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Continuous measurement of suspended sediment in rivers by means of a double beam turbidity meter

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ABSTRACT A turbidity meter for continuous monitoring of suspended sediment concentrations in rivers is described. The measuring principle automatically compensates for detector and light source ageing as well as for the accumulation of dirt and algae on the sensor windows. Data are recorded on a Read Only Memory (ROM) device which plugs into the instrument. After a ROM is full it is replaced and the ROM with the data is connected to a computer. The data are read directly onto a disc file. The ROM is cleared by passing it under an ultraviolet light after which it is ready for re-use. The instrument has an intelligent receiver unit which can be programmed to vary integration times, measuring frequencies and recording frequencies as a function of information received from the turbidity sensor or other sensor, *e.g.* of river discharge, connected to it. Initial laboratory and field tests indicate that the instrument is accurate and measures over a wide sediment concentration range (0-8 g l^{-1}). This combination of features makes this a highly suitable instrument for monitoring sediment concentrations for the purpose of calculating sediment discharge in rivers.

Mesure continue des sédiments en suspension dans les rivières au moyen d'un compteur à faisceau double

RESUME Les auteurs décrivent dans cet article, un dispositif de mesure de la turbidité qui enregistre d'une façon continue les concentrations de sédiments en suspension dans les rivières. Le principe de mesure sur lequel il est basé corrige automatiquement toute erreur qui pourrait être dûe au vieillissement du détecteur et de la source lumineuse, et à l'accumulation de débris et d'algues sur la vitre du capteur. Les données sont enregistrées par une mémoire morte qui est branchée sur l'appareil. Dés qu'une mémoire morte est pleine elle est remplacée. La mémoire avec ses données est alors branchée sur un ordinateur qui lit l'information directement sur un fichier-disque. La mémoire morte est ensuite effacée en la faisant passer sous une lumière ultraviolette, après quoi elle peut être réemployée. L'appareil est muni d'un dispositif de réception "intelligent" qui peut être programmé de façon à faire varier les temps d'intégration, les fréquences de mesure et les fréquences d'enregistrement en fonction des données émises par le capteur de turbidité, ou tout autre capteur qui lui est accouplé, comme par exemple un capteur du débit d'une rivière. Les essais initiaux de laboratoire et sur le terrain ont prouvé que l'instrument est précis et capable de mesurer une large gamme de concentrations de sédiments (0-8 g l^{-1}). Cette combinaison de caractéristiques en font donc un instrument des plus appropriés au contrôle des concentrations de sédiments enregistrées dans le but de calculer le transport solide des rivières.

INTRODUCTION

The major portion of South Africa falls in a semiarid climatic region. The average rainfall is relatively low at 480 mm $year^{-1}$ and has a strong seasonal character. This results in runoff of highly erratic nature. Sediment yields from South African drainage basins are generally high and sediment yields between 50 and 1000 t km^{-2} $year^{-1}$ were reported by Rooseboom (1975). This results in highly variable sediment concentrations in the rivers. Rooseboom (1974) found that no useful relationship exists between river discharge and sediment concentration in any of the major South African rivers. Therefore short term sediment rating curves cannot be used for estimating sediment loads from continuous flow records. The highly variable sediment concentrations in the rivers also require intensive sampling if accurate sediment load calculations are to be made. Rooseboom (1974) and Walling (1977) believe that serious over or under estimations can result in load calculations based on even daily sampling if a river is characterized by flash floods.

Traditional sampling programmes based on grab sampling at weekly or even daily sampling intervals are obviously not particularly suitable under South African conditions and continuous monitoring techniques for measuring sediment concentrations in rivers were investigated. Due to the extensive saving which would result if sediment concentrations could be measured *in situ*, compared to sampling and analyses of the samples in a laboratory, preference was given to *in situ* measuring devices. Initially two means of measuring sediment concentrations were investigated, namely a nuclear sediment gauge similar to those described by McHenry *et al.* (1970) and Welch & Allen (1973), and a turbidity

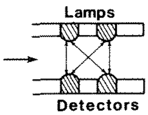

Fig. 1 Turbidity sensor.

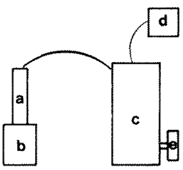

Fig. 2 (a) Housing for converter and amplifier, (b) flow-through sensor, (c) receiver and registration units, (d) battery charger, (e) ROM.

meter (Fleming, 1967; Walling, 1977). Initial tests by Grobler & Du Toit (1978) ruled out the nuclear gauge because it was too insensitive in the medium and lower sediment concentration ranges. Initial trials with a turbidity meter were very promising (Weaver, 1979). No turbidity meters suitable for field use were commercially available, and a turbidity meter was designed and built to specifications drawn up by the Hydrological Research Institute. This paper describes this turbidity meter and also presents results obtained with initial laboratory and field tests.

