Need assessment and detailed planning for a harmonious hydrometeorology system for the Sundarbans

Part – III

SPECIFIC REQUIREMENTS:

SEA LEVEL STATIONS, WEATHER STATIONS & LOGISTICS

The inadequacy of hydro-meteorological set up in Sundarbans spreading over India and Bangladesh has already been discussed in detail. The present emphasis is on Regional Programme rather than country specific programmes since Weather patterns such as tropical cyclones, monsoons and severe thunderstorms are trans-boundary and best monitored, understood and predicted from a regional and global perspective.

As indicated by the World Bank (http://www.worldbank.org/en/region/sar/brief/south-asia-hydrological-and-meteorological-hydromet-resilience-program) that 'Regional collaboration builds up on already existing information and forecasts rather than investing in new capacity. This approach fosters learning and innovation in the development and delivery of weather, water and climate information based services.' This approach has been kept in mind at the time of preparation of this document.

Hydrology Section

Background consideration for installation of Permanent Tide Gauge Stations in Sundarbans

5th IPCC report has indicated that Sundarbans is one of the most vulnerable areas in the world so far as Sea Level Rise (SLR) is concerned. IPCC has predicted that since the general ground level of Sundarbans is comparatively lower with respect to Mean Sea Level (MSL), slight change in "Eustatic" level of the sea due to global climate change may inundate huge areas of Sundarbans. It is also well known that the entire Sundarban delta is subsiding due to geological reasons and thus any change in sea level along Sundarbans may also be due to change in ground level as a result of subsidence.

The rate of sea level rise along Indian Sundarbans is completely unknown. All the predictions so far being made by IPCC is based on the permanent automatic tide gauge data in several tide stations in Bangladesh Sundarbans. All these stations are along the southernmost part the Sundarbans and along the estuary boundary with open sea which record data presumably through automatic sea level gauges over a considerable period of time, although data from these stations are sometimes not sent to PSMSL. Thus, changes in sea level rise along the Bangladesh part of Sundarbans are to some extent recorded, as has been clearly indicated in Part-I of this document.

In contrast to Bangladesh Sundarbans, no sea level gauge stations have ever been set up in Indian part of Sundarbans. Although about five numbers of tide-recording stations are there along Hooghly River, not a single one has its location in Sundarban. Moreover, most of these tide gauge stations record water level manually and cannot record data during night time. Kolkata Port Trust is looking after all the tide stations along Hooghly. Since, there is hardly any commercial vessel movement along Indian Sundarbans, the area is left out may be due to non-commercial and non-remunerative nature of the area.

So, it is high time to set up permanent tide gauge stations along the Indian Sundarbans. In case of Bangladesh part of Sundarbans, although the existing locations of tide stations have already been obtained from BIWTA and BWDB, but it is difficult to make any comment on the type of tide gauges existing in these locations, since no data has been provided regarding this either in any literature or in the respective websites of any of the agencies in Bangladesh. Moreover, it has come to the notice that Government of Bangladesh has been taking a sincere effort to upgrade the water level measuring stations (some of which are located in coastal zone and thereby tide gauge station in nature) and for that matter are now in the process of procuring and installation of about 60 (sixty) number of latest type of Radar Type tide gauge. Some of these tide stations will be expectedly installed in Sundarban region also. Thus, it is difficult to make any comment on future requirement of installations of tide gauge stations along Bangladesh part of Sundarbans without having a detailed knowledge about the ground reality. However, some generalised recommendations can definitely be made which will also be attempted in subsequent section.

Since, the sea level rise in Sundarbans is not only due to eustatic change in sea level but may be also due to change in ground level due to subsidence. It has already been discussed that the Relative Sea Level Rise (RSLR) is thus having two components: (i) Eustatic Sea Level Rise and (ii) Subsidence of the Ground Level. Both these two components are equally important for sustainability of Sundarbans as also future development and planning in this region. Interestingly, so far no initiative has been taken in both the countries to make an assessment of the subsidence of the ground level in Sundarbans. The best way to understand the amount of subsidence is to monitor the ground level on regular basis. It will be possible to monitor the movement of the ground only by placing a high end sophisticated DGPS set in each of the tide gauge platform so as to estimate whether the ground level is subsiding or not over a long period of time and also to estimate the quantum of subsidence on long term basis.

It is obvious that data output from these stations will be meaningful after a long time period say ten years and it is envisaged these data will be valuable for the scientists of the future generation and posterity. Thus, selection of locations of these tide stations is of vital importance. In case of Bangladesh, they have already installed four such tide gauge stations namely, Hiron Point, Khepupara, Charchanga and Cox's Bazar along West-East directions covering the entire sea facing islands. At the same time, they have set up three tide gauge stations namely Hiron Point, Mongla and Khulna over Passur River, one of the major estuaries in Bangladesh part of Sundarbans in a longitudinal direction perpendicular to the coast.

Bangladesh has built up all these facilities over a period of time. In case, the sea level stations in Sundarbans are augmented in a systematic manner now, scientists of India and Bangladesh as also from other parts of the world carrying out climate change studies and sea level rise can use these data from these stations. The site selection needs to be carried out judiciously so as to cover the entire Sundarbans (both India and Bangladesh) considering the availability of the already existing tide gauge stations in Bangladesh part of Sundarbans.

At the same time appropriate and state of art water level measurement instruments will also be required for accurate measurement of the water level along different estuaries running through Sundarbans. The following discussion is based on all these consideration with the objective of throwing light on different aspects of building up a strong network of measuring tide over the entire Sundarbans region in the coming days in a seamless manner.

Tide Gauge Equipment for installation in Sundarbans

Sea-level measuring instruments, initially known as tide gauges are now known today as sea level gauges. Most of the worldwide sea-level measurements available at present have been obtained from a variety of conventional and modern sea-level gauges. While the former were primarily designed for navigational and hydrographic survey applications, the modern sea-level gauges came into existence primarily as an effort toward improved measurements to observe the global climate change signal more accurately. These instruments at the same time are designed to make reporting in real time or near real time basis in designated website.

Advancement in technology and modernisation of techniques has resulted in progressively improved instrumentation for sea level measurements. In this effort, the Global Sea Level Observing System (GLOSS) of the UNESCO's Intergovernmental Oceanographic Commission (IOC) has played a key role, with the primary intention of obtaining high-quality sea-level measurements for studies of global climate change. The new-generation gauges have proved to be capable of recording even very weak changes in sea level, as indicated by different authors (Woodworth et al., 2005; Prabhudesai et al., 2008).

Different types of sea level measurement instruments are available in the market. In order to choose appropriate type of instrument, a brief discussion on different types of instruments, as available in the market and the technique being used for that has been discussed very briefly in the following section. International conventions used in sea-level measurements and various methodologies used for measurement of sea-level oscillations, together with the advantages and disadvantages of the different methods, are described so that the appropriate technology can be identified for developing a Hydro-met system for Sundarbans.

Chart Datum (CD)

Sea levels have been measured almost as long as human development. Sea level is defined as the distance of the sea surface above a recognized reference datum known as chart datum (CD). Thus, coastal and island sea-level elevations are always expressed with reference to CD. By international agreement, the level used as CD should be just low enough so low waters do not go far below it. The CD is, therefore, a safe low water level in order to maintain the minimum depth useful for guiding a vessel safely to port.

The device that carries out sea-level measurements with reference to CD has been conventionally called a tide gauge rather than sea-level gauge primarily because at most coastal locations the astronomically induced and topographically modified tide is the largest part of the sea-level oscillations for most of the time. The observed sea level can be viewed as oscillating about a mean sea level (MSL). These low-frequency oscillations in sea level are measured relative to the land, to which the benchmarks are permanently attached. For all nations the "datum of national levelling network" has been estimated from long-term sea-level measurements (Joseph A., 2011). The MSL is an important survey parameter because it is used as a reference level for heights. Although the sea level is being measured using different kinds of instruments, but in most of these measurements, tide staff readings have been used for setting the initial value for the recording devices and for periodic visual checking of the instrument readings. Tide staffs of various kinds and recommended ways of their uses are explained in the IOC manuals and guides (IOC, 1985; 1994; 2000; 2006; 2016).

Float-Driven Gauges

Float-driven gauge, or simply float gauge is the oldest standard recording instrument for automatic tracing of low frequency sea-level oscillations on graph paper is a mechanical device. In this device, sea level is detected by a “float” resting on the water surface that is confined within a vertical pipe known as “stilling-well.” The “well” is usually attached to a purpose-built in-water structure established in navigational ports. The stilling-well, which is set in the water and connected to the sea by an orifice, was conventionally used in most of the places worldwide for sea-level measurements.

However, in some countries (e.g., Japan) tide-wells of a different structure are also used (Satake et al., 1988), wherein the stilling-well is generally dug into a wharf and hydraulically connected to the sea through an intake pipe. An important component in this gauge is a cylindrical or conical float, which rests on the surface of the water within a large cylindrical pipe (7 to 15 m long) of 60 to 80 cm diameter with a tapered bottom end, known as a stilling well. The well is often attached to a vertical structure or a concrete wall that extends well below the lowest level to be measured. A hole located at the bottom end, whose diameter is 0.1 times that of the pipe, is known as an orifice. The orifice to well diameter ratio of 0.1 provides an area ratio of 0.01. By convention, the orifice is usually located at a point at least 1 m below CD and at least 1 m above the seafloor, after allowing for wave-induced fluctuations in sea surface elevation. This orifice forms a low-pass hydraulic filter that allows only the low-frequency oscillations within the well and suppresses the wave-induced high-frequency oscillations. By the action of this hydraulic filter, the float rests on an approximately quiet water surface. A float is used to detect the dampened motion inside the well, thus the name float-driven gauge. Usually the float is cylindrical or conical in shape, and its diameter is half of that of the well. The float, which is large enough to give sufficient force to overcome friction in the recording system, is weighted at the bottom so it floats upright and is balanced by a suitable mechanism that keeps its top clear of the water. This arrangement allows the float to rise and fall with the sea-level oscillations.

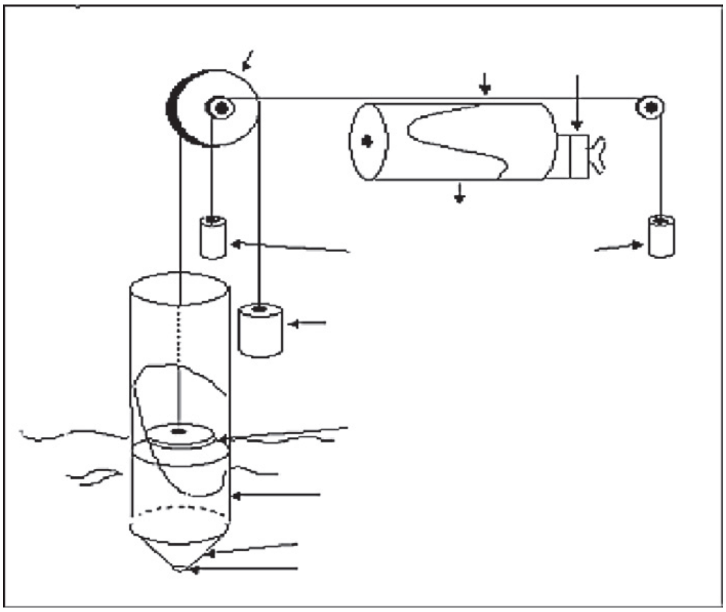


Figure – 1 : Recording of water level fluctuation using weight & drum

The float, which is attached to a counterweight via a taut flexible wire that passes over a pulley, energizes a pen via a set of gears. Alternatively, the float can also be linked to a sprocket wheel via a precisely perforated metallic band. As the float rises and falls with the tide, the pen moves back and forth on a sheet of paper rolled over a cylindrical drum. A mechanical-clockwork drives this roll of recorder paper at a constant rate. While the clockwork gives the recorder paper a continuous motion in the X-direction (time-axis), the float drives the pen over the paper in the Y-direction (sea-level-elevation axis), thereby continuously tracing the sea-level oscillations on the graph paper in a repetitive manner.

Float-gauges have served the purpose of recording sea level fluctuation over a long period of time and are still in operation in most of the sea/water level measurement stations in Bangladesh. These conventional tide-well (stilling-well) systems are robust and relatively simple to operate. But, they are known to have a number of disadvantages, such as large size and difficulty in installing. Until recently, inaccuracies in sea level measurements were not a serious consideration, since the data records were primarily used for navigational and hydrographical survey applications, where an accuracy of 10 cm was considered sufficient. Further, these type of tide gauges suffer from inherent problems, including slow and nonlinear responses to large-amplitude short-period waves such as those associated with tsunamis and storm surges, as a result of which they respond differently to tides, tsunamis, storm surges, and so on. Also, the problem with Float-gauges is that the rise in level of water depends on the density of water and in an estuary it becomes problematic since the density of water varies largely during different seasons. Further, high sediment load in water leads to chocking of mouth of the orifice and/or the connecting pipe leading to chocking. Thus, this type of gauge needs regular maintenance and time to time calibration also.

Shaft Encoders and Microprocessor-Based Loggers in Float Gauges

Due to modernization of the instruments, in many places conventional mechanical recording portion has been replaced with **Marigram** with an electronic counterpart known as shaft encoder. This development eliminates the need for external gears and chain interfaces during installation. In a shaft encoder, the angular motions of the float pulley, resulting from the vertical oscillation of the water-level within the stilling-well, are converted into electrical signals. At preset time intervals, the signals are output to a data logger for storage of the time-tagged data in a convenient medium.

Data downloading or configuration can easily be done directly using notebooks, palmtops etc or even through remote control and data transmission via serial modem (land line), GSM (cellular), and so on. This allows communication worldwide also. However, the inherent problems, as mentioned above, still persist even after this technological modification.

Electric Step Gauges

An electric step gauge is a combination of the age-old tide staff used for visual reading of sea-level with reference to CD, and the resistance-wire gauge (Ayers and Cretzler, 1963) that provides an electric output. In the electric step gauge, a row of horizontal electrodes mounted on an electric insulator staff that is vertically driven into the seabed is used to detect the position of the water surface. The electric step gauge works on the principle that if an electrode at the end of an insulated wire is submerged in water, the electrical resistance to the water is significantly lower than that when the electrode is above the water surface. This allows detection of the water surface with reference to the level of the highest submerged electrode while scanning the electrodes from the top of the staff to its bottom. In this device, the electrodes, normally made of manganese bronze, are scanned at a fast rate (at least twice every second) and averaged in real time to yield tidal height records free from the disturbances of wind-waves. Though the electrodes are usually 5 cm apart, the averaging process permits measurements of tidal heights with a resolution better than 0.5 cm in most applications (Botma and Leenhouts, 1993). An advantage with the electric step gauge is that it is installable on simple mechanical structures and does not require hydraulic damping devices for waves. Because the measurements are digital, it is more or less free from drift effects and temperature influences.

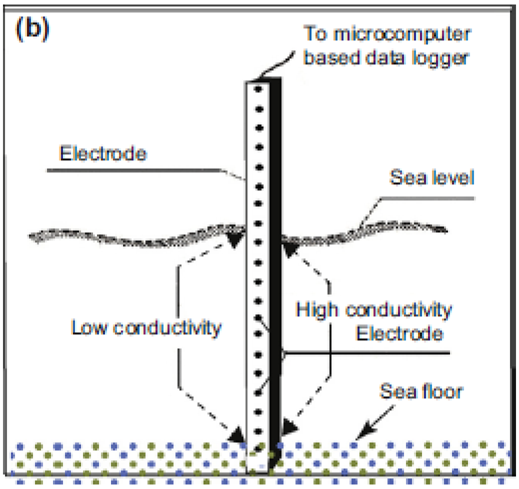


Figure – 2: Mechanism of Electric Step Gauge

A source of error associated with the electric step gauge, however, is water piling at the gauge staff due to flow and waves. Also, a layer of thick oil on the water surface, a possibility in oil berths, can be a serious impediment to the reliable functioning of this gauge, since it inhibits proper electrical contact of the electrodes with seawater.

