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Determining suspended sediment loads from turbidity records

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Abstract. The Pennsylvania Department of Transportation and the US Geological Survey are cooperating in several field studies to evaluate sediment control measures used during highway construction. Among the parameters being monitored are suspended sediment concentration and turbidity. Sediment loads are calculated from suspended sediment and water discharge data, but some sediment loads must be determined indirectly because it is virtually impossible to obtain sufficient suspended sediment samples to define all runoff conditions adequately. Sediment discharge–water discharge correlation curves have proved unreliable for streams affected by highway construction, so an alternative method using the turbidity record was developed during these studies.

The field data reveal a good correlation between daily mean discharge-weighted turbidity and daily mean discharge-weighted suspended sediment concentration. Turbidity is monitored and recorded continuously, and the daily mean discharge-weighted turbidity is calculated from the turbidity and water discharge data. During periods when there are insufficient suspended sediment data, the daily mean discharge-weighted suspended sediment concentration is determined from the turbidity–sediment correlation and used with the daily mean water discharge to calculate a daily sediment load.

This method of determining sediment loads from the turbidity record suggests a possibility for computation of sediment loads by computer. Instrumentation now in use for recording water quality parameters on digital punch tape could be used to record the output from a turbidimeter. Then, for streams having a good correlation between suspended sediment concentration and turbidity, simultaneous water discharge and turbidity data could be used to determine sediment loads by computer.

La détermination des charges en suspension des rapports sur la turbidité

Résumé. 'The Pennsylvania Department of Transportation' et 'the US Geological Survey' sont en coopération pour plusiers essais sur le terrain pour évaluer les mesures pour le contrôle des sédiments pendant la construction des routes. Parmi les paramètres qu'on étudie de près se trouvent la concentration de matière en suspension et la turbidité. Les charges en suspension sont calculées des données disponibles de matière en suspension et d'écoulement d'eau. Cependant on doit déterminer de façon indirecte quelques charges en suspension parce ce qu'il est à peu près impossible d'obtenir assez d'échantillons de matiére en suspension pour pouvoir bien définir toutes les conditions d'écoulement. Les courbes de corrélation débit solide–débit d'eau se sont montrées peu fidèles pour des cours d'eau influencés par la construction des routes, donc on a développé une méthode alternative en utilisant le rapport sur la turbidité pendant ces études.

Les données sur le terrain montrent une bonne corrélation entre débit moyen journalier-turbidité calculée et débit moyen journalier-concentration de charge en suspension calculée.

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On étudie de près et enrégistre la turbidité de façon continue et on calcule le débit moyen journalier-turbidité calculée des données de turbidité et de débit d'eau. Pendant des périodes où on ne dispose des données suffisantes pour la matière en suspension, le débit moyen journalier-concentration de charge en suspension est déterminé de la corrélation turbidité-sédiments et on l'utilise avec le débit moyen journalier d'eau pour calculer une charge en suspension journalière.

Cette méthode d'évaluer les charges en suspension du rapport de turbidité suggère la possibilité de calculer les charges en suspension à l'ordinateur. On pourrait utiliser l'instrumentation actuelle pour enrégistrer les paramètres de qualité des eaux sur bande poinconnée pour enrégistrer le rendement d'un turbidimètre. Il sera donc possible de calculer les charges en suspension à l'ordinateur quand il s'agit des cours d'eau avec bonne corrélation entre concentration de charge en suspension et la turbidité, en utilisant les données de débit d'eau et de turbidité simultanées.

INTRODUCTION

The US Geological Survey, in co-operation with the Pennsylvania Department of Transportation, has been collecting suspended sediment and turbidity data in streams affected by highway construction to evaluate the effectiveness of various erosion control and sediment control measures. Determining the suspended sediment discharges in each of these streams is an essential part of these studies. One problem encountered in computing suspended sediment discharges is the difficulty in estimating loads for periods when suspended sediment data are not available.

