Accuracy of Sediment Yield Measurements in small Catchments

JUSSI BAADE & CLAUDIA LIESE
Department of Geography, Friedrich-Schiller-University, D-07740 Jena, Germany
e-mail (JB): cub@geogr.uni-jena.de

Key words: suspended sediment yield, event based sampling, small drainage basins, accuracy of data, Germany

ABSTRACT

The most common used methods to determine sediment yield from small catchments (≈ 10 km²) are based on water sampling strategies, as flow depths are often too small and irregular to use optical sensors. In several sediment yield studies automatic sampling devices triggered by water stage recorders were used to determine sediment transport. Based on two field studies in a small loess-covered catchment in southwestern Germany (Kraichgau) and a former uranium-mining area in eastern Germany (Thurengia) we discuss several factors determining the accuracy of sediment yield data. These factors include accuracy of discharge measurements, timing of sampling, water sampling intervals and methods, as well as selected sediment concentration measurement techniques.

INTRODUCTION

Parallel to the progress in the mitigation of river pollution from point sources concern about so called diffuse sources of pollution has grown in the public and in science. Increasing awareness of the damages caused by sediment laden, muddy waters, calls for a better understanding of the processes involved in sediment mobilization by soil erosion and channel erosion as well as the sediment delivery problem.

In this context field observations and sediment yield data from small catchments are necessary to quantify relevant processes and to test models. In model testing exercises modeling results are compared with measured values and deviations are discussed. But quite often, no information is given on the accuracy of the measured values. In this paper factors determining the accuracy of suspended sediment yield data from small catchments will be discussed.

FACTORS DETERMINING SEDIMENT YIELD DATA ACCURACY

In many cases suspended sediment yield from small catchments (≈ 10 km²) in temperate environments is determined from continuous discharge data and sediment concentration data based on some kind of intermittent sampling strategy. This combination of continuous water level recordings and intermittent water sampling takes into account the high temporal variability in discharge and sediment transport in small catchments. Accuracy of resultant sediment yield data is determined by the accuracy of the runoff data and the accuracy of the sediment concentration data. In this context temporal resolution is a very important factor.

ACCURACY OF DISCHARGE DATA

The accuracy of discharge data depends on (a) the temporal resolution of water level records, (b) the accuracy of the water level readings and (c) the accuracy of the calibration curve for the gauging station.

(a) Using present day technology (data loggers and some kind of electronical water level recording device) water level records with a high temporal resolution are readily available. Therefore, temporal resolution of water level records from small catchments should always be better than 15 minutes. Longer time intervals (≈ 60 min) between water level measurements could yield errors in total storm runoff volume of up to 100%, depending on (i) the size of the catchment, (ii) land use characteristics in the catchment, and (iii) season. Therefore, highest temporal resolution is necessary for unforested first order basins with immediate response to rainfall events during summer conditions.

(b) At carefully planed and maintained gauging stations the accuracy of water level records should be in a range of 5 mm to 10 mm. But, under turbulent flow conditions accuracy of water level readings might drop to a few centimeters. A better than 5 mm accuracy of water level readings seems unrealistic because of the difficulties in determining the water level at the reference meter used to calibrate and check the continuous water level recording device.

(c) Assuming a consistent accuracy of water level readings, accuracy of discharge measurements depends on the type of weir used and the corresponding calibration curve. Figure 1 compares the relative error of discharge (in %) and discharge for four different types of weirs used in a 3-years nested catchment monitoring program, with catchments varying in size from 0,04 to 7,7 km². In general, the relative error of discharge measurements decreases with increasing water level and discharge. This means that accuracy of total storm runoff volume will be higher for large events, as compared to small events. In addition to this, total storm runoff volumes from larger catchments can be measured more precisely than runoff volumes from smaller catchments. Due to the changing accuracy of discharge measurements with flow level, mean accuracy for an individual runoff event is strongly depended on the