DESCRIPTION OF THE INSTRUMENT

Measuring principle

It is assumed that light absorption by sediment suspended in water can be described by Beer-Lambert's law which states that light extinction is a function of the sediment concentration. A major problem in using this measuring principle in single beam instruments is that ageing of the light source and detector, or partial obscuration of the light source and detector windows by algae and dirt, can result in a pronounced drift in the baseline reading. To overcome this problem the turbidity sensor was designed as shown in Fig. 1 with two lamps and two detectors. The actual measurement is made through a sequence of three steps, with lamp one on, lamp two on and both lamps off. By taking the ratios of the light intensities measured at detectors one and two in the first two steps and finally by dividing the two ratios a measurement is made which is both independent of changes in light source and detector characteristics, as well as being unaffected by partial obscuration of light source or detector windows.

Sensor unit

The lamps and detectors are mounted in a heavy duty high density PVC flow-through cell (Fig. 2). The cell was specifically designed to eliminate any interference by sunlight. This is joined to a sturdy brass cylinder in which the signal amplifiers and converters are housed. The analog signal from the detectors is converted to a frequency modulated signal.

Receiver unit

The turbidity meter has an intelligent receiver unit (Fig. 2) which receives the signals from the sensor. It does the required calculations and transfers the results to the registration unit. The receiver unit controls the sensor unit and the registration unit. It is used to set the integration times (presently 3 s) and to determine measuring frequencies. It also has the capability of receiving signals from other sensors and to change both integration times and measuring frequency according to the information received from other sensors. The receiver unit also has a clock which is accurate within 3-5 s month^{-1}.

Registration unit

The registration unit (Fig. 2) has a frequency meter with LCD display and which has a zero set and a constant multiplier control. This allows the instrument to be set to read directly in turbidity units or sediment concentration. The reading and the time are also recorded on a Read Only Memory (ROM) which is plugged into the instrument. The ROM serves as a digital recorder and the information stored is free from any electrical interferences. The information stored in the ROM is transferred to a computer using a RS232 coupling. After the information has been stored in a computer the ROM is cleared for re-use by illuminating it with ultraviolet light. The ROM is built into a metal case which protects it from mechanical damage and the whole unit simply plugs into the instrument.

Power supply
The power supply consists of two components, namely a commercial battery charger and two lead-acid batteries of the type normally used in motorcycles. This was done to facilitate the obtaining of replacements in areas far from industrial centres. The lower capacity 5 A h motorcycle batteries are used in the present model to make it portable. Once the instrument is installed at a gauging weir larger capacity motorcar batteries can be used. The power consumption of the instrument in full operation is about 1 A h. Battery life while measuring at discrete intervals can be calculated by taking into account that about 35 s is needed for a measurement and that this will consume 0.01 A h.

RESULTS

Laboratory tests
The manufacturers claim that the meter readings are accurate to 0.1% of full scale. If the frequency meter is calibrated to display readings equivalent to formazin turbidity units (FTU) the full scale reading is 4000 FTU. The claimed accuracy therefore amounts to readings accurate to the nearest 4 FTU. This was confirmed by taking repeated readings in formazin standards ranging from 50 to 1000 FTU. Larger deviations were expected when taking readings in sediment suspensions due to the inhomogeneity of the suspensions. The reproducibility and measuring range of the instrument was determined by taking repeated measurements in sediment suspensions with known sediment concentrations. These suspensions were made up by suspending known amounts of dried natural river sediments in water. The suspensions were vigorously agitated while the readings were taken to ensure that all the sediment stayed in suspension and to create conditions similar to the flow of water through the sensor. The results are given in Table 1. The meter readings increase with increased sediment concentration up to 8 g l^{-1}. Thereafter no further increase in meter readings with increased sediment concentration was noted. The standard deviations are higher than 0.1% of full scale reading except for the zero standard. However in terms of coefficients of variation only the zero standard had a value above 10%. The meter readings were plotted against sediment concentrations in Fig. 3 which shows a useful measuring range of 0-8 g l^{-1} for this instrument.

Table 1 Reproducibility and measuring range of the turbidity meter

Sediment concentration ($g\,l^{-1}$)	Average of 10 meter readings	Standard deviation	Coefficient of variation (%)
0	5	2	40
0.2	117	10	9
0.4	166	8	5
0.6	345	8	2
0.8	454	8	2
1.0	581	8	1
2.0	1111	15	1
4.0	1963	15	1
6.0	2604	22	1
8.0	2837	30	1
10.0	2840	27	1

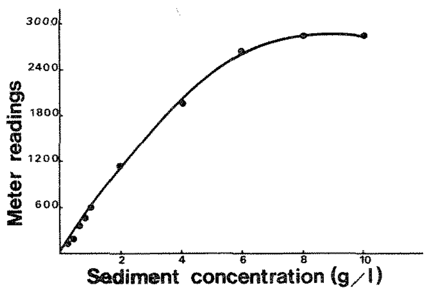

Fig. 3 Meter readings *vs.* sediment concentration.

Field testing

To assess the performance of the turbidity meter under field conditions, measurements were made in the Pienaars River during a flood. The instrument was programmed to take readings at 5 min intervals. Samples for gravimetric analysis of sediment concentrations were taken at hourly intervals. The meter readings were converted to sediment concentrations using the curve in Fig. 3 as a calibration curve. The sediment concentrations obtained from the turbidity meter and those obtained from from gravimetric analysis are given in Fig. 4. A close agreement between the two methods of measuring sediment concentration was observed.

