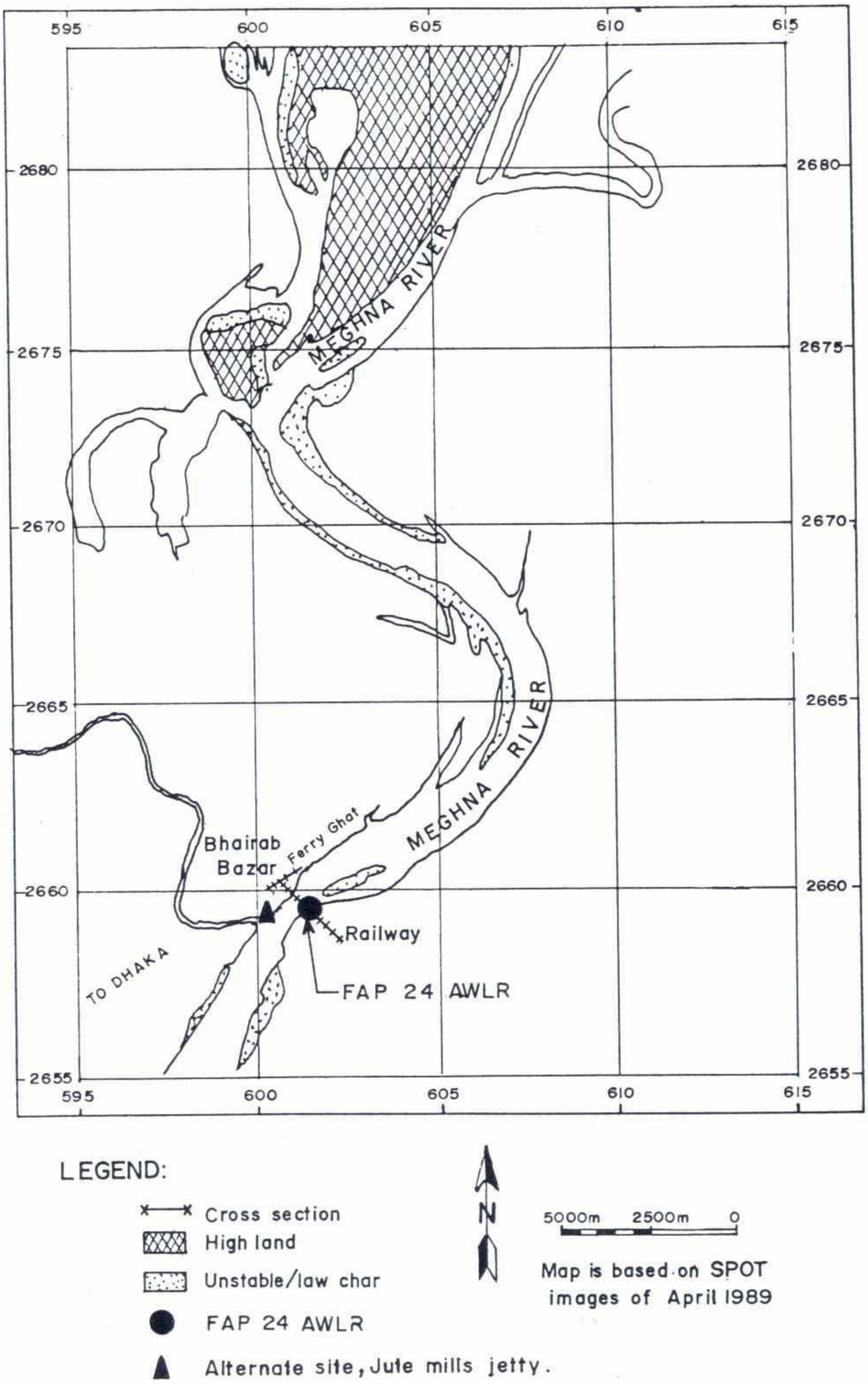
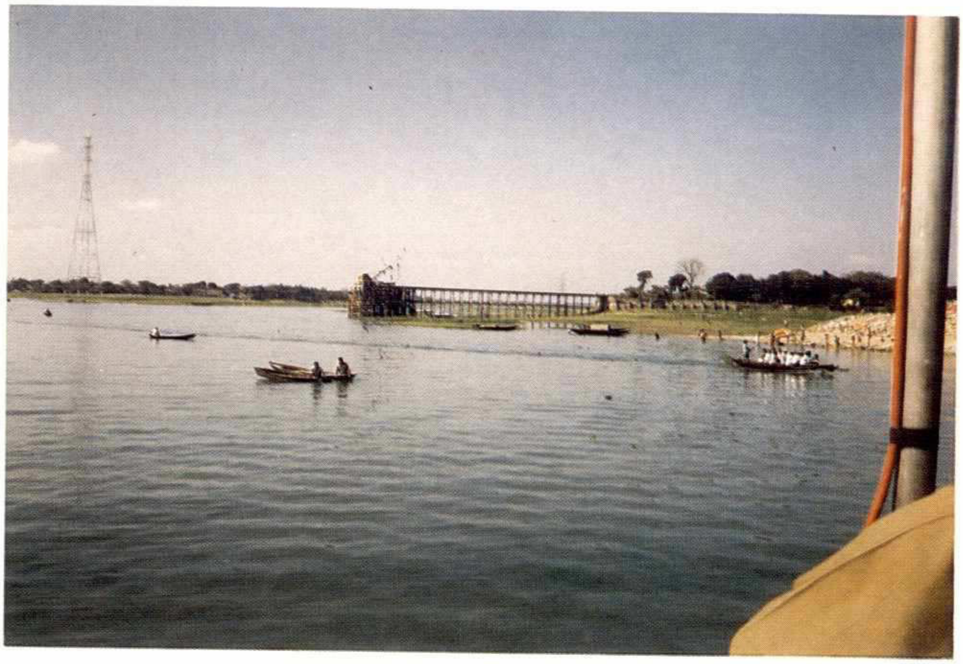
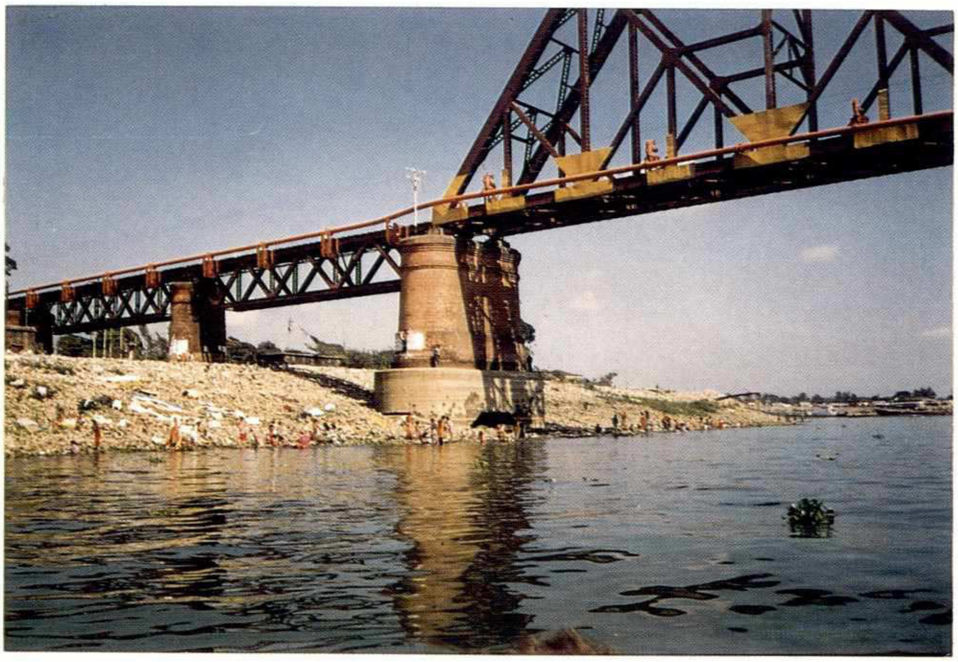


Figure 29: The gauging site at the Bhairab Bazar Railway Bridge on the Upper Meghna River



a. The jute-mills jetty near the confluence of the Old Brahmaputra River



b. The Bhairab Bazar Railway Bridge

Figure 30: Photographs of gauging sites at Bhairab Bazar

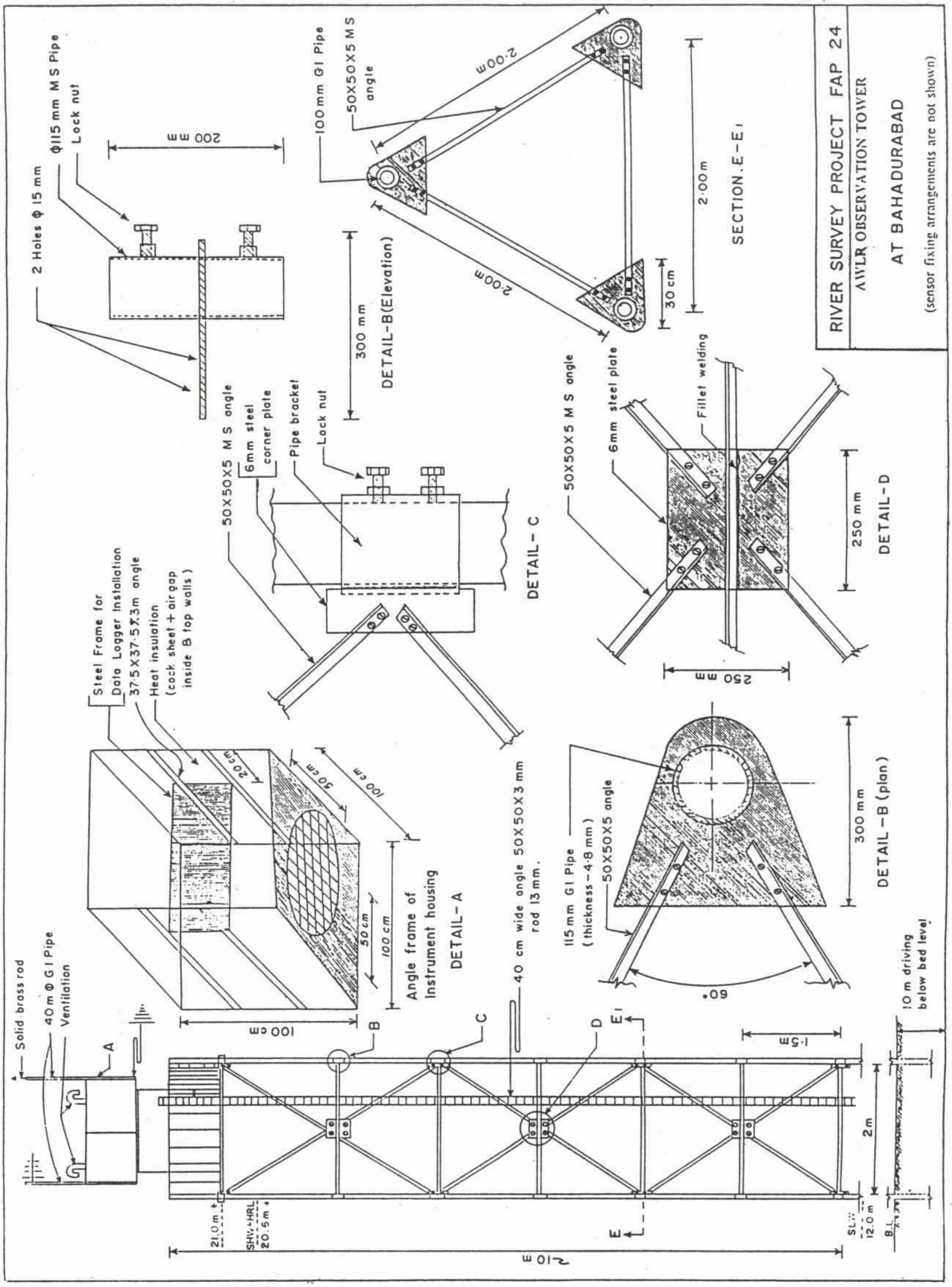


Figure 31: The design elements of the AWLR platform at Bahadurabad

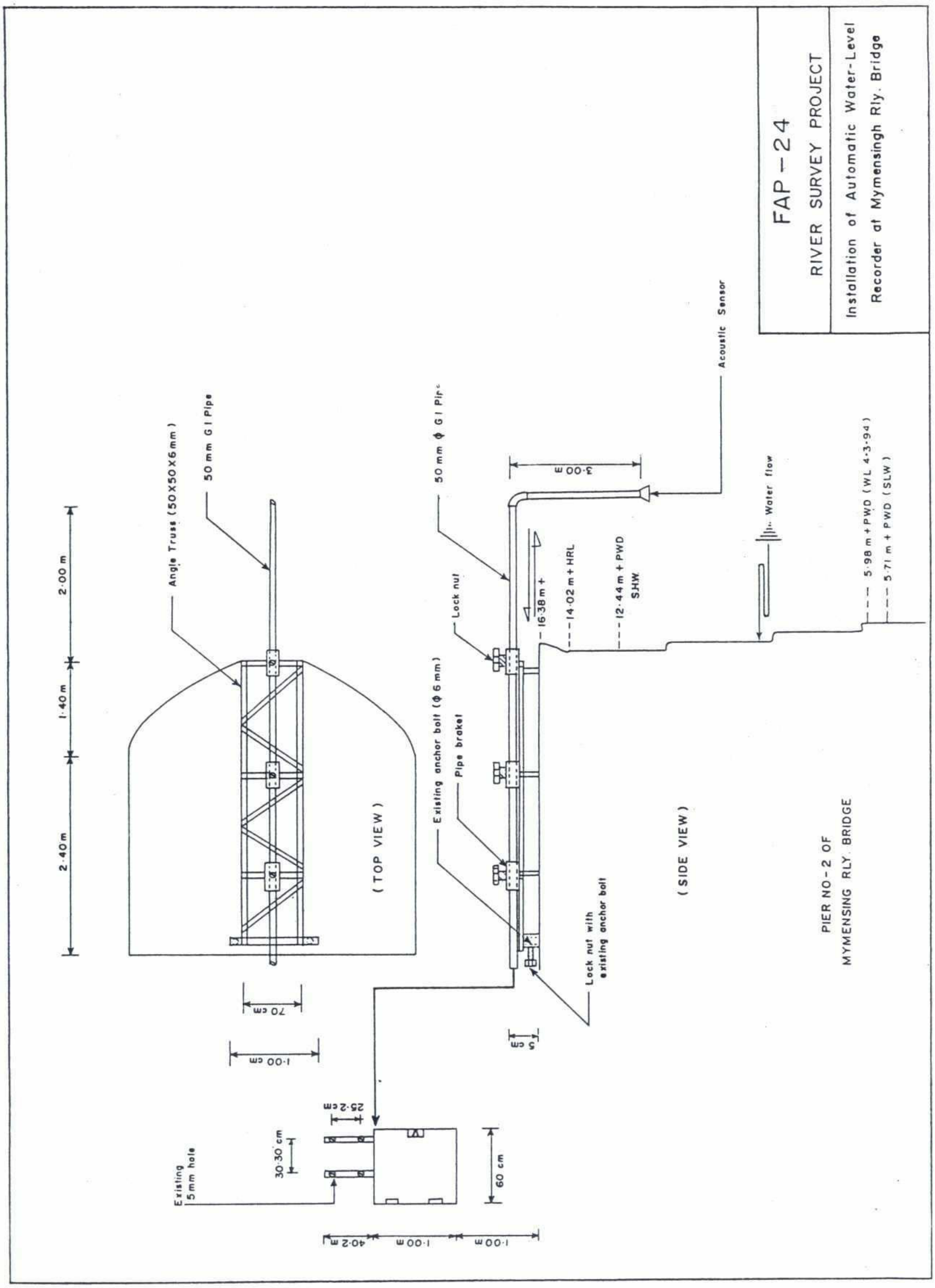


Figure 32: The design elements of the AWLR fixing at the Railway Bridge pier at Mymensingh

