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Use of turbidity monitors to assess sediment yield in East Java, Indonesia

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ABSTRACT A study to monitor sediment loss from the drainage basins of two reservoirs in East Java is described. Since 1977 up to eight turbidity monitors have been used to record continuous output of suspended sediment concentration at river flow measuring points within the drainage basins. Measurements of rainfall intensity and streamflow were made at the same time. Surveys of the reservoirs were undertaken to determine the quantity and distribution of the sediment deposits. The paper discusses the results obtained and outlines the equipment and calibration problems encountered in this tropical environment. A comparison is made between the soil erosion estimates obtained from the turbidity monitors and the annual sediment yield of 33 m^3 ha^{-1} obtained from the reservoir surveys. Studies are being continued so as to quantify the erosion in areas of particular land use. This information is being used to promote soil conservation programmes in areas of high soil loss.

Utilisation d'appareils de mesure de la turbidité pour évaluer la masse de sédiments dans la partie orientale de Java, Indonésie

RESUME L'article décrit une étude entreprise en vue de mesurer la masse de sédiments produite par les bassins d'alimentation de deux réservoirs dans la partie orientale de Java. Depuis 1977, jusqu'à huit appareils de mesure de la turbidité ont été employés pour donner un relevé continu de la concentration des sédiments en suspension aux points de mesure de débit à l'intérieur des bassins d'alimentation. En même temps, il a été procédé à des mesures de pluviométrie et de la vitesse du courant. Des études sur les réservoirs ont été entreprises afin de déterminer la quantité et la répartition des dépôts sédimentaires. La rapport examine les résultats obtenus, et il décrit les problèmes de matériel et d'étalonnage rencontrés dans ce milieu tropical. Il établit une comparaison entre la masse de sédiments estimée d'après les appareils de mesure de la turbidité d'une part et, d'autre part, la masse annuelle de sédiments de 33 m^3 ha^{-1} obtenue par les études sur les réservoirs. Les études se poursuivent en vue de quantifier l'érosion dans les régions où la terre est exploitée dans des conditions particulières. Cette information est utilisée pour encourager la mise en oeuvre de programmes de conservation du sol dans les régions où la sédimentation est élevée.

INTRODUCTION

The investigation of reservoir sedimentation and sediment transport in the upper basin of the River Brantas, East Java, is being undertaken jointly by the Hydraulics Research Station, UK, (HRS) and the Brantas River Development Executive, Republic of Indonesia (Brantas Project).

The objective of the investigation is to define the sedimentation problem in the Brantas basin, where siltation of the reservoirs and rivers is already severe. The River Brantas, basin area of 12 000 km^2, is one of the major rivers in Java, and is being developed to provide hydroelectric power and increased irrigation supplies.

Sedimentation of reservoirs causes loss of valuable water storage and reduces the effective life of an impoundment. High rates of sedimentation indicate the magnitude of soil erosion in the drainage basin. Soil lost from agricultural land cannot be replaced, but the rate of loss may be reduced if suitable agricultural practices are followed.

Two reservoirs and their drainage basins are under investigation, Selorejo and Karangkates (Brabben, 1978, 1979, 1981). The location of the study area is shown in Fig. 1 and details of the reservoirs are given in Table 1.

This paper is concerned with the performance of turbidity monitors that were installed upstream of the reservoirs (Table 2). In addition to reservoir surveys to calculate the volume of sediment deposited since impoundment, measurements on a continuous or very frequent basis of the sediment transport in the rivers are desirable.

Regular monitoring of sediment transport, in combination with river flow and rainfall intensity measurements and land use surveys are providing information on areas of high sediment yield so that conservation programmes can be promoted.

It appears that the major source of the sediment is topsoil erosion from unirrigated fields on the steep slopes within the drainage basins. The installation of the turbidity monitors has taken this into account, and new sites are being chosen to monitor sub-basins draining unirrigated areas.