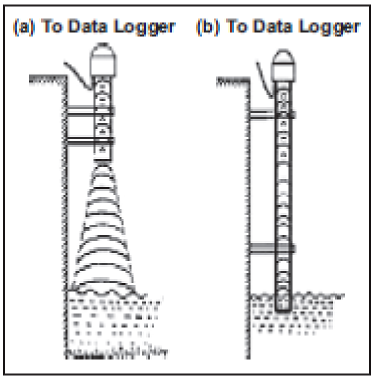
Air – Acoustic Gauges

Air-acoustics for sea-level measurements are based on the use of sound wave transmission through air and subsequent reception after reflection from the air-water interface. An air-acoustic gauge estimates sea-level using time-domain reflectometry technique. In this method, the vertical distance, D, between the sea surface and the face of a piezoelectric transducer that is positioned in the air is estimated by measuring the average time elapsed between transmission and reception of a series of acoustic pulses. The value of D is estimated from the measured elapsed time and the known or assumed value of the velocity of sound in air. The acoustic transducer is rigidly mounted at a known datum above the highest expected water level. Sea-level elevation is estimated by subtracting the measured distance from this datum level, which is usually the CD.

In operation, a piezoelectric transducer transmits a series of acoustic pulses vertically downward. The pulses are reflected by the sea surface and are returned to the transducer, which converts them into analogous electrical pulses. The electronic circuitry associated with the transducer determines the average time interval, t, elapsed between emission and reception of the pulses and measured the distance D with the help of assumed or measured velocity of sound at that point.

Although there is a self-calibration technique, but that does not account for variations in sound velocity between the fixed reflector and the sea surface. Thermal expansion of the calibration tube also introduces uncertainty because the stability of calibration relies on the stability of the calibration length in an operational mode.

There can be two different types of Air-Acoustic Gauges – (i) Unguided and (ii) Guided. In case of unguided type, the acoustic transducer mounted vertically above the sea surface produces unguided signals. But this type of gauges produces many problems like the amplitude of acoustic energy reflected back to the acoustic transducer varies considerably with changes in the angle of the liquid surface relative to the axis of the acoustic beam, such as that caused by waves and swells. At angles exceeding about 20 degrees from the vertical, the signal return from the water surface, due to scattering and absorption, can be below the lowest signal-to-noise ratio that is acceptable for reliable measurement of water level. Thus, there can be data gap in recording. Further, an unguided acoustic signal path may suffer from missing pulse returns from a wave-laden sea. Floating debris can also interrupt the acoustic path.



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Guided Air – Acoustic Gauges on the other hand has a long and narrow sounding tube that is protected by a stilling-well. Several problems with the unguided air-acoustic gauge can be circumvented by guiding the acoustic pulse along this sounding tube. Flow- and wave-induced errors arising from the use of a sounding tube are reduced by attaching a suitable hydro-mechanical front end at the lower end of its protective well. Although this method seems to be encouraging, there are some inherent problems. There is a possibility of systematic errors in sea-level measurements using a guided air acoustic gauge since it appears to be trapping lower-density water in its long and narrow sounding tube. The air-acoustic gauge's long and narrow sounding tube, in the present form, is devoid of any lateral perforations on its submerged portion and therefore can trap a lower-density water body even if there is good mixing within the protective well. Errors arising from temperature effects and trapped fluid in the sounding tube would be concerns when considering the overall accuracy attainable from guided air-acoustic gauges. There are other problems also.

Subsurface Pressure Gauge Systems

Due to some inherent problems in using different types of tide gauges, IOC has recommended the use of subsurface pressure sensors as backups to the microwave radar gauges because of their ability to record sea-level changes that exceed the limited height of the radar sensor. Also, sea-level measurements by subsurface pressure sensors are not deteriorated by objects floating on the sea surface. Most importantly, subsurface pressure sensors have advantages such as the ability to be sampled at a higher rate, linear response to large-amplitude waves such as tsunamis and storm surges, and reasonably good accuracy, except in heavily suspended sediment-laden water bodies (Joseph et al., 1999c).

The basic principle followed for estimating sea-level elevation using subsurface pressure sensors is to measure the hydrostatic pressure, P_d at depth d below the sea surface and to convert this pressure to the water level above the pressure inlet of the transducer by using the relationship:

$$P_d = P_a + (p \text{ X } g \text{ X } d)$$

where P_a is the atmospheric pressure, p is the mean density of the overlying column of water, and g is the local acceleration due to gravity. The measured pressure varies as the sea level varies. The subsurface pressure may be transmitted to a shore-based recorder through a narrow tube.

Local dynamic effects such as flows, waves, and a combination of both that operate in the vicinity of the pressure inlet influence the performance of a pressure-based sea-level gauge. Pressure measured by a pressure transducer is always relative to a reference pressure. There are three types of pressure transducers which are being commonly used: absolute, differential, and gauge pressure transducers. In a pressure transducer based sea-level measurement system, frequent pressure samples are averaged over duration of a few minutes to reveal only the low-frequency changes in the sea level. This rapid sampling and averaging technique removes wave-induced fluctuations from the sea-level data without the need for a stilling-well.

In an “absolute” pressure transducer, pressure is measured with respect to a vacuum reference (i.e., zero pressure) chamber. Such a pressure transducer, which is used for sea-level measurement, has only one pressure port and senses the total pressure (i.e., atmospheric pressure plus pressure due to the water column present over the submerged transducer). The absolute sensor has an advantage that a vent tube is not necessary. The disadvantage, however, is that the atmospheric pressure must be independently and accurately monitored and it must be subtracted from the absolute pressure measurement to compensate for the error in water pressure measurement due to temporal changes in atmospheric pressure.

A "differential" pressure transducer detects the difference between the pressures applied at its two ports. Two classes of differential transducers include "sealed" and "vented" types. A sealed reference is generally used in applications where the reference port cannot be vented to a desired external pressure reference or where the external environment is not suitable. In this case, the reference pressure cavity of the transducer is sealed at a desired pressure at the time of manufacture. For example, sealed differential pressure transducers have been successfully employed in seafloor-mounted gauges for deep-ocean measurements of low-frequency sea-level oscillations.

Figure – 4: Typical structure showing the subsurface Pressure Gauge

"Gauge" pressure is a form of differential pressure measurement in which atmospheric pressure is used as the reference. A gauge sensor has one face of the pressure diaphragm exposed to the measuring fluid pressure and the other face exposed to atmospheric air pressure. Accordingly, in a gauge device the (–ve) port is vented to the external atmospheric pressure, and the (+ve) port is exposed to the total pressure (i.e., water pressure + atmospheric pressure). The output of the gauge pressure transducer provides a signal representing the pressure difference at the two ports. Because the differential characteristic of the gauge transducer cancels out the contributions from the atmospheric pressure, it automatically removes measurement errors arising from changing atmospheric pressure conditions.

Different types of Pressure Gauges are now being used for measurement of sea levels, such as Hydraulic Coupling Pressure Ports, Venting Gauge Pressure Transducers, Strain Gauge Pressure Transducers, Metal-Alloy Strain Gauge Pressure Transducers, Silicon Thin-Diaphragm Strain Gauge Pressure Transducers and so on. However, the basic principles remain the same. Each type of pressure transducers has some advantages over the other and also at the same time some negative points. But, any/ all kinds of pressure gauge system will have limited application in Sundarbans, since in all cases, the transducers are subsurface in nature and remain in water. In an estuary with huge suspended sediments, the sediments will be deposited on the submerged transducers and will make it ineffective, if being used continuously over a long period of time.

Since in the present case, the tide gauges to be installed are expected to work over a long period of time, deployment of any kind of pressure gauge in Sundarbans is simply ruled out.

Downward Looking Aerial Microwave Radar Gauges

Downward Looking Aerial Microwave Radar Gauges normally known as microwave radar gauge is perhaps the best option and most appropriate for continuous sea level measurement in Sundarbans. The microwave radar gauge represents an alternate noncontact device that is capable of remote measurement of sea-level elevation from the air. The basic principle involves transmitting microwave pulses toward the sea surface and receiving the reflected/backscattered microwave energy. The reflected micro waves are analyzed to estimate the two-way distance travelled by a given pulse. The operation of this device is based on the time-of-flight principle used with the air-acoustic gauge. The time of flight can be determined by measuring the phase of the return wave and knowing the frequency of the microwave signal that was transmitted. Further, the time of travel can be measured using the well-known digital sampling techniques. Depending on the device model, the transmission frequency ranges from almost 10 GHz to almost 24 GHz, and the beam width is almost ±5 degrees (for example, OTT microwave radar designed for sea-level measurement application operates at about 24 GHz; wavelength = 1.25 cm). Microwave signals in the form of linear sweep (chirp) are normally used for achieving better precision in distance measurement. The microwave-level gauge typically includes a microwave feed-horn directed on the sea surface, electronics housing spaced apart from the feed-

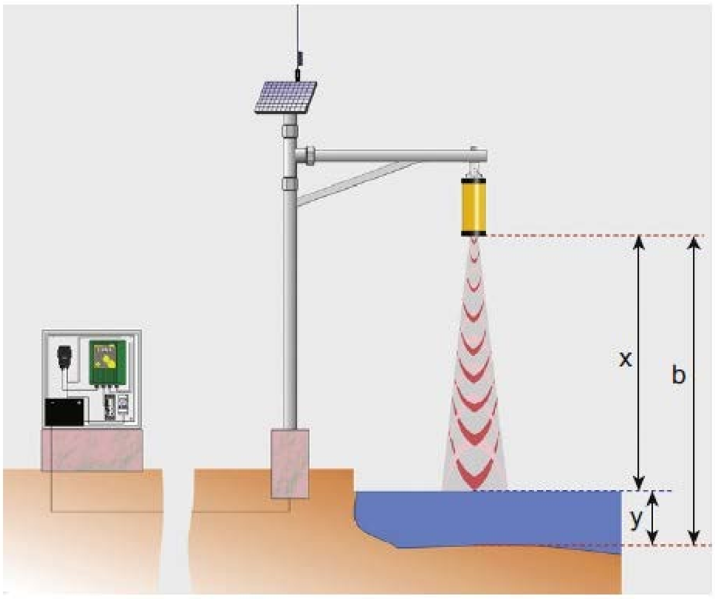


Figure – 5: Downward Looking Aerial Microwave Radar Gauge

...nd the feed-horn for carrying ...te cabling can also be used as a substitute for the wave-guide.

A microwave transducer in the housing couples to the wave-guide and sends and receives microwave signals. A microprocessor in the housing measures the distance x in air based on a microwave echo from the air-water interface and a microwave echo from the feed-horn. A known microwave distance measurement technique is frequency modulated continuous wave (FMCW), in which the transmitted microwave signals are mixed with the signals reflected from the sea surface to determine the phase shift between the two waves and thereby the range. Some FMCW radar gauges are capable of sampling sea levels as rapidly as subsurface pressure gauges can. In another method involving Fourier analysis, any target within the microwave beam shows up in the output spectrum. This includes the end of the antenna that is transmitting the microwave beam. The microprocessor compensates for the effect of propagation delay through the wave-guide on distance measurements by using the feed-horn echo as a reference signal. By dynamically compensating for errors arising from variations in the length of the wave-guide due to temperature changes or other factors contributing to length variations, the gauge is expected to provide superior performance even under adverse environmental conditions. The water level y with reference to a preferred datum (e.g., CD or harbor datum) is estimated from the known vertical height b of the sensing plane of the sensor head from

Figure – 6: Platform for setting up of Downward looking Microwave Radar Gauge being constructed at Bangladesh

the chosen datum. Wind-induced high frequency oscillations on the sea-level are filtered out with the online application of an integrated software filter. The microwave radar gauges can be installed from coastal jetties, bridges, harbor piers, or offshore platforms with relatively fewer logistical problems. The measurements can be transferred to a data logger by suitable means over distances of up to 1 km or even be uploaded to internet using mobile phones etc.

The main advantage of the microwave radar gauge over the air-acoustic gauge is that the electromagnetic transmission/reception signal used in the former is independent of variations in site conditions such as air temperature, humidity, and rainfall. The accuracy of sea-level measurements using the microwave radar principle is claimed to be within ±1 cm over the complete measuring range (Joseph, 2013). Improved microwave signal processing methodologies are still evolving. Competing manufacturers continue to contribute significantly toward such improvements. For example, one of the unique features of Saab Marine Electronics' technology is claimed to be the incorporation of Fast Hardware Adaptive Signal Technology (FHAST) method, whereby the microwave signal is passed through a digital hardware filter that removes irrelevant signals and background noise from the sea-level signal (Terdre, 1995). Another important benefit is the excellent stability of the sensor that exhibits virtually no drift; in other words, there is negligible variation in the signal for the same known distance in the case of varying environmental conditions such as temperature change and over the long term as the sensor ages.

Bangladesh

From an operational point of view, an advantage with the noncontact measuring principle used in the microwave radar gauge is that problems such as disruption of measuring operation caused by high water, silt accumulation, debris, plant growth, and so forth, as well as time-consuming maintenance, are reduced considerably. In the event of any maintenance requirement, the difficulty

involved is relatively less because of land-based operations. Because of its compact design and the noncontact measuring principle, the gauge can be installed easily and inconspicuously, without the use of cumbersome stilling wells/ protective-wells. Further, the device is particularly suitable for areas where conventional measuring systems cannot be used or where a station needs to be set up quickly and inexpensively. Because the gauge does not come into direct physical contact with water, it is particularly useful for measurement from locations where the water contains a large amount of suspended matter (e.g., Hugli Estuary, Sundarbans).

Based on a one-year test at Liverpool over a wide range of weather conditions and tides, Woodworth and Smith (2003) made the following observations on the microwave radar gauge:

- Relatively low cost and ease of installation and maintenance (no need for divers or stilling-wells, etc.) make them attractive.
- Fully digital (so can be "real time").
- Accuracy approximately 1 cm as claimed.

This accuracy is consistent with the accuracy required for sea-level measurements for global networks.

Figure – 8: Tide Gauge Tower with Radar Gauge Type in Bangladesh

Radar gauges encompass a new technology. Nevertheless, experiences so far are generally favourable – at least with several renowned company make tide gauges like OTT Kalesto radar gauge that has undergone performance evaluation tests in several waters. Because radar technology has advantages over other types of gauges in ease of installation and maintenance, their findings suggest that radar has to be given strong consideration in future applications, especially at locations where variations in water density preclude the effective use of pressure systems.

Perhaps, a meritorious feature that can be attributed to radar gauges is their suitability for measuring large sea-level oscillations such as those occurring during tsunamis. However, this feature can be achieved only if the gauge is suitably installed, taking this requirement into consideration. For example, the measurement range of the Kalesto radar is 1.5 to 30 m.

However, the footprint of the beam increases as the distance of the radar from the sea surface increases. Thus, the greater the distance between the radar sensor and the sea surface, the greater the safety distance between the centre axis of the radar beam and the wall of the jetty where the gauge is erected. The recommended safety distance for the Kalesto radar (radiation angle $\pm 5^0$) to achieve the full range of 30 m is 3 m, which is again quite long.

National Institute of Oceanography (NIO), Goa, India, has designed and developed microwave radar gauges incorporating Kalesto radar sensors and established several of them on the Indian coasts in a project mode along western coast. NIO developed a sensor namely RLS Sensor, based on OTT Kalesto radar sensor which seems to be more appropriate and easy to handle due to comparative light weight. It is specifically designed for use in open air locations that have no requirement for mains power supply like forested part of Sundarbans. The special flat antenna design construction and its minimal energy consumption make the RLS an economical, practical, and reliable alternative to conventional level gauges (Joseph, 2013). The experiences of NIO with microwave radar gauges are encouraging so far. Its insensitivity to changes in water quality parameters, such as turbidity and suspended sediments, and hydrodynamic parameters, such as flows and waves, is particularly useful when water-level measurements must be taken at locations that are prone to sudden water-level changes.

Figure – 9: Radar Gauge Tide Station at Finolex Jetty, Ratnagiri

Most of these stations were powered by solar power as can be seen from the radar gauge that was installed at Finolex Jetty, Ratnagiri, India. The data transmission was through Cellular GPRS connectivity and the power supply was by 12 Volt – 48 AH Lead Battery with Solar Panel for Charging.

Measurements using microwave radar gauges can, however, get severely contaminated by man-made lapses such as anchoring of floating objects below the radar sensor. Numbers of such incidences are known where floating objects, like boats etc have interfered with the continuous measurement. These incidents indicate the sensitivity of microwave radar gauges to floating objects and the importance of protecting the footprint area of the microwave radar from contamination by such objects if high-quality data are to be gathered.