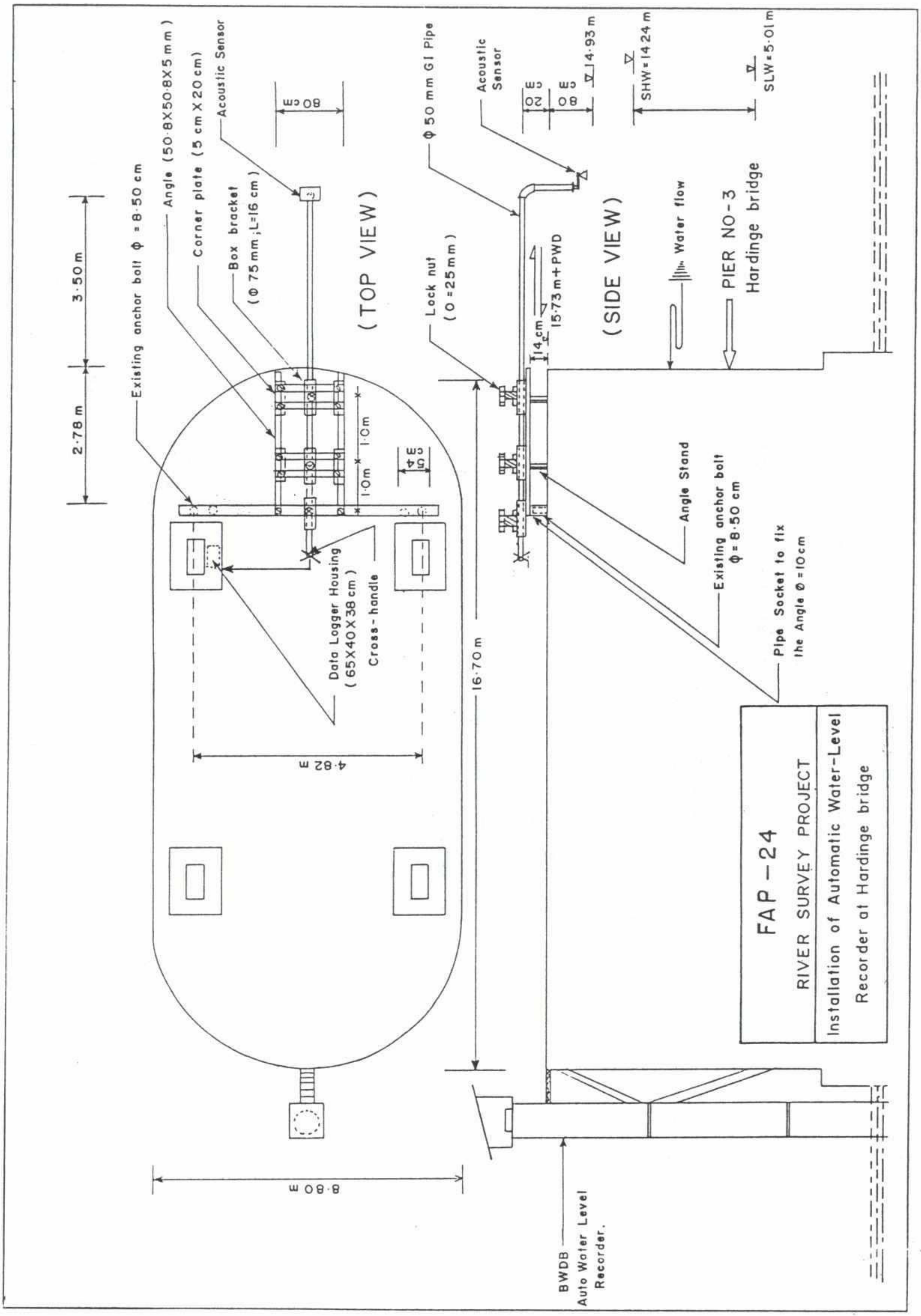


Figure 33: The design elements of the AWLR fixing at the Railway Bridge pier at Hardinge Bridge

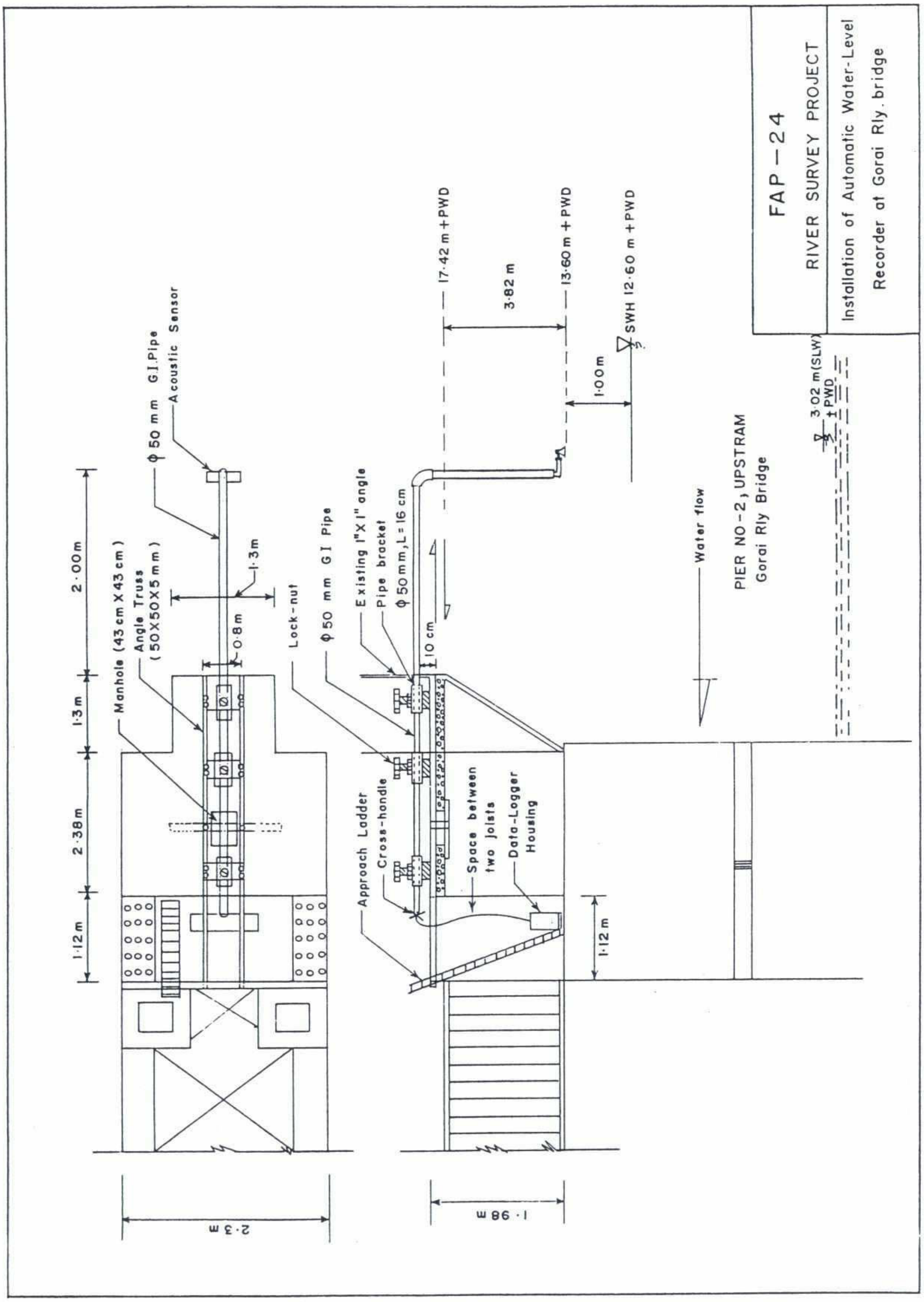


Figure 34: The design elements of the AWLR fixing at the Railway Bridge pier at Kushtia

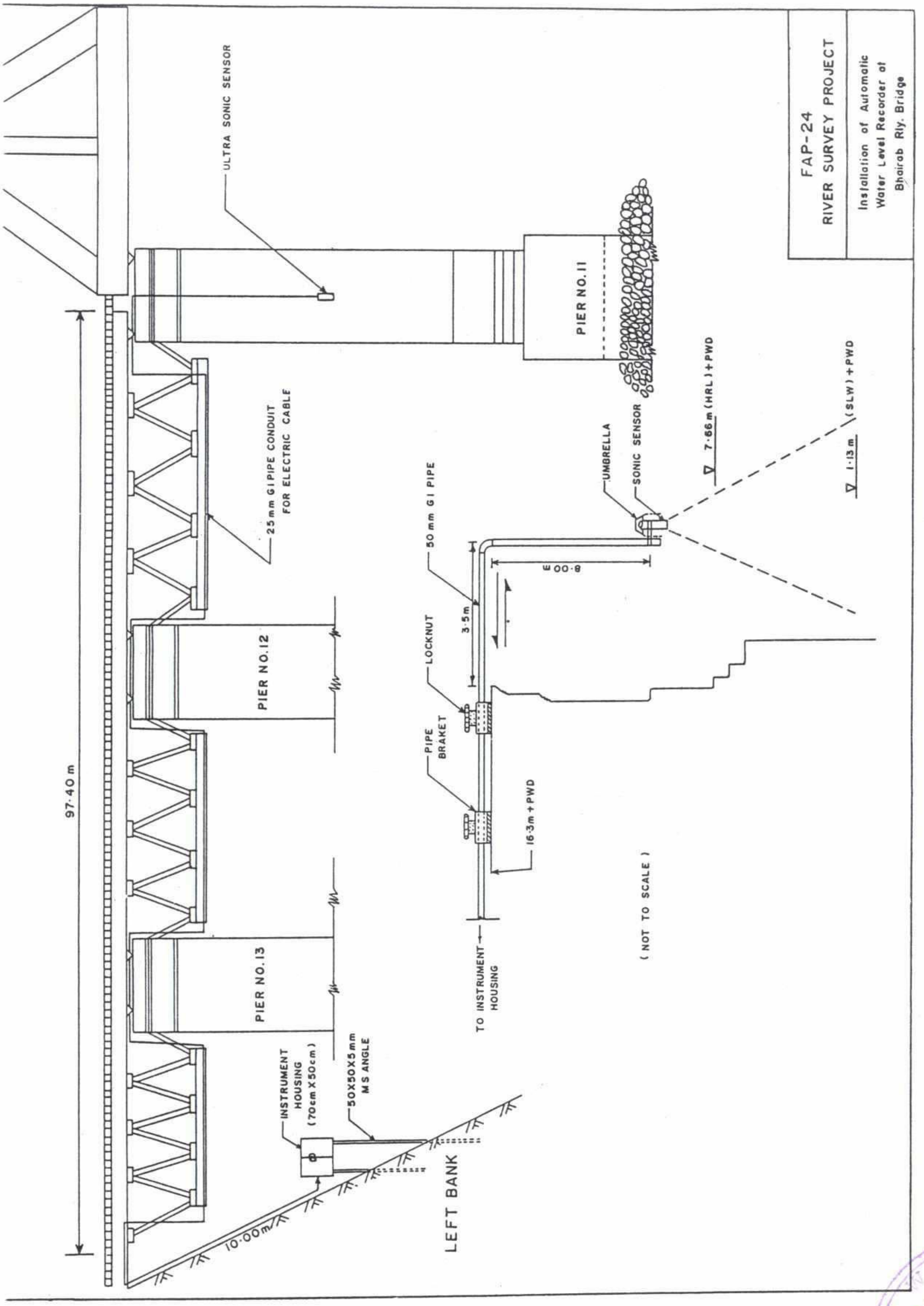


Figure 35: The design elements of the AWLR fixing at the Railway Bridge pier at Bhairab Bazar

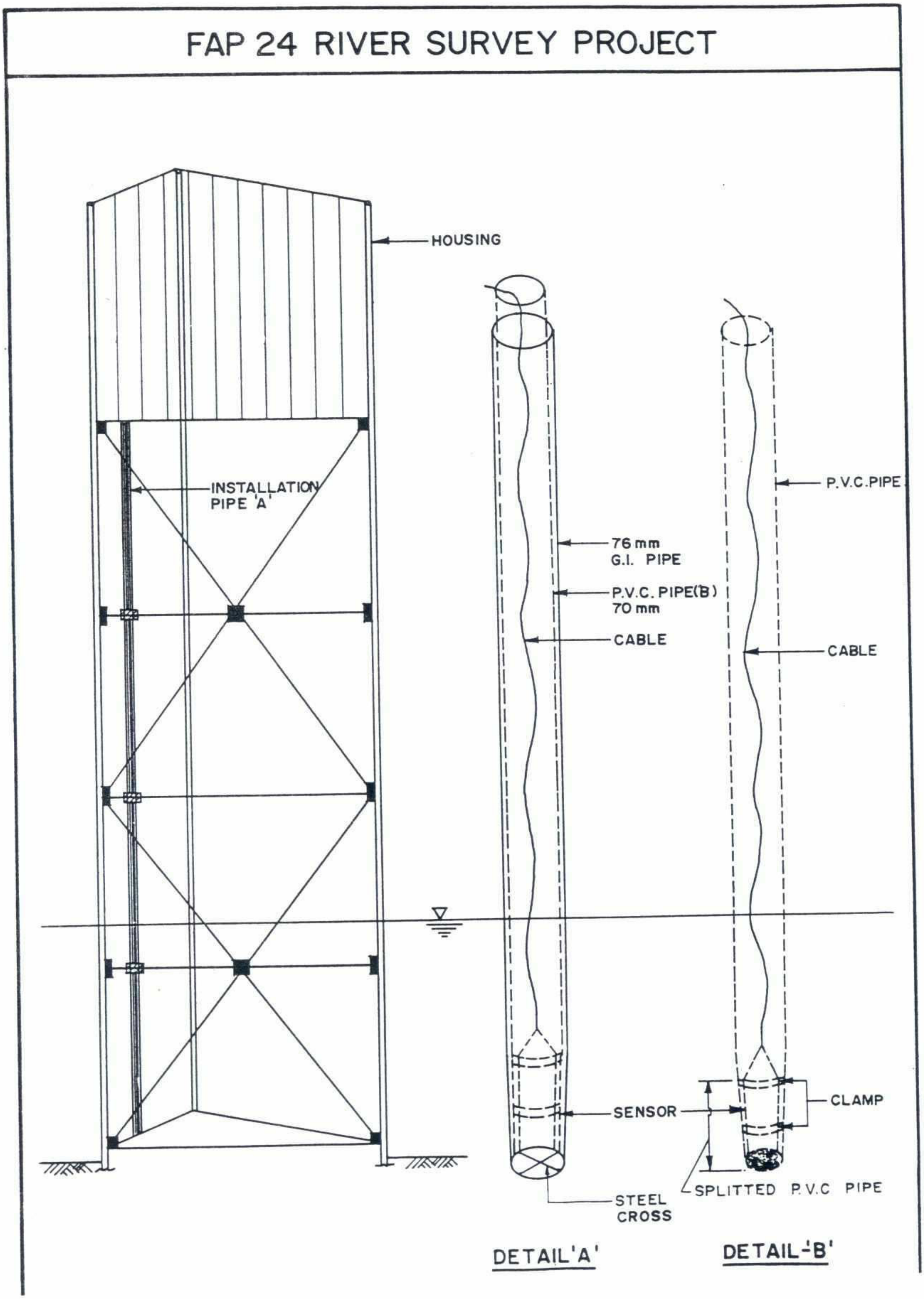
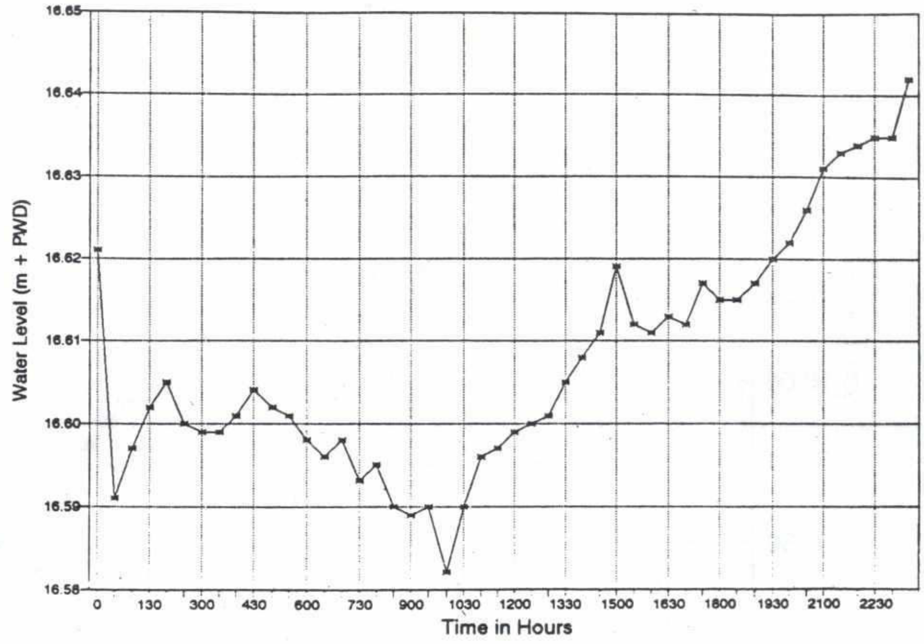
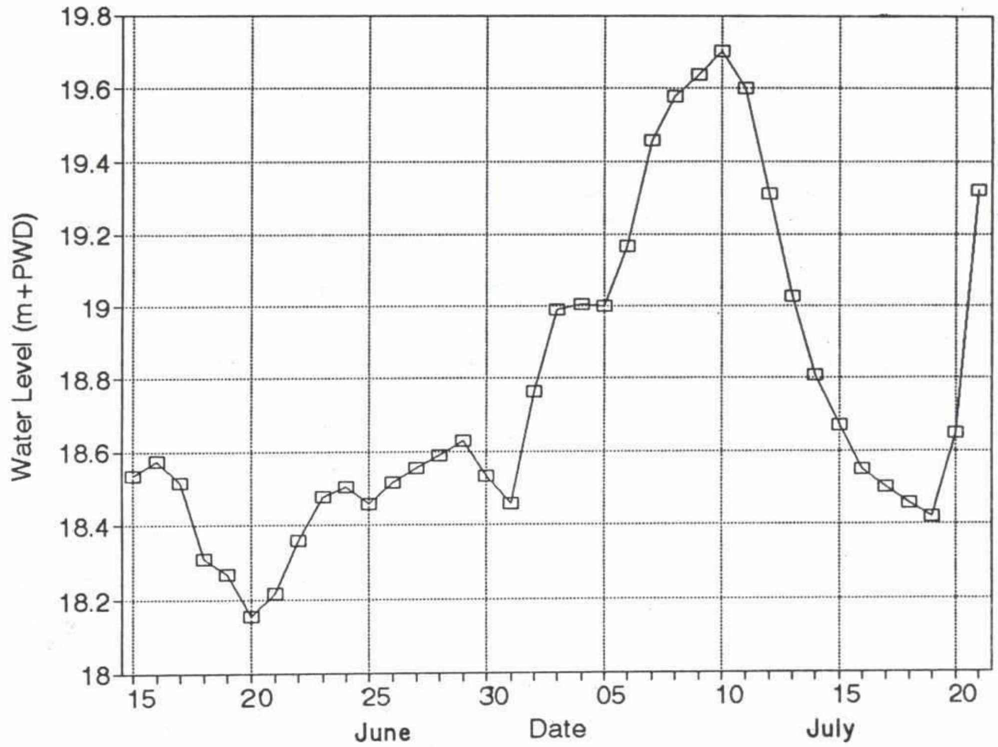


