2.1.1 Acoustic Gauges with Sounding Tubes

2.1.1.1 The NOAA NGWLMS System

In the early 1990's the US National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS) began the implementation of the Next Generation Water Level Measurement System (NGWLMS) based on acoustic gauges with sounding tubes. These gauges now form the basis of the US national tide gauge network. The new acoustic systems were operated alongside the previous analogue-to-digital (ADR) float and bubbler tide gauges at all stations for a minimum period of one year to provide datum ties to, and data continuity with, the historical time series. Dual systems were maintained at a few stations for several years to provide long term comparison information.

The NGWLMS tide gauge uses an Aquatrak water level sensor made by Bartex with a Sutron data processing and transmission system. The Aquatrak sensor sends an acoustic pulse down a 13 mm diameter PVC sounding tube towards the water surface. The elapsed time from transmission until the reflection of the pulse from the water surface returns to the transducer is used as a measure of the distance to the water surface. The sound tube has a discontinuity (the calibration reference point), which causes a decrease in acoustic impedance as the pulse passes it, resulting in another reflection, which propagates back towards the transducer. The elapsed time for this reflection is also measured. Since the distance to the calibration reference point is known (approximately 1.2 m), this distance and the travel time can be used as a measure of sound speed in the calibration tube (i.e. the section of the tube between the transducer and the calibration reference point). This information is then used to convert the travel time of the reflection from the water surface into a distance. Air temperature affects the speed of sound, but as long as the temperature is the same throughout the whole tube, the resulting measurement will be very accurate. However, if the temperature in the tube below the calibration point is different from that above it, an error in the water level measurement will occur. (For example, for water level 2 m below the calibration point and temperature 1 ˚C higher in the calibration tube than the mean for the whole tube, an error of 3.6 mm will occur.)

Field installations are designed to minimise the significance of temperature gradients by painting the protective wells in a light colour, ventilating them to promote air circulation, and avoiding the head of the tube being in the tide gauge hut while most of the lower part of the tube is exposed to the sun. Even with these precautions, there may still be situations where significant temperature-gradients could result in errors, especially for the long tubes required in areas of high tidal range. Therefore, as a further precaution, two thermistors are placed in the tube, one at the middle of the calibration tube above the reference point, and one beneath it. With each acoustic range measurement, the temperatures are also recorded in the data loggers and can be used in further analysis to remove temperature-gradient related errors.

The PVC acoustic sounding tube (bottom section copper to stop bio-fouling) is mounted inside a 15 cm diameter PVC protective well which has a symmetrical 5 cm diameter double cone orifice at the bottom. The protective well is more open to the local dynamics than the traditional stilling well used for float gauges and does not filter as much of the wind waves and chop. (Nevertheless, in principle, the same criticisms can be made about the PVC protective well as about a traditional stilling well.) In areas of high velocity tidal currents and high energy sea swell and waves, parallel plates are mounted below the orifice to reduce the pull down effects; these may be dispensed with in areas of low currents. Figure 2.1 is a schematic of a typical NGWLMS installation

The NGWLMS also has the capability of handling up to 11 different ancillary oceanographic and meteorological sensors (e.g. a sub-pressure transducer (Druck) is often used to provide backup to the acoustic system). The field units are programmed to take measurements at 6-minute intervals with each measurement consisting of 181 one-second interval water level samples centred on each tenth of an hour. Software rejects outliers etc. and measurements have typically 3 mm (0.01 foot) resolution. Data are transmitted via telephone or satellite connections.

For further information on US acoustic gauge deployments, see Gill et al. (1993) and Porter and Shih (1996) and http://www.opsd.nos.noaa.gov/.

2.1.1.2 The Australian SEAFRAME System

The Australian SEAFRAME (Sea Level Fine Resolution Acoustic Measuring Equipment) system is essentially the same as the NGWLMS and is being used to detect sea level changes around Australia and the Pacific Island Countries. The SEAFRAME station acquires, stores and transmits water level, weather and other data from a field unit, the main requirement for which is to measure sea level with low power consumption, high reliability and high (millimetric) resolution, often in hostile conditions. The main field unit is a Sutron 9000 Remote Terminal Unit (RTU) which is a modular unit containing:

- power supply;
- communications controller;
- UHF satellite transmitter;
- central processor unit;
- memory expansion module;
- telephone modem; and,
- "Aquatrak" controller.