TURBIDITY MONITORS

The Partech turbidity monitor (Fig. 2) measures the intensity of a beam of light passing through a turbid suspension; the source and measuring device, in this case a photo cell, being in a straight line. The intensity of a light beam transmitted through a medium containing suspended particles is decreased by the amount of light scattered by the particles. The meter is fitted with an inverse logarithmic scale and measures the ratio of incident to transmitted light, making the reading independent of the incident

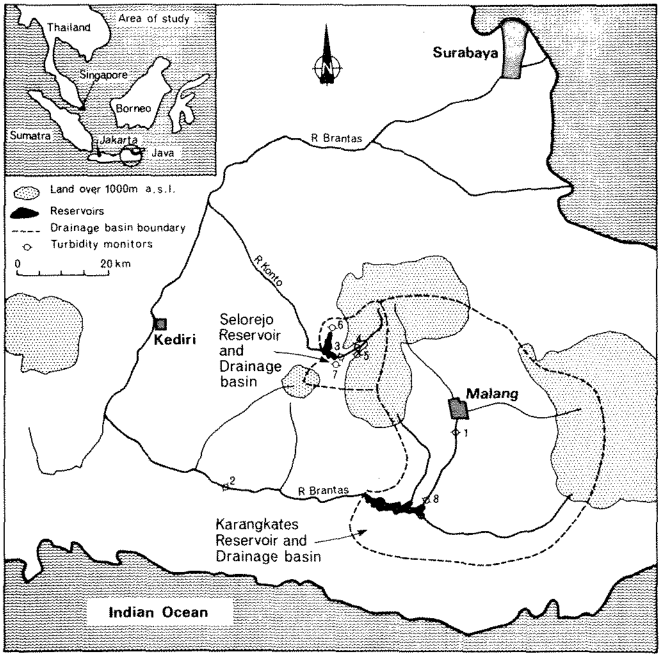

Fig. 1 Location of turbidity monitors within the Brantas study area.

Table 1 *Details of reservoirs and their drainage basins*

	Karangkates	Selorejo
Drainage area (km^2)	2050	238
Mean annual rainfall (mm)	2032	2300
Mean annual inflow (Mm^3)	2126	320
Capacity gross (Mm^3)	343	62
active (Mm^3)	251	55
Surface area (km^2)	15	4
Average channel slope	0.038	0.086
Impoundment date	1973	1970

Table 2 Location of turbidity monitors, as on 31 December 1979

Site	River	Lat.	Long.	Drainage area (km^2)
1 Gadang	Brantas	8°01'S	112°38'E	770
2 Glondong	Brantas	8°10'S	112°13'E	2937
3 Kambal	Konto	7°53'S	112°23'E	142
4 Kedungrejo	Konto	7°51'S	112°26'E	109
5 Kedungrejo 'B'	Sereng	7°52'S	112°27'E	24
6 Kwayangan	Kwayangan	7°50'S	112°22'E	53
7 Pinjal	Pinjal	7°54'S	112°22'E	43
8 Sengguruh	Brantas	8°11'S	112°33'E	1593

light intensity (Brabben, 1980).

The probes of the turbidity monitor are the twin path, nominal range 0-1000 mg l^{-1}, as shown in Fig. 2, and the single path, 0-5000 mg l^{-1}, Fig. 3. The twin path design compensates for the fouling of the optical surfaces by measuring the difference between the output of the two photo cells. The single path probe has been used most frequently in this study because of the higher range of response.

The probe is fixed either to bridge piers (Fig. 4) or river side installations (Figs 5 and 6). The probe is mounted on a trackway, to allow easy access for daily cleaning, inside a screen to afford security, and shielding from direct sunlight. Brabben (1980), found that, because of the turbulent nature of the rivers, there is very little horizontal variation of suspended sediment concentration. Therefore measurement at one point can be considered as representative of the whole cross section.

The continuous output from the monitor is recorded on a small strip chart recorder. Maximum, minimum and mean values are obtained from this chart at 15 min intervals and converted to suspended sediment concentration by means of calibration curves for each monitor.

Calibration is carried out in two stages. Firstly, the equipment is set up in the laboratory and calibrations carried out using a range of Formazin turbidity standards (Hydraulics Research Station, 1977).