Figure 36: Pressure sensor fixing arrangement in AWLR towers

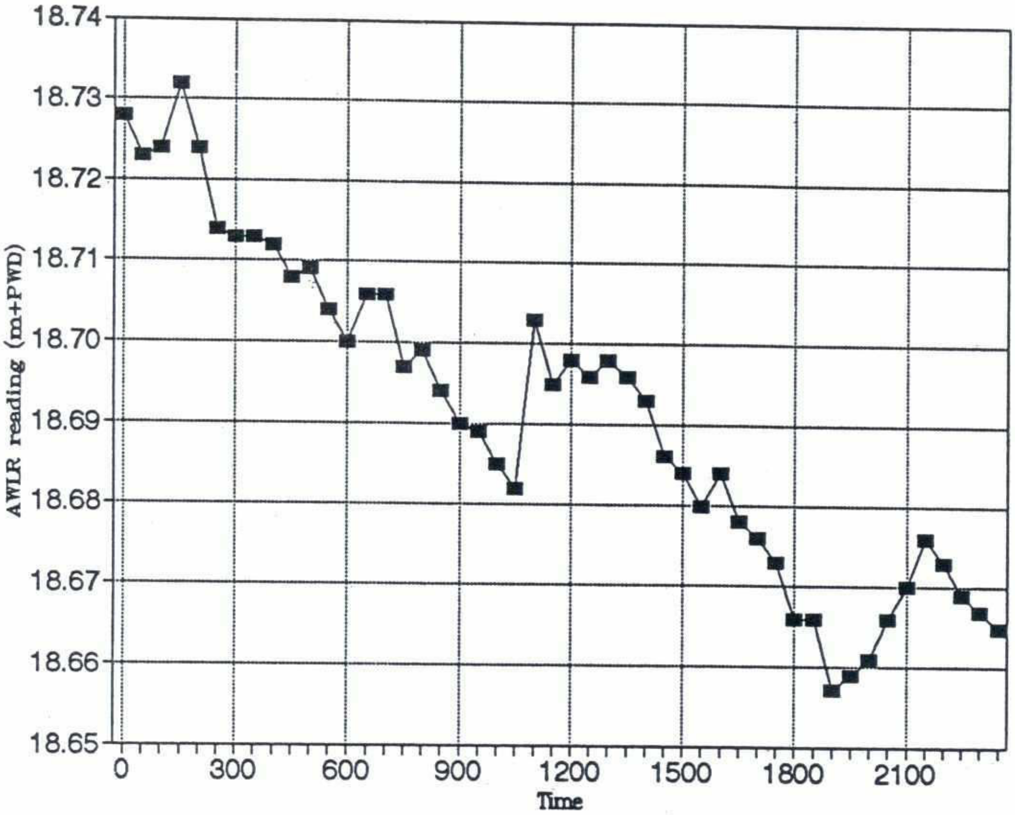


a. 1/2 hourly reading on 3 June 1993 River

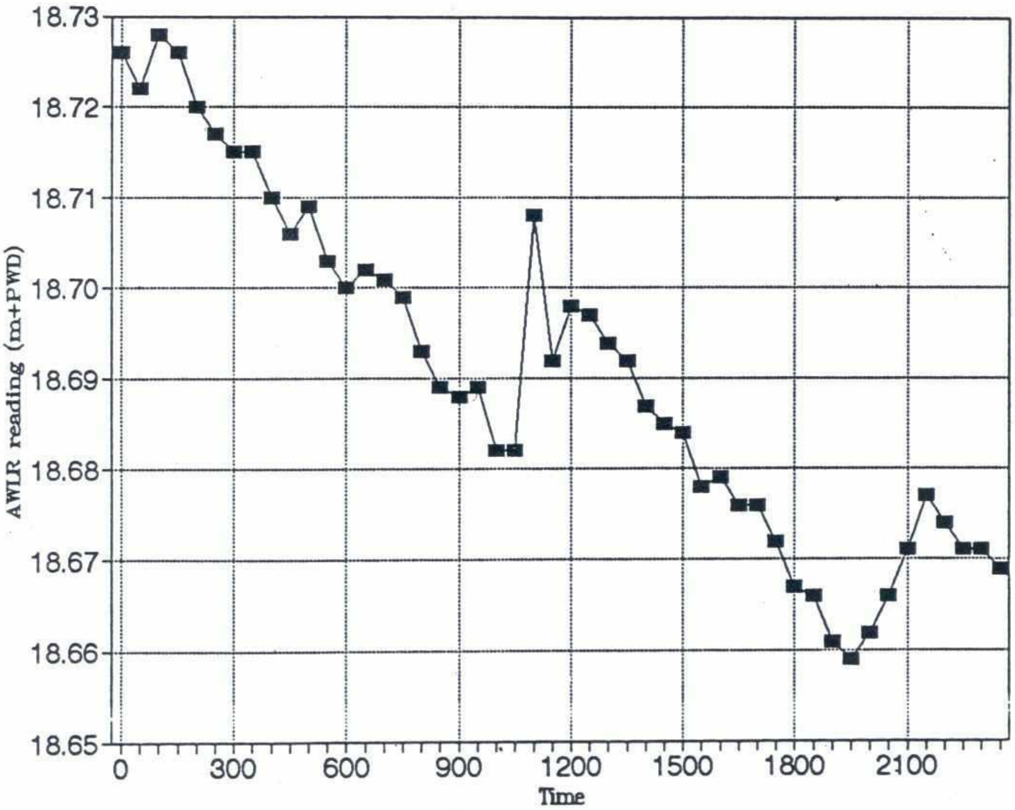


b. Daily reading recorded at 0600 hrs in June–July 1993

Figure 37: AWLR reading at Bahadurabad



a. $^1/_2$ hourly pressure sensor record



b. $^1/_2$ hourly acoustic sensor record

Figure 38: AWLR reading at Gabgachi on 17 July 1993

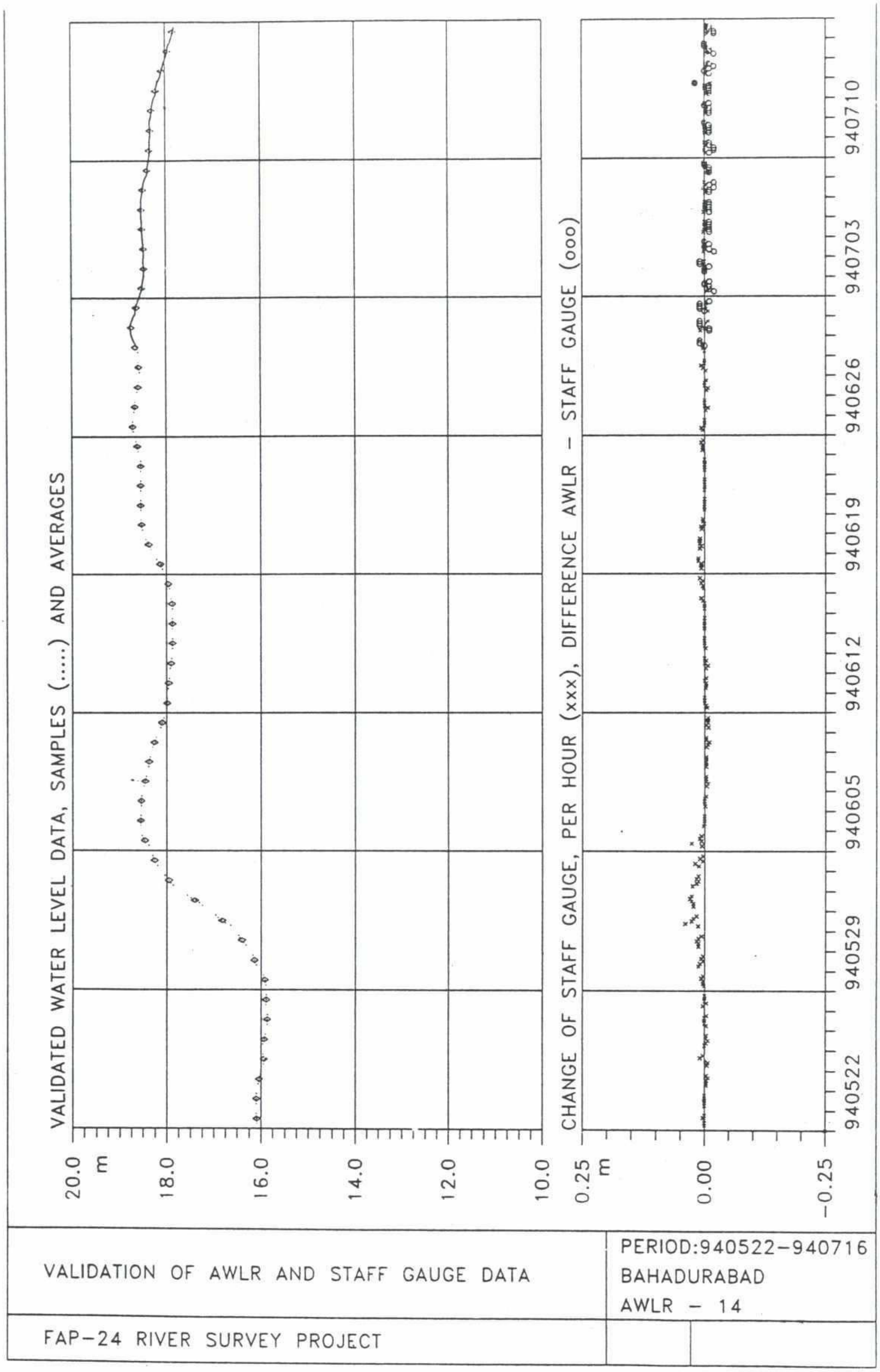


Figure 39: Validation of AWLR and staff gauge data at Bahadurabad