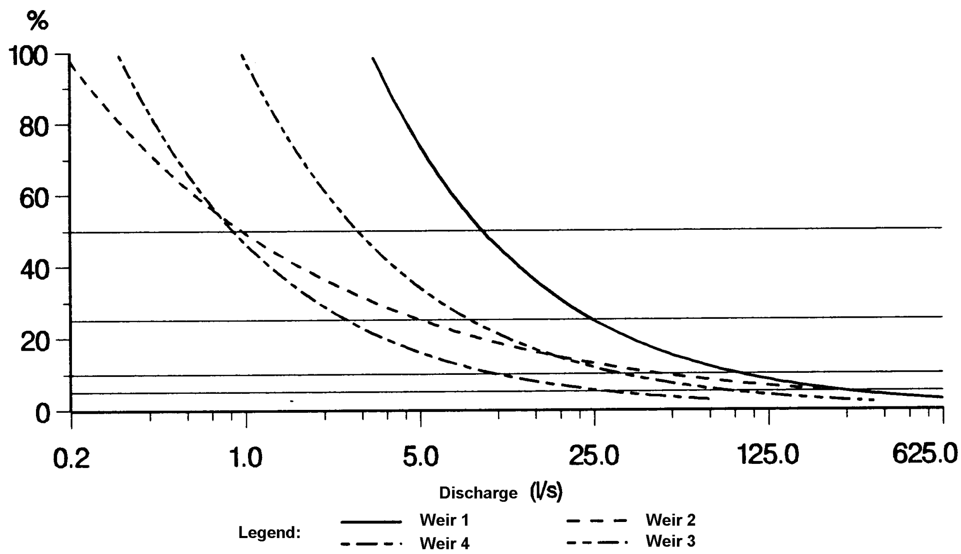

Fig.1: Relative error of discharge measurements for four different types of weirs

characteristics of the event, i.e. previous level, time and intensity of rise, peak flow, and post event level of flow. Previous and post event level of flow determine the lower level of accuracy, while peak discharge determines the upper level of accuracy. Because of the skewed distribution of flow levels within an event, the median of flow level should be used to characterize the overall accuracy of storm discharge data. Nonetheless, as mean flow is more easily calculated, it is suggested, that the accuracy for the mean flow could as well be used to express the accuracy of discharge data for a given event. Based on the experience from a 3-years study in a loess-covered catchment in southwest Germany one thus can estimate the over all error for storm runoff volume to be < 10 % for small catchments (< 10 km²) and from 22 to 7 % for very small catchments (< 1 km²).

ACCURACY OF SEDIMENT CONCENTRATION DATA

The accuracy of sediment concentration data depends on (a) the temporal resolution of water sampling, (b) the variability of sediment concentrations within a given stream cross section (not dealt with in this presentation) and (c) the methods used to determine sediment concentration in the lab.

(a) It has been long recognized, that temporal resolution of water sampling is the most important factor when discussing accuracy of sediment yield data. The results from the 3-years sediment yield monitoring scheme showed that over 90% of the total amount of sediment (860 t) leaving a small catchment in southwestern Germany was transported in the course of only 9 events, lasting less than 2% of the total investigation period. Therefore, continuous, fixed interval sampling is usually of little help in measuring sediment yield from small catchments, because this either creates numbers of samples far exceeding handling capacities or has a good chance to miss the times when stream flow and sediment concentrations are high. Under conditions limiting the amount of samples to be handled, some kind of intermittent, event based sampling strategy using an automatic sampling device connected to a water level recorder or a flow meter should therefore be applied. Nonetheless, even with these devices, some adjustments are necessary in order to accommodate seasonal variations as well as differences in runoff generation within catchments of different size and land use characteristics and thus ensure high quality sediment yield data. Due to lower baseflow during the summer, the benchmark for triggering the sampling device needs to be set at a lower level as compared to the winter time. In addition to this, sampling frequency needs seasonal adjustment. Based on our experience, during the winter time a sampling interval of 30 min in very small catchments (< 1 km²) and 60 to 90 min in small catchments (< 10 km²) is sufficient. During the summer, sampling intervals should be around 15 min for very small catchments, although this might already be too long to get representative samples from intense summer thunderstorms, and around 30 min for small catchments.

(c) Further minor errors in determining the sediment concentration can occur due to deviations from what might be regarded as a standard method, i.e. vacuum filtration of water samples using membrane filters with a pore size of 0,2 and 0,45 µm. With high sediment concentrations (> 1,000 mg l^{-1}) filtration tends to become a very time consuming procedure, specially if silt and clay contents are high. In order to deal more time efficiently with these samples two alternative methods were used to divide suspended solids from water and determine sediment concentrations. Depending on availability of man power water samples were either left to settle down for a certain amount of time or suspended sediment was settled using a large centrifuge (5,000 rpm). Afterwards, the excessive, macroscopic clear water was pored away and the reminder was dried at 105 °C. In order to determine the loss from poring away the excessive water, several samples of excessive water were filtrated using 0,2 µm filters. Results show that both, centrifugation and settling over several weeks, introduces only minor errors (<1 to 3% of the sediment content measured in the dried samples). But, when settling time is in the order of one week only, excessive water can still contain up to 100 mg l^{-1} of solids, and the error can rise up to 6%.

CONCLUSIONS

Due to the high temporal variability of discharge and sediment concentration in runoff, data with a high temporal resolution are a prerequisite for accurate sediment yield measurements in small catchments. Automatic sampling devices connected to water level recorders or flow meters provide the necessary technique. But, when setting up representative sampling schemes the size of the catchment and the season should be considered. With a proper temporal resolution for discharge measurements and sample collection and with the equipment properly working, sediment yield from small catchments can be determined with an error of less than 10 %.