Best Possible type of Tide Gauge to be installed in Sundarbans

A comparative study regarding authenticity of sea level data recorded by two different types of tide gauge namely pressure gauge and Microwave Radar Gauge has been carried out by National Institute of Oceanography, Goa, India during 2009-2011 along the western coast of India (Mehra et al, 2013). The basic purpose was to ascertain the reliability of newly introduced Microwave Radar Technology in sea level measurements as also a comparative analysis with regarding the consistency in reading with age-old technology of pressure gauge technology. This was also carried out to meet the GLOSS recommendations (IOC, 1994) to keep an overlapping period of at least 1 year to assess the reliability and accuracy of new equipment with enough data to make a comparison between the old and the new technology. The results pointed out that sea level

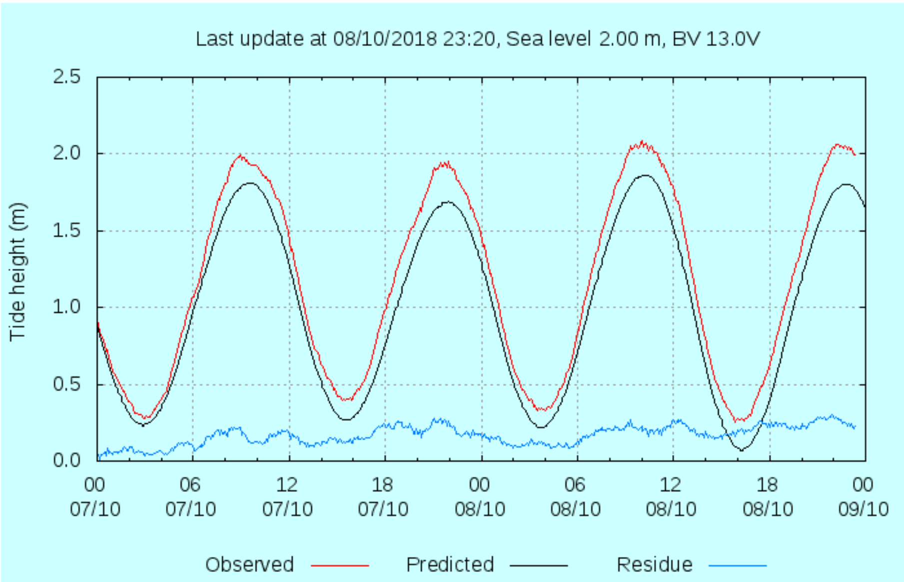


Figure – 10: On time display of tide data from Dona Paulo station in website of National Institute of Oceanography, Goa, India

measurement gauges based on Microwave Radar technology is equally reliable and consistent in nature. In subsequent projects with National Institute of Oceanography (NIO), Goa, Space Applications

Centre–Indian Space Research Organisation (SAC-ISRO) established a calibration verification of the Microwave Radar gauges and the technique of real time communication of the sea level from the Microwave tide gauges to the concerned website has now been standardized. The above figure represents the real time display of sea water level from the microwave radar gauge at Dona Paula. The three different graphs in three different colours represent the Observed water level, Predicted level and the Residue at this site at that moment. The residue indicates the difference between Observed and Predicted tide at that coast. Sudden changes in sea level due to natural calamities like tsunamis or storm surges can well be understood from such graphs when residue will quite high.

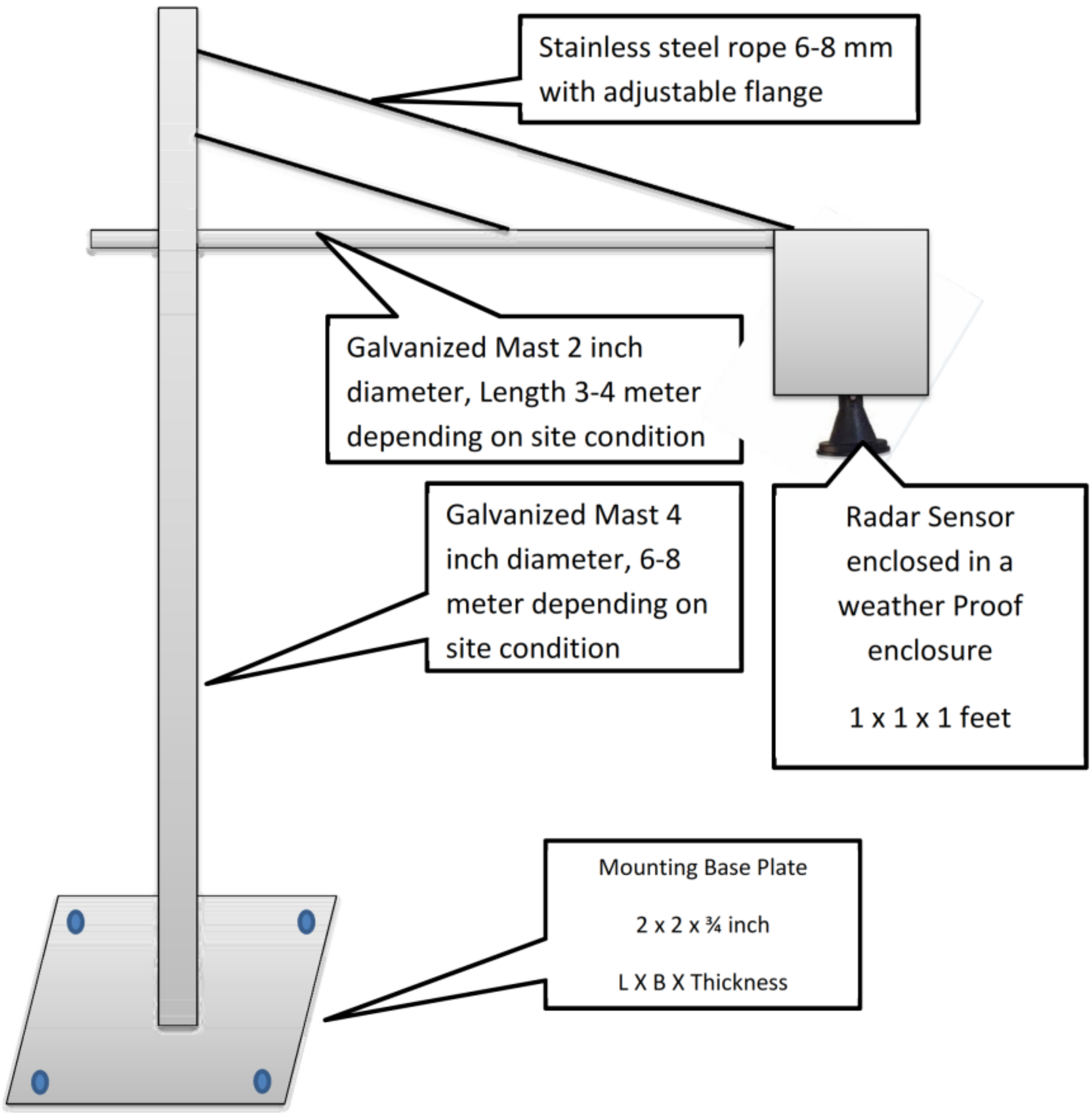
In muddy estuaries like Sundarbans, where suspended sediment load in estuaries is very high, subsurface pressure gauges cannot function correctly over a long period of time due to sediment deposition (Joseph et al, 1999). In such situations, as prevail in Sundarbans, microwave radar gauges have definite advantage since these can operate from above the water level in a non-contact basis. So, it will be better if the microwave radar gauges be considered for installations in Sundarbans to develop a robust hydro-meteorological network. Incidentally, BIWTA, Bangladesh is in the process of procuring 58 (Fifty Eight) such microwave radars for modernisation of its tide gauges and sea level stations, although it is not known how many of these will be set up within Bangladesh Part of Sundarbans.

A major advantage of the microwave radar gauge is that the electromagnetic transmission/reception signal used is independent of variations in site conditions such as air temperature, humidity, and rainfall. Further, from operational point of view, another advantage with the non-contact measuring principle embodied in the microwave radar gauge is that the performance of the radar gauge is not influenced either by the quality of the water (whose elevation it measures) or its dynamics (i.e., water currents, waves) and therefore problems such as disruption of measuring operation caused by silt accumulation, debris, plant growth and so forth, as well as time-consuming maintenance are reduced considerably. In the event of any maintenance requirement, the difficulty involved is relatively less because of land-based operations. Because of its compact design and the non-contact measuring principle, the gauge can be installed relatively easily and inconspicuously, without the use of cumbersome stilling-wells/protective-wells etc. Further, the device is particularly suitable for areas where conventional measuring systems cannot be used or where a station needs to be set up. Because the gauge does not come into direct physical contact with water, it is particularly useful for measurement from locations where water currents are large (e.g., Hoogly estuary, Sundarbans) and water contains a large amount of suspended matter (e.g., Sundarbans, Hoogly). Also, because radar gauge measurements are independent of atmospheric pressure variations, there is no need of establishing a Met station near to the gauge station.

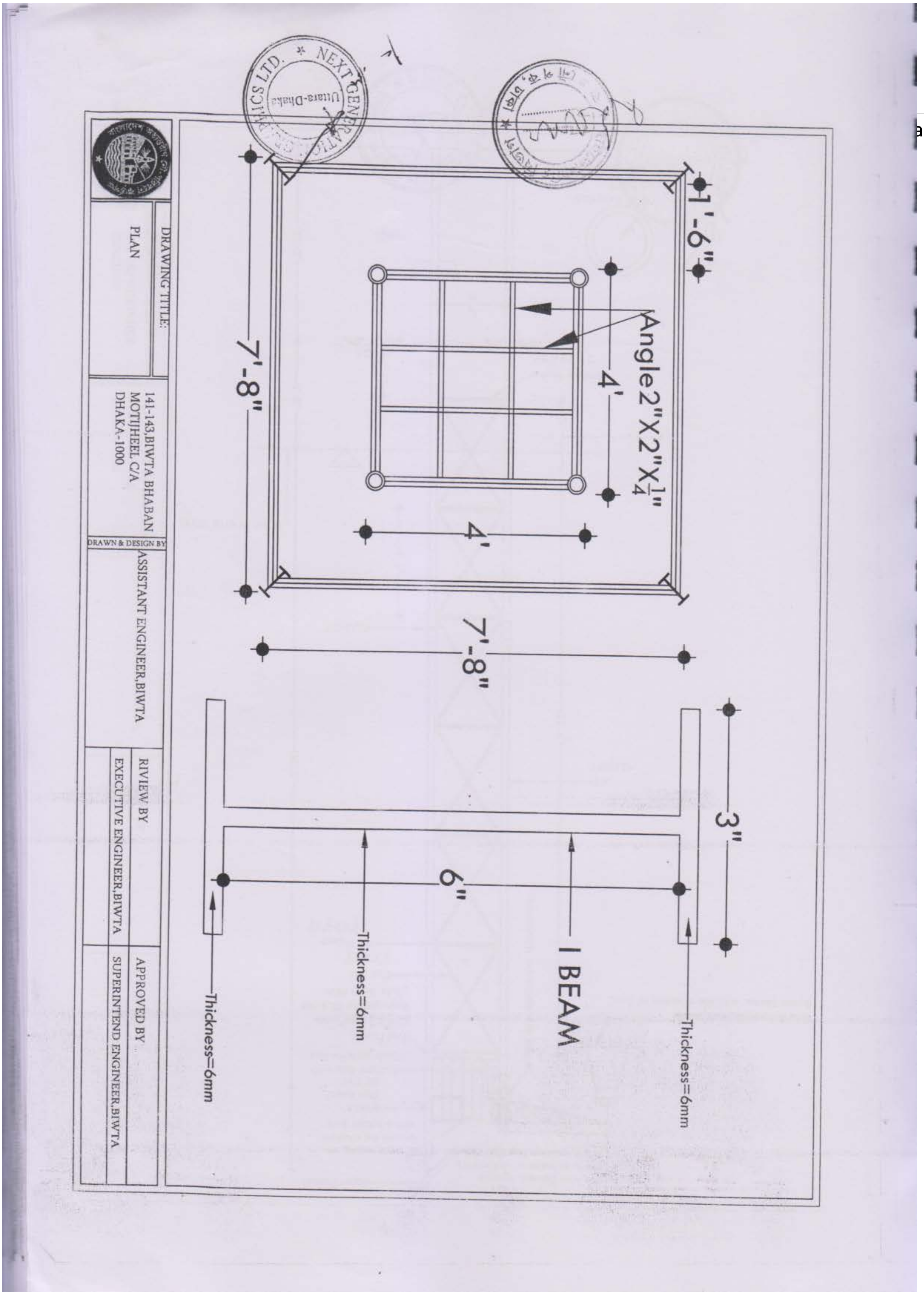
Brief introduction about the Tower Assembly for Installation

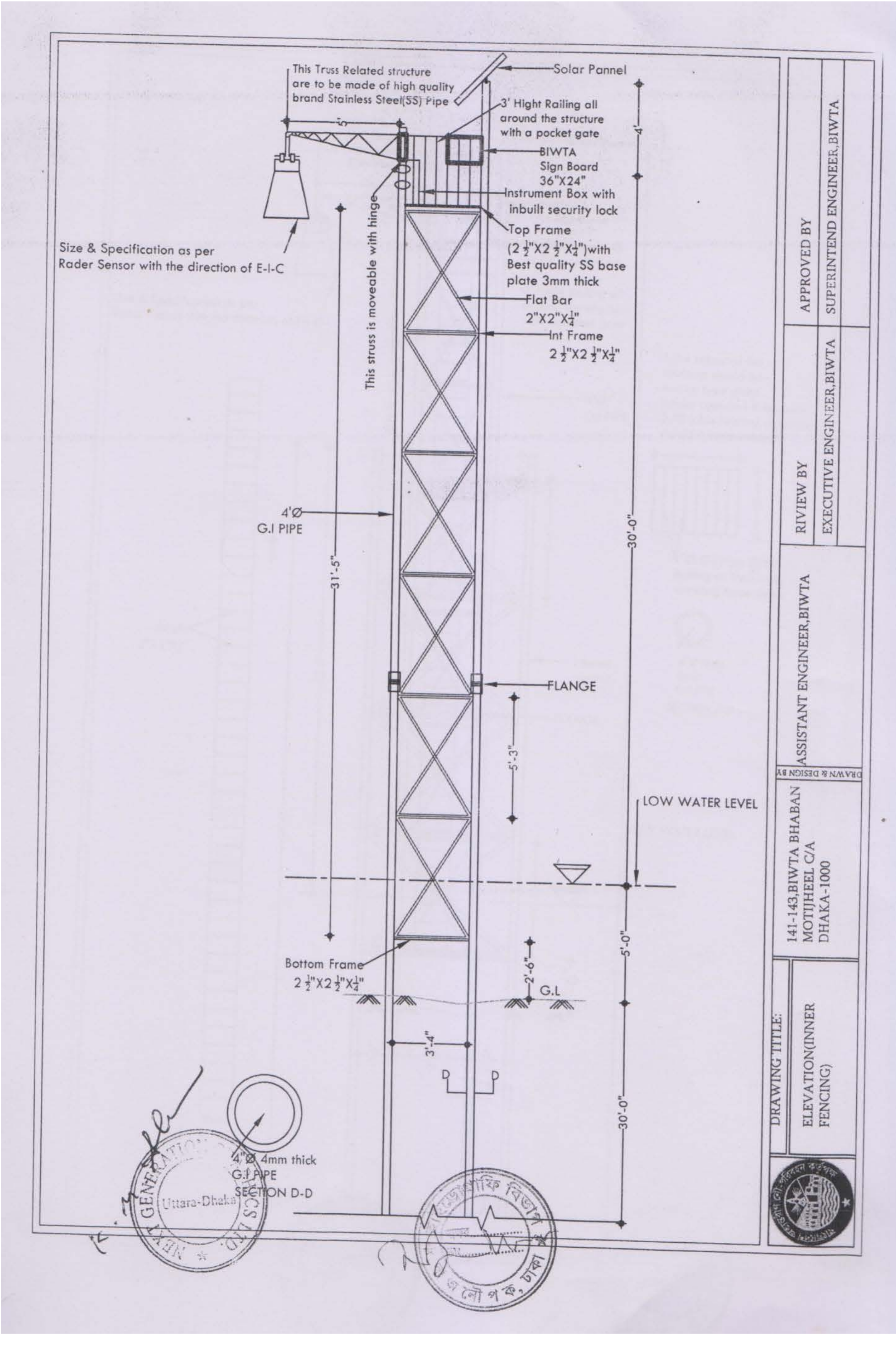
A schematic drawing for tower for installation of microwave radar gauge is placed below:

Figure – 11 : A schematic Drawing displaying Mast/ Cantiliver for Radar Gauge Installation



