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## A Technique to Circumvent Lower Density Water Trapping by Tide- Wells

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### Abstract

A 3-year study of water density differences inside and outside of a conventional tide-well indicated that the average water density within the well is consistently lower than the external ambient waters. The tide-well at Goa is situated at the mouth of the Zuari estuary, and anomalies were reported at all periods except during peak summer and the onset of the summer monsoon. These anomalies lead to an over-estimation of tide levels by well-based gauges. The monthly-mean over-estimation in sea level [ $\Delta h$ ] is a minimum (2 mm) during the summer monsoon, rises rapidly to over 22 mm after the monsoon, and remains around this peak value for about 3 months before slowly decreasing to about 4 mm by peak summer. The annual over-estimation in the mean sea level (MSL) was 11.3 mm. The limitation of the conventional tide-well could be minimized by arrays of perforations on its entire submerged portion, that serve the dual purposes of (1) good mixing between well and external waters, and (2) minimizing the Bernoulli dynamic pressure effects. Density measurements during different seasons indicate that these perforations allow free exchange of the waters within and outside the tide-well, improving measuring accuracy, but slightly increasing wave effects in the well.

### Introduction

Various techniques are currently available for the measurement of sea level in coastal waters [1]. Sea level in coastal waters is currently measured using the oldest and ubiquitous *float-driven gauge* and its more recent version of a *guided air-acoustic gauge*, both these being tide-well based gauges. The tide-well is basically a pressure device wherein an equilibrium is sought between the hydraulic pressures imposed at the orifice by the water heads inside and outside of the tide-well [2]. It also dampens high frequency oscillations to facilitate water level measurements. Accurate measurement of sea level is vital to understand the variation in MSL, which is considered to be an indicator of global climate change. In this paper we address the problem of over-estimation of sea level measurement by tide-well based gauges, based on our analysis of water density difference observed inside a conventional tide-well at the Marmugao sea level station, for a period of over 3 years.

## Water density difference inside and outside of a conventional tide-well

Preliminary studies by Joseph et al., [3] have shown that conventional tide-wells have a tendency to trap water having a different density structure from that of the open water outside the well. The density difference ( $\Delta\rho$ ) of these two waters appears to be related to (1) flushing of the estuarine waters, in the vicinity of the gauge, by lower density river water during the summer monsoon season, (2) subsequent thorough mixing of this lower density water with that in the well as a result of strong wind forcing during the onset of the summer monsoon, (3) trapping of lower density water in the well in the post monsoon period as a result of poor mixing between the waters inside and outside of the well. The resulting drawback of these tide-well devices is the introduction of an over-estimation in sea level measurement. To examine the problem in detail, surface water samples were routinely collected since June 1995, from inside and outside of a conventional tide-well (Fig. 1) at Mormugao sea level station, Goa.