The unit receives data from up to 16 sensors which measure the water level and meteorological parameters. Six channels are currently used in the unit used in Australia taking data from five sensors:

- primary water level sensor (the Bartex Aquatrak acoustic-in-air sensor) (6 minute interval);
- wind speed, direction and maximum hourly gust (1 hour interval);
- air temperature (1 hour interval);
- sea water temperature (1 hour interval); and,
- atmospheric pressure (1 hour interval).

A sixth channel contains data from the backup data logger in the Sutron 8200 unit described below. The Sutron 9000 RTU data logger runs unattended, collecting and storing data from all the sensors. Each sensor is represented by a data record created by the data logger, which records at 1 to 10 records per hour, depending on the type of the sensor.

As for the NGWLMS, the SEAFRAME's acoustic head emits a sound pulse, which travels from the top of the tube to the water surface in the tube, and is then reflected up the tube. The reflected pulse is then received by the transducer, and the Aquatrak controller, or water level sensor module. The Sutron 9000 unit then calculates the distance to the water level using the travel time of the sound pulse. As well as the reflected pulse from the water level, there is a reflected sound from a hole in the side of the tube at an accurately known distance from the transducer head. This measured reflection is used by the computer software in the Aquatrak controller to continually "self-calibrate" the measuring system. The Aquatrak sensor is able to resolve variations in sea-level to the required accuracy and precision. Temperature variations in the tube can affect the speed of sound, so the temperature is measured at two locations on the sounding tube and a correction factor can be applied if required.

Each SEAFRAME has a stand-alone backup data logger which measures and stores water level data from a pressure transducer (IMO Delavel) mounted close to the sea bed, and water temperature from a separate thermistor. The readings are averaged over three minutes and logged every six minutes into the memory of the 8200 data logger as well as to one of the channels of the Sutron 9000 unit, via a one-way communication link. The memory of the Sutron 8200 can hold three months of data. Should there be problems with the primary data logger, the data is retrieved during an on-site visit. This 8200 unit uses a 12 Volt 24 Ah Gel-cell battery, which is "trickled-charged" by a solar panel. The SEAFRAME unit itself can use a variety of power sources, including mains power, solar panels or wind generators. A trickle-charged 40 Ah Gel-cell battery provides about ten days reserve operating power in case of loss of primary power. The operating system and data memory are also supported by back-up lithium batteries.

The sampling rate for all parameters is one sample per second. However not all of this data is stored. The primary water level measurements are averaged over a three minute period and are stored in the memory every six minutes. Each weather parameter is stored hourly, and is the average of two minutes of sampling on the hour. The expanded memory of the unit has a "rolling log" which retains the last 30 days of data. The SEAFRAME station has the capacity to operate with various, site-specific combinations of sensors, averaging and sampling intervals. These combinations can be adjusted by using a personal computer connected to a communication port in the unit, either directly at the site, or remotely with a telephone modem. Data can be retrieved from the Sutron 9000 unit by (a) on-site retrieval, using a personal computer communication program, and (b) remote retrieval, where data is retrieved by automated modem dialup or by automatic hourly satellite transmissions via the Japanese Geostationary Meteorological Satellite (GMS) and by telephone links direct to the Australian National Tidal Facility (NTF).

For more information on the Australian SEAFRAME gauges, see:

http://www.ntf.flinders.edu.au/TEXT/PRJS/PACIFIC/seaframe.html

2.1.1.3 Other Users of Acoustic Sounding Tube Gauges and Calibration Comments

Experience of acoustic sounding tube gauges such as those deployed in the US and Australia has been obtained in a number of other countries:

- India, see Joseph et al. (1997).
- Saudi Arabia where systems were deployed at Al Wedj, Jeddah, Haql and Gizzan on the Red Sea coast in 1992. (Although the first 2 are not functioning at the time of writing, we understand they still exist and that efforts are being made to bring them back on-line.)
- Caribbean, see http://www.ima-cpacc.gov.tt/index.htm
- New Zealand, an installation at Jackson Bay in collaboration with the Australian NTF
- Several Pacific islands, see http://www.soest.hawaii.edu/UHSLC/

- UK where one gauge (no longer operational) was tested at Holyhead by Vassie et al. (1993) with comparisons to conventional (float stilling well and bubbler) systems.