Erosion and fluvial sediment movement from construction areas are highly variable and much greater than normal. Sediment discharge-water discharge correlation curves are not reliable for estimating suspended sediment discharge under these conditions. This paper presents a method for determining suspended sediment loads based on the correlation between daily mean discharge-weighted suspended sediment concentration and daily mean discharge-weighted turbidity.

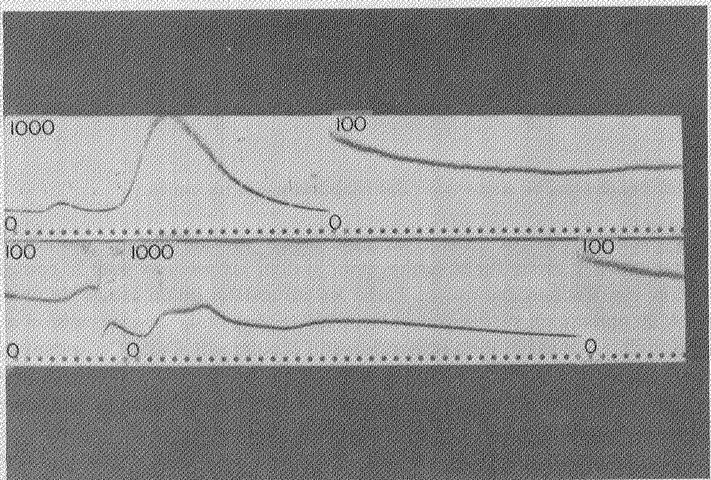


FIG. 1. Part of continuous turbidity record showing three automatic range changes. Tick marks indicate when suspended sediment samples were collected by automatic sampler.

EQUIPMENT

Gauging stations for the sediment control studies are equipped with digital and graphic stage recorders, automatic sediment samplers, and continuously operating surface-scatter turbidimeters with strip-chart recorders. The turbidimeters have been modified to change ranges automatically, so that the turbidity record is well defined at both low and high turbidity. A part of the turbidity record for 13-14 September 1974, obtained at one of the gauging stations, is shown in Fig. 1. Discontinuities occur where the turbidimeter switched ranges, first from the 0-1000 range to the 0-100 range on the upper strip chart, then back to the 0-1000 range on the lower strip chart, and finally back again to the 0-100 range.

The turbidimeter provides a signal that activates the automatic sediment sampler when the turbidity rises above a pre-set level. A small lamp added to the turbidimeter is wired so that it lights each time the sediment sampler collects a sample. This causes an apparent increase in turbidity, which marks the turbidity record, as can be seen in Fig. 1. Also, the time of sampling is marked on the graphic stage record by draining a portion of the water circulated through the sediment sampler into the stilling well.

COMPUTATION OF RECORDS

During periods when suspended sediment data are available, sediment discharge is computed on a daily basis according to the methods described by Porterfield (1972). Daily mean discharge-weighted suspended sediment concentration and daily mean discharge-weighted turbidity are computed as shown below:

$$C_w = \frac{\Sigma(tqc)}{Q_w T} \quad (1)$$

or

$$C_w = \frac{Q_s}{Q_w k} \quad (2)$$

where

$$J_w = \frac{\Sigma(tqj)}{Q_w T} \quad (3)$$

C_w = daily mean discharge-weighted suspended sediment concentration
t = time interval of a subdivided day
q = mean water discharge during time interval t
c = mean suspended sediment concentration during time interval t
Q_w = daily mean water discharge
$T = \Sigma t$ (24 hrs)
Q_s = daily suspended sediment load
k = constant (0.0864 for Q_s in tonnes and Q_w in cubic metres per second, and 0.0027 for Q_s in tons and Q_w in cubic feet per second)
J_w = daily mean discharge-weighted turbidity
j = mean turbidity during time interval t.

The methods for determining t, q, and c are explained by Porterfield (1972). The value j is obtained from a turbidity-time graph in the same way that c is determined from a concentration-time graph.