Natural sediment will not necessarily give the same reading as the Formazin standard. Shape, colour, refraction index, grain size distribution all affect the calibration and it is necessary to determine a correction factor for the suspensions under study. The second stage is field calibration which should be carried out at least once a week and certainly at every visit to the site, when the batteries and charts are changed. Samples of river water are taken and analysed gravimetrically in the laboratory. A factor which is the ratio between the suspended sediment concentration as determined in the laboratory and the concentration determined from the Formazin standard can be obtained. This factor is then used to convert the Formazin standard readings to true sediment concentrations.

Suspended sediment is defined for the purposes of this paper as the sediment in suspension that can be measured by the turbidity monitor system. As the response of the turbidity monitor is not stable for grain sizes greater than 60 μm, the sediment concentrations obtained with these instruments refer only to fine grained material.

RESERVOIR SURVEYS

The two reservoirs, Selorejo and Karangkates, were surveyed by echo-sounder in June 1977 and the results compared to the original bed profiles. The results indicate that the sediment yield, since impoundment, from the drainage basins was 33.3 m^3 ha^{-1} for Selorejo (Brabben, 1978) and 34.1 m^3 ha^{-1} for Karangkates (Brabben, 1979). These surveys are to be repeated

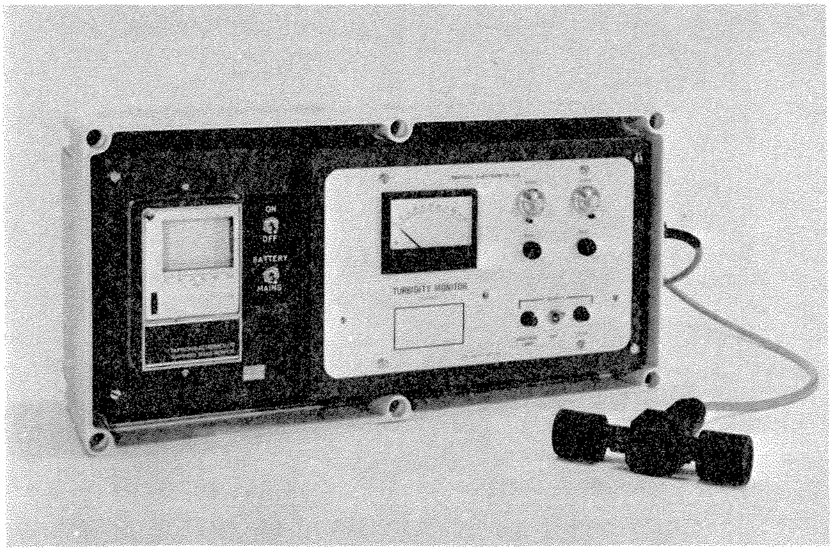

Fig. 2 Front view of Partech turbidity monitor. 0–1000 mg l^{-1}, twin path probe is attached.