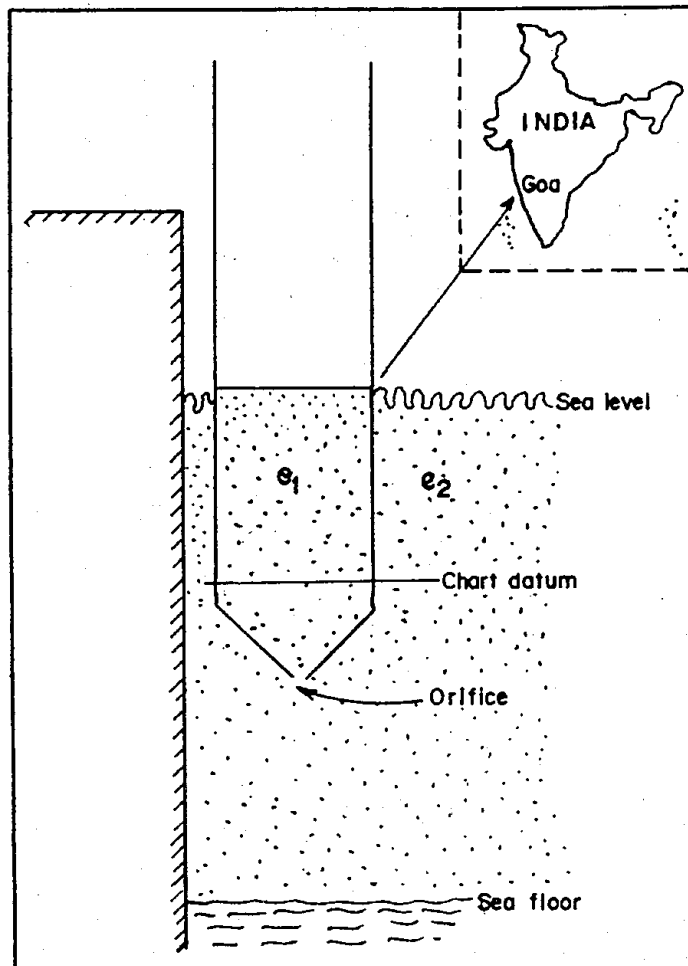


Fig.1 Schematic diagram of a conventional tide-well at Mormugao sea level station, at the Zuari estuary, Goa, used for measurements of  $\rho_1$ .

Water density measurements were made using a precision density meter [4] having an accuracy of  $\pm 0.001 \text{ g.cm}^{-3}$ . It has been observed that, except during the peak summer season (April/May) and the onset of active summer monsoon (June), the density of surface water samples from inside the tide-well remained lower than that of the ambient waters outside. In an attempt to understand the lower density water trapping mechanism, the time-series of the density difference  $\Delta\rho$ , [where  $\Delta\rho = (\rho_2 - \rho_1)$ ], was examined together with the local wind forcing (Fig. 2). The figure shows that the maximum wind speed ( $\sim 6$  to  $7 \text{ m.s}^{-1}$ ) in the vicinity of the tide station corresponds to June -August (summer monsoon months) during which the values of  $\Delta\rho$  were the minimum. This shows that the mixing of water inside the tide-well with that outside of it is related to the local wind forcing. This also provides an indication that the lower density water trapping effect may be expected to be more predominant when the wind is weak.

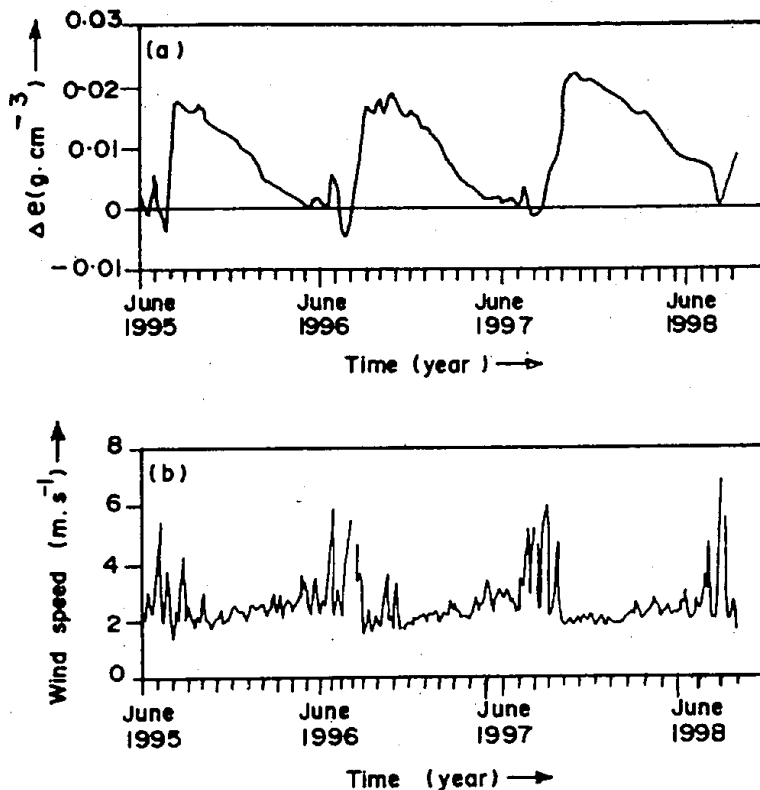


Fig.2 A three-year record of (a) density difference,  $\Delta\rho$ , inside and outside of a tide-well at Mormugao sea level station, and (b) the corresponding local wind.