When insufficient data are available to develop a concentration graph, the turbidity graph can be used with the corresponding hydrograph to determine a daily mean discharge-weighted turbidity. The daily mean discharge-weighted suspended sediment concentration can then be determined from the correlation between turbidity and suspended sediment, and suspended sediment discharge can be computed by the formula:

$$Q_s = Q_w C_w k \qquad (4)$$

CONCENTRATION-TURBIDITY CORRELATION

The correlations between daily mean discharge-weighted suspended sediment concentration and daily mean discharge-weighted turbidity for several streams below areas of

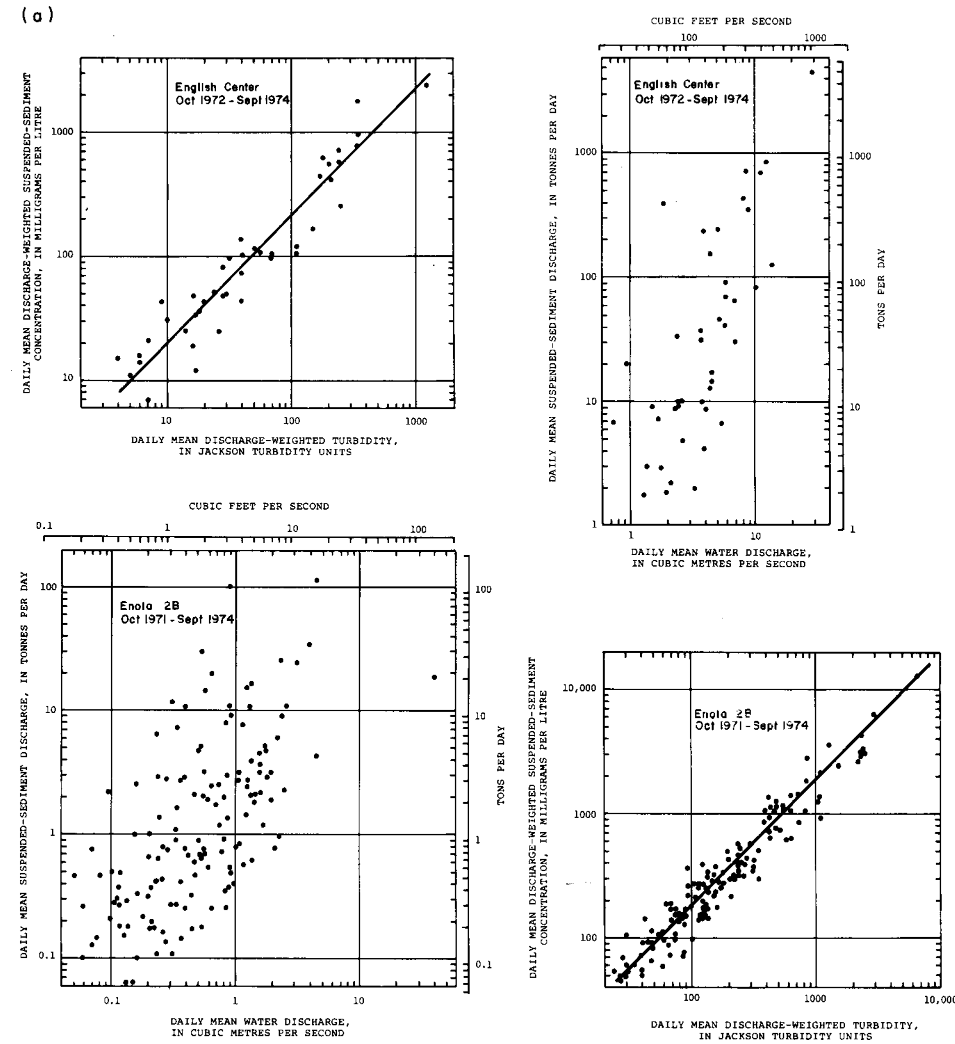
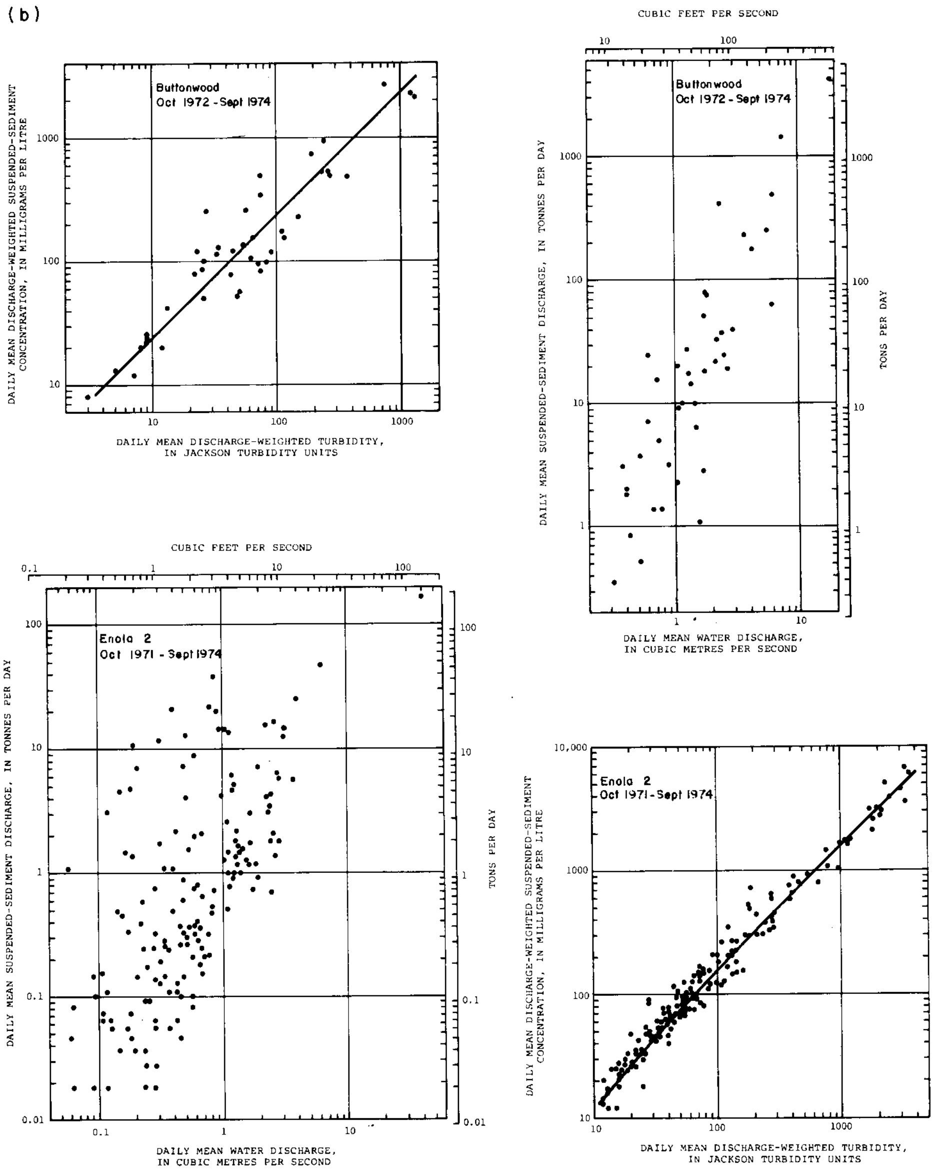
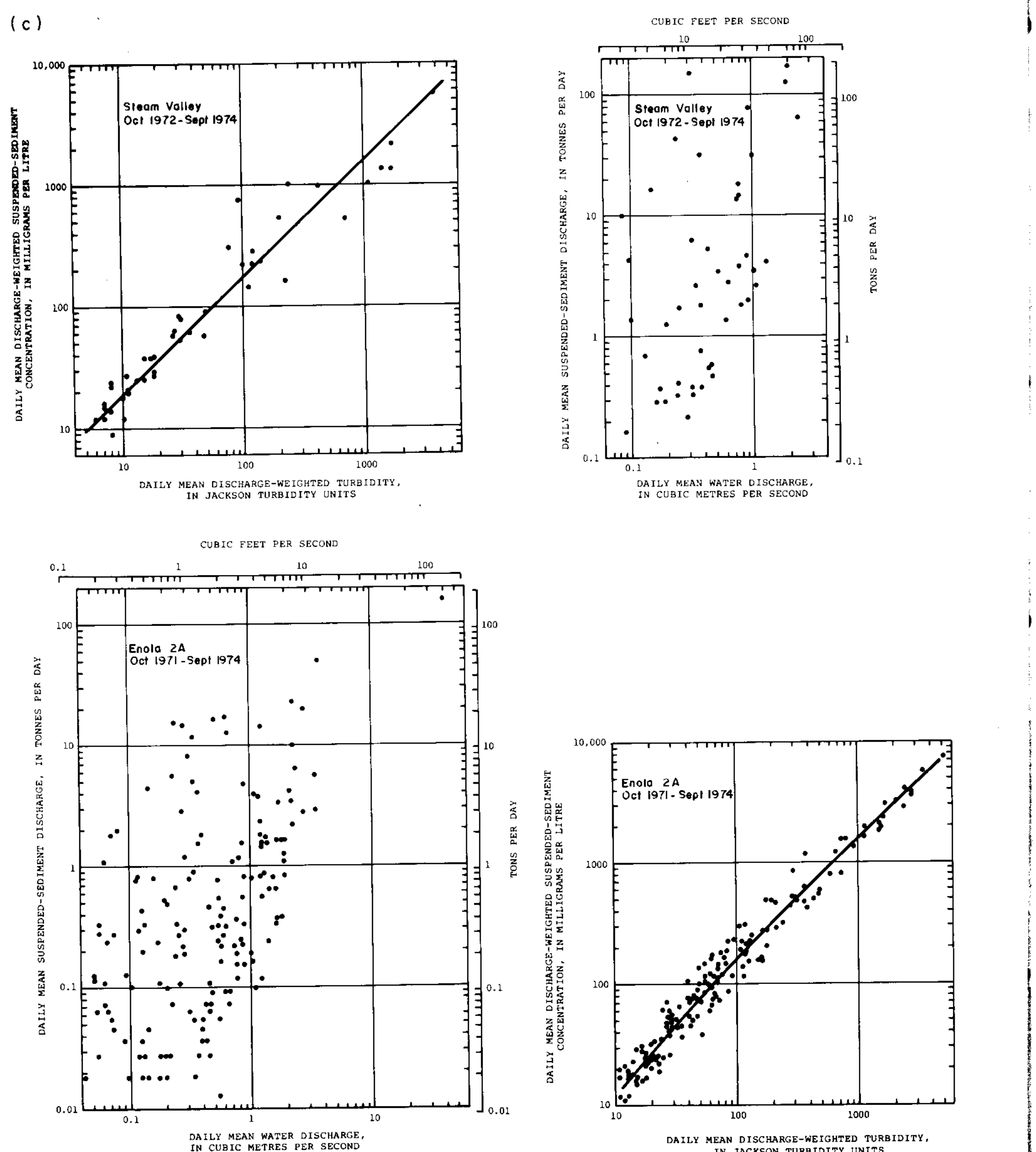