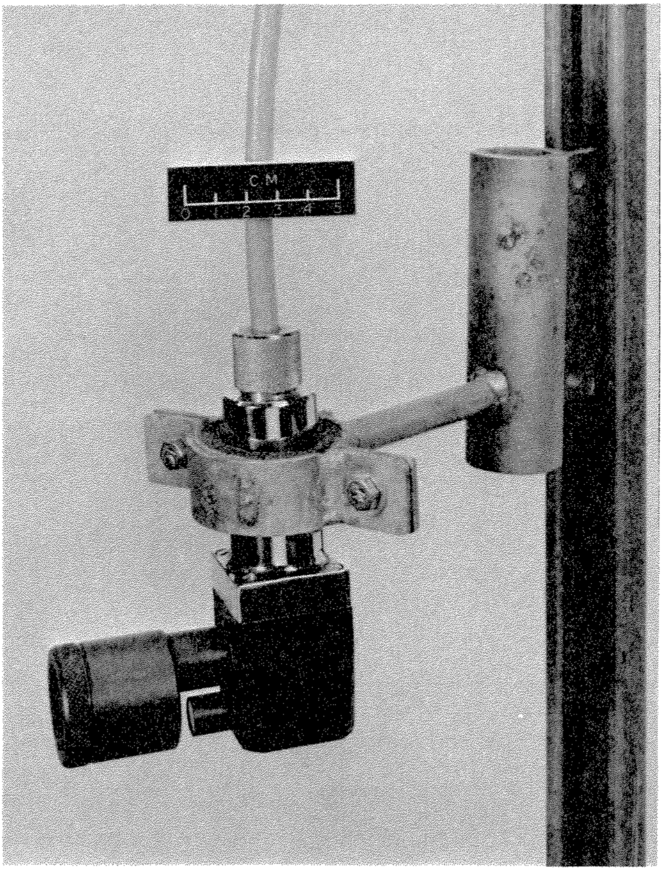

Fig. 3 Single path, 0–5000 mg l^{-1}, probe mounted on trackway.

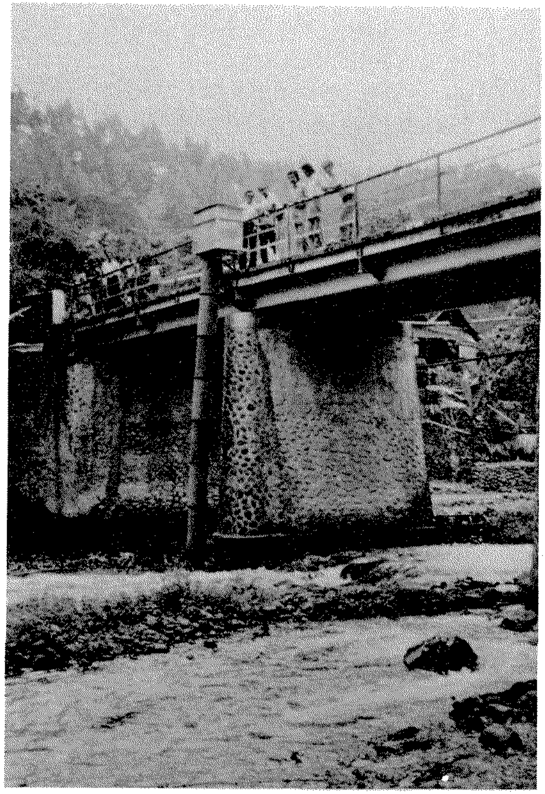

Fig. 4 Kedungrejo, River Konto. Probe housing and cabinet attached to downstream side of bridge.

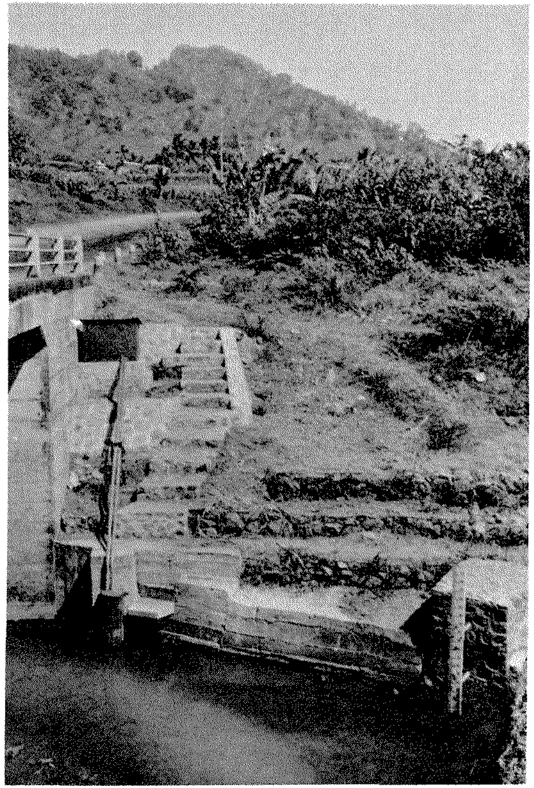

Fig. 5 Kwayangan, River Kwayangan. Probe and monitor located on right bank.