In order to estimate the error in sea level measurement arising from the lower density water trapping, density profiles from inside and outside the tide-well were obtained using a portable CTD profiler (Seabird). The profiles showed that the depth-mean water densities  $\bar{\rho}_1$  (inside the well) and  $\bar{\rho}_2$  (outside the well) are closer to each other during June, the value of  $(\bar{\rho}_1 / \bar{\rho}_2)$  being equal to or very close to 1.000. Subsequently  $(\bar{\rho}_1 / \bar{\rho}_2)$  decreases, reaching a minimum value of 0.990 in September.

### Higher water level within conventional tide-well

The consequence of lower-density water trapping is a systematic increase of water level inside the tide-well compared to that external to it (which is the true sea level). This is because the pressure balance at the orifice depends both upon the water heads inside ( $h_1$ ) and outside ( $h_2$ ) of the tide-well above its orifice level and the depth-mean densities  $\bar{\rho}_1$  (of water column  $h_1$ ) and  $\bar{\rho}_2$  (of water column  $h_2$ ). Thus, during a given sampling period,

$$h_1 \bar{\rho}_1 g = h_2 \bar{\rho}_2 g \quad (1)$$

so that

$$h_1 = h_2 (\bar{\rho}_2 / \bar{\rho}_1) \quad (2)$$

Thus, the generally reduced value of  $\bar{\rho}_1$  (relative to  $\bar{\rho}_2$ ), resulting from the trapping of a lower-density water body, gives rise to a systematic seasonal over-estimation of the water level inside the tide-well relative to the true open sea level outside. The over-estimation, ( $\Delta h$ ), in sea level measurement is given by  $(h_1 - h_2)$ . From Eqn. (2),  $h_2 = h_1 (\bar{\rho}_1 / \bar{\rho}_2)$ . Thus, the over-estimation in the measurement of sea level, by a sea level gauge deployed in a tide-well, is given by:

$$(\Delta h) = (h_1 - h_2) = h_1 [1 - (\bar{\rho}_1 / \bar{\rho}_2)] \quad (3)$$

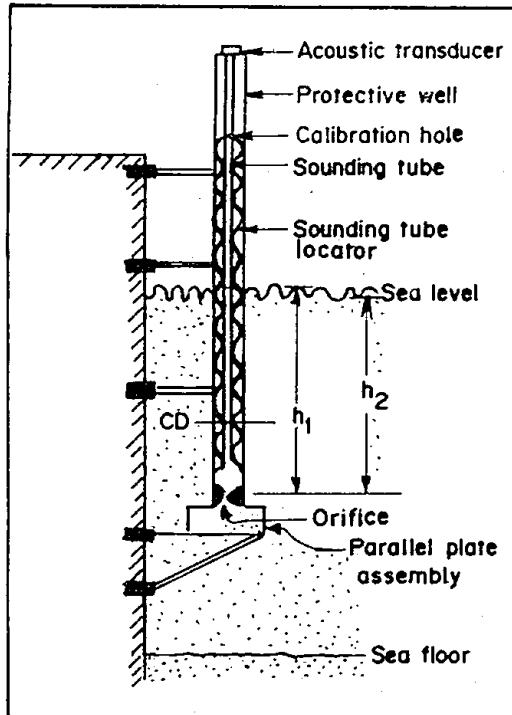


Fig.3 Schematic diagram of an air-acoustic gauge at Mormugao sea level station used for sea level measurement in the present study