It has already been pointed out that longer the arm of the pillar, the greater the distance of the sensor from the shore to avoid interference from floating objects like migrating boat etc. But, there is also a limit to this. In case of long arm, there is always a possibility of vibration of the arm with high wind or even the arm can get inclined from horizontal position. Some of the structural drawings, based on which BIWTA, Bangladesh has been carrying on the present installations are given below:




This Truss Related structure are to be made of high quality brand Stainless Steel(SS) Pipe
Solar Pannel
3' Hight Railing all around the structure with a pocket gate
BIWTA Sign Board 36"X24"
Instrument Box with inbuilt security lock
Top Frame (2 1/2"X2 1/2"X1/4")with Best quality SS base plate 3mm thick
Flat Bar 2"X2"X1/4"
Int Frame 2 1/2"X2 1/2"X1/4"
Size & Specification as per Rader Sensor with the direction of E-I-C
This struss is moveable with hinge
5'
4'
31'-5"
30'-0"
4'Ø G.I PIPE
FLANGE
5'-3"
LOW WATER LEVEL
5'-0"
Bottom Frame 2 1/2"X2 1/2"X1/4"
2'-6"
G.L
3'-4"
D
D
30'-0"
4"Ø 4mm thick G.I PIPE SECTION D-D
APPROVED BY
SUPERINTEND ENGINEER,BIWTA
RIVIEW BY
EXECUTIVE ENGINEER,BIWTA
ASSISTANT ENGINEER,BIWTA
DRAWN & DESIGN BY
141-143,BIWTA BHABAN MOTIJHEEL C/A DHAKA-1000
DRAWING TITLE:
ELEVATION(INNER FENCING)
Uttara-Dhaka

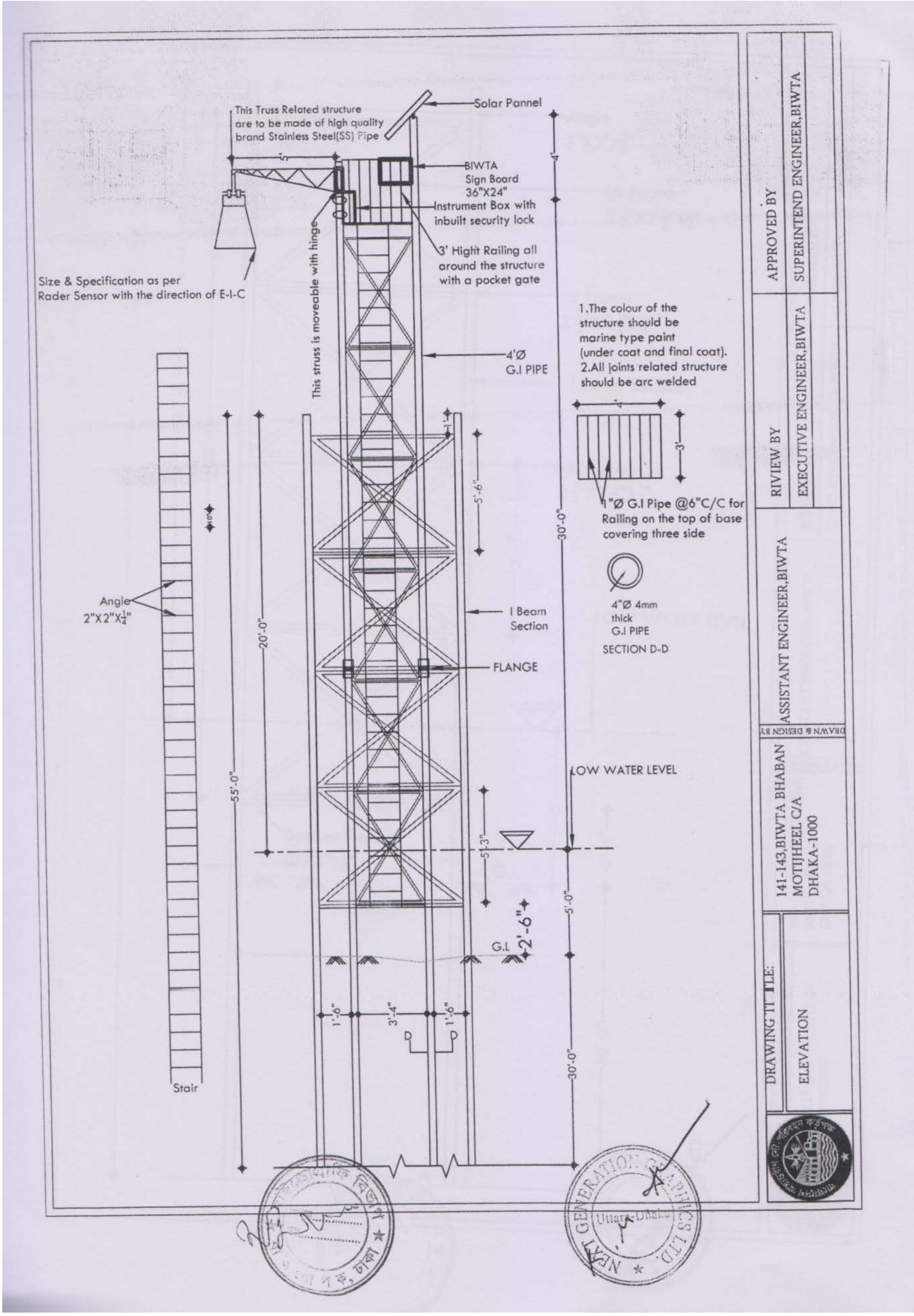


Figure – 11 to 14: Structural Drawings being used by BITWA for installations of Microwave Radar Gauges for sea level stations in Bangladesh

Figure–15: Photograph of the Microwave Radar Gauge Tower under construction in Bangladesh

Installations of Automatic Sea Level Measurement Stations in Sundarbans

Possible design of the assembly of the tower has already been discussed. For a smooth seamless hydromet system in Sundarbans, it is required to have a number of sea level measurement stations with facility of automatic recording and simultaneous communication on real time basis to designated server through telemetry. It has already been noted that data from these stations will be valuable to the scientific community after few years with a historic database so as to understand the relative rate of sea level rise along Sundarbans as also the quantum and rate of subsidence of the ground level accelerating the sea level rise in this part of globe. It would be possible to understand and delineate the entire physical phenomenon only if the locations of the sea level measurement stations be properly identified.

So far as Indian part of Sundarbans is concerned, only a number of tide stations are in operation along Hooghly River under the supervision of Kolkata Port Trust over a considerable period of time with historic database. Incidentally, Hooghly River marks the western boundary of Sundarbans and all the tide stations there need to be upgraded to Automatic Station with Microwave Radar Gauge sensor and telemetry so as to understand the state of affair along western part of Sundarbans. In case of other sea level measuring stations in Sundarbans, the stations should be located in such a manner so as to cover the entire latitudinal axis along the southern border of Sundarbans and at the same time longitudinal axis along the major rivers to understand the nature of tide as it travels inland. A detail survey is required before making decision regarding exact locations of sea level measurement stations. However, an attempt has been made to indicate the possible locations of these stations as below:

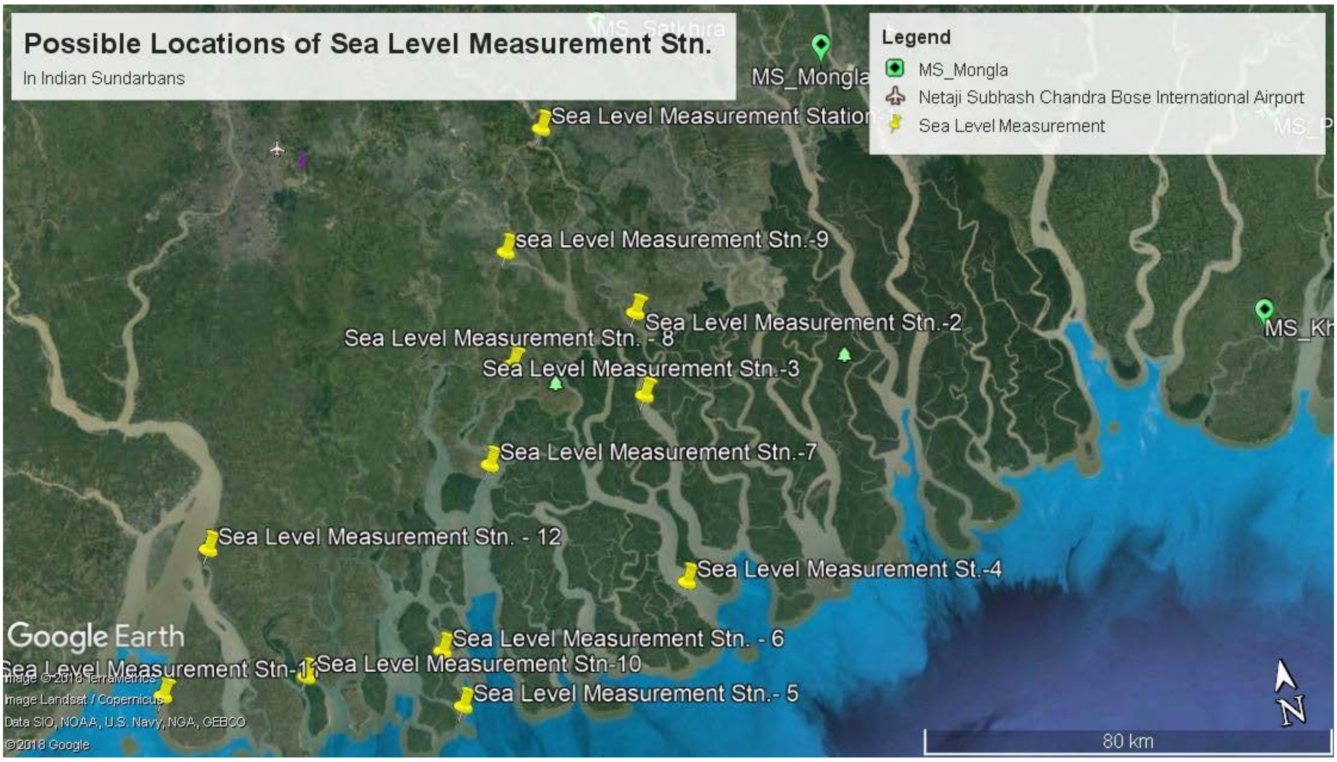


Figure – 16: Possible locations of the Sea Level Measurement Stations in Indian Sundarbans

Many other logistic parameters, like providing continuous security, availability of GSM / CDMA facilities for continuous communication of data are also equally important. A detailed scientific study needs to be conducted for finalisation of the locations of these stations along

Sundarbans. A knowledge based organisation like National Institute of Oceanography, Goa who are having sufficient knowledge regarding installations of sea level measurement stations and at the same time well aware regarding the requirement of data for estimation of sea level measurement may be entrusted for this job. A brief Terms of Reference (ToR) for this study has also been prepared as Annexure-1 for carrying out this study and knowledge based support.

Regarding Bangladesh part of Sundarbans, number of sea level measurement stations is in operation for quite long time. Most of these stations are systematically installed covering the entire longitudinal axis along specific rivers/ estuary. These stations are mostly 'Float Type' gauges. However, BIWTA, the nodal agency for looking after these stations are upgrading these stations and are in the process of procurement of 58 Microwave Radar gauges, which has already been noted. It is expected that the existing sea level measurement stations in Sundarbans will be upgraded with these newly procured instruments. Interestingly, there is hardly any sea level station along Baleswar River, the eastern boundary of Sundarbans. It is difficult to make any comment on the possible locations of the sea level measurement along Baleswar River, since ground reality is not known to the extent required for such work. But, the knowledge organisation, which will carry out the study regarding selection of sites for sea level measurement stations in India, may also cover the Bangladesh part as well to keep the requirement in the same tune.

A detail technical specification for procurement of microwave type sea level stations has been prepared and enclosed as Annexure-2. This is a draft generalised specification prepared based on looking at different brochures. So, it needs fine tuning by technical consultant(s) before actual procurement subject to the approval of the respective agencies at two countries.

Setting up of a DGPS Network in Sundarbans using Sea Level Stations

It has already been described that apart from climate-change-induced sea level change, any change in sea level in the Sundarban and its neighbouring regions may also be due to change in ground level as a consequence of the subsidence of Sundarban delta due to geological reasons. Based on this consideration, the proposal to put one DGPS set in each of the tide gauge platforms to examine whether the delta is sinking and to estimate the quantum of subsidence over a period of time on long term basis. A detail discussion on this aspect with technical details is presented below:

GPS Monitoring for measurement of Land Subsidence in Sundarbans

The possibility of land subsidence due to compaction of sediments as well as subduction and tilting due to neo-tectonic movements along Sundarbans have been discussed at length by different authors as also in the Part-I of this document. Such subsidence of land has definite impact on SLR resulting in higher eustatic sea level. In order to understand actual sea level rise along Sundarbans, the component of SLR due to land subsidence needs to be understood at different points. In order to understand this component, a network of sophisticated DGPS with triple frequency is being proposed along Sundarbans and is discussed below:

Continuously Operating Reference Stations (CORS) for Sundarbans

A continuously operating GPS reference station - or permanent reference station as it is often called - comprises a GPS receiver and antenna set up in a stable manner at a safe location with a reliable power supply. The receiver operates continuously, logging raw data, perhaps also streaming (continuously outputting) raw data, and often outputting RTK (Real-time kinematic positioning – a satellite navigation technique) and DGPS (Differential Global Positioning Systems) data for transmission to RTK, GIS and GPS navigation devices. The receiver is usually controlled by a computer that can be located remotely if necessary. The PC will usually download data files at regular intervals and pass them to an FTP server for access by the GPS user community.

Number of single reference stations supplying GPS services to different receiving sets or Rovers at different tide stations in the immediate surrounding areas of Sundarbans may be all that is required in this case. However, during implementation of the scheme, it may be needed even to establish networks between different reference stations - perhaps 3 to 4 or even more stations - to provide complete GPS services over entire Sundarban regions covering both the countries. A single server (computer) running a GPS reference station software and communicating by telephone, LAN, WAN or Internet can control all the stations, both Reference stations in the network as also Rovers to be augmented on individual tide stations.

This brief introduction illustrates that reference stations and the network can vary considerably in extent and complexity, depending on many factors like desired accuracy in measurement of coordinates, sophistication and cost.

GPS Reference Stations

Interestingly, the first reference stations, in the days when GPS was in its infancy, were set up along coastlines to transmit DGPS corrections to improve the accuracy of ship navigation.

Today, with the widespread acceptance of high-precision GPS measurement techniques, GPS reference stations are being established all over the world in ever increasing numbers. They are used to monitor the Earth's crust, to provide geodetic control, to support surveying, engineering, GIS data collection, machine control and precise positioning, as well as to monitor crustal movement. GPS reference stations provide the control needed for a wide variety of applications.

Geodetic control for surveying, mapping, navigation cadastre etc.

A network of continuously operating GPS reference stations along with the rovers is more efficient than a traditional triangulation and traverse network. It has been considered that the 3 to 4 reference stations may be set up in the inhabited islands of Sundarbans of both the countries. However, more detail survey and study needs to be carried out before finalization of the locations of the Reference Stations along Sundarbans.

Network geometry is not as critical as with traditional networks, and the accuracy is higher and more consistent. The field receivers (or Rovers) will be set up over the platforms in the tide Gauge stations along the estuaries, as already discussed. There can be an option that these individual rovers in each tide stations under different authority may download reference station data via the Internet, and compute their positions. The reference stations can also transmit RTK and DGPS data for direct use by RTK and GIS field rover equipment or even for other purposes like navigation of ships etc.

Such a network can be of almost any size. Whilst one or two stand-alone reference stations may be all that is required for a specific area or region of Sundarbans, a multi-station network will usually be needed to provide full GPS service coverage for the entire Sundarban area covering both the countries.

GPS Reference Stations and its Utility

Normally, in regions where earthquakes are likely to occur, along major fault lines, and in areas of volcanic activity, networks of suitably positioned GPS reference stations are often used to monitor movements of the Earth's crust.

A central computer with reference station software controls the receivers, downloads data, and computes the network to determine the positions of the antennas. Movements can be analyzed.

GIS data collection

It is being envisaged that a joint committee or a commission similar to Mekong River Commission (MRC) will ultimately be operational to look after the environmental issues related with Sundarbans and provide different Hydro-meteorological information on Real Time Basis. In such a situation, such establishment is bound to use the Geographical Information System (GIS). It is expected that the GIS database along Sundarbans will be able to show and reveal many information, including water qualities at different points of Sundarbans on temporal basis, which is absent now. In that situation, such a network of Reference Stations will be of much use.