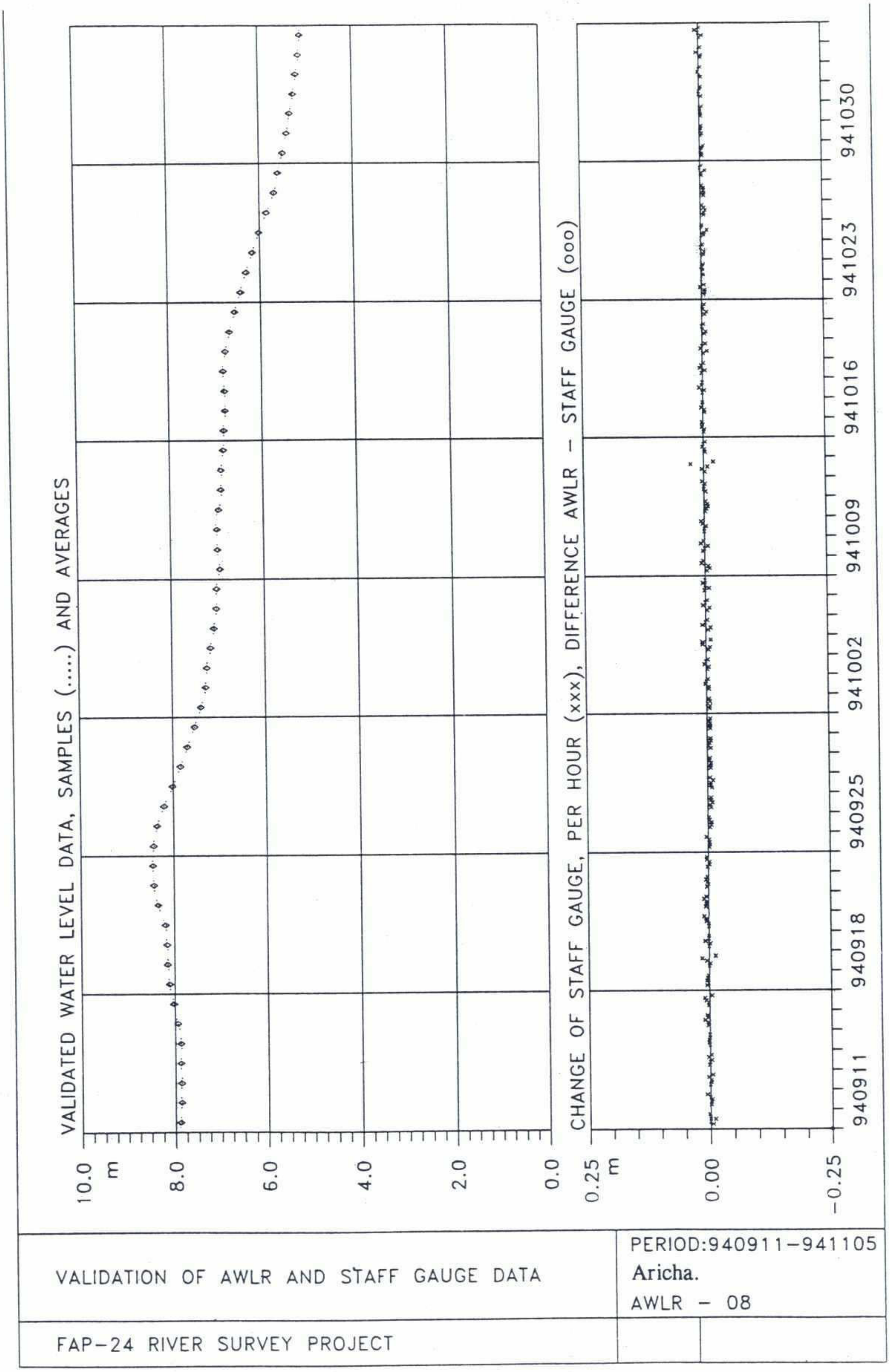


Figure 40: Validation of AWLR and staff gauge data at Aricha

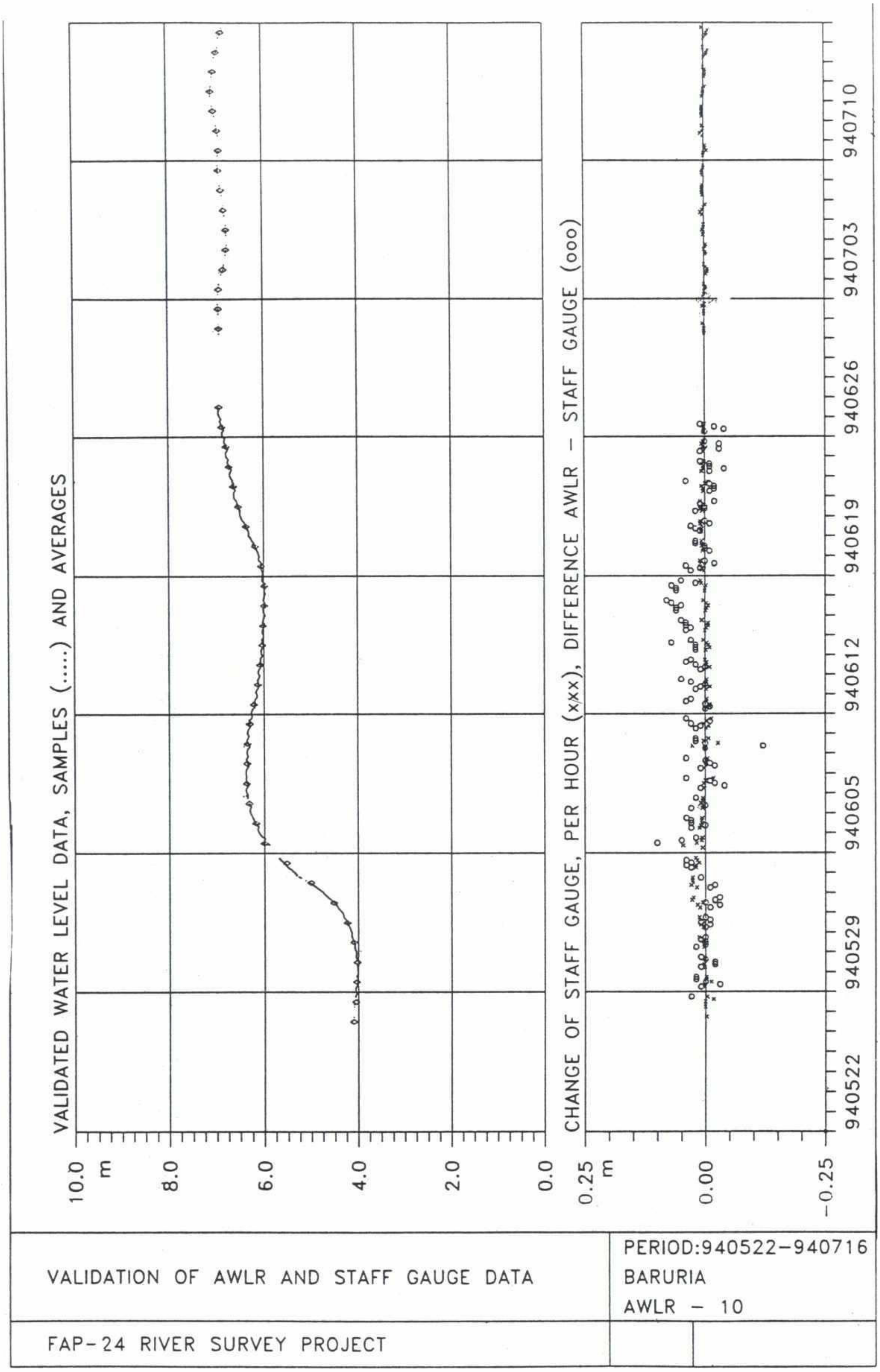


Figure 41: Validation of AWLR and staff gauge data at Baruria

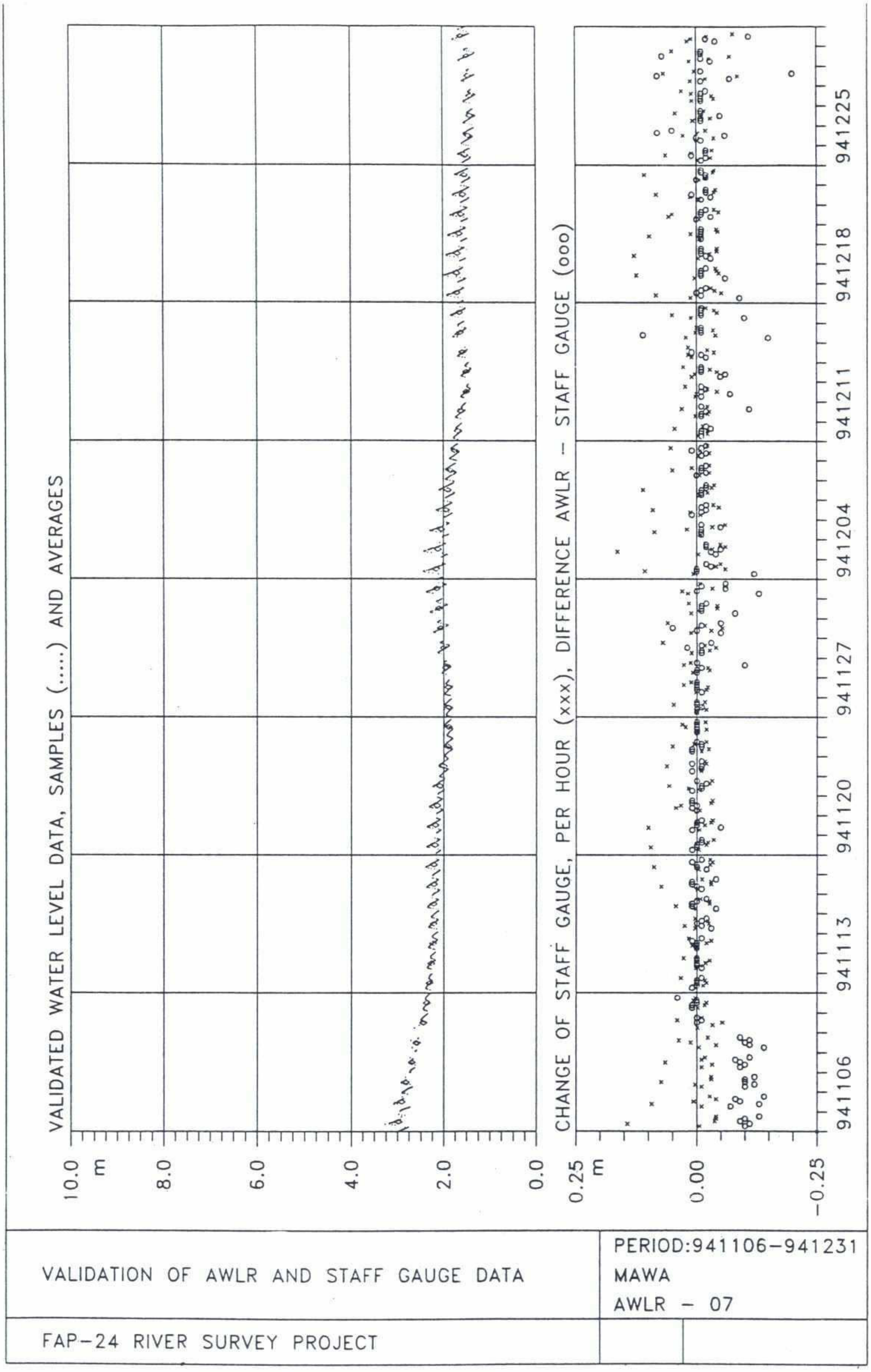


Figure 42: Validation of AWLR and staff gauge data at Mawa

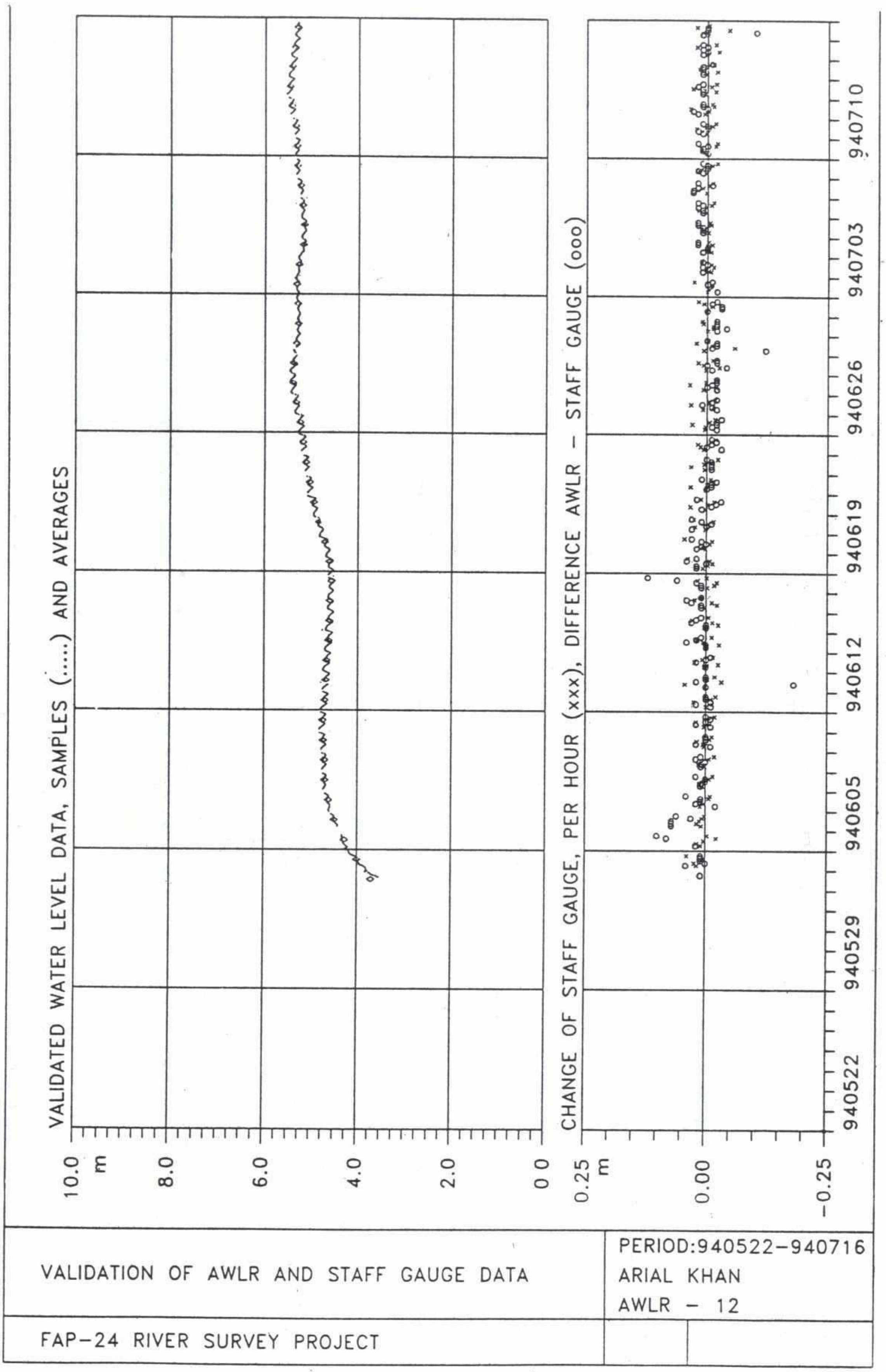


Figure 43: Validation of AWLR and staff gauge data at Arial Khan

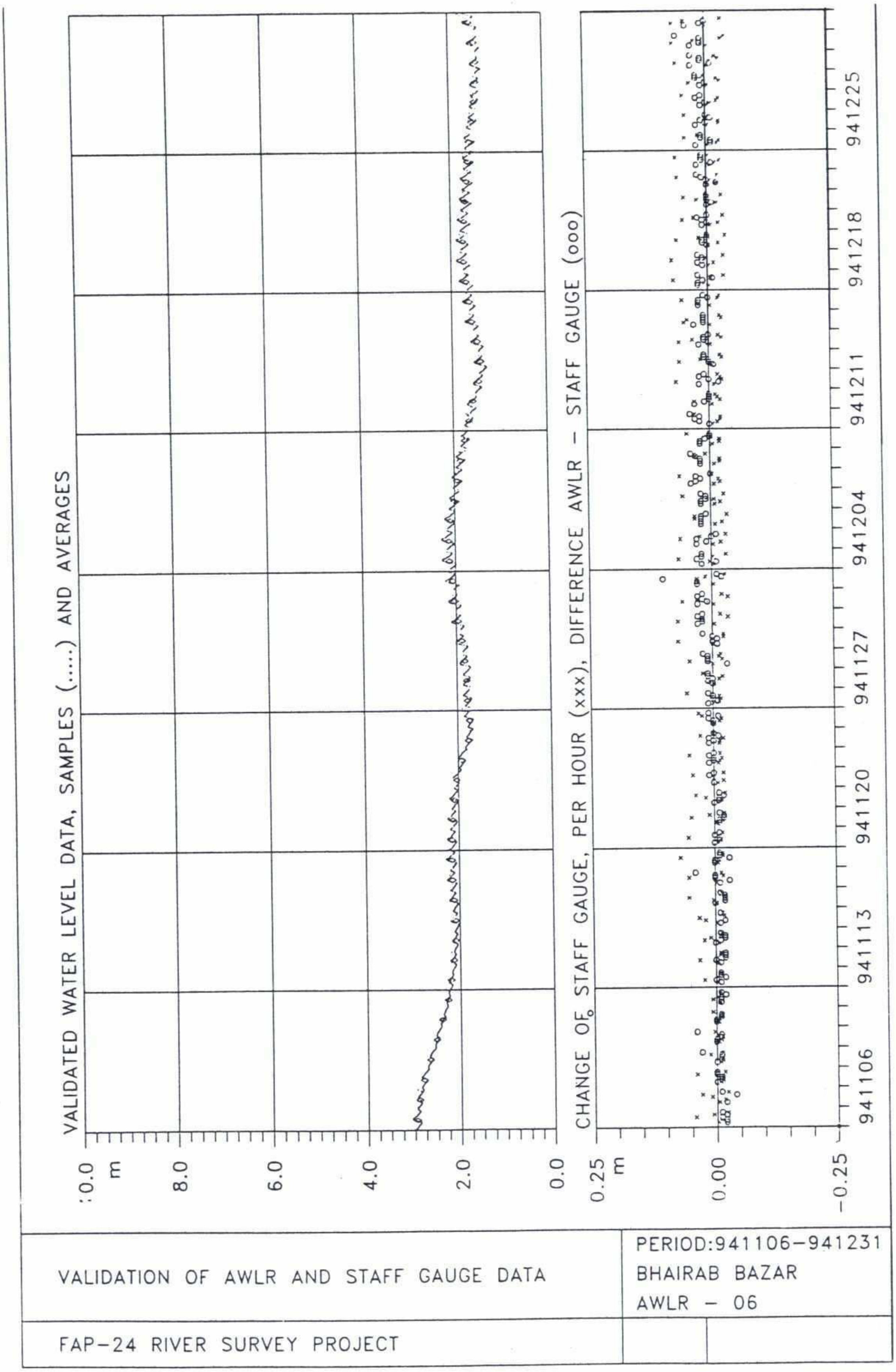
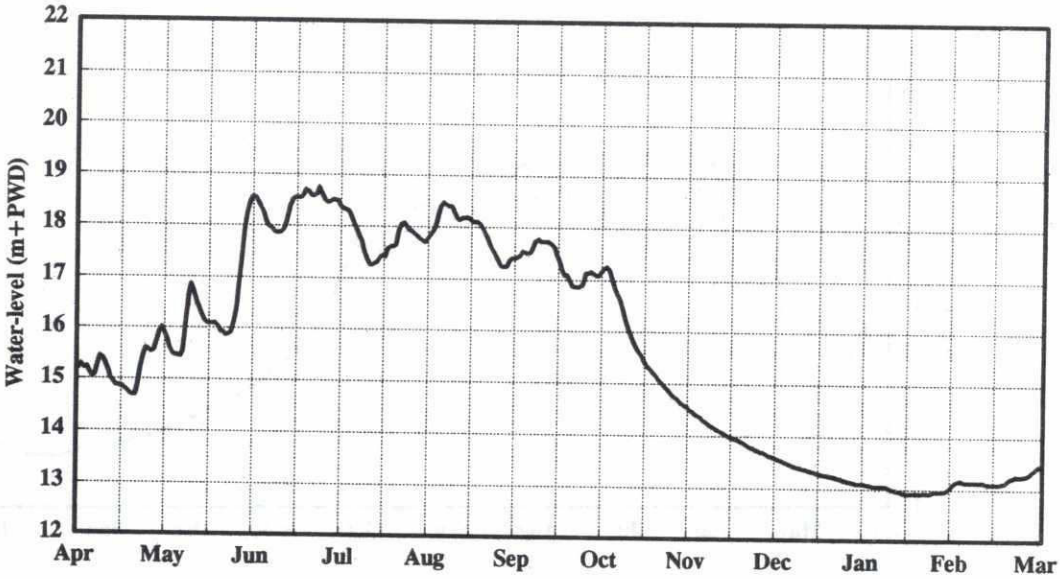