In addition, gauges have been deployed in several countries, including Cape Verde Islands, Senegal, Nigeria, Argentina and Azores (Portugal), by NOAA as part of its former Global Sea Level programme. Operations at these sites are now the responsibility of the host country.

Essential to both the US and Australian networks is a calibration facility in which the acoustic transducer and its sounding tube are calibrated in a laboratory over a range of temperatures prior to deployment at the tide gauge station. Of course, the acoustic unit (i.e. the acoustic transducer and calibration tube) will have been delivered from the supplier together with calibration information. However, to obtain the best accuracy it will be desirable to check the calibration from time to time, at typically yearly intervals. In this procedure, the acoustic sensor is re-calibrated by reference to a stainless steel tube of certified length, and the zero offset is re-determined (Lennon et al., 1993). The experience with each particular gauge unit adds significantly to the accuracy achievable by an off-the-shelf unit. The US and Australian agencies should be contacted for advice on the calibration methods they have developed.

2.1.1.4 Similar Hardware Available

The manufacture of acoustic sounding tube systems similar to the NGWLMS/SEAFRAME has been attempted by other groups during the past decade (e.g. in South Africa, now discontinued). The only system known to be under manufacture at present is that of the Indian National Institute of Ocean Technology which is claimed to use novel calibration methods to handle temperature-gradients and is currently subject to patent application, see http://www.niot.ernet.in/m4/ATG.html

Although US and Australian stations are based primarily on Sutron equipment, alternatives (e.g. data loggers by Vitel, see the suppliers file on the PSMSL training web page) are available.

2.1.2 Acoustic Gauges in the Open Air

The HT200 Harbour Tide Gauge manufactured by MORS Environment uses a 41.5 KHz transducer with a beam width of 5º which can be operated in an existing stilling well or in the open. A temperature sensor in the air column is used to compensate for variations in the velocity of sound, and the measurement range is up to 15 metres. These systems have been deployed at a number of locations in France and at other sites (Dupuy, 1993). The manufacturers claim an accuracy of 2 cm.

An instrument by Sonar Research and Development (SRD) has been developed which operates at 50 KHz with a similar beamwidth. It can be operated in the open or, as the manufacturers recommend for permanent installations, in a plastic tube. Compensation for variation in the velocity of sound is achieved by use of a bar reflector mounted 75cm from the acoustic transducer. The manufacturers claim an accuracy of 0.05% over a range of 15 m, which would correspond to 0.2 cm over a typical range of 4 m (but see following sections).

For both these systems, datum control needs to be verified externally, for example by long periodic tide pole checks (see Sections 2.2.1.1 and 2.5).

2.1.2.1 Experience in Spain

The REDMAR network of Puertos del Estado (Spanish Harbours) was established in 1992 for harbour operations. It consists of 14 stations along the Spanish coast, two of which are in the Canary Islands. The selected equipment is the SRD acoustic tide gauge with real time radio transmision to the harbour office. The characteristics of the equipment are:

- height measurement range: 10 meters
- height measurement resolution: 1 cm
- height measurement accuracy: 0.05 % (better than 1 cm for instantaneous levels)
- time measurement resolution: 1 s
- time measurement drift lower than 1 minute per month
- acoustic frequency: 50 KHz
- telemetry output: RS 232 every minute
- sampling period: 1,2,3,4,5,6,10,15,20 and 30 minutes
- averaging period: number of measurements used to provide averaged tide height
  can be: 1,2,4,8,16,32,64

The transducer is located above the sea surface, at a distance not less than 2 m during high tide and not more than 9 m during low tide (highest tide range in Spain is around 5 m). The transducer has to be mounted within 2º of horizontal to achieve optimum results. The view of the transducer should be unobstructed within a 10º conical angle to avoid interfering targets. For permanent installations it is strongly recommended that the system operates down a plastic tube.

