Estuaries Vol. 4, No 3, p. 161–166 September 1981

Electromagnetic Measurements of Tidal Transports in Estuaries

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ABSTRACT: Measurement of the electric potential produced across a tidal stream is an inexpensive and relatively maintenance free means of monitoring volume flow. Comparison of the electric signal to transports determined from current meter records is used to calibrate the system. A volume flow of 100 m^3 per sec will induce a potential near 1 mV. Salinity and temperature changes at the electrodes will induce potentials of 500 μV per ‰ and 350 μV per °C. Transport estimates may need to be corrected for such effects. Examples of measurements made at two locations, Great Bay, New Hampshire, and Lake Pontchartrain, Louisiana, illustrate that the method is capable of yielding volume flow measurements with an uncertainty of about 15%.

Introduction

Estuarine salt marshes may play important roles as sources and sinks for materials (nutrients, carbon, etc.) cycled thru nearshore ecological systems (Teal 1962; Gardner and Kitchens 1978; Hopkinson et al. 1978). In order to quantitatively investigate the importance of an estuarine system in this regard, accurate determination of material fluxes are needed. Thus, measurements of tidal transports are required. Past measurements of tidal flows have relied mainly upon current meter arrays. However, these measurements are usually of short duration. It is desirable to have long time series data of tidal transport if general trends are to be discovered. Conventional current meter moorings to make such measurements are both costly and difficult to maintain. An electromagnetic method, which is inexpensive, relatively maintenance free (once deployed), and gives a continuous record of transports, provides a possible alternative transport measurement system. Periodic intercalibration with current meter measurements is still needed.

The Electromagnetic Method

The electromagnetic method depends upon the measurement of the electric potential produced across a tidal channel by tidal currents. In 1832, Michael Faraday first suggested that such an electric potential would be produced by the interaction of tidal currents and the magnetic field of the earth. This effect, a result of the law of electromagnetic induction (Stommel 1948), is shown diagrammatically in Fig. 1. The induced potential ($\bar{E}$) is proportional to the vector cross product of the magnetic field of the earth ($\bar{H}$) and the water velocity ($\bar{V}$). The potential is measured by Silver-Silver Chloride electrodes placed on opposite sides of the stream (A and B in Fig. 1) and connected to a recorder by cables. Early measurements were mainly concerned with verifying the existence of the effect, the researchers did not devote much time to the determination of tidal transports (Stommel 1948; see Longuet-Higgens 1952).

Theoretical models relating transport to electric potential have been developed by many authors (Stommel 1948; Malkus and Stern 1952). These early papers derived general relationships based upon simplifying assumptions which are not applicable in a shallow estuary. Previous successful measurements in shallow systems were due to the integrating character of the relationship and an empirical calibration instead of the use of an applicable model (Sanford and Flick 1975). If shallow transport measurements are to be modelled correctly, the spatial distribution of velocity over the bottom

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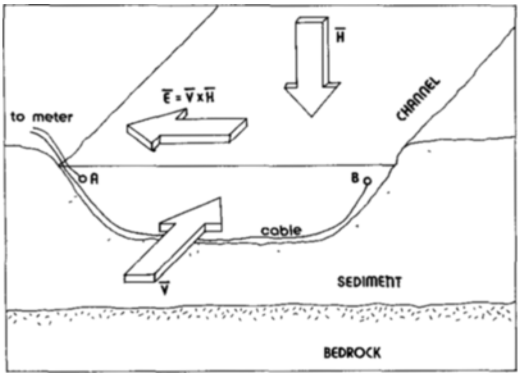

Fig. 1. Diagram of the electromotive force (E) induced in a tidal channel of width L, by the interaction of the magnetic field of the earth (H) and the velocity (V) of the water. The induced potential is proportional to the vector cross product of V and H, but due to the integrating character of the relation, it is a measure of transport (integrated velocity).

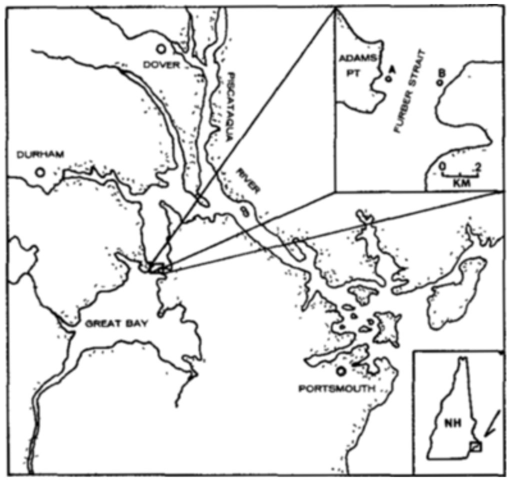

Fig. 2. Map showing location of study site in Great Bay, New Hampshire. The electrodes were placed on either side of Furber Strait (see insert upper right) at points A and B.

topography and the electrical conductivity distribution in the channel must be taken into account (Sanford and Flick 1975). Hence, an empirical calibration to measurements made with a current meter rather than a complete geophysical model is a far simpler procedure. This calibration will allow one to estimate transports from the electrode data.