RTK and DGPS measurement techniques are widely used for updating the database, surveying new features, and re-surveying existing features to improve the accuracy of the data.

Endless possibilities

GPS reference stations provide the control and support needed by RTK and GIS rover equipment. GPS reference stations and networks can be used in many ways for many applications. Even for profiling different estuaries at different points over time using Echo-sounders and current measurements by ADCP, such a network of reference station will be used. It can be designed to be multi-functional to support a wide range of applications and a multitude of users including for navigational purpose with proper authentication. Thus, the permutations are endless.

Since, in this case monitoring of the crustal movement along entire Sundarbans will be carried out repeatedly for a long period of time, more than one permanent reference stations will be needed covering both the countries.

What does a GPS reference station or a network of stations have to do?

The GPS receivers at reference stations will run continuously. The raw code and phase measurement data are usually logged internally in files of specified length. Depending on the application, the file length can be set to any required value from a few minutes to several hours or even to a full day.

Reference station software running on a computer - the server - controls the receivers and downloads the data files at regular intervals. If required, the raw data can also be streamed continuously, second by second, from the receivers to the server. The reference station software running on the server converts the data to RINEX (Receiver Independent Exchange format) and produces compressed RINEX files. The RINEX files will pushed to an FTP server for easy Web access by the users and are also archived for safekeeping. Since, these data are in RINEX format, any kind of GPS receiver can use this data for resolution of ambiguity.

A server running reference station software can control a single receiver at a stand-alone reference station or an entire network comprised of many receivers. In case of a single stand- alone station, the computer will often be connected directly to the receiver. In case of a multi-station network, the server will usually be at a control center and connected to the receivers by telephone, LAN, WAN or Internet. In the present case, the server can handle multiple number of 'Reference Stations', which can reduce the cost. However, it will depend on the decisions of the authorities in two countries.

Once set up and configured, the stations and network will run fully automatically. However, there will be system supervisors, who will time to time log in, inspect the receivers and the network and make any changes that are necessary.

One of the major requirements along Sundarbans is to provide the data needed by real-time survey and GPS rover equipment. The receivers at the reference stations can output data in standard RTCM formats and in other proprietary formats (like Leica, CMR, CMR+) for transmission to and use by RTK and GPS field rover receivers. Communication for transmission of RTK and DGPS data will usually be by radio, high-speed wireless (GSM, GPRS, CDMA etc) or even by the Internet.

However, the major requirement in the present case is to monitor any movements within the network, especially the positions of the antennas of the Rovers set up over the platforms of the tide stations and it needs to be computed automatically at regular intervals.

Suitable Sites for Receiving Stations

It has already been discussed that for carrying out this work 3 to 4 Reference stations will be required – two in Indian Part and two in Bangladesh Part. However, when selecting exact location for continuously operating GPS reference stations, careful considerations of the following are required:

- The need for an open view of the sky
- No objects in the vicinity that could cause multipath
- No transmitters in the area that could cause interference
- How to provide a stable mount for the antenna?
- How to provide reliable power and communication?
- How to house and protect the equipment?
- How to ensure security against vandals and passers-by?
- Accessibility for inspection and service
- Cost, which is also important.

Open View of the sky is most important for a place like Sundarban, especially when the receiving set over the tide gauge station will be put inside the forest area. Receivers at reference stations will usually be set to track satellites down to 10° above the horizon (10° cut-off angle). For the present case, it may even be required to track satellites down to the horizon, i.e. to 0° elevation. This is particularly important for reference stations that will form part of a high accuracy geodetic network. The best, of course, is if there will be no obstructions at all above the antenna horizon. So, the best option is to put the GPS receiver above the height of the surrounding buildings, since the best option is to put the reference stations in inhabited portion away from the mouths of the estuaries for use in inland navigation also. However for the rovers to be set up in tide gauge stations, the antennas of the rovers need to be put in a height over the surrounding forest cover.

Obstructions can lead to loss of satellite signals and may also cause multipath (reflected signals). Multipath can have a negative influence on the quality of the data and, therefore, accuracy.

One way to make fully certain that a site is absolutely perfect for a geodetic reference station is to set up the receiver and antenna, log data for several days and then analyze the data using TEQC tool from UNAVCO (http://www.unavco.org/facility/software/preprocessing/preprocessing.html). This may be true for Reference Stations, but for the rovers there are other considerations since these are linked with the setting up of tide gauge stations also.

One of the most important tasks for setting up this network is the setting up of **Reference Station**. It is proposed that altogether Four Reference Stations will be required to cover the entire Sundarbans – two (Sagar Island and Jharkhali Island) in Indian Sundarbans and two (Koyra and Southkhali) in Bangladesh part of Sundarbans. In both the countries, the reference stations will be located to cover the western part and eastern parts of two segments of Sundarbans in two respective countries. However, with a proper joint committee or commission like Mekong River Commission, number of Reference Stations can be reduced even to three. In that case the reference station at eastern part of Indian Sundarbans may be able to cover the receiving stations at the western part of the Bangladesh Sundarbans. But, before considering this proposition proper diplomatic arrangements is required to take over regarding Sundarbans between these two countries.

Each reference station will serve the purpose of ambiguity resolution of the rover stations set up on the tide gauges within a radius of 50 kilometers of the reference stations. Thus the area covered by a single reference station will be approximately 7,800 km^2 and total area covered by these four reference stations will be around 32,000 km^2, which will be sufficient to cover the entire Sundarban and its impact zone covering both the countries.

Setting up of Reference Stations on Pillars

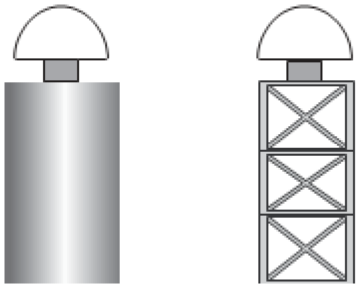
Well-constructed pillars with solid foundations, ideally on bedrock, will usually be preferred for stations that are to be used for monitoring movements of the earth. However, in case of Sundarbans, since there is a thick piling of sediments, it would not be possible to find out the bedrock. So, deep digging and making a broad concrete base of considerable thickness (as has been done by Geological Survey of India for constructing such Reference Station in Kolkata – Verbal Communication of the concerned geologist) may be the only option. The pillar will be placed over this concrete base.

If pillars are to be used the following should be considered carefully:

- How to provide reliable power and communication?

• Where to place the receiver, power supply and communication device?

• Security



Pillars can be of concrete or metal. In hot climates, very tall pillars could be liable to slight diurnal deformations caused by the heat of the Sun. However, chances of that kind of deformation is remote in case of Sundarbans, where the temperature seldom exceeds 40^0 C.

Figure–17: Pillar for Reference Station of GPS

The pillar needs to be suitably designed so that it may be possible to place the GPS receiver, power supply and communication device inside the pillar itself. Otherwise these items will have to be located in a suitable container, shed or nearby building. Although, it has been advised in some cases that air conditioning is necessary, but considering the climate of Sundarbans, even proper ventilation can work. However, it needs to be kept in mind that this instrument will work continuously for 24 hours and over a long period of time.

If the equipment can be placed in a nearby building, the required power and telephone connections will often be available. However, the buildings in the Sundarbans are hardly having any deep concrete piling, so the possibility of keeping this GPS in Reference Stations in buildings is simply ruled out. Since the equipment has to be placed in the pillar or in a container, special power and telephone lines may have to be arranged, which may increase costs significantly.

In case of Sundarbans, since the climate is mostly sunny in remote location, even for reference station, it is possible to arrange a bank of batteries with a solar panel charging system to power the GPS receiver and a communication device, such as a satellite phone or mobile phone

Unless the reference station can be set up within a secure area, a high fence may be needed to protect the equipment from vandals and passers-by.

GPS Receivers, GPS Antennas, Cable

<u>GPS Receivers</u>

Modern, universal, dual-frequency receivers are by far the most suitable for reference stations as they produce all types of measurement data (L1, L2, code, phase), generate all required outputs (RTK, DGPS, NMEA) and support every kind of application. However, in the present case, it is being proposed to use triple-frequency (L1, L2 and L5, code and phase) receivers for accuracy. In order to be able to provide the required services to different users at the same time in an optimum manner, it is best if the receiver can log data at high rates, continuously stream raw data, and also output RTK and DGPS data in all commonly used formats (RTCM, CMR, CMR+ and so on).

The receivers used at reference stations should have sufficient ports for:

- Connecting to a control computer running the reference station software
- Streaming raw data to the control computer i.e. the server
- Attaching communication devices for transmitting RTK and DGPS data
- Connecting primary and backup power supplies
- Connecting peripheral devices such as meteorological and tilt sensors

Single-frequency receivers are limited in performance and hence not suggested in this case.

<u>GPS Antennas</u>

Since the reference stations form part of an International, first-order, geodetic-control network serving a large area like Sundarbans, IGS type choke-ring antennas fitted with Dorne & Margolin elements may be required in this case. Any reference station that forms part of the global International GPS Service (IGS) network will also usually require a choke-ring antenna. This type of antenna has very high phase-center stability, suppresses multipath to negligible levels, and helps to ensure that measurement data will be of the highest possible quality.

Compact geodetic antennas also provide good quality data that are sufficient for most types of applications and they are significantly less expensive than choke-ring antennas. But, since in this case high accuracy is required, that is why choke-ring antennas are being prescribed.

<u>Antenna cables</u>

A standard 10m cable will often be sufficient to connect the antenna to the receiver. If the receiver has to be located further away from the antenna, a longer cable will be needed. Antenna cables up to 100m or more are obtainable, but the longer the cable the thicker it has to be to minimize loss of signal and the heavier and more unwieldy it becomes. Extra-long cables also cost much more than standard cables. The best is to use cables that are as short as possible. Cables longer than 30m should be avoided in this case.

Power Supply

<u>Power Supply at the receivers</u>

A GPS reference station needs a reliable, continuous power supply. An AC to DC converter connected to the mains (line) will normally be used for powering the receiver and any other ancillary equipment such as communication devices. Since, it has been envisaged that the reference stations will be located in inhabited regions, so it is expected that Grid Electricity will be available in these locations. However, in absence of Grid Electricity, the only option is solar electricity.

A UPS (Uninterruptible Power Supply) unit will provide backup power for a limited time (in case of use of grid electricity) should the mains (line) supply fail. Considering the long power failures in the coastal zones, it is advisable to use UPS with a larger capacity. Nevertheless to mention that the larger the capacity, the longer the UPS will power the equipment.

If one station in a network of stations should stop operating very occasionally for a short period of time due to power failure, the field receivers, at the GPS rovers at the tide gauge stations as also the RTK and GIS rovers being used by other users in the estuaries may be able to obtain the data and services that they require from other nearby stations and continue to work; thus the occasional short power failure at one station may not be too critical. However, in the present case, there will be limited Reference Stations with horizontal distance of about 50 kilometers.

The reference stations will act almost like is a single, stand-alone station (not part of a network) - i.e. the only station supplying GPS services to the surrounding area – a power failure will result in loss of data in all the surrounding rovers. Hence use of large capacity UPS at each reference station will be mandatory. UPS units of appropriate size will probably be obligatory. Modern GPS receivers used for reference stations will restart automatically when power is restored.

The rover stations over the tide gauge stations in some cases may be installed in an area where there is no power, such as within the Forest area itself. At these remote sites with sunny climates, it is required to arrange a bank of batteries with a solar panel charging system to power the GPS receiver and a communication device such as a satellite phone or mobile phone.

Power Supply for the Computer running the reference station software

It is advisable to consider installing a UPS (Uninterruptible Power Supply) unit to provide backup power for the computer running the reference station software. The UPS will bridge short power cuts and will also enable the software to shut down safely before power fails completely.

A UPS of appropriate size may well be mandatory if the computer controls an entire network of receivers. At a stand-alone reference station, a UPS (if required) should be able to provide backup power for both the receiver and the computer.

If power fails at the computer but not at the reference stations, the receivers will continue to operate normally, log data, and transmit RTK and DGPS data. As soon as power is restored, the computer will reboot and the software should restart automatically and download the data files from the receivers. Thus power failure may lead to a delay in downloading data but may not result in a loss of data.

GPS Reference Station Software and Control Computer

The plan is to set up a computer based network system for measurement of horizontal as well as vertical coordinates of the platform on which different tide gauges along Sundarban estuaries have been installed. It has to be kept in mind that even for a single, stand-alone reference station and/or rover, it is always advantageous if the receiver can run continuously, the data can be downloaded fully automatically at regular intervals, and the entire operation can be controlled and inspected as required by a supervisor. Otherwise, since the raw data has to be archived and made available for post-processing etc., perhaps every evening the logged data from different DGPS sets need to be downloaded manually. That is why, it has also been envisaged that the entire system will be automatic in operation with provision of time to time monitoring by the supervisors at different stations.

These computer systems will be high end workstations capable of handling huge quantity of data as received from the DGPS units for continuous processing over a long period of time. Thus, these workstations will virtually control the entire network of DGPS and will act as servers. There may be number of options for installations of these servers, which are detailed below.

Reference Station Software and the Server

Reference station software running on a computer – that is the server - can control a single receiver at a stand-alone station or all the receivers at all stations in a network.

In case of a single stand-alone station, the receiver will often be connected directly to the computer. Since this is a multi-station network, the server will be at a control center and connected to the receivers by telephone, LAN, WAN or Internet.

GPS receivers at reference stations as also the rovers will run continuously. The raw measurement data are usually logged internally in the receivers in files of the required length. Reference station software running on the server controls the receivers and downloads the data files automatically at regular intervals. Receivers can also stream raw data continuously to the server instead of logging data or even stream raw data at the same time as they are logging data.

In addition, software running on the server can also check the raw data from Reference station for completeness, compresses the raw data, converts it to RINEX, compacts RINEX, archives raw data and RINEX files, and pushes raw data and RINEX files to an FTP server for easy access by the other GPS user community like for navigation etc. The software also monitors the operation of the receivers, the quality of the data, the communication links, the functioning of the entire network, and generates messages and reports as necessary.

System supervisors can have full control over the receivers at the stations and the entire network. They can log in to the server, perhaps even from remote locations, inspect the operation of the receivers and the network, start and stop the various operations, change configurations, parameters and operating modes, upload new firmware to the receivers etc.

Once configured and started, a reference station or a network of reference stations and rovers controlled by software running on a server will operate fully automatically. Well-designed reference stations and networks are extremely powerful yet, once set up, they are very easy to use.

Reference station software: continuous network analysis and calculation of correction parameters for enhanced RTK

The maximum range from a reference station at which a standard RTK rover can operate successfully (i.e. resolve ambiguities) is usually quoted **as about 30km**. This assumes favourable atmospheric conditions and that the rover is receiving standard RTK data from the station. The limitation in range is due to the effects of distant dependent errors relating to satellite orbits, ionospheric delays and tropospheric delays. In this particular case, rather than RTK, data from the rovers will also be sent to the servers for ambiguity resolution through post-processing. But, in that case also the distance limitation between Reference Station (i.e. the Base) and the Rover will be applicable. However, since in this case rather than Dual Frequency, Triple Frequency GPS are being proposed, so this distance may be increased up to 50 kilometers depending on a study to be carried out at the time of actual execution of the work.

Using a network of several reference stations, it is possible to model these distance dependent errors and to correct for them. The raw data have to be streamed continuously from the receivers to the server. Network analysis software running on the server continuously analyzes the “state” of the network data and models the distance dependent errors. Correction parameters are computed continuously.

In case of navigational supports using these reference stations, it is expected that the RTK rover receivers will be equipped with the appropriate algorithms and these correction parameters can be transmitted to the RTK rovers and the RTK rovers can apply them. Alternatively, the correction parameters can be applied at the server and corrected RTK data can be transmitted to the rovers. In both cases, improved RTK at longer ranges can be achieved.

Reference station software: calculation of the positions of the antennas

This Networks of GPS reference stations along with the rovers will be used for monitoring movements of the Earth's crust along Sundarbans due to subsidence as also due to tilting along the hinge zone. A software component running on the server can compute the baselines of the network continuously or at regular intervals to determine the positions (coordinates) of the antennas. Depending on the applications and the requirements, slow, long-term movements, rapid, short-term movements, and even vibrations can be investigated.

RTK and DGPS data: computed and output at the server

It is proposed to have the distribution of RTK and DGPS data managed from one or two central locations, rather than transmitting directly from the receivers. This allows better control over user access and facilitates charging for data for revenue generation also. This is especially required, in case this data be used for navigational purpose also.