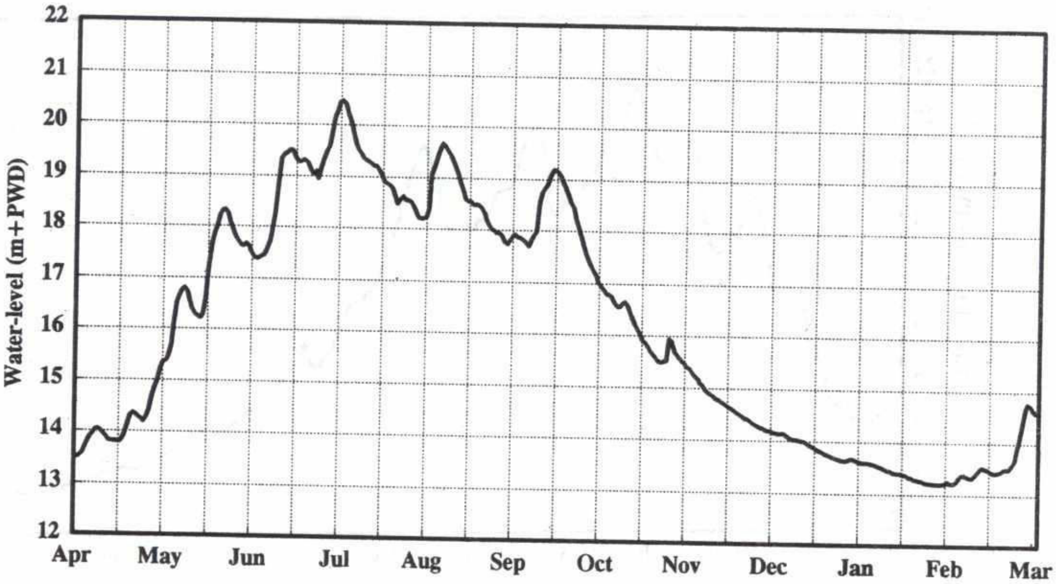


Figure 44: Validation of AWLR and staff gauge data at Bhairab Bazar

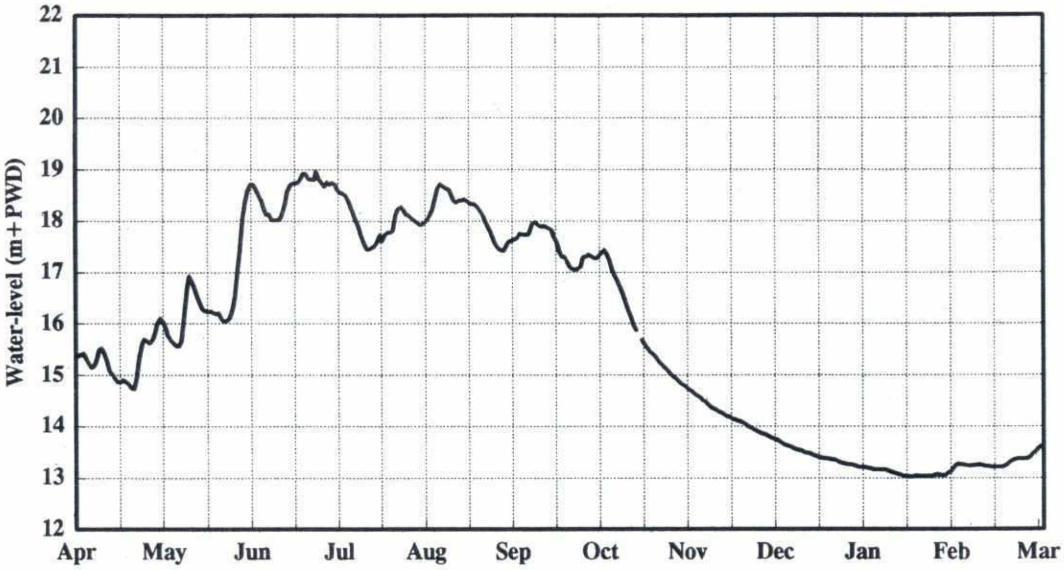


a. 1994

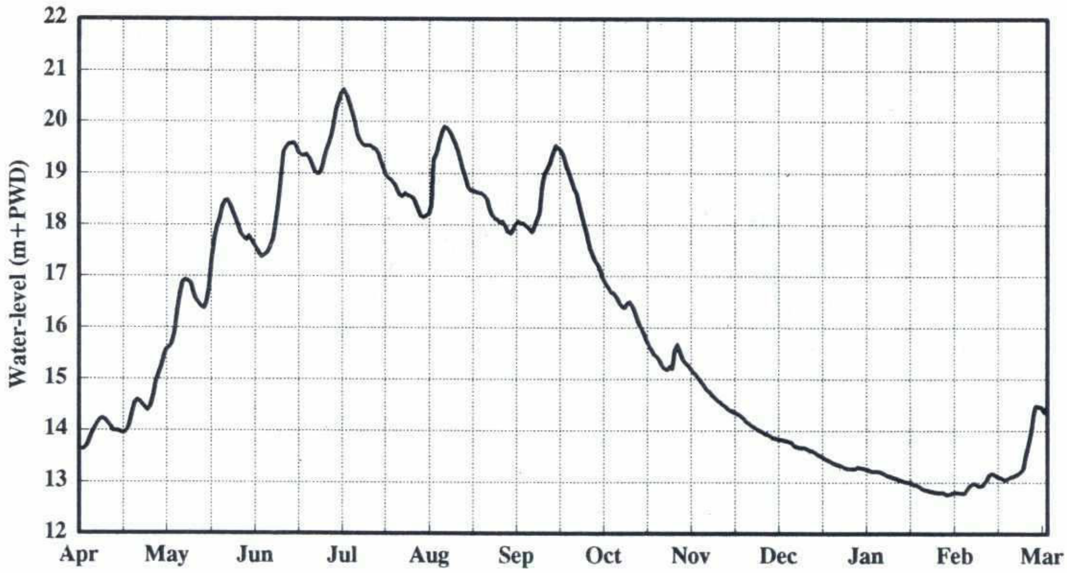


b. 1995

Figure 45: Validated water level data at Bahadurabad



a. 1994



b. 1995

Figure 46: Validated water level data at Gabgachi

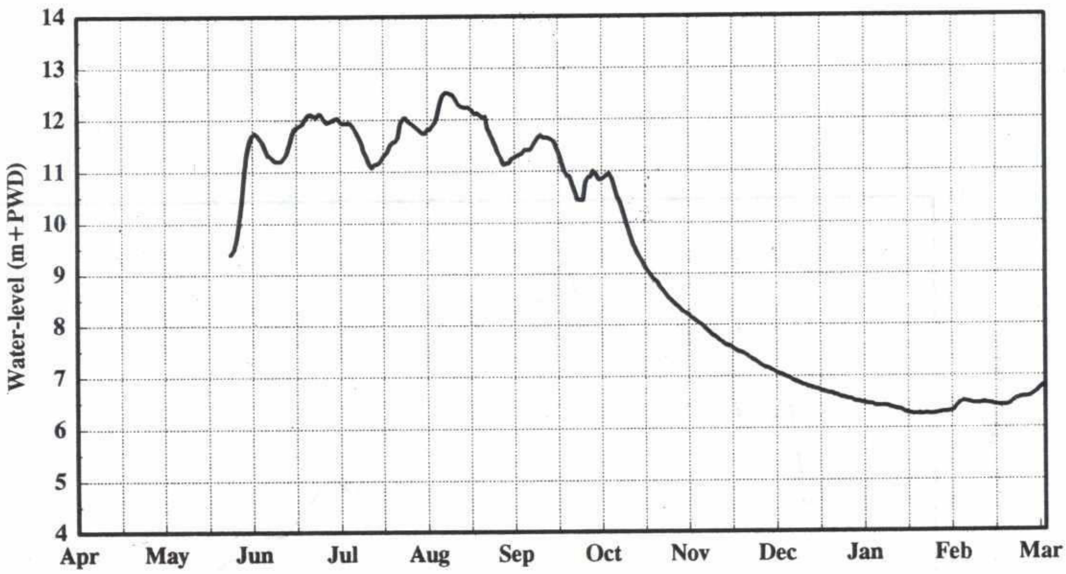
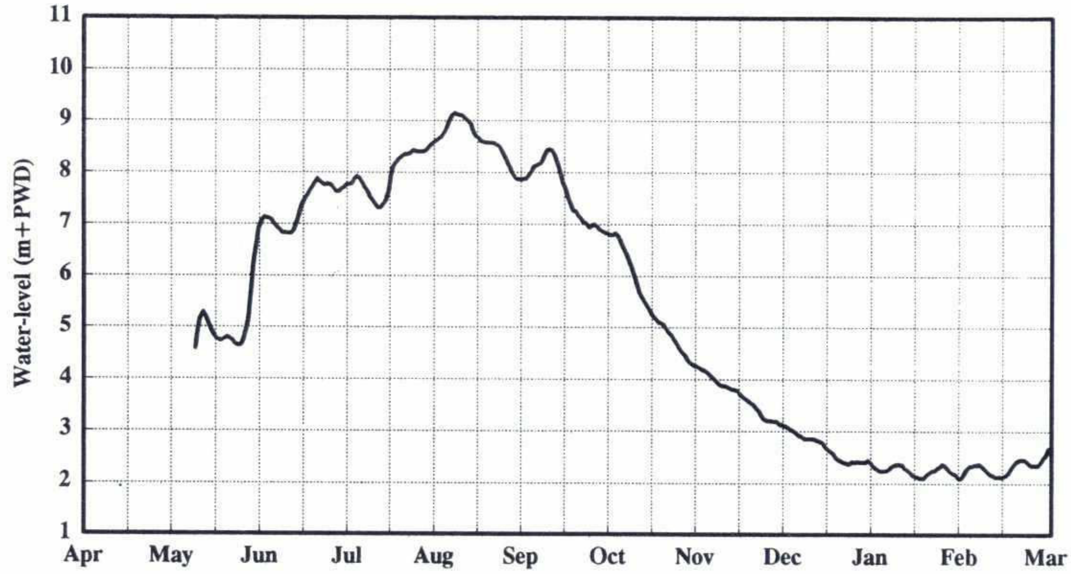
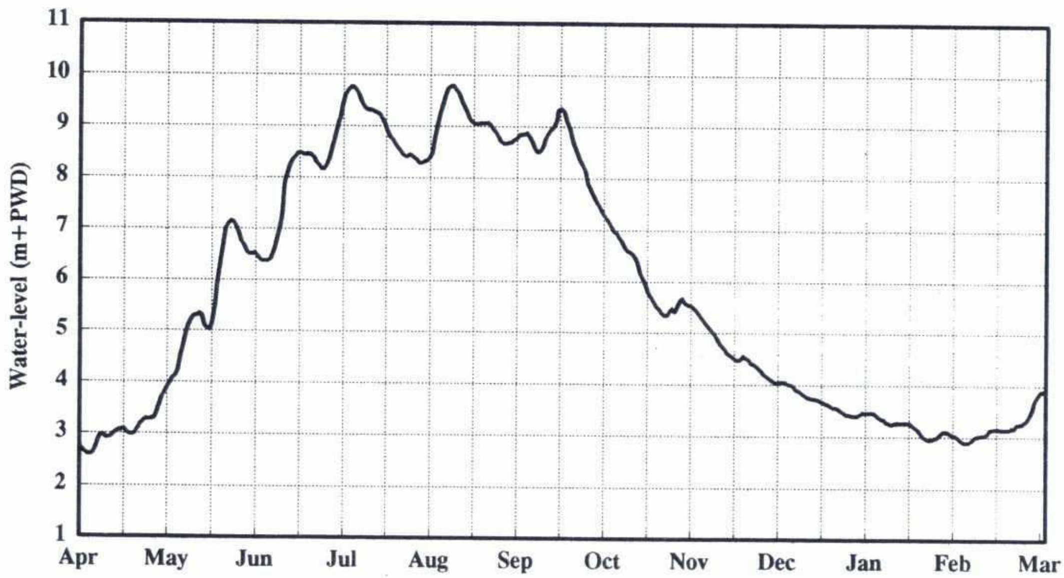


Figure 47: Validated water level data at Bhuyanpur (1994)