DISCUSSION

In South African rivers high sediment concentrations are associated with flood events. The result is that the major portion of the annual sediment discharge takes place during the few floods occurring in a year. It is therefore important to measure the sediment concentration during flood events as accurately as possible. The high coefficients of variation of 40-9% for sediment concentrations of 0-0.2 $g\,l^{-1}$ are therefore

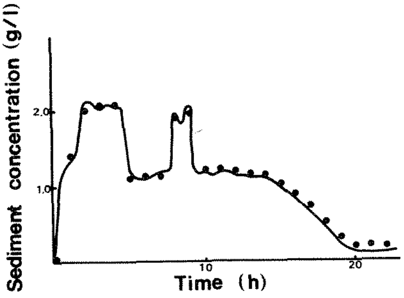

Fig. 4 Comparison of sediment concentrations obtained using the turbidity meter and from gravimetric analysis.

relatively unimportant. The higher sediment concentrations (0.2-8 g l^{-1}) occurring during flood events can be measured with sufficient accuracy as shown by coefficients of variation ranging from 9 to 1%. If the sediment concentration in a particular river is generally low, a sensor with a longer light path should be used to obtain sufficiently accurate readings. The sensor used with this instrument covers a range of sediment concentrations of 0-8 g l^{-1}. This range is sufficient for most rivers but in exceptional cases where suspended sediment concentrations of higher than 8 g l^{-1} are expected a sensor with a shorter light path should be used. This however will result in larger inaccuracies in the low concentration range.

The results obtained in the field show a good agreement between concentrations measured with the turbidity meter and gravimetric analysis. The intelligent receiver unit makes this a highly versatile instrument. It can be linked to a sensor measuring river discharge and both the integration time and the measuring frequency can be varied e.g. a low measuring frequency at periods of low discharge and low sediment concentration and a high measuring frequency at periods of high discharge and high sediment concentrations. This allows for optimal use of the storage space on the ROM and of the batteries. The use of frequency modulation to transmit the information from the sensor unit to the receiver unit has several advantages. The distance over which the analog signal, which is susceptable to interferences, is transmitted is kept to a minimum. Transmitting the signal by means of frequency modulation which is interference free, to the receiver unit, allows for the use of inexpensive cable of virtually unlimited length between the sensor and receiver units. Also, no special precautions have to be taken to prevent traces of moisture collecting in the cable, with the result that cables can be joined in the field without special equipment being required. Because of the measuring principle used the sensor can be left unattended for periods of up to 2 weeks before being cleaned. A disadvantage is that the sensor unit, which can be damaged or washed away by extreme flood events, is expensive and makes up about 40% of the cost of the complete instrument (about $2000). The changing of recording units by plugging in a ROM and returning the one with data on to the laboratory makes it possible for unskilled staff to visit the instruments to change batteries, clean the sensors and replace the ROMs. The use of ROMs for recording the data has the additional advantage that the information is read directly onto disc files where it can be edited and stored in a data bank.

Finally none of the features of the instrument described above are unique in the field of continuous monitoring of water quality. However the combination of these features in one instrument makes it a highly versatile and accurate instrument for the monitoring of sediment concentrations in rivers for the purpose of estimating sediment discharge.

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REFERENCES

Fleming, G. (1967) The application of a continuous monitoring instrument in sediment transport and water pollution studies. *Bull. IASH* XII (4), 34-41.

Grobler, D. C. & Du Toit, P. R. (1978) Voorlopige verslag oor die gebruik van 'n X-straal apparaat vir die meting van sediment konsentrasie (Preliminary report on the use of an X-ray gauge for the measurement of sediment concentrations). *Report no. N3/0401/3 Hydrological Research Institute, Pretoria, RSA.*

McHenry, J. R., Coleman, N. L., Willis, J. C., GKL, A. C., Sansom, O. W. & Carroll, B. R. (1970) Effect of concentration gradients on the performance of a nuclear sediment concentration gage. *Wat. Resour. Res.* 6 (2), 538-548.

Rooseboom, A. (1974) Meting en analise van sedimentafvoer in riviere (Measurement and analysis of sediment transport in rivers). *Tech. Report no. 58, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria, RSA.*

Rooseboom, A. (1975) Sediment produksie kaart vir Suid-Afrika (Sediment production map for South Africa). *Tech. Report no. 61, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria, RSA.*

Walling, D. E. (1977) Assessing the accuracy of suspended sediment rating curves for a small basin. *Wat. Resour. Res.* 18 (3), 531-538.

Weaver, A. van B. (1979) An initial report on the MEX 2 Photometer. *Report no. N3/0401/3, Hydrological Research Institute, Pretoria, RSA.*

Welch, N. H. & Allen, P. B. (1973) Field calibration and evaluation of a nuclear sediment gage. *Wat. Resour. Res.* 9 (1), 154-158.