A major problem associated with the electromagnetic method is noise. This noise arises from both the environment and the electrodes. The major limiting factor is the noise of the electrodes themselves. Properly matched electrodes will have an emf well below one millivolt (typically it is on the order of 100 microvolts) (Filloux 1973). Present solid state operational amplifiers have an input voltage noise which is about 10 times lower than that of median electrode pairs (Filloux 1974), thus amplifier noise is no problem. Environmental noise arises because the electrodes are sensitive to salinity and temperature changes. Although the magnitude of these effects are not precisely known, they appear to be approximately 500 μV per ‰ and 350 μV per °C (Filloux 1973).

The induced transport signals appear to be on the order of about 1 mV per 100 m^3 per sec of transport (Morse et al. 1958; Swenson 1978; Swenson 1980). Thus, the overall accuracy of the method is limited by environmental parameters (salinity and temperature fluctuations, volume of flow) and the electrode stability. It is possible (see below) to remove the salinity and temperature effect, thus increasing the measurement accuracy. If special precautions are taken to isolate the electrodes from the environment, measurements of transports in very small channels can be made (see Sanford 1977).

Examples of Electromagnetic Measurements

Great Bay, New Hampshire

The Great Bay system is located in southeastern New Hampshire and southwestern Maine. The current flow into the estuary is predominately tidal, the freshwater component being less than 1% of the tidal prism (Reichard and Celikkol 1978). An experiment, outlined below, was performed to test the feasibility of the electromagnetic method for the monitoring of tidal volume fluxes. The measurement site used was a tidal channel approximately 0.5 km wide and 10 m deep (Fig. 2). Previous data collected at the site (Swenson et al. 1977) indicated that transports were on the order of 1,000 m^3 per sec. Salinity and temperature changes in the strait were about 3 ppt and 3 °C per tidal cycle. Thus, the expected environmental noise signal was about 25% of the expected transport signal. Two electrodes were used

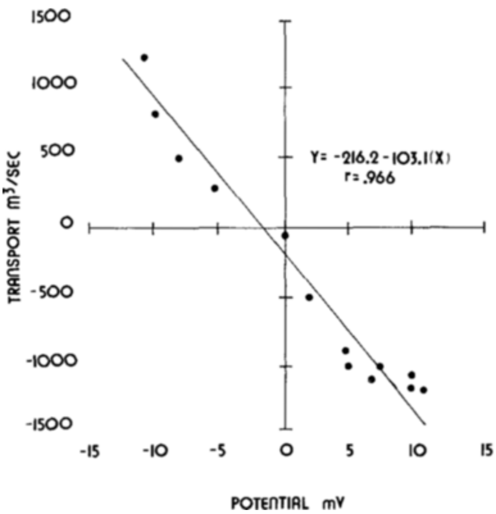

Fig. 3. Calibration curve for the electrode system. The measured potential is plotted against transports determined with current meter measurements. The results of a regression analysis are indicated on the plot.

in the study, one on either side of the channel in about 4 m of water at MLW. A complete description of the field procedures can be found in Swenson (1978).

Before the system was deployed, the electrodes were tested in order to establish a reference potential for the pair and to monitor the fluctuations in that reference with changes in temperature and salinity in order to determine appropriate correction procedures. The transfer function, using the recorded temperature as the input signal and the recorded electrode potential as the output signal, was computed. These data were collected when the electrodes were side by side on the estuary bottom, hence any potential measured was assumed to be due to the salinity and temperature changes since there was no volume flux between the electrodes. The transfer function was then used with measured temperature fluctuations to correct the electrode signal (when the electrodes were separated) for temperature effects. In using this approach, it was assumed that the transfer function remained constant throughout time, and that both temperature and salinity effects were accounted for, since they are frequency coupled.

Calibration of the system was determined by comparing electric potential measurements with transports determined from current meter measurements (Fig. 3). These data indicate that the method has an uncertainty of about 10%, the approximate error in transport as determined by current meter measurements (MaGuire, Rust, and Smith unpublished data).

A time series of tidal height and transport determined from the measured electric potential is shown in Fig. 4. The potential data have been corrected for salinity and temperature effects (as discussed above). The maxima in transport (potential) occur at approximately midtide, which is to be expected for this location, where a standing wave exists (Reichard and Celikkol 1978).

Lake Pontchartrain, Louisiana

Lake Pontchartrain is a shallow (4 m) estuary located in southeastern Louisiana. The lake is connected to the Gulf of Mexico through Chandeleur and Breton sounds by three tidal passes: the Inner Harbor Navigational Canal, Chef Menteur, and The Rigolets (Fig. 5).