The distance to the water (air distance) is obtained from the sound velocity and the time the ultrasonic ray needs to reach the water surface and travel back to the transducer. The distance from the sensor to the reference level or zero is called the datum; sea level is then calculated as the difference between the datum and the obtained air distance. As sound velocity depends on environmental conditions, especially on the temperature, it is calculated before each measurement by sending ultrasonic pulses to a fixed target located at 0.75 m from the sensor (this distance is factory set). In this way, each measurement lasts around 36 seconds: the first 10 seconds are used to determine the sound velocity by sending 128 valid echoes to the target; then another 128 valid echoes are sent to the water surface and a mean value is calculated to filter the high frequency waves. For most of the REDMAR stations the transducer measures inside a 0.30 m diameter plastic tube, with its lower extreme at a point below the lower low water and an small hole of 3 cm. The role of the tube is of course not only to filter the waves but also to protect the ultrasonic rays path. In some places, like Santander, it was possible to install it in an existing stilling well, inside a small building.

Although the reference target is employed to take into account variations in temperature and other parameters, this is done in the first 1 m distance of the tube, so it is still possible that strong temperature gradients along the tube affect the signal. This has happened especially in southern harbours where the summer is very hot. Recomendations to the harbour authorities are the same as for other acoustic sensors: to employ white painted tubes, to avoid different ambient temperatures along the tube, to make small holes above the higher high water to facilitate ventilation and even to construct a protection from the sun. This has proven to be a very good solution.

From experience gained in Spain, the above mentioned requirements for the installation are critical to get the accuracy claimed by the manufacturer. It has also been noted that the system works perfectly inside a building above a stilling well, like the station in Santander harbour. Even without a stilling well, as is the case for Villagarcia, the careful design of the installation to protect the tube from the sun has provided data with accuracy better than 2 cm. The principal disadvantage of this type of acoustic sensor is that it is very dependent on these conditions of the installation.

The tide gauge Contact Point (CP) is a ring around the centre of the transducer. This is levelled to the Tide Gauge Bench Mark (TGBM) with a few mm precision, by the responsible tide gauge maintenance person. As recommended by the supplier, the datum is initially adjusted to give the expected tide height as indicated on a local tide staff, or by measuring manually (e.g. an electric tape datum probe) the distance to the water surface; this allows any small anomalies between the reference measurement and the tide measurement to be assessed. Experience is that this calibration is needed the first time the gauge is installed, and is checked twice a year, together with the levelling of the tide gauge CP to the TGBM. However, due to the resolution of the datum value (1 cm), the reference level for this equipment is fixed at best with 1 cm accuracy.

Also the conditions to make the manual measurement or the reading of the tide staff influence very much the accuracy of the first establishment of the reference. It is very easy when the gauge is measuring inside a stilling well where the water is quiet (for example the station in Santander), but when the acoustic system is used in a tube, it is not possible to open it and measure inside without affecting the sensor, so it has been suggested to the harbour authorities to make an installation of a parallel calibration tube that filters the waves, in order to check the reference with more reliability.

The ultrasonic transducer is connected to an intelligent unit (LPTM: Low Power Telemetry Unit), which allows selection of the sampling interval (5 minutes at the moment for all REDMAR stations), the averaging period, the station number and to establish the tide gauge datum, as well as to adjust the clock time, display the data and store them. It also provides the power supply. The LPTM may be connected to a personal computer and transmit data by modem to the harbour and to the central station in Madrid or, as is the case for most of the stations of REDMAR, it may transmit the data by radio to the harbour office, where data are stored in a PC and transmitted by mail to the central station. More information on REDMAR can be found via http://www.puertos.es/Mareas (in Spanish).

2.1.2.2 Experience in South Africa

Extensive experience on SRD acoustic gauges has been obtained in South Africa. However, at the time of writing, information has not been collected together. The South African Hydrographic Office may be contacted for details hydrosan@iafrica.com.