Sea level measurement is conventionally referenced to a datum, known as chart datum (CD). Thus,  $h_1$  is the measured sea level plus the depth of the orifice below the CD. In the present study, the values of  $h_1$  during each sampling were obtained from a guided air-acoustic gauge. In this gauge a vertical narrow cylindrical tube (known as *sounding tube*), which guides the acoustic pulses generated by a piezoelectric transducer located in air, is mounted along the axis of a protective-well. The bottom portion of this tide-well (Fig. 3) is attached to a double-cone and a parallel-plate assembly to minimize the flow- and wave-induced Bernoulli draw-down effects [5, 6]. The orifice of this protective-well was  $\sim 5$  cm in diameter, which was equal to the orifice diameter of the conventional tide-well (Fig. 1). Thus the *conventional tide-well*, which was used by us for the measurement of  $\rho_1$ , and the *protective-well* of the air-acoustic gauge, from which the values of  $h_1$  were obtained during each sampling, can be expected to have suffered from similar lower-density water trapping problems (water density measurement from the protective-well was not practical because of the presence of the acoustic head and its attachments including the sounding tube and its locator).

Despite a self-calibrating technique used in the air-acoustic gauge, it is known to exhibit temperature-induced-noise in the measurement of sea level [3, 7, 8]. Our studies have indicated that this noise (up to a maximum of 6 cm for a short duration in the morning), though serious while considering individual measurement, is periodic in nature and, therefore, might largely be averaged out while estimating yearly-mean sea level. Thus, our evaluation of the systematic over-estimation of the monthly-mean and yearly-mean sea level measurement, arising from trapping of a lower density water body within the tide-well, is unlikely to have been influenced by the temperature-induced noise in the air-acoustic gauge measurements.

#### Over-estimation in mean sea level

The monthly-mean over-estimation,  $\bar{\Delta h}$ , in the measurement of sea level, arising from trapping effect, for a typical one-year period from July 1997 to June 1998 in the Zuari estuary is shown in Fig. 4.

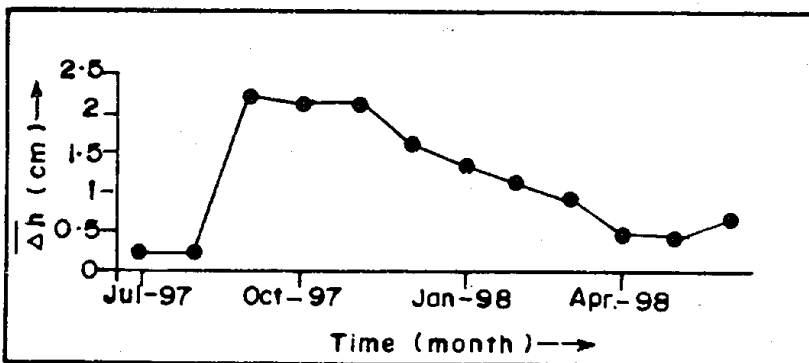


Fig.4 Monthly-mean over-estimation, ( $\bar{\Delta h}$ ), in the measurement of sea level from the Mormugao sea level station over a one-year period from July 1997 to June 1998.

It is observed that the over-estimation during the summer monsoon months of July and August was 2.2 mm. However, with the weakening of the summer monsoon the over-estimation shot

up to 22.2 mm, and remained close to this peak value for a period of 3 months in the post-monsoon period, from September through November. Subsequently, the value of  $\bar{\Delta h}$  began falling gradually, reaching a value of 4.5 mm in May. The value of  $\bar{\Delta h}$  remained at 6.7 mm in June which experiences both the peak summer period and the beginning of summer monsoon season. The observed yearly repetition in the trend of  $\Delta p$  (Fig. 2) suggests a similar yearly repetition for  $\Delta h$  as well. The annual over-estimation in MSL during July 1997 - June 1998 was found to have been 11.3 mm.