In connection with an environmental study of the lake and its surrounding wetlands, transports were measured, by the electromagnetic method at two of these passes: The Rigolets and the Inner Harbor Navigational Canal. In this study, the electrodes and the cables connecting them to the recording equipment were attached to highway bridges located in the tidal passes. A description of the methods can be found in Swenson (1980).

Since data from the passes (Swenson 1980) indicate that transports could be relatively high (3,000 m^3 sec) and salinity and temperature changes were small (about 1 °C and 1 ppt) per tidal cycle, it was decided to ignore the salinity and temperature effects on the electrodes. This introduces an uncertainty of <10%.

Figure 6 shows data collected from a calibration cruise during which transports were computed from current meter measurements and compared with the measured electric potential. Figure 7 shows the limited time series data collected in the lake. Although tidal height data are not presented, the local diurnal tide (Marmer 1954) is reflected in the potential signal.

The data, which was collected primarily to test the feasibility of the method in a low

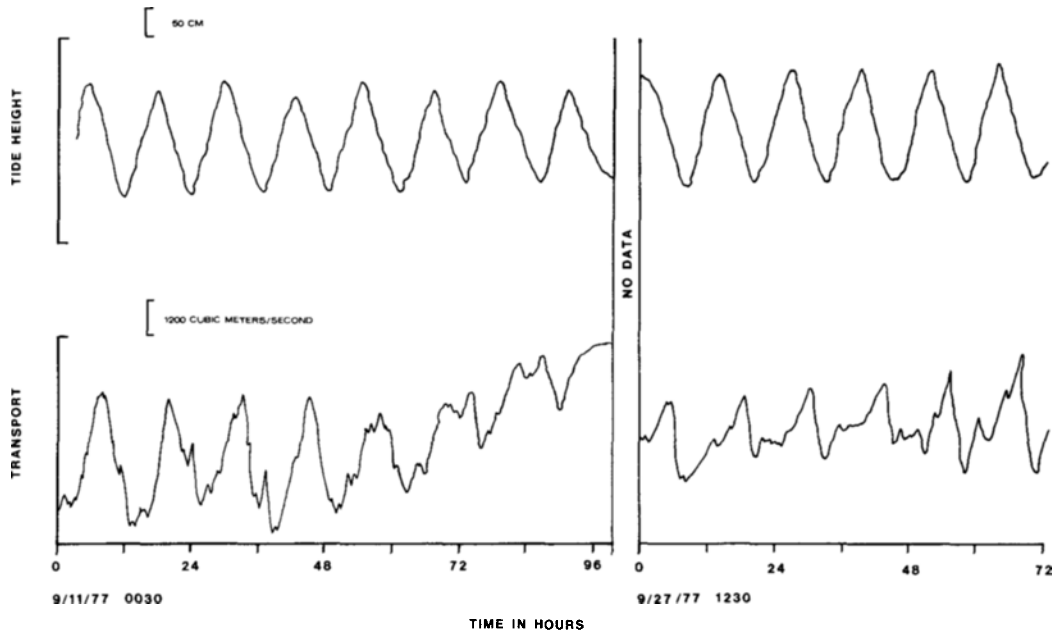

Fig. 4. Time series plot of tidal height and transport as measured by the electrodes for Great Bay, New Hampshire. The starting date and time is given at the origin of each series. A scale is indicated above the series.

salinity (5 ppt) environment such as Pontchartrain, do demonstrate that the system will function if deployed properly. The calibration data (Fig. 6) indicates that uncertainties of about 15% are feasible.

Discussion

The electromagnetic method offers substantial utility in the monitoring of gross and net tidal transports in shallow and brackish estuarine systems. The method does, however, have some drawbacks or limitations. These are environmental noise due to salinity and temperature changes, calibration drift, and lack of definition of the spatial characteristics of the flow.

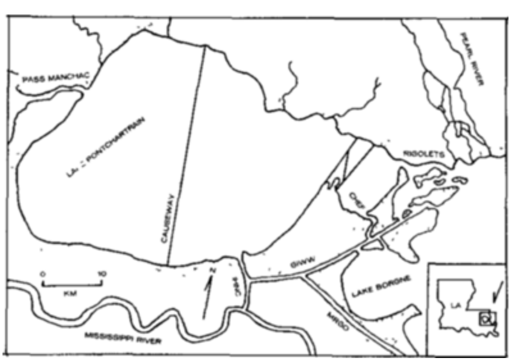

Fig. 5. Map showing location of the study sites used in Lake Pontchartrain, Louisiana. Two deployments were made, one in the Rigolets tidal pass, and the other in the Inner Harbor Navigational Canal (IHNC).