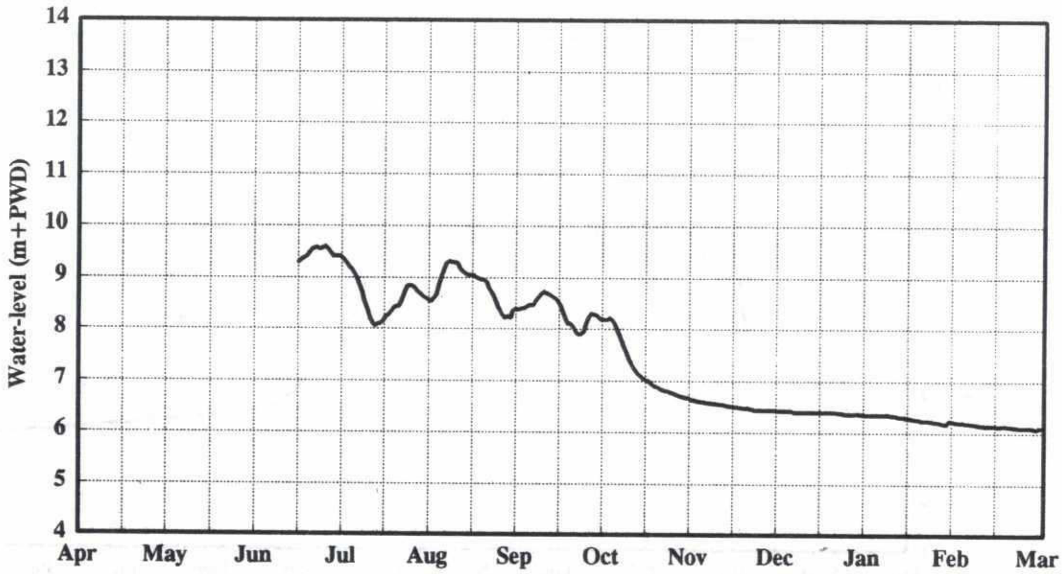


a. 1994

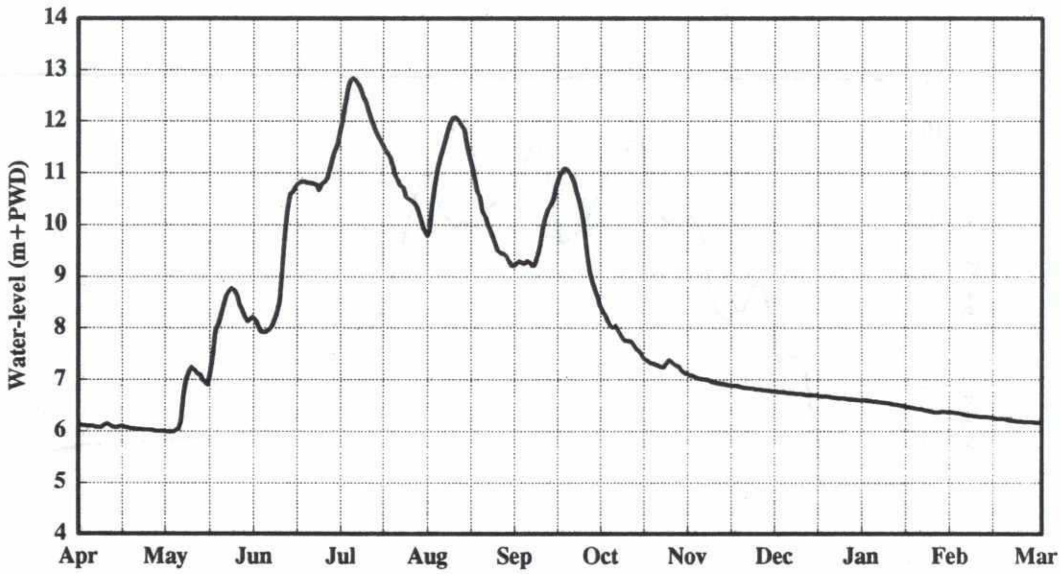


b. 1995

Figure 48: Validated water level data at Aricha (Teota)

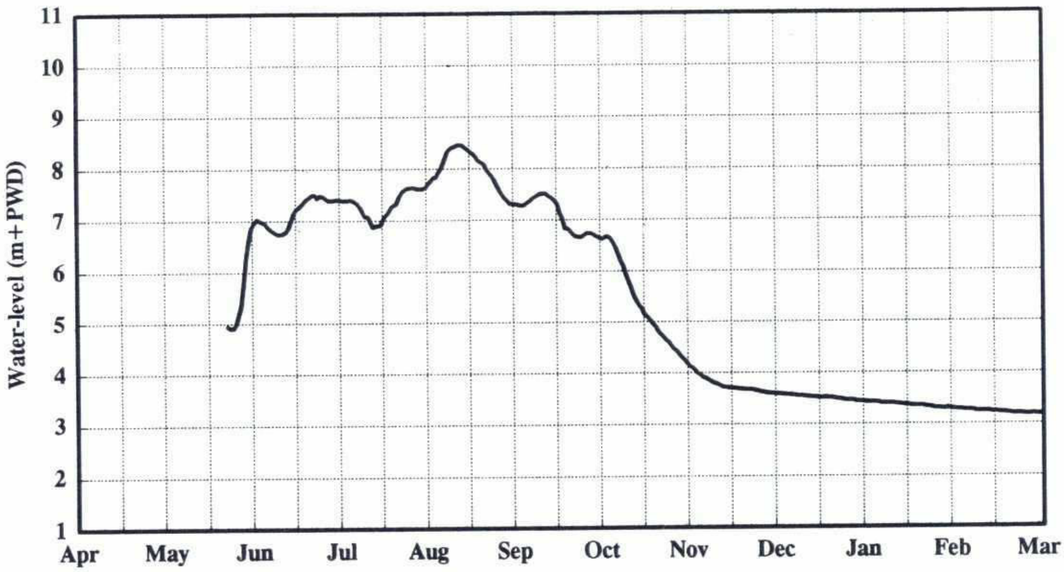


a. 1994

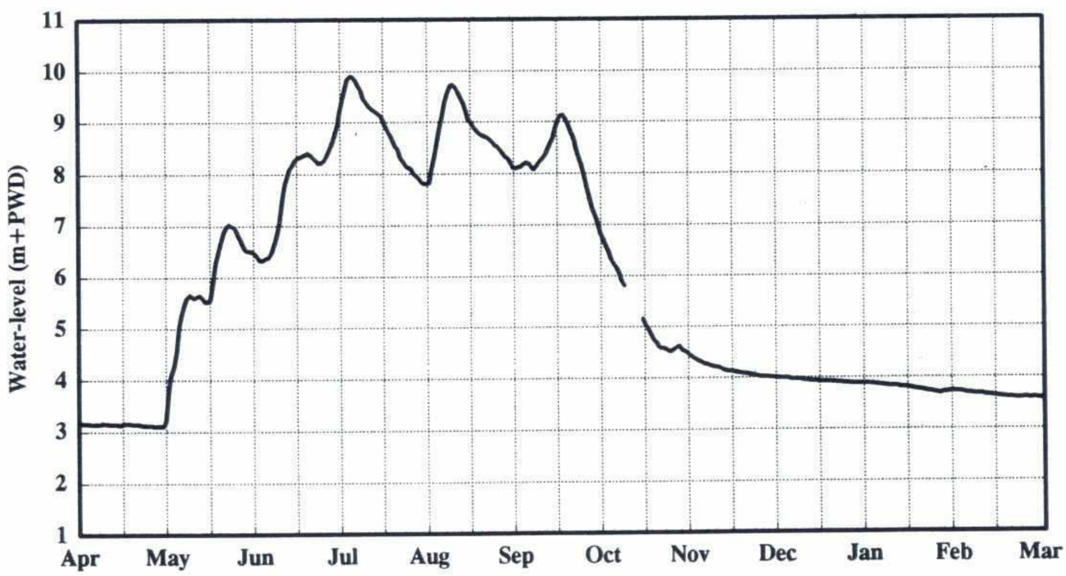


b. 1995

Figure 49: Validated water level data at Mymensing



a. 1994



b. 1995

Figure 50: Validated water level data at Tilly

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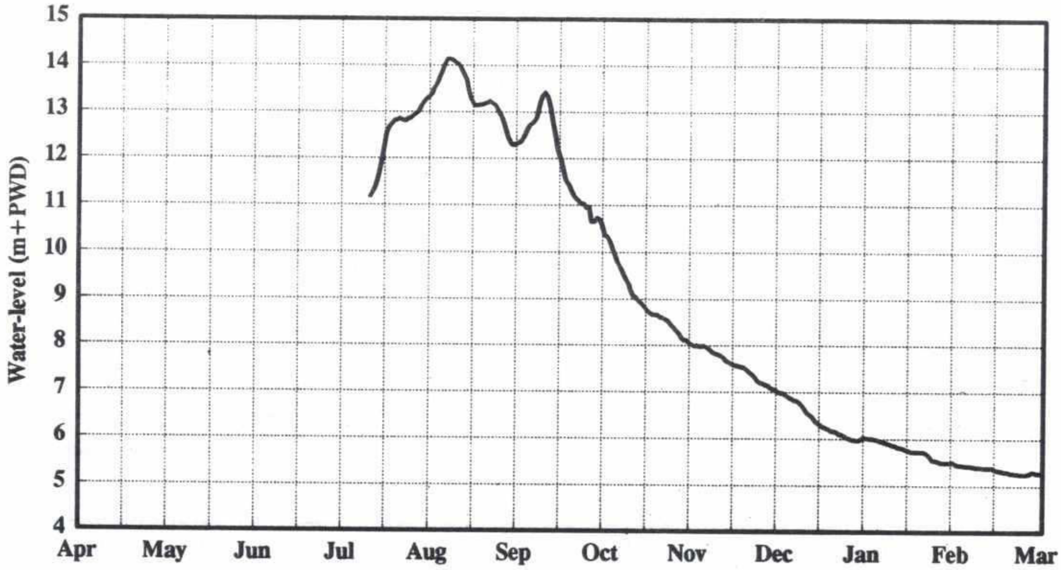
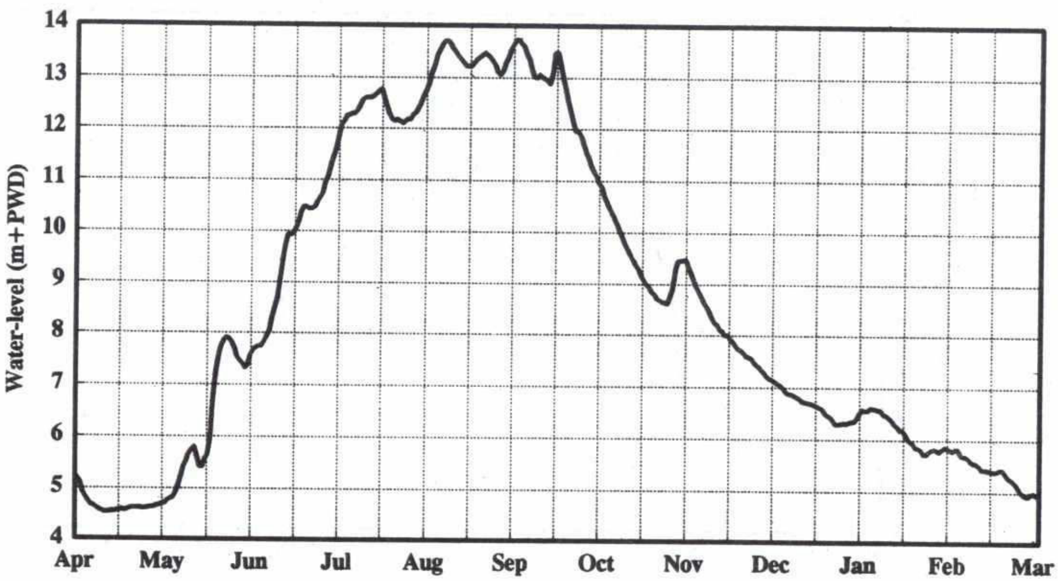
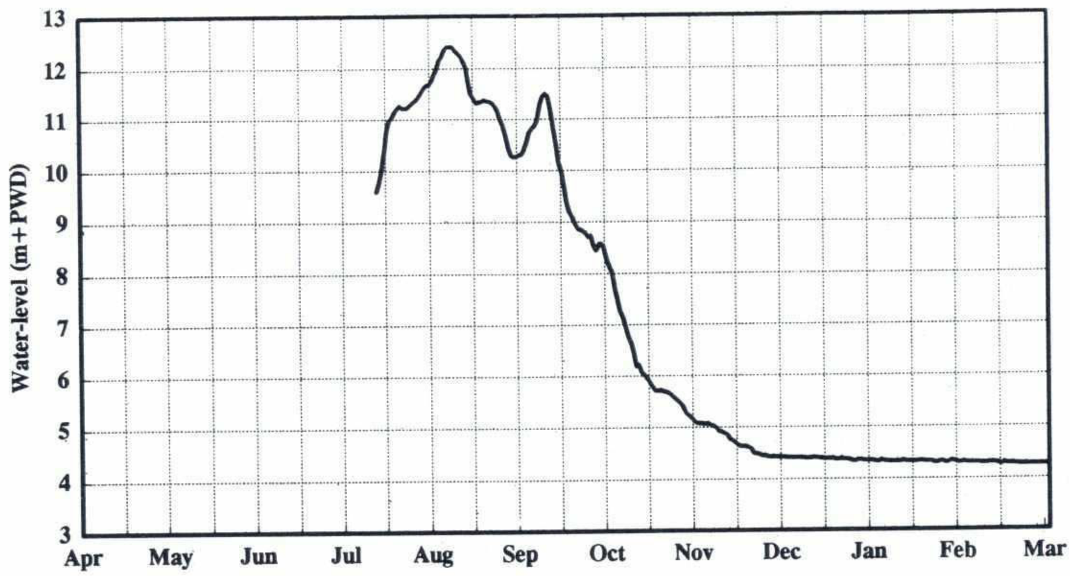