Using permanently open communication links, raw data can be streamed continuously from the receivers to the server. Software running on the server will compute the required RTK/DGPS data continuously in standard RTCM (Radio Technical Commission for Maritime Services) V2.1/2.2/2.3/3.0/3.1 formats and/or in proprietary formats like Leica, CMR and CMR+. The data are output in the required format(s) and transmitted to RTK and GIS rovers. Radios, phones and even the Internet can be used to transmit the RTK/DGPS data.

Reliable communication

Reliable communication is vital for the efficient operation of the proposed network of GPS reference stations and rover stations located on the tide gauge platforms.

- The reference station software running on the server has to control the receivers and download the data.
- The software running on the servers has to download the data from the concerned rovers located at the tide gauge platforms at specific intervals
- RTK and DGPS data have to be transmitted for use by RTK and GIS rover receivers, in case there is plan to use these reference stations for navigational purpose also.

Communication technology and information technology are evolving very quickly. The availability of the various techniques - or at least the feasibility of using them - can also vary considerably depending on the objective situation, budget as also the available logistics.

When selecting the most suitable method for communication between the server and the receivers, various factors need to be considered carefully, including:

- The communication technologies that are available locally and for which reliable support is available
- The cost of the communication equipment and the installation costs
- The running costs
- The service and support costs, etc.

When making a decision on the most suitable means for transmitting RTK and DGPS data to RTK and GIS rovers, mostly for navigational purpose of the ships and boats, the following should also be taken into account:

- Approximate number of RTK and/or GIS rovers that the station or network has to support in future
- The range at which RTK rovers have to operate
- The communication equipment that will be needed by RTK and GIS rovers
- The cost of this equipment and the running costs, etc.

From the above it will be obvious that there is no standard solution. What is best for a station or network in one part of Sundarbans may not be appropriate for a station or network in the other part. Hence a discussion is being made in the following section regarding various communication methods that may be considered. The final decisions as to which methods are the most suitable should only be taken after consulting carefully with communication and information companies and specialists that understand the requirements and that are thoroughly familiar with the local situation.

Communication between the server and the receivers

The reference station software running on the server has to control the receivers and download the internally logged data files. In the present case, the server may be configured in a manner to stream the raw data continuously (second by second) from the receivers to the server instead of downloading the logged data files. There may have options for both streamed data and downloaded files.

For controlling the receivers and downloading logged data files, the communication links can be either dial-up (i.e. opened when required after a specific time interval) or permanently open (i.e. continuously on). Dial-up links will usually be preferred, however, as the costs are generally lower than for permanently open links

If the raw data have to be streamed continuously, permanently open communication links are essential. However, the costs of permanently open links - in particular the running costs - are usually higher than those of dial-up links. But, due to availability of cheap mobile phone service now-a-days, this may not be too high also.

Dial-up links (open when required)

If standard telephones are available at the reference station sites, standard landlines and telephone modems can be used to connect the receivers to the server. The reference station software running on the server will dial the receivers and download the logged files automatically at preset times. However, in case of Sundarbans, availability of standard telephones is a remote possibility.

Mobile phone modems (GSM, CDMA, TDMA, GPRS etc) can then be used if standard telephones are not available at the reference station sites. The phones have to be powered and permanently switched on. Another solution could be to use the Internet.

Permanently open links (continuously on)

If the raw data have to be streamed continuously from the receivers to the server, the communication links between the receivers and the server have to be permanently open. Standard landline telephone modems and mobile phone modems can be used, however the running costs (call charges) will often tend to be high. It is also worth investigating the possibility of using leased lines, as these will usually provide very high reliability, particularly for the reference stations, since these will be presumably located in locality.

A port and telephone modem will be needed at the server for each GPS station from which data is to be streamed. Thus a 10-station network will require 10 permanently open lines, a modem at each of the 10 receivers, and 10 modems at the server. Another possibility is to use a telephone access router at the server.

The trend today is to try to make use of the Internet to achieve permanently open links for streamed data between the receivers and the server. Running costs with the Internet should be significantly lower than with telephone connections.

Processing baselines between stations to check coordinates of Tide Gauge Platforms and monitoring natural movements of earth's crust

Processing the baselines between the stations of a network

Baselines between the reference stations and rovers of the network can be computed in real time or by post processing.

For **real time processing**, raw data have to be streamed continuously from the receivers to the server running the reference station software. A software component computes the baselines between the DGPS stations continuously in real time as the data are received. The computation process resolves the ambiguities continuously and is similar to the real time processing in an

RTK receiver. The accuracy that can be expected and the length of baselines that can be processed are also essentially the same as for RTK receivers.

For **post processing**, data files logged in the receivers and downloaded at regular intervals are normally used. The reference station software passes the files collected from the reference stations as also from the rovers to the post processing software that can be configured to process the baselines automatically as the files are received. With sufficient data - i.e. from sufficiently long observation periods - post processing can successfully compute baselines of almost any length and achieve higher accuracy than real-time processing. Coordinate results can be output for further analysis.

Since in this case, the requirements is to understand the “Z” value of the platform over which the tide gauge has been installed, the preferred process is Post Processing and with a long time interval say 24 hours or seven days.

<u>Checking the positions of the antennas</u>

Antennas will be set up in a stable manner at the stable platform from which the tide gauge will be augmented. Ideally, these should not move horizontally as well as vertically. However, since the GBM Delta is in a continuous dynamic stage due to subsidence and subduction and also due to movement along the Kolkata – Mymansingh Hinge Zone, it is better to be assured at regular intervals that the antennas have not been disturbed due to such natural events. In other words, the quantum of movements of earth’s crust may be measured in specific intervals to get the component of subsidence in Sea Level Rise on a long term basis.

The positions (coordinates) of the antennas can be determined by real time processing or by post processing as already explained. As the requirement is usually one of periodic checking, it is sufficient to post process the baselines between stations once a day, or once a week, or perhaps even once a month. Depending on the software, processing can often be organized to run automatically at the required time intervals.

ed by GSI

Monitoring movements of the Earth's crust

Networks of GPS stations provide the most effective method for measuring movements between tectonic plates, in earthquake zones, along major fault lines, and in areas of high volcanic activity. Such networks are equally important for measurement of slight changes in vertical directions due to subsidence also.

If rapid, short-term movements, and even vibrations, have to be detected and monitored, real time processing as described above will usually be needed. Real time processing produces a continuous stream of independent position coordinates. Movements can be identified and analyzed.

- Real time processing uses raw data that are streamed continuously through permanently open communication links. Running costs for permanently open links can be high.
- Post processing can use data files that are logged internally in the receivers and communication links that need to be opened only when files have to be downloaded. Thus running costs may be lower than with permanently open links.

However, since in this case the movements that have to be monitored are known to be slow and to occur over a relatively long period of time, it may be more economical and more suitable to use post processing method. Post processing will certainly be preferred since the baselines between stations are very long. Normally, networks with stations that are far apart and that cover very large areas, like Sundarbans, are often used for monitoring the movements of tectonic plates also.

Communication: transmission of RTK and DGPS data required for Navigation – Secondary Output

This is of secondary importance and may be considered as a by-product of the installation of network. The huge investment to be made for setting up this network may also be used for direct economic activities like navigational purpose. The GPS receivers used at reference stations can output RTK and DGPS data from one or more ports in standard RTCM formats and/or in other proprietary formats. The data can be transmitted directly from the receivers. If raw data are streamed continuously from the receivers to the server through permanently open links, software running on the server can compute and output RTK and DGPS data in standard RTCM formats and/or in proprietary formats. These data can then be used for navigational purpose by different users paying appropriate charges.

Using the Internet or Other IP-Based methods, for communication between the server and the receivers (Rovers)

There is a rapidly growing interest today in using IP-based methods for communication between the receivers and the server running the reference station software, and also for distribution of RTK and DGPS data.

IP-based communication can be LAN, WAN, WLAN, Internet, Intranet, and Radio IP etc. For simplicity, this document refers to the Internet to represent all IP-based methods.

The main attraction of using the Internet for communication between the server and the receivers is that it is usually possible to reduce running costs. If raw data have to be streamed continuously from the receivers to the server as already indicated, the running costs with the Internet will usually be much lower than with telephone connections. A possible disadvantage of using the Internet could be that the reliability and quality of standard Internet connections may not be quite as high as with standard telephone connections.

Internet connections of very high reliability can normally be guaranteed if dedicated (leased) lines or MPLS (Multi Protocol Label Switching) are used between the server and the receivers. Although it seems difficult to get internet facilities in all places of Sundarbans, but for the tide stations located in different ports or in localities can avail such facilities. However, the cost is likely to be higher than the cost of standard Internet connections.

The costs and reliability of the various options can usually be clarified by discussing carefully with the local Telecom Company and Internet Service Provider at the time of execution of this project. In order to access the Internet, the receiver at a reference station will require a modem, a Com Server or Ethernet port, and a static IP address. The modem could be a telephone, cable, or broadband/ADSL modem. The server will require a suitable modem and one IP port for each reference station from which data will be streamed (i.e. 10 IP ports are needed if data is to be streamed from 10 stations).

However, since the server has to receive continuously streamed raw data simultaneously from several reference stations and rovers - the best would be a broadband/ADSL or cable modem with a suitably large bandwidth. The reference station software running on the server operates in exactly the same way with Internet connections as with standard telephone connections.

Distribution of Data from the network control centre or Server for Navigation

Although there are other methods for distribution of data, but in this particular case there will be a network of receivers or rovers in different navigational systems with reference to three to four reference stations attached to servers. So, the specific type of distribution required in this case has been discussed below:

In this case, the server will be at the control center. Raw data have to be streamed continuously from the receivers to the server. The connection between the server and the receivers can be made via the Internet as already explained. Software running on the server computes the required RTK/DGPS data in the required format (standard RTCM formats or proprietary formats) for each reference station. The computed RTK/DGPS data can be output via the Internet. The server needs one IP port for each reference station for which RTK/DGPS data are to be output (i.e. if RTK/DGPS data are to be output for 10 stations, 10 IP ports are needed).

RTK and GIS rovers in navigational systems, equipped with Internet capable devices, access the IP ports and obtain the RTK/DGPS data for the stations. Multiplexing software running on the server allows several rovers to access the RTK/DGPS data from the same the IP port at the same time.

It is possible to have a single IP port for all reference stations if the rover receivers that are equipped with Internet capable devices can send their positions to the server. The rover accesses the server via the IP port and sends its position coordinates in NMEA format. A software component running on the server decides which reference station is closest to the rover. The RTK/DGPS data for this station are then transmitted to the rover.

Multiplexing software running on the server allows several rovers to access the server via the same IP port at the same time.

Continuous Network Analysis and Calculation of Network Correction parameters for enhanced RTK

Considering different issues like unique physiographic set up of Sundarbans, the inaccessibility, problems in setting up of multiple reference stations for accurate measurements, and data navigability and transmission, this particular issue is extremely important for measurement of vertical subsidence in Sundarbans.

When receiving standard RTK data from a reference station, an RTK rover can usually operate successfully (i.e. resolve ambiguities) at ranges up to about 30km in reasonably favourable conditions. In some regions of the World, where conditions for RTK are often exceptionally good, ranges of about 40km or more may be achieved at times. In other areas, especially during the afternoon and in periods of high ionospheric activity, the maximum range for RTK may be reduced significantly.

The accuracy of RTK is normally quoted as about 10mm + 1ppm root mean square. Thus the positional accuracies that can be expected are approximately as follows:

- At 1km: 10mm +1mm = 11mm rms
- At 10km: 10mm +10mm = 20mm rms
- At 30km: 10mm + 30mm = 40mm rms

If RTK measurements could be carried out in an absolutely perfect environment, there would be no ppm accuracy component and no restriction to range. Unfortunately, however, the environment is never perfect and it also changes continuously. Various influences, particularly those relating to ionospheric delays, tropospheric delays and satellite orbits, lead to distance dependent errors and restrict the range at which the rover can resolve the ambiguities.

It follows that if the distant dependent errors within the network can be modeled with a reasonable degree of success and appropriate corrections can be computed and applied, the accuracy and range of RTK can be improved.

Network analysis and computation of network correction parameters

The raw data have to be streamed continuously from the receivers at the network reference stations to the server through permanently open communication links. Use of the Internet will generally be preferred, as the running costs should be much lower than with telephone connections. For a terrain like Sundarbans, this option seems to be most optimum.

A network analysis component of the reference station software processes the incoming data continuously in order to analyze the state of the environment within the network. It models the distance dependent errors and computes network correction parameters. The entire process runs continuously and automatically. There are two ways in which the network analysis and network corrections parameters can be used to improve the performance of RTK:

- The network data in RTCM V3.1 format and the network correction parameters can be transmitted to the rover and the rover applies them.
- The network correction parameters can be applied at the server and the server transmits “corrected” RTK data to the rover.

However, it seems that the second method seems to be more appropriate for Sundarbans, hence discussed below:

Application of Network correction parameters at the server and Transmission of “corrected” RTK data from the server to the rover

The network analysis software running on the server analyzes the network and computes the network correction parameters for the network, already explained. With this method, however, the network correction parameters are applied at the server and not at the rover.

In order to obtain the required data, the RTK rover has to transmit its position in an NMEA message to the server. Using this position information, the network analysis software identifies which reference station is closest to the rover.

The software then applies the network correction parameters to the measurements from this reference station in such a way that a baseline computation between the reference station and the rover should be free of the distance dependent errors.

"Corrected" RTK data in the formats RTCM V2.3/3.0/3.1 or in propriety format, can then be output for transmission to the rover. The RTK rover receives the data and processes the baseline from the reference station, resolves the ambiguities, and derives position coordinates.

As the RTK data received by the rover are already "corrected", the accuracy and range are superior to those of standard RTK. As the RTK rover has first to send its position to the server, two-way communication is needed. Thus, phones and the Internet can be used but not radios.

As the "corrected" RTK data transmitted to the rover depends on the position of the rover, all roving receivers operating within the network area will receive different individual data streams. If phones are used, all rovers will dial a single number in order to obtain "corrected" RTK data. The software ensures that each rover receives the RTK data stream that it requires. A suitable telephone access router will be needed to ensure simultaneous multiple user access.

If the Internet is used, all rovers will access the same IP address in order to obtain "corrected" RTK data. The software ensures that each rover receives the RTK data stream that it requires. Multiplexing software running on the server permits simultaneous multiple user access.

With this method, the RTK data can be output in any required format. Rover receivers do not need to be RTCM V3.0 compatible. However, the software needed at the server will be slightly complex, although available readily from the standard suppliers.

As a result of this networking system,

- Accuracy will be improved, as the ppm accuracy component - i.e. the distance dependent component - will be reduced significantly.
- Thus RTK accuracy will be much more uniform at different distances.
- The reliability of RTK position fixes (ambiguity resolution) will be improved, particularly under difficult ionospheric conditions and at longer ranges.
- The time needed for RTK position fixes will be reduced when operating at long ranges and under difficult ionospheric conditions.
- The maximum range will be improved.

As the range of RTK is increased, reference stations can be further apart. Thus fewer stations are needed to provide RTK coverage for Sundarbans. However, the reference stations should be reasonably evenly distributed throughout Sundarbans in order that the software can effectively analyze the state of the environment within the network and compute the appropriate network correction parameters.

Cost for Products such as RINEX (Receiver Independent Exchange Format) and RTK/DGPS Sets etc.

Reference stations, Rover sets and networks require significant investments. Running costs, particularly for networks, have also to be considered. Presently RINEX Version 3.03 is now in operation. So, the latest version needs to be considered. A general estimates for setting up this system, only for the equipment and software are given below. However, this estimate has not considered the cost of networking through Internet / Telephone / Mobile, as the case may be.

Sl. No.	Description	Unit Price (in INR)
1.	Triple Frequency RTK GNSS DGPS Receiver, Geodatic Antenna with accessories and Field Controller for 'Base' or 'Reference Station'	16,00,000.00
2.	Civil Construction for setting up of batteries for Solar Power, Solar Panel, fencing etc.	5,00,000.00
3.	GSM Radio and accessories for 'Base' or 'Reference Station'	1,60,000.00
4.	Triple Frequency RTK GNSS DGPS Receiver, Geodatic Antenna with accessories and Field Controller for 'Rover' or 'Receiver station'	16,00,000.00
5.	Civil Construction for setting up of batteries for Solar Power, Solar Panel, fencing etc.	5,00,000.00
6.	GSM Radio and accessories for 'Rover' or 'Receiver station'	1,60,000.00
7.	Suitable High Speed Server with required number of channels etc. (without cost of civil construction for safe keeping, air-conditioning etc.	20,00,000.00
8.	Suitable Software for Post-processing of data	50,00,000.00

Other Type of Hydrological Measurements along Sundarbans

For hydrological measurements along other kinds of regular monitoring of the estuaries are also required. There may be a long list. But to start with three essential monitoring of the major rivers/ estuaries of Sundarbans on regular basis are: (i) Cross-sectional profiling/ Bathymetry, or in other words Depth Measurements (ii) Current Profiling and (iii) Water Quality. There may be other parameters like discharge measurements along the rivers, which can be done based on these primary measurements also.