### A technique to remove lower-density water trapping

Our improved tide-well (Fig. 5) is provided with arrays of perforations on its entire submerged portion. These perforations serve the dual purposes of (1) good mixing between well- and external-waters, and (2) minimizing the Bernoulli dynamic pressure effects, as reported by Lebreton et al., [9], Joseph, et al., [10]. As copper is known to act as a repellent for marine growth [11], all the perforations were passed through copper strips to avoid their possible closure from marine growth during long-term deployments. Density profiles of the waters inside and outside of the conventional tide-well (Fig. 6a) and the modified tide-well (Fig. 6b) showed that these perforations have a profound influence in allowing free exchange of water in the tide-well with the ambient waters. Good mixing between well and external waters avoid the lower-density water trapping effect.

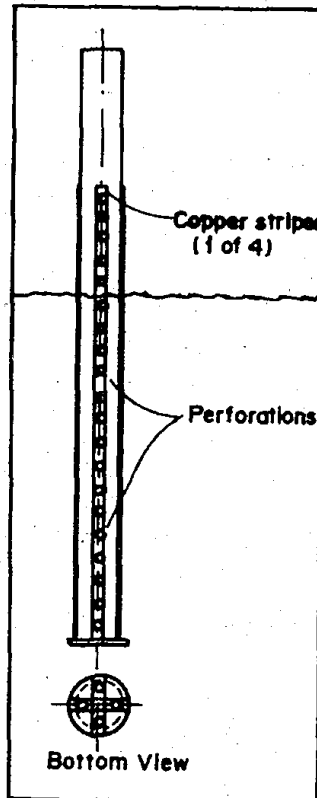


Fig. 5 Schematic of the improved tide-well having perforation on its submerged portion.

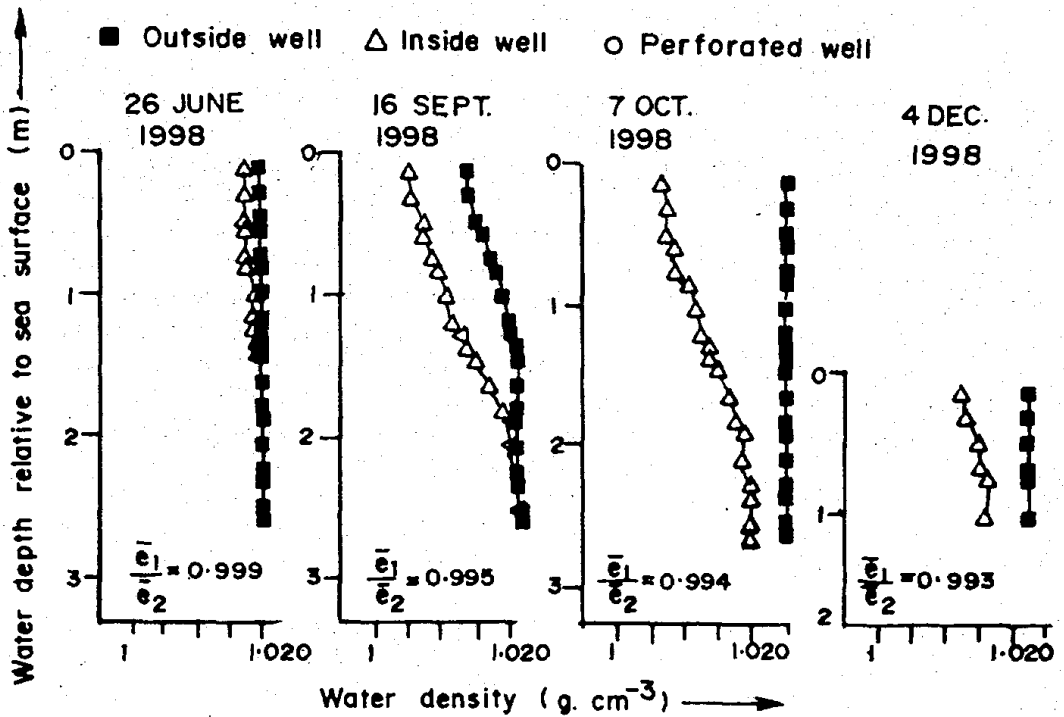


Fig. 6a Typical profiles of the water densities inside and outside of a conventional tide-well