a. 1994

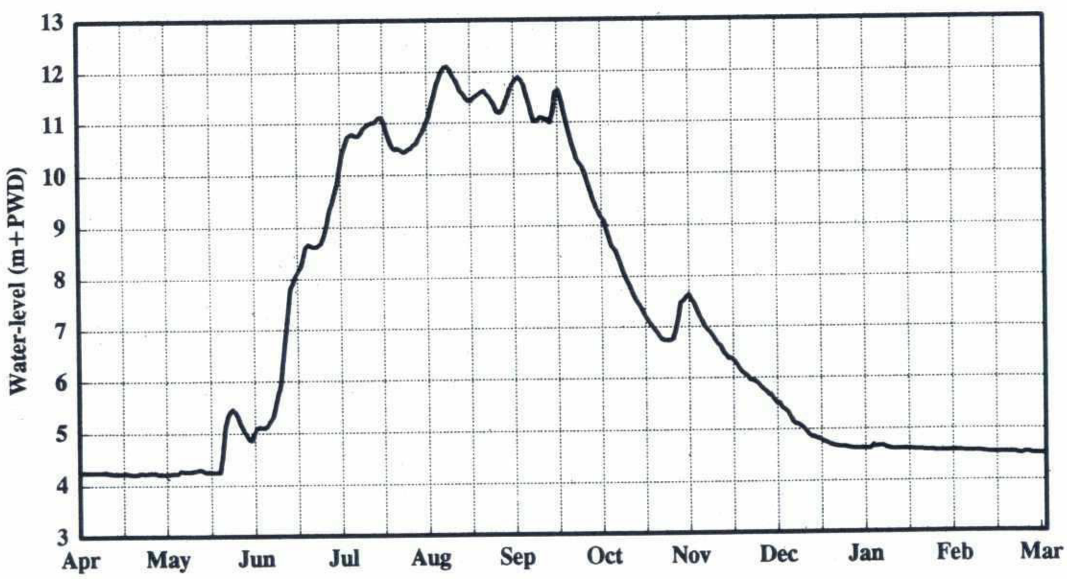


b. 1995

Figure 51: Validated water level data at Harding Bridge

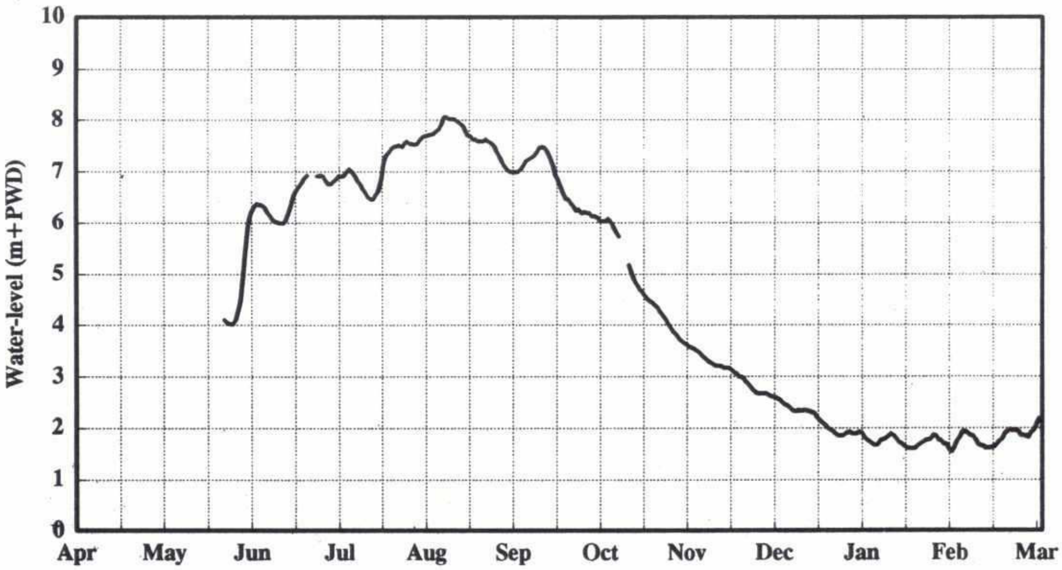


a. 1994

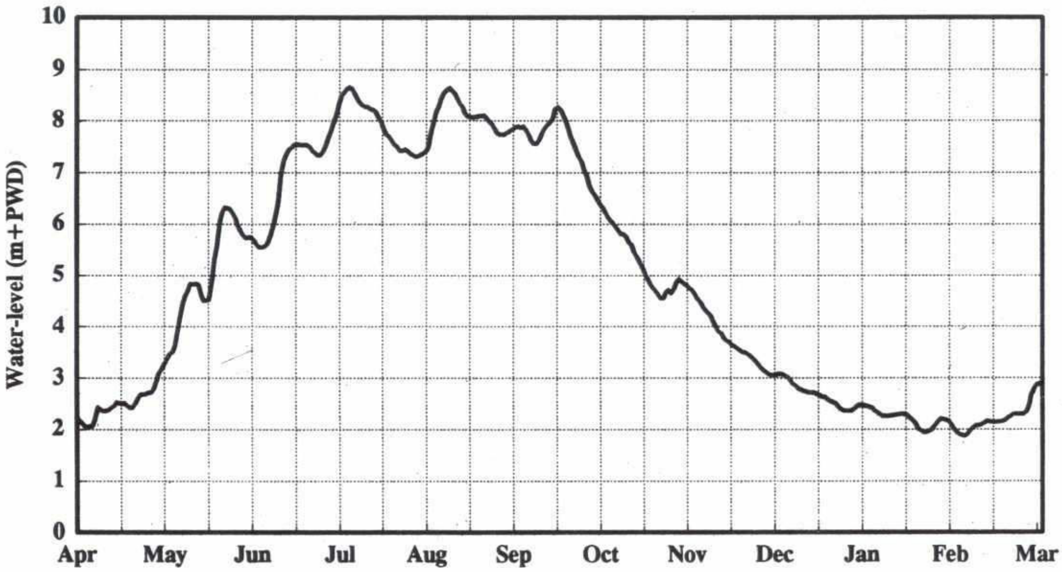


b. 1995

Figure 52: Validated water level data at Gorai Railway Bridge

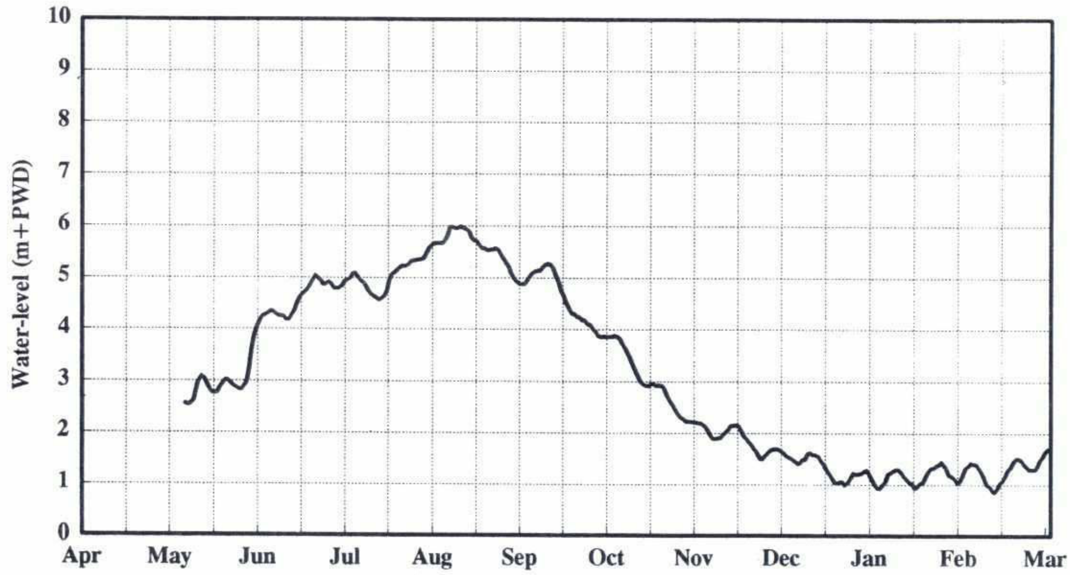


a. 1994

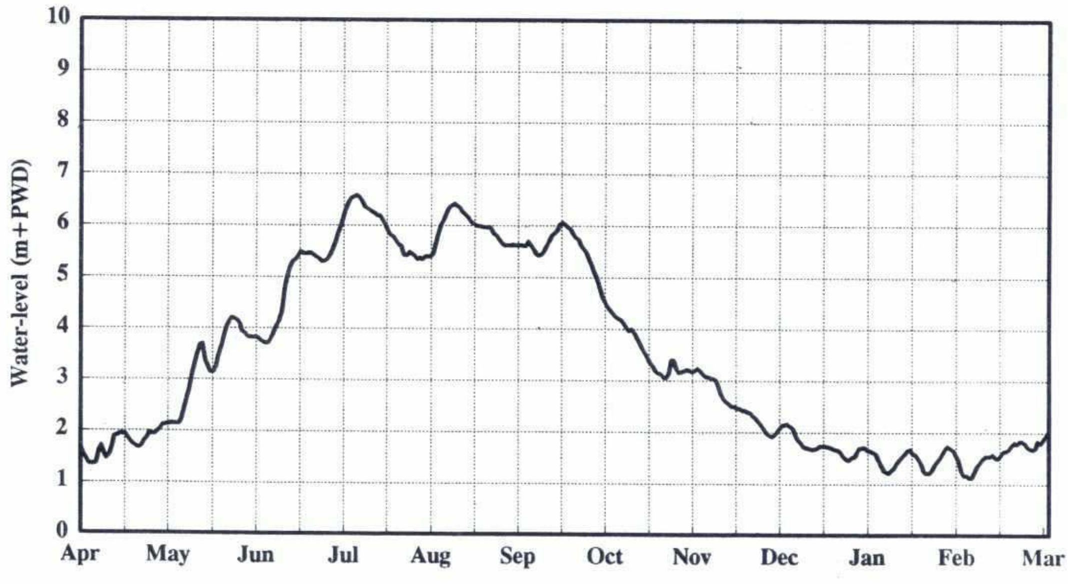


b. 1995

Figure 53: Validated water level data at Baruria

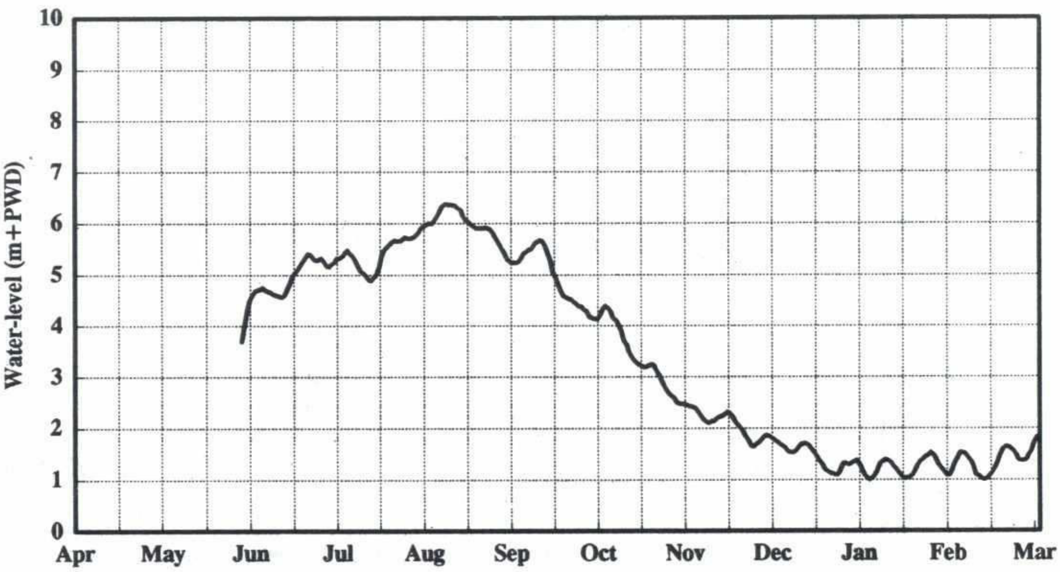


a. 1994

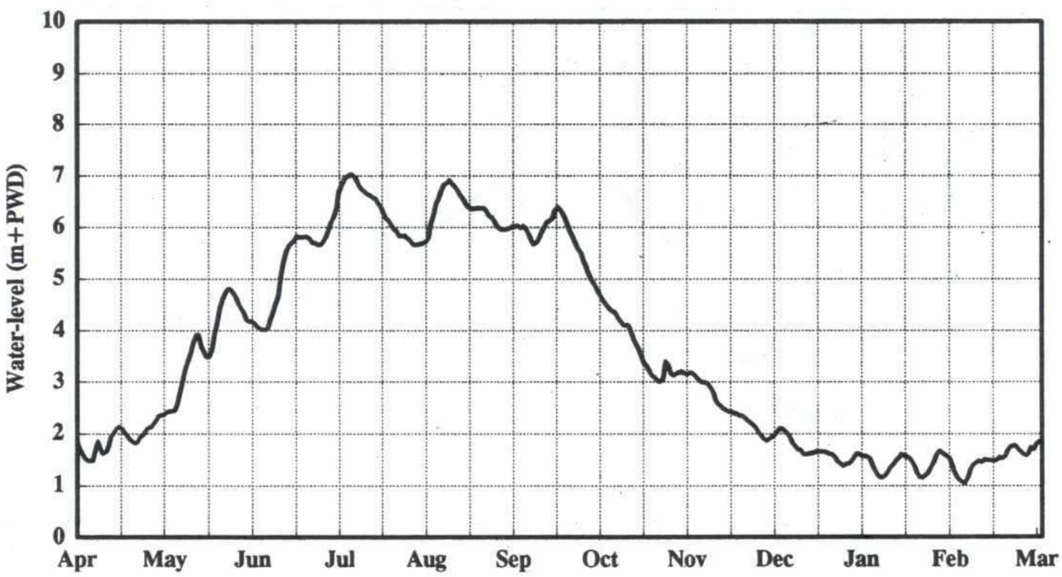


b. 1995

Figure 54: Validated water level data at Mawa



a. 1994



b. 1995

Figure 55: Validated water level data at Arial Khan

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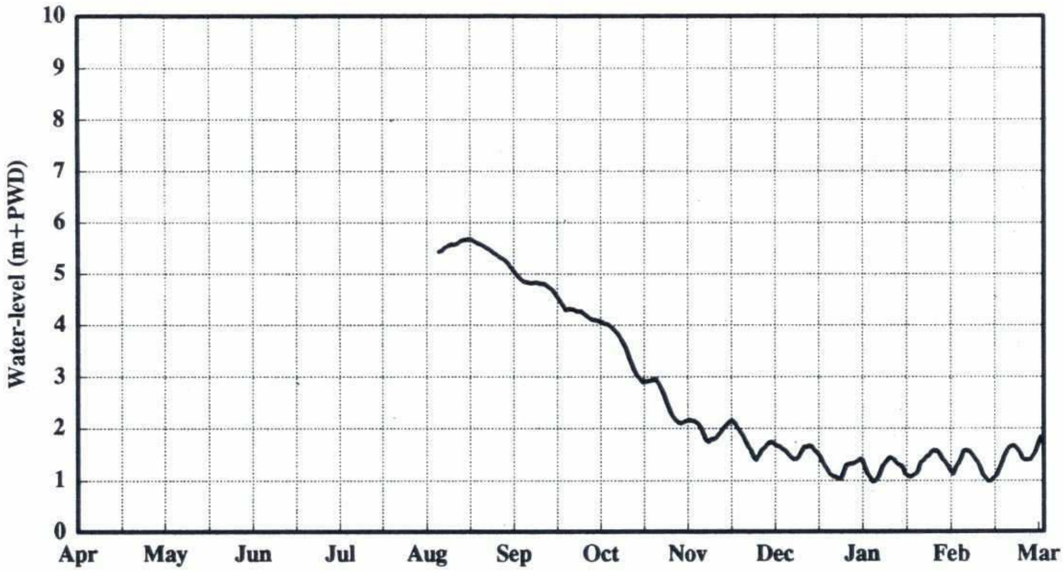
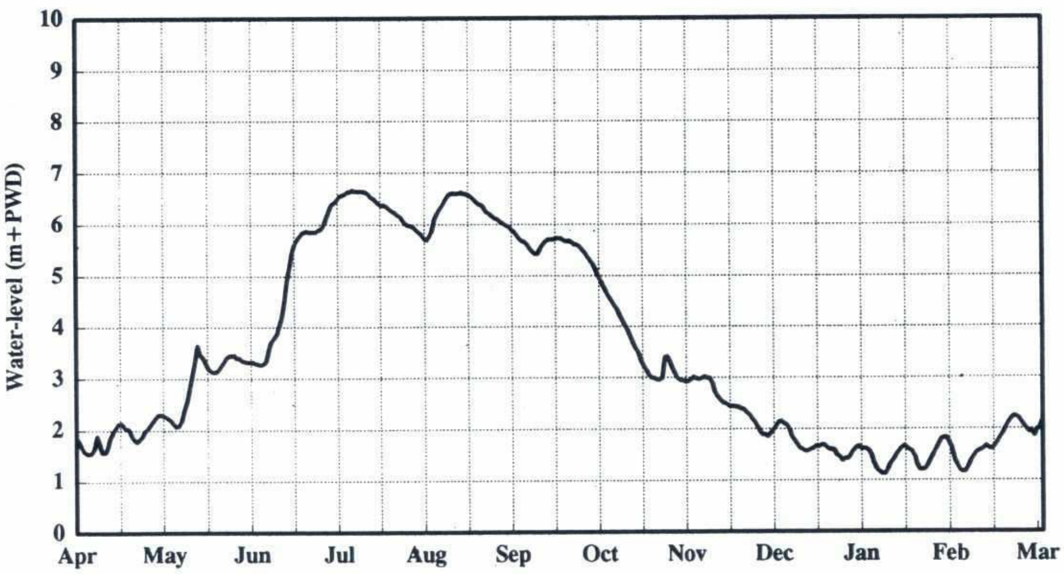


a. 1994



b. 1995

Figure 56: Validated water level data at Bhairab Bazar

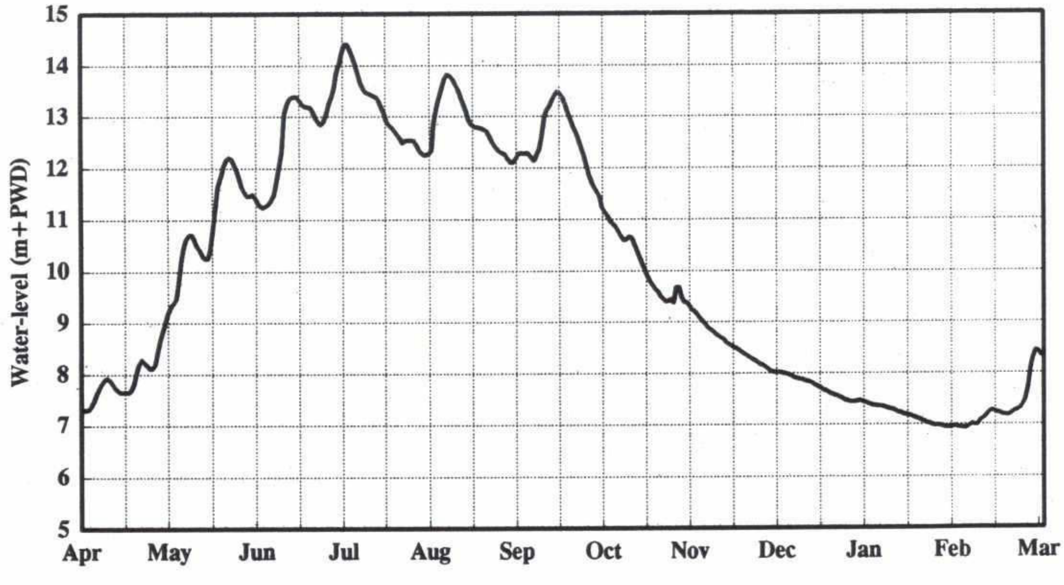


Figure 57: Validated water level data at Sirajganj (1995)