Cross-sectional Profiling of Estuaries/ Bathymetry

Since rivers/ estuaries of Sundarbans are under huge siltation primarily due to premature reclamation and now climate change (Roll Over of sediments from Bay of Bengal – explained in Part-1), the river beds are experiencing upliftment as a result of this huge siltation. This has created a major problem of navigability for the local populations. At the same time, the hydrodynamics of the region is also getting changed since the carrying capacities of the rivers/ estuaries are changing on regular basis. In some of the areas, for the sake of maintaining navigability, maintenance dredging may also be required. Thus, the bathymetry/ cross-sectional profiling or depth profiling of the rivers/ estuaries at pre-selected points along plan lines needs to be carried out on regular basis, preferably on quarterly basis. The best way to carry out these measurements is by Echo Sounders, tied to small boats so that the boat can go up to the edge of the rivers/ estuaries even with depth of one meter or so. During these measurements, DGPS Rover set needs to be tied with the boat so as to maintain the plan lines as drawn on the map and also the locus of the boat during this bathymetry survey.

Echo sounding is a type of active sonar technology used to determine the depth of water by transmitting sound waves into water. The time interval between emission and return of a pulse is recorded, which is used to determine the depth of water along with the speed of sound in water at the time. This information is then typically used for navigation purposes or in order to obtain depths for charting purposes. Echo sounding can also refer to hydroacoustic "echo sounders" defined as active sound in water (sonar) used to study fish. Although Multi Beam Echo Sounders are available in market and is being used in developed countries also for measurement of depth of the river/ estuary and also the thickness of unconsolidated sediment on the river/ estuary beds, but in case of Sundarbans, these types of instruments have limited success since the thickness of unconsolidated sediments are quite high and it is difficult to get reflection from bottom of the sediments. Experiences from Sundarbans suggest using Single Beam Echo Sounders rather than Multi Beam. Single beam echo sounders (SBES), also known as depth sounders or fathometers determine water depth by measuring the travel time of a short sonar pulse, or “ping”. The sonar ping is emitted from a transducer positioned just below the water surface, and the SBES listens for the return echo from the bottom. SBES are cost effective also.

Requirement of number of SBES depends on the number of survey team that will be constituted by the authorised agencies for Sundarbans as also the location of offices. The bathymetry data, which actually indicates the cross-sectional profiles of the rivers/ estuaries can also be directly uploaded into the website, as is being done by Mekong River Commission. In case of MRC as also in Bangladesh, such survey instruments are kept in the regional offices from where the local offices hire the instruments for carrying out the survey work and then return the instruments back to regional offices. That practice also ensures optimum resource utilisation.

Current Profiling along Rivers/ Estuaries

Measurements of Currents along the rivers / estuaries are important for a wide spectrum of applications extending from the domain of scientific research to the domain of a multitude of operational applications, especially to understand the movement pattern of the suspended sediments and for construction of bridges, wharves and any other structures. Over the past few decades, various methods of current measurement, through a variety of instrumentation ranging from the conceptually simple time-series position measurement of drift bottles, poles, and parachute drogues to the sophistication of current meter (CM) moorings, HF Doppler radar systems, satellite imagery, satellite altimetry, satellite-tracked surface/ subsurface drifters, and remote profiling using a variety of free-falling/ rising devices and acoustic Doppler techniques, have been employed. However, in case of rivers/ estuaries and near-shore measurements, mostly Eulerian-style current measurements are being used and continue to be widely used to support construction projects and other environmental projects. In such applications, regimes of interest range from the surface to maximum hundred meters and from concentrated, short-term measurements to sparse, long-term measurements of up to three years or more. The timeliness, reliability, and availability of the data are frequently more important to the operational user than absolute data accuracy. However, more and more requirements were felt for measurements of vertical profiles of horizontal current flows.

General knowledge of oceanic motions increased considerably during the past few decades, primarily due to the successful use of moored current meters. The technology of mooring and maintaining chains of Current Meters in the deep depths of estuaries and ocean steadily improved and moorings became maintainable for over a year or more, yielding time-series measurements long enough to cover the greater part of the spectrum of movement of water columns in estuaries and oceans. Fortunately, as a result of decades of design and development efforts by oceanographic technologists, laboratory-scale experimentation, flow flume experiments, and field inter comparison studies, a number of promising state-of-the-art current sensors were developed and incorporated into current meters for judicious selection by the user communities to suit their specific application needs. In some instances, modifications and adaptations of current sensors have been made to facilitate at-sea testing on subsurface arrays designed to decouple the sensors from the effect of surface waves. Some modern current meters have been designed with remote capability to allow controlling and monitoring of the status of current measurement subsystems from the surface during short term, at-sea testing as well as near-real-time data transmission capability.

Ocean currents, both on the surface and at mid-depth, have been measured and analyzed since the early 1900s. Several time-series records of horizontal currents and temperatures exist from fixed instruments on taut-wire moorings in the deep ocean and on continental shelf and slope locations. These measurements have shown that the data for horizontal currents can be estimated reliably through these current meters on temporal basis to a large extent. Unfortunately, data from fixed instruments tell a rather complicated story about vertical spatial structure. Records from adjacent instruments on an array in the vertical plane show low coherence at all but the lowest temporal frequencies (quasi-geostrophic).

The often-observed extremely low correlation between currents at different depth levels together with the great expense of current meter chains, indicated the necessity for additional tools (say, a vertically moving sensor package providing high-resolution profiles) to effectively measure ocean currents over a variety of space and time scales. Thus, although in the past the moored current meters were useful, their limitation of poor spatial coverage became more and more prominent. Furthermore, although Eulerian-style current meters deployed from moorings have been able to measure the mean currents fairly accurately, measurements of very slow currents (such as vertical currents that are usually less than 0.001 cm/s) was not possible. In the absence of suitable instrumentation for direct measurements, these small currents were computed from wind stresses or from horizontal velocity fields using the equation of continuity. Flow determination by computation only is less complete unless supported by actual measurements, at least for cross-checking. The growing emphasis is, therefore, to achieve still lower threshold, greater accuracy, and resolution so that very slow motions such as upwelling currents especially in estuaries, which have significant biological importance, may actually be measured instead of depending entirely on mathematical calculations.

Various difficulties associated with freely sinking/ rising probes and the increasing requirement for time-series measurements of vertical profiles of currents led to the development of acoustic Doppler techniques, borrowed from the radar techniques used in meteorology for wind velocity Profile measurements. Although Doppler sonar techniques were investigated several decades ago and were implemented for measurement of ship's speed based on "bottom track" in shallow waters and "water track" in deep waters (Joseph, 2000), power requirements proved a serious impediment to incorporation of the Doppler sonar techniques in battery-powered self-recording current meters. Availability of low-power microprocessors removed this hurdle, and Doppler signal processing in self-recording moored instruments thus became feasible. This paved the way to the success of stand-alone self-recording of Acoustic Doppler Current Profiler (ADCP) development, leading to the development of appropriate technology for the measurement of high-resolution vertical profiles of ocean currents.

An ADCP is a type of hydroacoustic device that measures and records water-current velocities over a range of distances both horizontally and vertically over a range of depths. ADCPs are now being widely used from requirements for research in upper ocean processes in the context of climate research, whereas in the shallow-shelf seas and estuaries, current profiles are needed in connection with the proving of three dimensional circulation models, navigation, sediment transport, and fluid loading of structures.

Through development of technology, these instruments can now remotely measure both horizontal and vertical profiles of water currents in sequential layers of water columns. The ADCPs break up the water-velocity profile into uniform segments or depth cells, often called "Bins". The fact that ADCPs can measure flow velocities from such discrete distances (i.e., bins) from the sensor face has led to an almost universal adoption of this instrument for such measurements. Bin lengths and locations are determined by various parameters that set the transmit pulse length, receive window length, and blank after-transmit length. At present, ADCPs are used in l offshore renewable energy applications, coastal applications, and can be configured for side-looking into rivers and canals for long-term continuous discharge measurements, mounted on boats for instantaneous surveys, and moored on the subsurface and seabed locations for long-term current and wave studies.

Thus, for Sundarbans it is advisable to use ADCP for Current Profiling at different points as well as for discharge measurements. It is also better to use boat/buoy mounted bottom looking ADCPs fitted with GPS for measurements of discharge and current profiling. For regular monitoring purpose, use is river bed attached ADCPs are discouraged since mooring of such instruments is always a problem. Secondly, the instrument becomes static to a particular point for some days, which may be required for specific research purpose rather than regular monitoring of the instruments. The type of instruments to be used should be suitable for using in rivers/ estuaries and looking up to a depth of 40 meters or so with a minimum stream size of 0.5 meters. There are different varieties of such instruments being manufactured by different reputed agencies and are available in market.

Number of such instruments to be procured depends on the number of survey teams and regional/ local offices to be actually constituted at two parts of the Sundarbans. One instrument at each local station is sufficient since that can be transported at the actual point of monitoring before survey and then returned back to the regional/ local office. However, the freshwater discharge measurement along any river/ stream / streamlet needs to be carried out only at a spot where there is no tidal effect and the river flows steady-flow condition. The GPS network built up for tidal stations will help in identification of the exact location of ADCPs along the rivers at the time of measurements.

Water Quality Measurements

In case of Mekong River, water quality measurements are carried out normally on bi-monthly basis at several fixed points over the years for monitoring of water quality. This monitoring is required to understand the pollution level of the estuaries to protect the biodiversity of this ecologically fragile area. At the same time, the suspended sediment load as also the sediment load along the bottom part of the estuaries indicate rate of erosion at the catchment area. Also, it indicates the rate of change in estuarine water quality due to climate change since the nearby sediments on the sea bed near the coast are getting reworked and pushed into the estuaries due to climate change effects.

At present, water quality measurements at several fixed points along some of the estuaries in Indian part of Sundarbans are getting monitored by West Bengal Pollution Control Board (WBPCB) and Central Pollution Control Board (CPCB). However, numbers of such stations are very small and the monitoring intervals are also quite high. In most of the cases, it is annual measurements i.e. once in each year. In case of Bangladesh part, physical and chemical composition measurements along different estuaries are hardly being carried out. So, this process needs to be introduced and the water quality analysis data needs to be shared between two countries. At the same time, for the purpose of uniformity, the techniques for measurements of different compositions need to be standardised and uniform, as being done by MRC, in case of Mekong. Since the entire area of Sundarbans is quite large, it may be required to set up at least 4 (Four) laboratories – 2 (two) in India and 2 (two) in Bangladesh part for analysis of water with required instrumentation. These instruments need to be calibrated on regular basis with respect to standard solutions for reliable results.

However, it is also proposed that at 20 (twenty) locations – 10 (ten) in India and 10 (ten) in Bangladesh along the major estuaries like Matla, Saptamukhi etc in India and Pasur, Baleswar etc. in Bangladesh, especially at the locations where the major estuaries enter Sundarbans, continuous monitoring of water quality may be carried out. These kinds of monitoring are normally being carried out using buoy mounted sensors. These buoys will be fixed at these locations and the measurements will be continuously disseminated by telemetry to servers using GSM/GPRS. Man power requirement for carrying out water sample analysis is minimum, if not zero, for these kinds of set up. But, it requires considerable manpower for time to time monitoring of the set up and calibration of the sensors on regular basis. Technical specification of such "Buoy mounted Sensors for Water Quality Analysis" has been described at Annexure-3.

Meteorology Section

Background

The Sundarbans represent a unique but one of the most fragile eco-climate systems. Many components of this system, from forest regeneration to insect life cycles, are sensitive to weather and environmental variables; as the ecological processes often depend on thresholds, even small changes in the local climate can affect the ecological regime. Similarly, precise knowledge of the weather patterns and changes in them are critical for improving livelihood of the local populace.

The Sundarbans lying in the head bay of the dynamic Bay of Bengal and being a source of monsoon lows and depressions represent a unique climate system that has been little explored for its meso and micro climate; it is also one of the most endangered eco systems. For pro-active and knowledge-based measures on long term basis, a clear understanding of the interrelations between the various components of the Sundarban eco system in terms of land/vegetation, ocean and atmosphere is essential. Well planned observations from representative sites over the ecosystem will provide critical inputs towards building suitable models for the environment assessment and impact studies.

Since climatic information of Sundarbans is important for future (say next 100 years), it has been felt that without having the climate data especially wind speed & direction and rainfall data, it would not be possible to make any kind of forecast and model, whatsoever with the collected tide and current data from the sea level installations, discussed above. Interestingly, weather observations over Sundarban region covering both the countries (with a population of about 13 million people) is susceptible to storms etc and is very megre in nature. A critical requirement for addressing most of these questions is a carefully designed sustained observation network. However, this region is completely unprepared in terms of necessary information for mitigation and adaptation to climate change; very little systematic efforts have also been made in the past.

As a climatically sensitive region, Sundarbans is vulnerable to climate change; the region is frequently affected by high-intensity storms and cyclones like Aila, Cidr. However, very little systematic and planned study of the weather and the climate of the region has been carried out.

Carefully planned climate observations provide the first critical ingredient for understanding a climate system like Sundarbans; this is essential for drawing up a sustainable development plan for the region. For pro-active and knowledge-based measures, a clear understanding of the interrelations between the various components of the Sundarban eco-climate system is essential.

Undoubtedly, this area needs a much denser network of observations as envisaged than the existing observational network, which has already been discussed in detail in Part-I. Considering the highly vulnerable nature of the coast, it is very much essential to strengthen the observation network with appropriate middle range climate profilers and/or Automatic Weather Stations (AWS) in appropriate observation centers. Besides helping in improved forecasts of cyclones such as the recent Alia, the network will lead to an accurate time series of data for future studies on climate change impacts.

Figure – 19: Climate Profiler at Nellikuppam, Karnataka, India

Thus, the idea is to create a reliable and adequate knowledge base for the fragile coastal ecosystems like Sundarbans' environment and climate in particular. Although a number of surface observation stations are there located in both Indian and Bangladesh part of Sundarbans, these are quite few in number. It has to be kept in mind that frequency of major cyclones like Aila, Cidr etc are maximum one per year as per last 100 years of data. In India, IMD gives a forecast on a grid 25 km X 25 km and also on a grid 9 km X 9 km for a regional model, which is not sufficient for a climatically sensitive region like Sundarbans. As per WMO guidelines, maximum distance between two surface based climate profilers is 25 kilometres, which has not so far been followed in case of Sundarbans in both the parts namely India and Bangladesh. This needs to be changed for the future sustenance of Sundarbans.

Given the demographic and climatic inhomegenity of the area, it is desirable to have about 60 (sixty) to 70 (seventy) multi-level (at least 3 level) climate profilers, each covering about 300 square km of different land types namely forested and inhabited region. Out of these climate profilers, 30 – 35 climate profilers will be installed in Indian Part of Sundarbans and equal numbers of climate profilers will be installed in Bangladesh part of Sundarbans. Idea is to get weather data in a much detailed manner so as to prepare a local level model on a grid of 2 km X 2 km which may cater the need of this terrain.