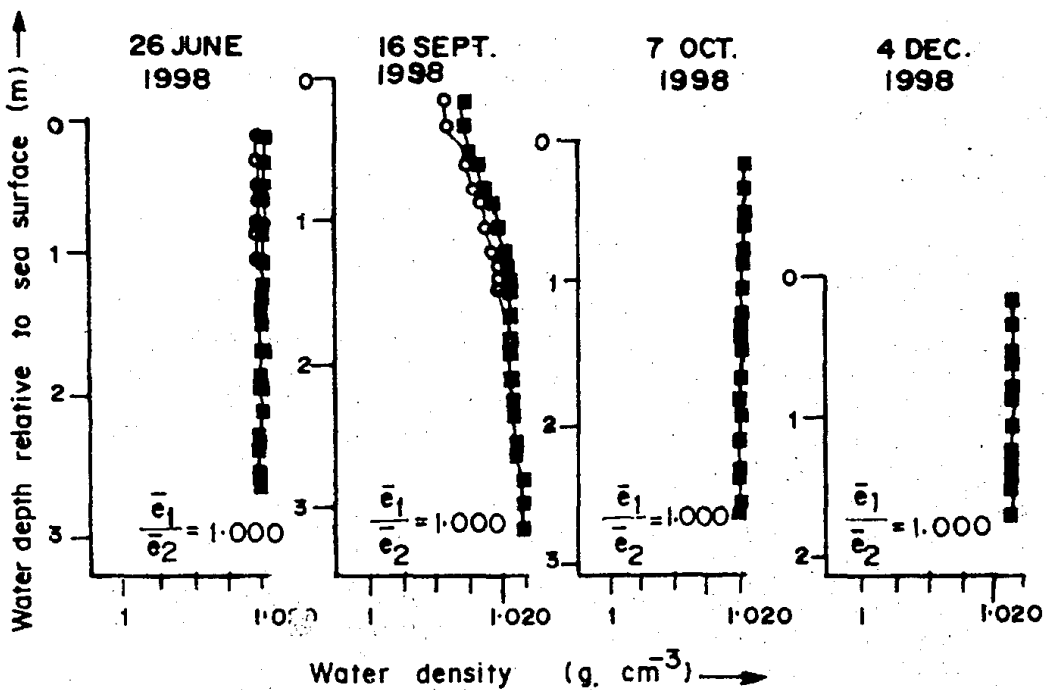


Fig. 6b Typical profiles of the water densities inside and outside of the modified tide-well

## Conclusions

This paper has addressed a systematic over-estimation in the measurement of sea level by any gauge deployed within a tide-well, such as float-driven gauge, guided air-acoustic gauge and so forth, arising from trapping of lower density water by the well. Our 3-year measurements in the Zuari estuary have indicated that except during the peak summer season and active summer-monsoon season, the depth-mean density of the water inside the tide-well remained to be consistently lower than that outside of it. Our analysis has indicated that the density difference ( $\bar{\Delta\rho}$ ) of these two waters is primarily related to (1) flushing of the estuarine waters, in the vicinity of the gauge, by lower density river water during the summer monsoon season, (2) subsequent thorough mixing of this lower density water with that in the well as a result of strong wind forcing during the onset of the summer monsoon, (3) trapping of lower density water in the well in the post monsoon period as a result of poor mixing between the waters inside and outside of the well. The trapped lower density water is retained inside the well for a long time until February because it is flushed out very slowly as a result of weak wind forcing after the summer monsoon.

The limitation of conventional tide-wells was sought to be minimized by a modified tide-well, which permitted free exchange of the waters within the well with the ambient waters external to it (Indian patent pending No. 2378/DEL/98). We must caution, however, that whilst this solution is useful in float-driven gauges and any sea level gauge deployed in the tide-well, the existing guided air-acoustic gauges may not be able to take the full advantage of the said improvement to the conventional tide-well. This is because the air-acoustic gauge's sounding tube, in the present form, is devoid of any lateral perforations on its submerged portion, and therefore can still trap a lower-density water body.

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