Figure 58: Collapsed AWLR platform at Bhuapur

Figure 59: Collapsed AWLR platform at Baruria

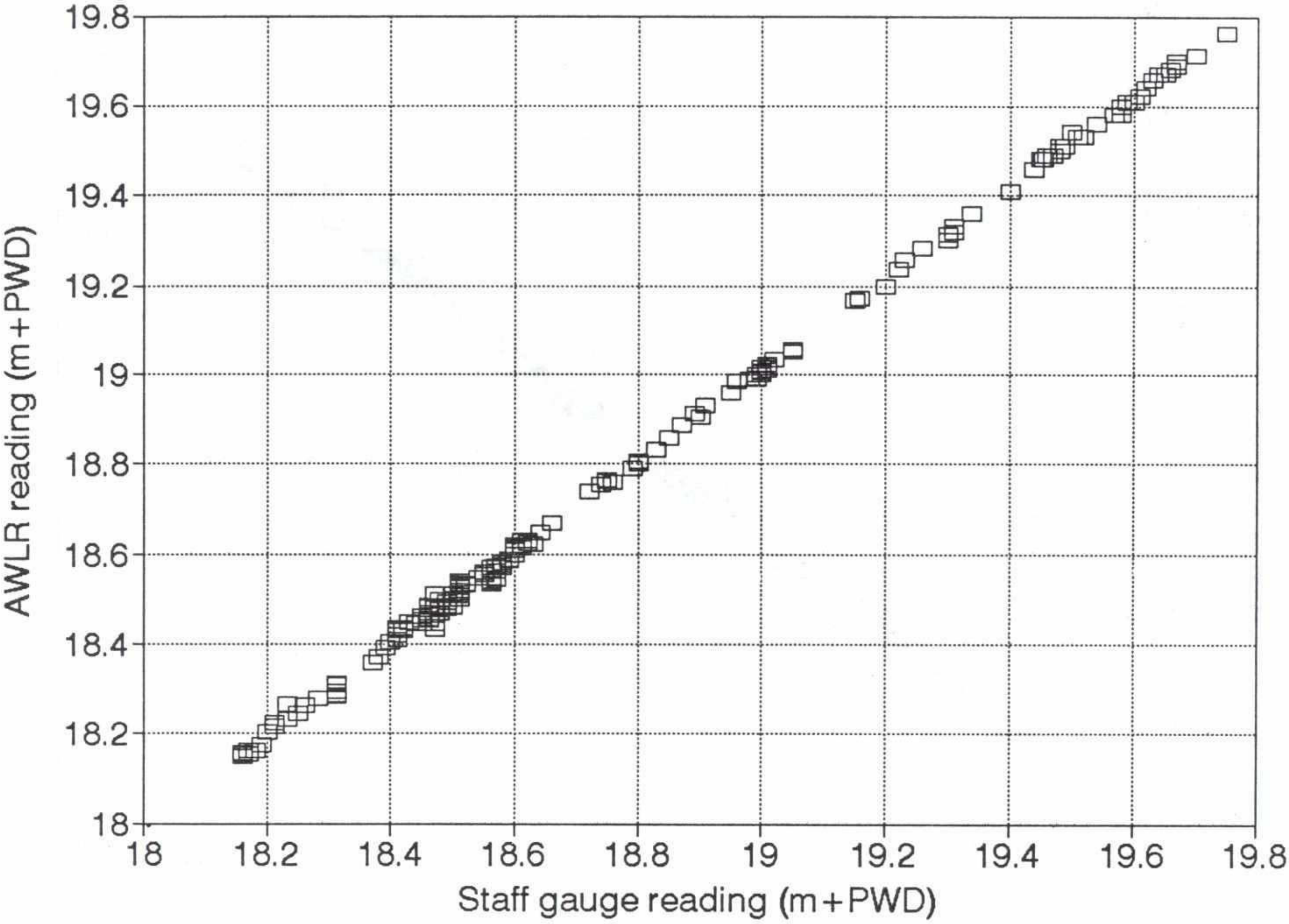


Figure 60: Comparison of raw data between pressure sensor record and staff gauge record at Bahadurabad station from 15 June to 21 July 1993

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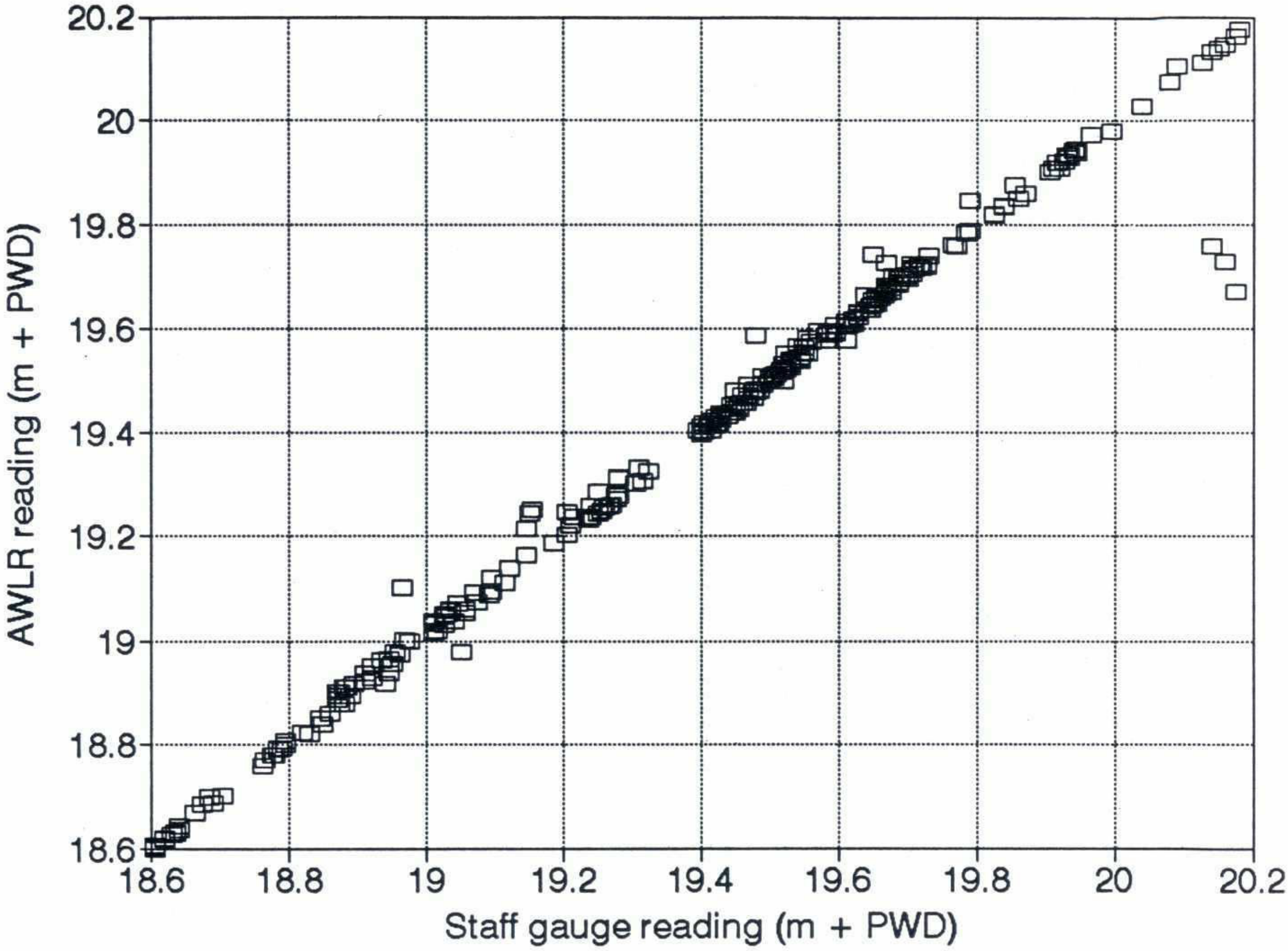

Figure 61: Comparison of raw data between pressure sensor record and staff gauge record at Gabgachi station from 4 July to 31 August 1993

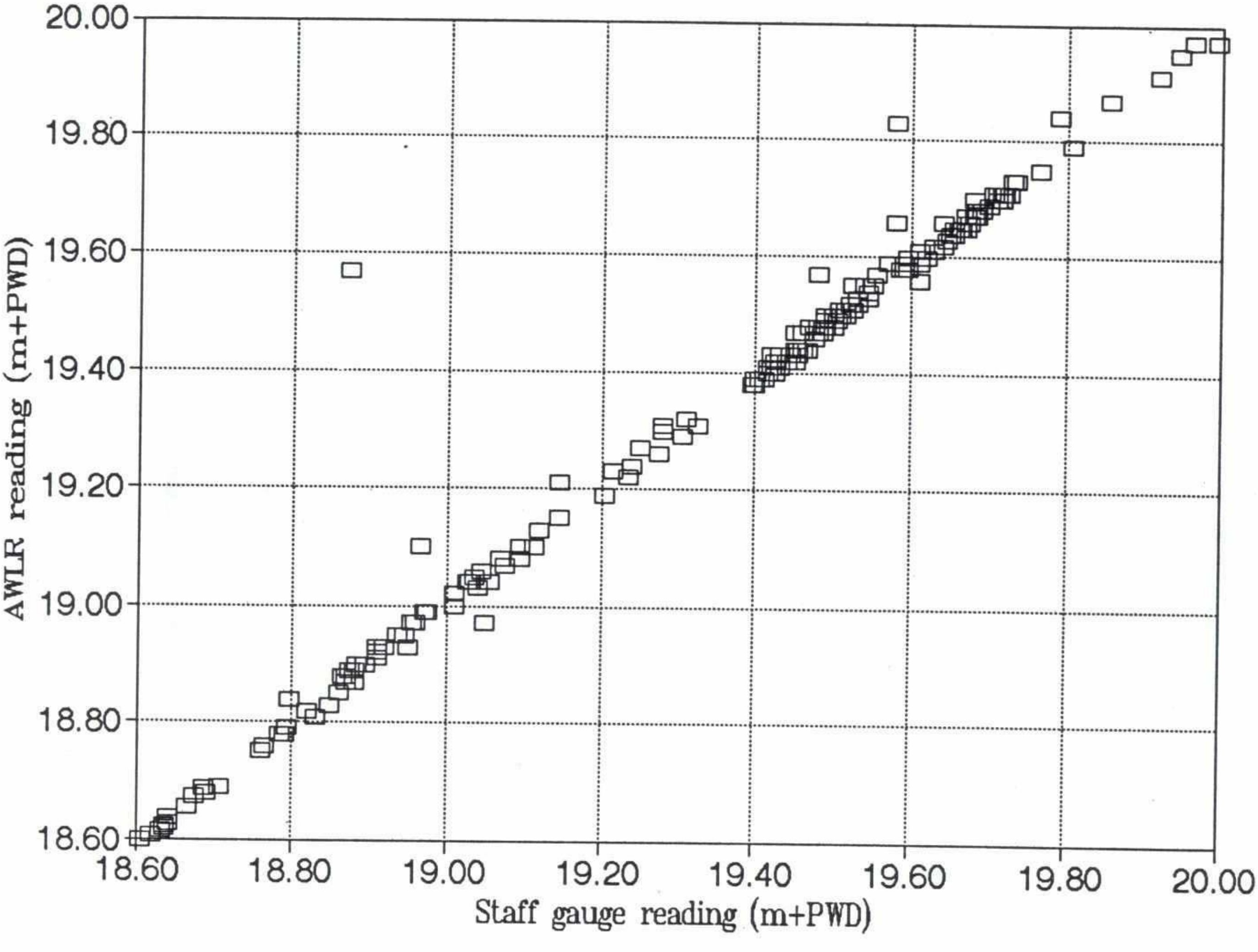

Figure 62: Comparison of raw data between acoustic sensor record and staff gauge record at Gabgachi station from 16 July to 31 August 1993

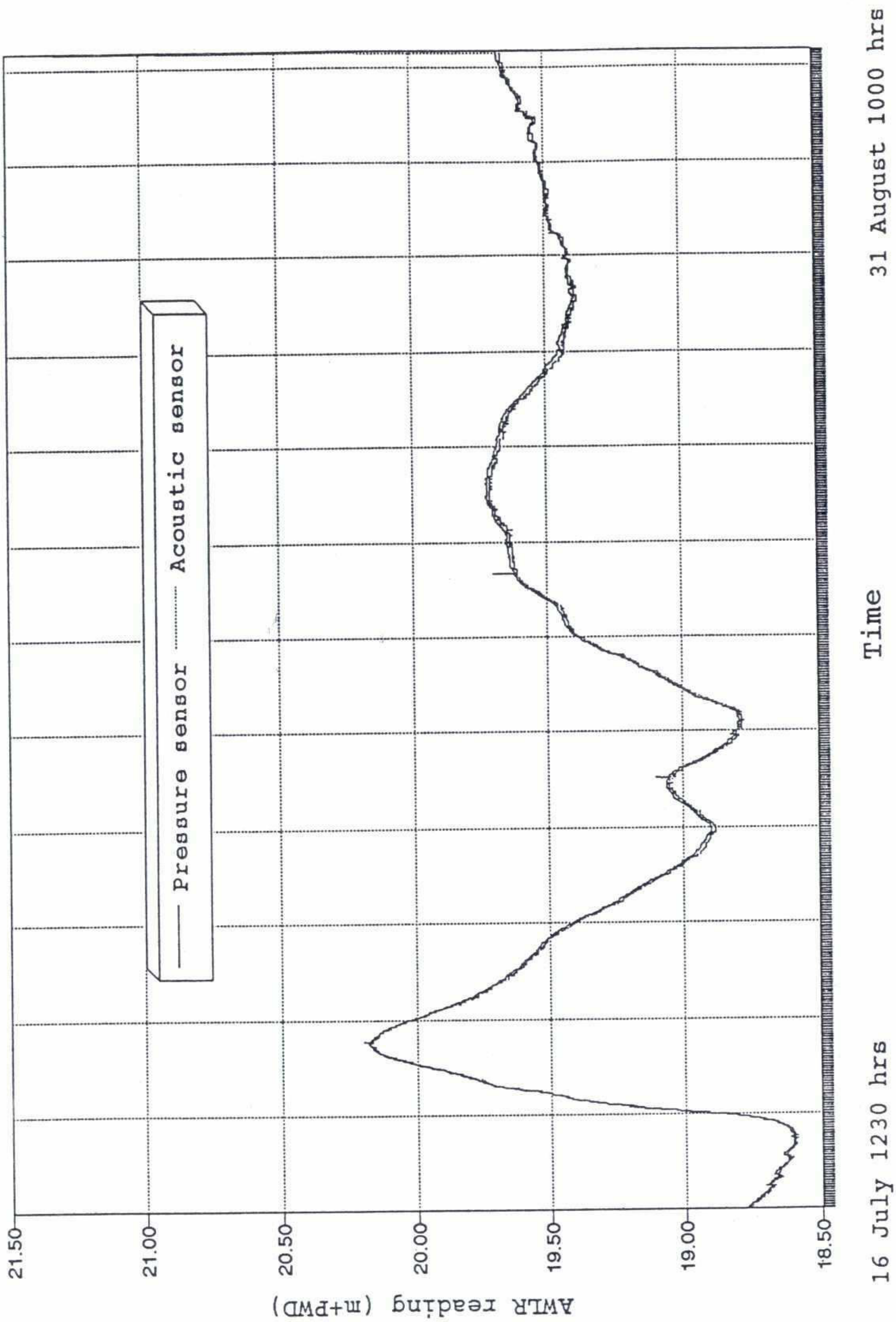

Figure 63: ½ hourly acoustic and pressure sensor record at Gabgachi from 16 July to 31 August 1993