Objectives

The objective of setting up of such a network is generating climate and environmental data in a sustained and comprehensive manner. The network will be designed in an application-oriented manner; the major outcomes of such a network will be:

- Advance prediction of rainfall intensity and its duration; this will reduce unnecessary harnessing and tapping of irrigation facilities/ resources and in the process it will ultimately reduce the cost of crop production. This will also promote water conservation in the region.
- Provide information about extreme events like heavy rainfall in this vulnerable area.
- Near real time weather informatics to all Administrative Officers such as BDO, SDO, DM, Police stations etc. in the Sundarban through a telemetric system; this will significantly aid disaster management
- Community awareness and outreach through weather data displayed on Digital boards in some selected Ferry ghats of Sunderbans,
- In the long-term, the network will enable identification of hot spots for knowledge-based adaptation and mitigation

Description of Network and Equipment

As an integrated and critical component of coastal zone management, especially for creating essential knowledge base, it is therefore proposed that a Sundarban Climate Observation Network (hereafter referred as SuCON) will be established to monitor and model the unique and fragile climate system of the entire Sundarban area covering both India and Bangladesh. SuCON in its first phase will comprise of 20 (twenty) Climate Profilers (10 in Indian part and 10 in Bangladesh part) of a height of 32 meters having sensors at different heights say 2 meters, 10 meters, 20

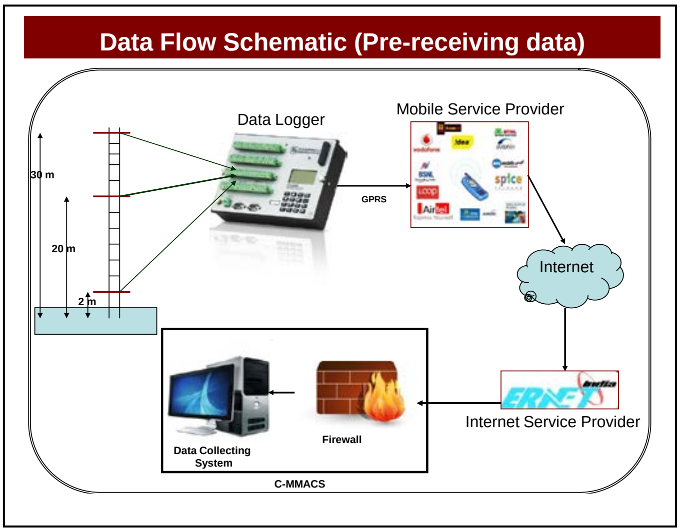


Figure – 20: Schematic Diagram for Data Management in proposed SuCON network of climate profilers

meters and at 30 meters. The Climate Profiler is designed based on extensive research carried out by climate modelling groups in this sub-continent and will have multi level sensors for high frequency observation of weather and climate related parameters. Such observations are essential for characterizing the climate systems over the ecosystem and compute energy and flux parameters required for models. These 20 Climate Profilers (10 in Indian part and 10 in Bangladesh part) will be installed at different locations within Sundarban as per suggestion of a knowledge based organization (to be selected through bidding) and subsequent approval of the concerned authority(s)/ departments/ agencies of two countries looking after meteorology and/or Sundarbans.

Detail specifications of SuCON towers with necessary sensors have been narrated in detail in Annexure-4. For the sake of brevity, this has not been reiterated here once again. This specification document has been prepared with the objective of preparation of bid document for procurements of the climate profilers. A prototype design of the climate profiler has also been worked out for reference to the bidders. It is expected that the bidders will prepare site specific design for individual profiler on the basis of the prototype design.

Unlike conventional Automatic Weather stations, a SuCON profiler will be of a height of 32 meters with sensors at different heights (say 2, 10, 20 and 30 meters). In addition, a SuCON profiler will have sensors that allow monitoring of various variables for comprehensive assessment and modelling. Besides, a SuCON installation will have multi-level sub-surface observations of soil properties also.

These profilers are of small (18”) cross section and occupy very little physical space; the space around the profiler can support short vegetation; thus the installation will be unobtrusive to the natural system. As the entire establishment will be on solar power, no pollution will take place.

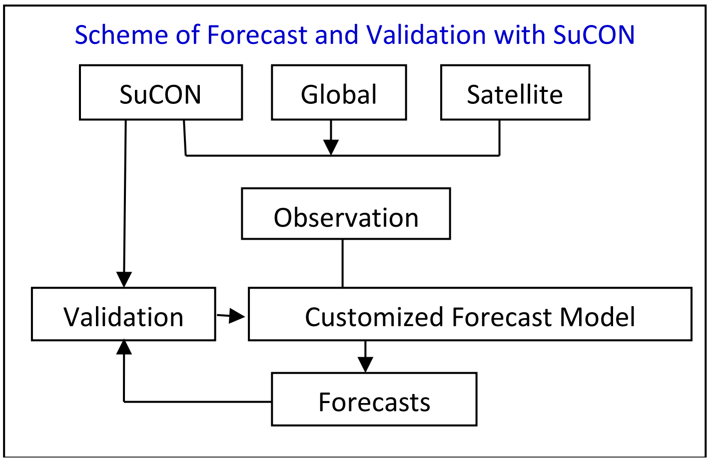


Figure – 21: Schematic Diagram for Forecast and validation in proposed SuCON network of climate profilers

The data from SuCON sensors will be received telemetrically and organized and archived after quality control, as shown schematically. The data will be used for analysis, modeling and projections at local scale. One or two Central Monitoring System – one in India and one in Bangladesh with data mirroring, will be used to ensure proper, continuous functioning of the system. The idea is to make the analysis of the climate data being sent to the Central servers on time basis using standard climate models so that local level forecasting of weather can be made twice in a day – one in the morning 8-30 am and the second at 6-30 pm on daily basis.

Along with the observations, it is planned to provide region-specific weather forecasts with a customized forecast model for the Sundarban on a grid scale of 2 Km X 2 km on daily basis as applicable products for the people.

Schematic: Outreach with Weather Informatics

er Data

An outreach model, with SuCON data and forecasts, similar to one successfully practiced in different parts of South Asia (like the State of Karnataka, India) and found to be extremely useful, is schematically shown with a Help Desk. Such multi-layer outreach can help farmers, fishermen and other communities as well as decision and policy makers.

ch with weather
rk of climate profilers

As for outreach purpose, the weather forecasts will be displayed in LED boards to be installed in the public places like markets and/or ferry ghats of the fringe areas of the inhabited part from where the fishermen normally sets of by boat for fishing purposes. The announcements will be made in vernacular language i.e. in Bengali twice in 24 hours – one at 8-30 am in the morning and the next at 6-30 pm in the evening. The forecasts will be made based on the analysis of on time observation data sent to the servers by the sensors of the climate profilers.

SuCON as well as weather informatics can help improve livelihood of people through knowledge-based 'Best Practices'. For example, rainfall forecasts can be used to avoid unnecessary irrigation and application of fertilizer/pesticides. In the long term, such practices can contribute to conservation of the eco system, such as through reducing fertilizer and pesticides loads.

As a knowledge and outreach infrastructure of immense societal values, SuCON is expected to receive long-term and sustained support for its continuation. However, resource-sharing models with beneficiary departments are possible and may be worked out in a need based manner after the initial phase or even during the actual implementation of the project.

Suggested locations of the Climate Towers

Success of this entire programme depends on careful selection of the type of instrument as also the locations thereof so that the entire Sundarban region can be best covered with this network of climate profilers and/or AWS network, since this is extremely important for future (say next

100 years) for 13 million people of Sundarbans. It is expected that these climate profilers will be continuously provide climate data so that ultimately region-specific weather forecasts with a customized forecast model for the Sundarban on a grid scale of 2 Km X 2 km on daily basis can be made for the benefit of the people and data can be stored for future projections due to climate change.

Such measurements will also enable studies of coastal processes through appropriate modeling such as coastal erosion/accretion, mean sea level change, etc along Sundarbans. And can also make timely forecast for storm surges (due to devastating cyclones like Aila etc). It is expected that this knowledge based institution will carry out detailed fieldwork along the entire Sundarbans for identification of locations and make suggestions after thorough study of the environs of the Sunderbans ecosystem and detailed spot visits, identified most ideal locations which are representative and satisfy site conditions as laid down by international standards (WMO).

Carefully planned climate observations provide the first critical ingredient for understanding a climate system for Sundarbans, which will also be essential for drawing up an Integrated Coastal Management (ICM) Plan for Sundarbans. SuCON aims at sustained observation of the Sundarban climate system through a sustained observation programme and will provide benchmarking of the climate system and long term time series data. . The profilers placed at the strategic positions will also provide input so that the data for hydrodynamic model to be developed for different estuaries of Sundarbans can be worked out with various institutions of these two countries like Central Water Commission (CWC), India and/or Institute of Water Modeling (IWM), Bangladesh. At the same time, the real time data will help in forecasts for safeguarding the safety & security of the traditional inhabitants of the entire Sundarbans.

It has already been indicated that as per WMO guidelines, maximum distance between two surface observation stations is 25 km. Thus, it is expected that individual climate profilers will cover an area of approximately 300 sq km. Thus to cover an area of 10,000 sq. km of Sundarbans in India total number of climate profilers required is about 30 to 35. This is equally true for Bangladesh part of Sundarbans also. Thus, total number of climate profilers finally required to cover the entire Sundarbans and its Impact zone covering both the countries is about 65 to 70. However, it may be decided to install this huge number of climate profilers in phases. In the first phase, it has been proposed to install 20 number of climate profilers – 10 in Indian part and rest 10 in Bangladesh part.

Rest of the climate profilers will be installed after making an assessment of the efficacy and reliability of data being received and utilised for making the regional forecasting based on customised region specific climate model. However, for this purpose, selection of locations for installations of these climate profilers is vitally important to cover the entire Sundarbans with practically 1/3 of the actual requirement of climate profilers.

This job is extremely specialized, and, therefore, it is advisable to involve a specialized climate modeling institution (like CMMACS, CDAC etc. in India) or any other international institutions having vast experience of successful installation of a large network of Internet-accessible real/near-real time reporting different kinds of climate observations, and expertise in the analysis of huge climate related data in a timely manner for regular forecasting etc. Detail specifications of SuCON are already been in place and may be accessed from the website of the concerned authority(s). The SuCON is expected to be in installed after a suitable agency is selected through standard bidding procedures, following the procurement manual of this project. A detail Terms of Reference (ToR) for selection of this knowledge based institution has been prepared and enclosed herewith as Annexure-5.

Although, this knowledge institution will make ultimate selection of locations of the climate profilers, however based on the field knowledge ten possible locations for ten climate profilers are being indicated below:

Table – 1: Suggested Locations of Ten Climate Profilers in Indian Part of Sundarbans

Stn. No	Station Name	Latitude	longitude	Road Connectivity
1	Canning (Inhabited area)	22° 20' 39.95" N	88° 33' 46.95" E	Kolkata to Canning via Baruipur Canning Road
2	Gosaba (Inhabited area)	22° 9' 9.37" N	88° 48' 26.16" E	Kolkata to Godkhali via Basanti Road, Godkhali to Gosaba by Vessel
3	Forest Office, Khatuajhuri	22° 3' 17.82" N	88° 59' 18.88" E	Kolkata to Godkhali via Basanti Road, Godkhali to Tiger Camp by Vessel
4	Dobanki	21° 59' 19.98" N	88° 45' 17.49" E	Kolkata to Jharkhali via Basanti Road, Jharkhali to Dobanki Camp by Vessel
5	Bonny Camp	21° 49' 46.75" N	88° 37' 54.92" E	Kolkata to Kaikhali via Kultali Road, Kaikhali to Bonny Camp by Vessel
6	Baghmarai Tiger Camp	21° 43' 32.65" N	88° 58' 43.80" E	Kolkata to Godkhali via Basanti Road, Godkhali to Baghmarai Tiger Camp by Vessel
7	Lothian	21° 40' 22.04" N	88° 19' 50.84" E	Kolkata to Namkhana via NH 117, Namkhana to Lothian by Vessel
8	Sandeshkhali (Inhabited area)	22° 21' 34.78" N	88° 53' 24.65" E	Kolkata to Dhamakhali via Sorberia Dhamakhali Road,

				Dhamakhali to Sandeshkhali by Boat
9	Sagar (Inhabited area)	21° 38' 47.34" N	88° 3' 17.16" E	Kolkata to Lot no.8 via D.H Road, Lot no.8 to Kachubaria by Vessel, Kachubaria to Sagar by Car
10	Chhotahardi Forest Office	21° 41' 1.08" N	88° 44' 1.48" E	Kolkata to Godkhali via Basanti Road, Godkhali to Chhotahardi by Vessel

Figure-23: Suggested Locations of Ten Climate Profilers to be installed in first phase in Indian part of Sundarbans under SuCON Programme; yellow line demarcates the border between India and Bangladesh

However, it is difficult to make any such suggestions on Bangladesh Part of Sundarbans due to lack of field based knowledge on Bangladesh part of Sundarbans. It is expected that the knowledge institution entrusted with this work will carry out the selection of the location based on extensive field work considering the logistic part also i.e. accessibility from main land, safety and security, mobile connectivity etc, which has been detailed in the specific ToR drawn for this purpose (Annexure – 5).

Automatic Weather Stations (AWS)

Although installations of middle range climate profilers of height 30 to 35 meters with multi level sensors (at least 3 levels) are the best solution for covering the entire Sundarbans under SuCON programme, but this will be comparatively costly. As an alternative installations of Automatic Weather Station (AWS) at the selected locations may also be considered, in case of serious constraint of fund. But, under no circumstances the efficacy of data from AWS will be equivalent to that from the climate profilers, which will be definitely more useful.

An automatic weather station (AWS) is defined as a "meteorological station at which observations are made and transmitted automatically" (WMO, 1992*; WMO, 2015*).

An AWS is now standard equipment in a surface meteorological observing station, as the majority of the sensors are connected to an electronic data acquisition system. A surface observing station with an AWS may be fully automatic or part of a mixed system, allowing the addition of visual observations by a human observer. The main functions of an AWS are the conversion of the measurements of meteorological elements into electrical signals through sensors, the processing and the transformation of these signals into meteorological data and the recording and/or the transmission of the resulting information.

Such a combined system of instruments, interfaces and processing and transmission units is usually called an automated weather observing system (AWOS) or automated surface observing system (ASOS). It has become common practice to refer to such a system as an AWS, although it is not a "station" fully in line with the stated definition. Nevertheless, an AWS may refer to just such a system. Data loggers are sometimes used as the acquisition equipment of the system and they are considered as a part of an AWS.

AWS networks decrease (sometimes to zero) the number of observers, but increase the staff needed for the maintenance , inspections, the system and software design and update, the calibration of electronic sensors, etc. So, the major problem associated with AWS is the maintenance, which is the major problem in case of existing AWS in Indian Sundarbans. Cost of the AWS including installation is quite less than the climate profilers. A good quality AWS with number of sensors cost about USD 14,000 (USD Fourteen thousand) only as per the present market value. However, range of AWS is quite less than the 32 meter profilers, as described above. So, it will be extremely difficult to make region-specific weather forecasts with a customized forecast model for the Sundarban on a grid scale of 2 Km X 2 km on daily basis, as has been proposed under SuCON. Further, even for running region specific weather forecasts using customised software, number of AWS will be more than as indicated for the climate profilers. Exact number of AWS required to cover the entire Sundarbans will ultimately depend on the type of AWS being used and the height at which these will be placed. Exact number of requirements of such AWS and the locations where these can be placed can be best indicated only after detailed fieldwork which may be undertaken by the knowledge Institution, as per the ToR, already described above.

A generalised technical specification for AWS has been presented at Annexure-6.

Meteorological Observation from Sea Side along Sundarban Coast

It has already been indicated that there is not a single buoy based meteorological observation station along Sundarbans, although a number of such stations are there along some coasts in other parts of India under OON (Ocean Observation Network) programme. One of buoy mounted weather station has been installed in Digha Coast to monitor physical conditions of coast and at the same time weather around that station. It has already been discussed that this type of buoy mounted stations has coverage of 30 km radius around the station. Since the single buoy mounted station is located in Digha, it cannot indicate the actual physical and chemical conditions of the coast along Sundarbans.

This type of buoy mounted stations is equipped with different sensors for measurement of three types of parameters, namely (i) Meteorological parameters like air temperature, relative humidity, barometric pressure, wind speed and direction, rainfall solar radiation etc. (ii) Water quality measurements like temperature, conductivity, Dissolved Oxygen, pH, turbidity, and even biological parameters like Chlorophyll and Blue Green Algae (if required) etc.; (iii) Physical oceanography parameters like current speed and Current direction, wave parameters like wave height, direction and period. Data collected from these stations will be directly communicated to the server for running the region specific weather models as also storage and post processing for display in the website.

Total distance along the coast from western branch of Hooghly River (locally known as Rangafala Channel) around Sagar Island in India which marks the western boundary of Sundarbans to Baleswar River in Bangladesh marking the eastern boundary of Sundarbans is about 220 km. Thus, altogether 5 (five) to 6 (six) buoy mounted multi-parameter measurement systems will be required to cover the entire coast along Sundarbans. Data to be collected from these stations may be directly sent to the nearest server telemetrically using GSM / GPRS. A detail specification for this kind of buoy mounted stations has been described in Annexure-7.

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