FIG. 2. Correlation of daily mean discharge-weighted suspended sediment concentration with daily mean discharge-weighted turbidity compared with sediment discharge-water discharge correlations for several streams affected by highway construction.

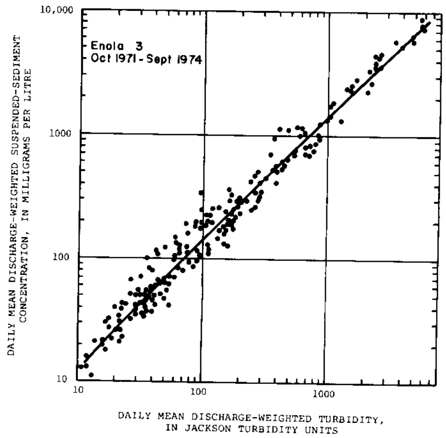


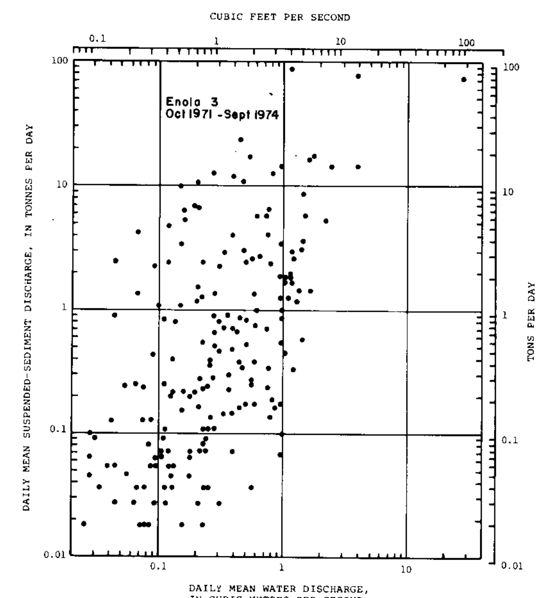
(FIG. 2. *continued*)



(FIG. 2. *continued*)

(d)





(FIG. 2. *continued*)

active highway construction are shown in Fig. 2. The sediment discharge-water discharge correlation for each stream is also shown for comparison. The superiority of the concentration-turbidity correlation is easily apparent in the slope as well as in the smaller amount of scatter. Thus, turbidity-concentration relations are more accurate than sediment discharge-water discharge curves in determining daily loads.

Not all of the scatter in these sediment discharge-water discharge correlations is the result of highway construction. Concentration-turbidity correlations and sediment discharge-water discharge correlations for two streams not affected by construction are shown in Fig. 3. These graphs show about the same scatter as those for the streams affected by construction.