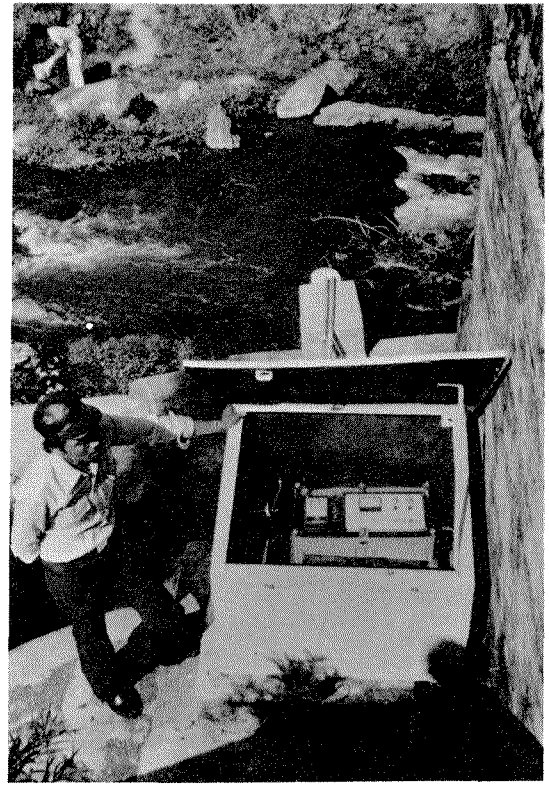

Fig. 6 Pinjal, River Pinjal. Showing housing for monitor and batteries.

in 1982 when a more accurate figure of sediment yield over the period 1977-1982 can be obtained. There is no evidence yet to determine whether the rate of deposition is increasing or decreasing.

PERFORMANCE OF TURBIDITY MONITORS

The overall operational performance of the turbidity monitors has not been totally satisfactory. Technical breakdowns can be attributed to the high temperatures, humidity and slow maintenance in the study area. Most problems have occurred with the strip chart recorders with failures of the motors and styli. This coupled with a high rate of power consumption from the lead acid batteries has resulted in an average of 30% of the potential records being lost at all sites (Brabben, 1980). Mechanical failures far outweigh electronic failures. Overall the electronic components have operated well.

To overcome these problems a switched system has been developed and is to be incorporated. This involves switching the main battery supply (24 V d.c.) on and off at preset time intervals. The whole system will only be activated when water covers the probe, therefore saving chart paper and power.

Leaks in the seals of the probes have not been a problem but cleaning of the optics by a local observer has been required every day. Optical surfaces were replaced after 3 years as they had become severely scratched by the sediment.

Calibration in the laboratory and in the field is most important and from the studies carried out so far it is clear that calibration requires far more attention (Brabben, 1980).

ANALYSIS OF SUSPENDED SEDIMENT DATA

The quantity of daily mean suspended sediment discharges is severely limited due to the technical problems described above and to the problem of maintaining concurrent records of sediment concentration and flow. The sediment yields, from the various drainage basins, using the turbidity monitor data appear much lower than those indicated from the reservoir surveys.

For Gadang the sediment discharge varies from 4.5 to 115.2 kg s^{-1} with a mean of 30 kg s^{-1}. Assuming a sediment density of 1.4 t m^{-3}, this is equivalent to 9 m^3 ha^{-1}. This low figure is attributed to an underestimate of the total load in the river for two reasons. Far more sediment is transported in the flood spates, which because of their magnitude and the risk to life have not been gauged by current meter. Bed transported material has not been measured as no reliable and realistic method has been found suitable for these rivers. Until a suitable method has been found bed load is estimated by means of the Ackers-White equation (Ackers, 1972; White, 1972).

Similar results have been obtained at Kedungrejo. Sediment discharge varies from 71.5 kg s^{-1} to less than 1 kg s^{-1}. If maintained on an annual basis these figures are equivalent to a

Table 3 Summary of streamflows, suspended sediment concentrations and discharges, 1977-1979

Site	Streamflow ($m^3 s^{-1}$)	Suspended sediment: Concentration ($mg l^{-1}$)	Suspended sediment: Discharge ($kg s^{-1}$)
Gadang	4.7- 41.1	50-5000	4.5-115.2
Glondong	52.0-303.0	100-4000	16.8-235.1
Kedungrejo	2.7- 26.8	130-5000	0.3- 71.5
Kwayangan	0.1- 2.7	450-5000	0.1- 6.8
Pinjal	0.2- 3.5	170-2000	0.1- 3.8
Sengguruh	17.0- 90.0	30-5000	71.1-225.6

mean sediment yield of 20 m^3 ha^{-1}. Flows at Kedungrejo are highly variable and more frequent current metering would enable a more accurate figure of sediment yield to be calculated.