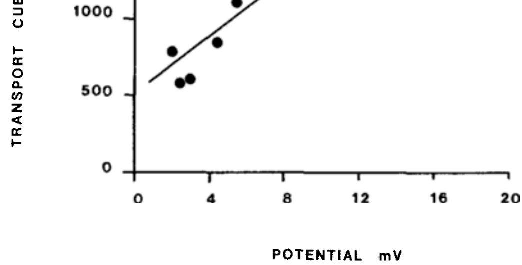

Fig. 6. Calibration curve for the electrode systems. The measured potential is plotted against transports determined with current meter measurements. The results of a regression analysis are indicated on the plot.

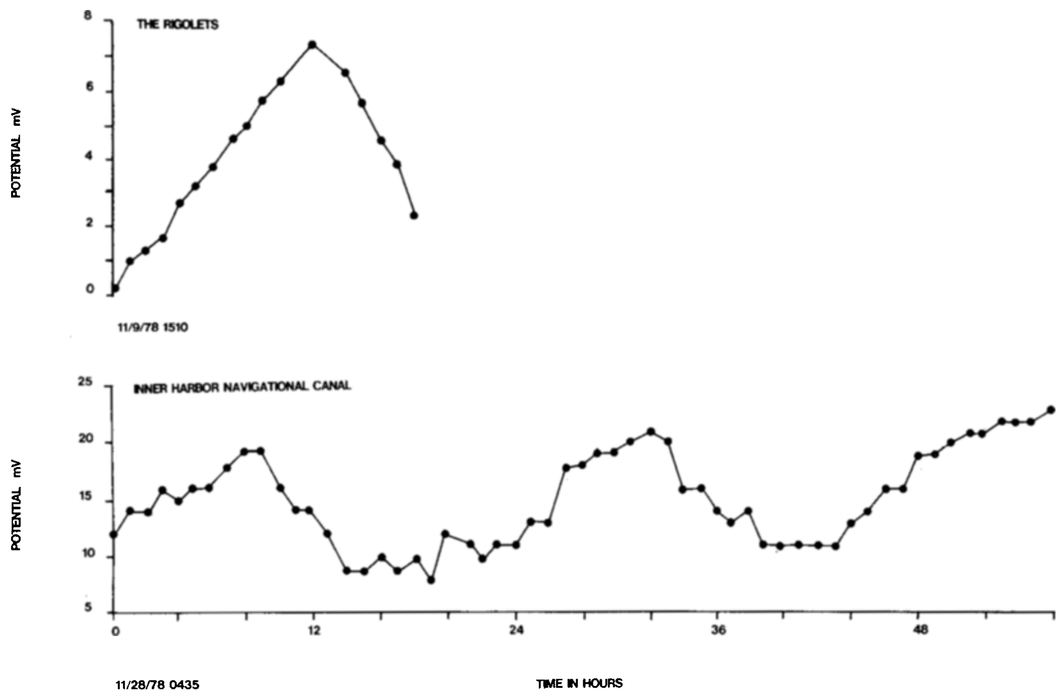

Fig. 7. Time series plot of potential measurements for the Rigolets tidal pass (top) and the Inner Harbor Navigational Canal (bottom). The starting date and time are indicated at the origin of each series.

Environmental noise in the estuarine system may have to be accounted for if this noise is much larger than the expected transport signal. Thus, the accuracy of the measurements is limited by the magnitudes of the volume flux to be measured, and the magnitude of the salinity and temperature variations. In addition, the calibration, which is determined by using conventional current meters, may not be constant with time (as I have assumed), but might exhibit a seasonal variation. Future studies are needed to access the possibility of this long term drift of an electrode system. A possible method might be to rely on periodic (seasonal) intercalibrations with a current meter. Even assuming a current meter is purchased for these intercalibration studies, the system would still have the advantage of being less costly and require less maintenance than an array of conventional meters, while yielding valuable data on the time history of tidal transport. Kjerfve (1979) has shown that the time variation of net transport in an estuarine system may be considerable. It is imperative to know this variation if one is to attempt to construct a material budget.

Acknowledgments

I wish to thank South Central Bell and American Telephone and Telegraph Company for allowing the use of the underground cable in the Inner Harbor Navigational Canal (Lake Pontchartrain, LA). I also acknowledge the assistance of the Louisiana Dept. of Transportation and Development for allowing us to place equipment on the Bridges in the tidal passes. I am also thankful to Dr. Wendell S. Brown of the University of New Hampshire for his guidance with the work done in Great Bay, N.H. and for his review of the manuscript. Funding for the research undertaken at the University of New Hampshire was provided by the University of New Hampshire Sea Grant Program (04-5-158-50) and the Central University Research Fund (CURF grant # 616). Funding for the work in Louisiana was provided by the U.S. Army Corps of Engineers (Contract # DACW29-77-C-0253).

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