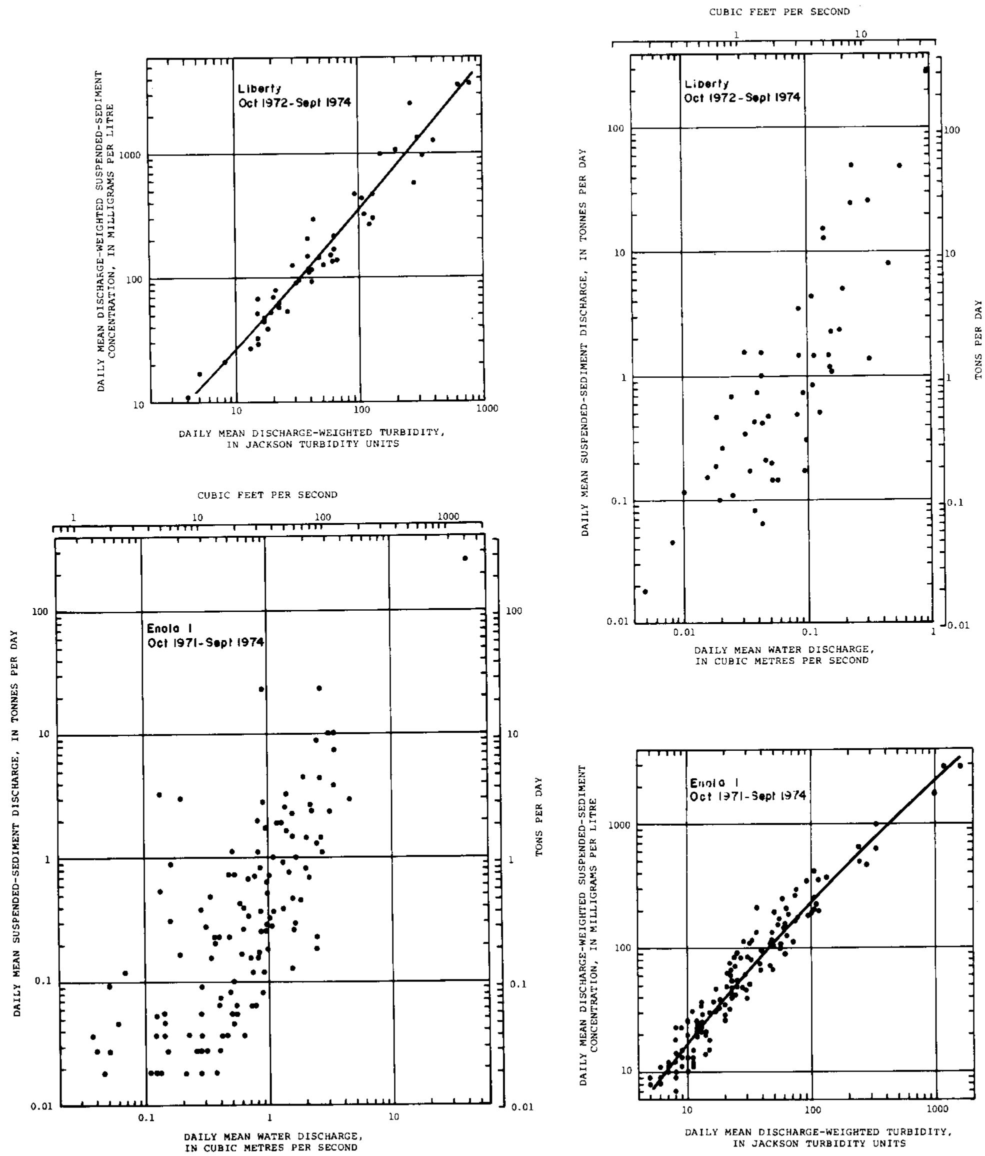


FIG. 3. Correlation of daily mean discharge-weighted suspended-sediment concentration with daily mean discharge-weighted turbidity compared with sediment discharge-water discharge correlations for two streams not affected by highway construction.

DISCUSSION

There is no universal relationship between turbidity and suspended sediment concentration, but there is often a good correlation for individual streams, probably because the material in suspension in a stream is a characteristic of the basin.

It seems reasonable to expect a better correlation between turbidity and suspended sediment concentration than between water discharge and suspended sediment discharge because turbidity and suspended sediment concentration respond similarly to many factors that are not directly related to water discharge. For example, in a highway construction area the quantity of sediment entering a stream is not necessarily related to runoff but may be related to earthmoving near the stream.

Water discharge and suspended sediment concentration may not correlate well for many reasons (Gregory & Walling, 1973). Poor correlation for the two streams not affected by construction results partly from influences such as occasional grading of dirt and gravel roads and dairy farming. Variations in the magnitude and rate of water discharge increase also have a great effect on sediment concentration and load. No seasonal effects are apparent for these streams, but the hysteresis effect is very obvious, both for individual storms and for storm periods lasting several days.

A continuous turbidity record makes it possible to develop good sediment discharge records with fewer sediment samples than might otherwise be needed because there is a good correlation between turbidity and suspended sediment concentration for many streams. It greatly increases the reliability of pro-rated concentrations determined from intermittent samples and also helps in shaping concentration graphs during storm periods.

Turbidity records might also be used for determining suspended sediment discharges by computer methods for streams where there is a good correlation between turbidity and suspended sediment. Instrumentation presently available could be used to record turbidity on digital tape. This record and the turbidity suspended sediment relationship could be used in conjunction with water discharge records for computer computation of sediment loads. Naturally, it would still be necessary to obtain enough suspended sediment and turbidity data to develop a correlation and to verify it occasionally. Loss of accuracy in determining sediment loads by using the correlation between sediment and turbidity rather than by conventional methods would have to be evaluated. This could be complicated by the fact that the absolute accuracy of computed loads is unknown because there are many uncertainties in sampling for and computing sediment loads by conventional methods (Guy, 1970).

Disadvantages of obtaining turbidity records are that turbidimeters require a 120 V AC power supply and that the pumps and intakes require frequent maintenance. A disadvantage of using the turbidity-concentration correlation to determine sediment discharges is that the correlation may become poorer as the percentage of sand in the sediment mixture increases.

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