The results obtained from Glondong, which is downstream of the major reservoirs on the River Brantas, show the general reduction of sediment concentration due to trapping of sediment in the reservoirs.

The two small rivers, Kwayangan and Pinjal, draining into Selorejo reservoir have very similar discharges (Table 3) but the sediment concentrations are markedly different. The Kwayangan basin contains a high proportion of unirrigated cultivation such as maize which exposes far more soil to topsoil erosion than the padi rice cultivation in the Pinjal basin. The higher incidence of rock outcrops and steeper slopes in the Pinjal basin appear to account for the higher runoff.

The highest suspended sediment discharges have been recorded at Sengguruh, immediately upstream of Karangkates reservoir, where the River Brantas is joined by the sediment laden River Lesti. Work has already been commenced by the Brantas Project to identify the areas of potentially high erosion in the Lesti basin and to promote conservation schemes there.

CONCLUSIONS

This study has shown that sediment loads in the rivers of the River Brantas basin are high, fluctuate widely and that only by continuous or frequent measurements of sediment concentration and river flow can a reasonable estimate of sediment yield be made. The Partech turbidity monitor provides one method of measuring the rapid variation of sediment concentration in remote areas. With improvements to the instrument and with a suitable back up of river flow measurements and frequent field calibrations there is every reason to expect that the study can be continued successfully.

Many of the problems encountered in the study have been due to the hostile environment in which the equipment is used. Similar experiences have been gained in North Sumatra (Hydraulics Research Station, 1980). The turbidity monitor has been used successfully in the UK by Thorn & Burt (1975, 1978) who give good accounts of the equipment and its value in sediment flux studies.

Results from particular turbidity monitors are being used to provide quantitative evidence for the Brantas Project to promote soil conservation schemes, improve reservoir designs and to build sediment exclusion devices.

The ultimate solution to topsoil erosion is a social one, involving improvements in cultivation techniques. This study has started to help in this solution by providing valuable information and increasing the awareness to the problem.

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REFERENCES

Ackers, P. (1972) Sediment transport in channels: an alternative approach. *Report no. INT 102, Hydraulics Research Station, Wallingford.*

Brabben, T. E. (1978) Reservoir sedimentation study, Selorejo, East Java, Indonesia: reservoir survey and field data. *Report no. OD 15, Hydraulics Research Station, Wallingford.*

Brabben, T. E. (1979) Reservoir sedimentation study, Karangkates, East Java, Indonesia: reservoir survey and field data. *Report no. OD 22, Hydraulics Research Station, Wallingford.*

Brabben, T. E. (1980) Performance and use of turbidity monitors in the Brantas River basin, East Java, Indonesia. *Report no. OD 31, Hydraulics Research Station, Wallingford.*

Brabben, T. E. (1981) Reservoir sedimentation studies in East Java. In: *Proc. Southeast Asian Regional Symp. on Problems of Soil Erosion and Sedimentation* (January 1981, Asian Institute of Technology, Bangkok).

Hydraulics Research Station (1977) The measurement of suspended solids with the Partech turbidity monitor. *Equipment Notes no. 5, Hydraulics Research Station, Wallingford.*

Hydraulics Research Station (1980) Port of Belawan, Indonesia. Third report: hydraulic studies, Parts I and II. *Report no. EX 879, Hydraulics Research Station, Wallingford.*

Thorn, M. F. C. & Burt, T. N. (1975) Transport of suspended sediment in the tidal River Crouch. *Report no. INT 148, Hydraulics Research Station, Wallingford.*

Thorn, M. F. C. & Burt, T. N. (1978) The silt regime of the Thames Estuary. *Report no. IT 175, Hydraulics Research Station, Wallingford.*

White, W. R. (1972) Sediment transport in channels: A general function. *Report no. INT 104, Hydraulics Research Station, Wallingford.*