Monitoring sediment load from erosion events

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ABSTRACT A mobile station has been constructed for monitoring erosion on plots or other erosion sites. Climatological data and flow data are collected by a datalogger that also triggers an automatic water sampler and a modified camcorder. A station for detailed monitoring of sediment transport from a basin was established in order to evaluate the contribution from erosion. Flow is measured by a flow meter that triggers an automatic water sampler. The sediment concentration is also determined indirectly using an IR light transmission sensor.

INTRODUCTION

Erosion leads to deterioration of agricultural land which is a major problem in mankind's endevours to cope with the increasing demand for food caused by the Earth's still growing population. Erosion also causes serious offside effects such as silting of reservoirs and eutrofication in water courses, lakes and coastal waters. In order to predict and quantify erosion resulting from climatological events and to evaluate the effect of conservation measures great efforts are made to develop soil erosion models, (Chisci & Morgan, 1988), (Foster & Lane, 1987). The trend is toward development of physically based models which include mathematical description and quantification of the erosion processes and their mutual interaction, Morgan et al. (1991), (Styczen & Nielsen, 1989). The work with the models often identifies problem areas where insufficient knowledge of processes delimits the possibilities of creating physically based algorithms.

In particular, problems are encountered when trying to model the initiation and development of rills and the effect of frozen soil. Another difficult area is to describe the routing of sediment to streams and to evaluate the impact from different sediment sources. Therefore there is a need for a better description and quantification of rill erosion and the reaction of basins to erosion events.

The aim of this paper is to describe the monitoring system created in Denmark as a contribution to the STEP programme which aims at a validation of the European Soil Erosion Model (EUROSEM), (Morgan et al., 1991), and the erosion model (SEM) built on top of the SHE-model, (Styczen & Nielsen, 1989).

METHODS

Major erosion most often occurs as a result of climatological events of a rather short duration which are difficult to forecast; furthermore, areas with erosion hazards are seldom situated near research facilities, a fact that calls for the use of automatic monitoring stations. In order to describe the succession of different processes, f.i. head cut and wall collapse, and in order to interpret the sediment transport record, there is a need for visual registration during an event. In the following is first given a description of the monitoring system at a single erosion site scale, f.i. an erosion plot or a river bank, and then a description of the monitoring at a basin outlet.

Below are listed the requirements to a monitoring station at an erosion site:

1. Time resolution minutes to seconds
2. Continuous flow record
3. Continuous, or very frequent registration of sediment concentration
4. Visual registration with time and scale incorporated
5. Climatological record, f.i. rainfall and temperature
6. Measurements of microtopography, f.i. rill volume
7. Soil variables, f.i. bulk density, shear strength etc.
8. Logistic requirements: station should be mobile, flexible and have a low power consumption independent of AC-mains.

To meet the requirements above, a station with the following configuration of instruments was constructed:

1. Instrument platform
2. Weather-proof housing for samplers, datalogger and batteries
3. Flow recording unit
5. Visual recording unit

Testing of the station takes place at the Agriculture Research Station at Foulum where an erosion research programme is carried out by the Danish Research Service for Plant and Soil Science as well as by the Danish Society for Land Development. This project is described in detail in Hansen et al. (1991), the author participates in the programme by monitoring the rill evolution on the plots.

In brief, there are 8 similar erosion plots with different crops and treatment of the soil. Each plot is 22.1 m long and 3 m wide, the slope is 9%. At the lower end of each plot, water and sediment are collected in a PVC gutter and conveyed to a collecting tank covering 1.4 m^2 and 1 m deep. The monitoring station is placed at plot No. 5 where the crop is winter wheat sown perpendicular to the contours. Climatological parameters and soil parameters are measured within the main project and will be available when they have been elaborated and controlled; these measurements are therefore not recorded at the station. Station and plot are shown in Fig. 1.

The instrument platform is a foldable aluminium stand for construction works. The weather proof box is of plywood insulated with plastic foam.

As flow recording unit a Campbell 21x datalogger is used together with a pressure transducer. The latter is placed in a tube protected against the sediment-loaded water by a filter. The logger is programmed either to record solely the stage, or both the stage and flow-rate together with the time of occurrence. The Campbell logger is chosen because of its ability to sustain different kinds of sensors in case no

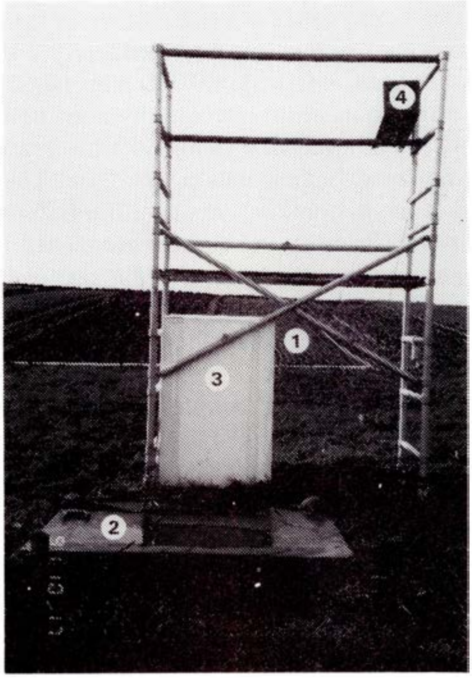

FIG. 1 1. Erosion plot 2. Collecting tank
3. Datalogger and batteries 4. Camcorder.

other climatological records are available and also due to its ability to act as steering device for the other functions of the station.

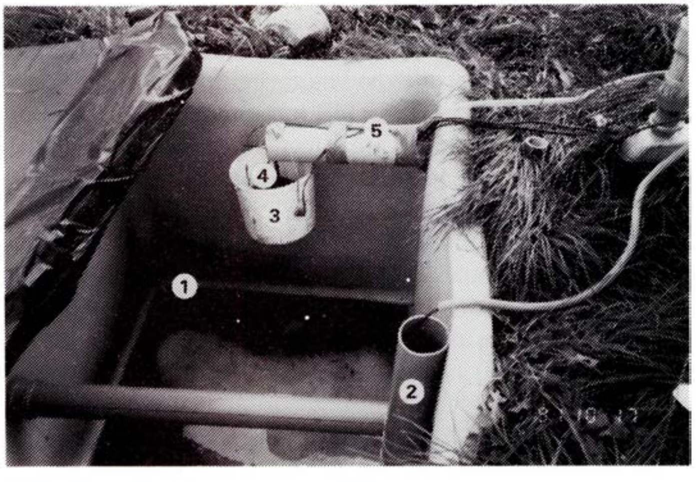

FIG. 2 1. Collecting tank 2. Pressure transducer 3. Borda bucket
4. IR-sensor 5. ISCO intake tube.

The sediment concentration is recorded indirectly by use of an IR-single gap sensor manufactured by Partech, the readings are collected every 2 min on a Grant 8-bit datalogger. Two sensors are used, one with a 0-300 ppm range and the other with a 0-1500 ppm range. In order to measure, the sensors must be covered by water, therefore the water from the plot must be stemmed a bit in a measuring chamber. The chamber must not cause sedimentation, however. The sensors are placed in a bucket with a hole in the bottom that acts as a Borda type flowmeter and allows water and sediment to pass. Chamber and sensors are shown on Fig. 2.

Because the IR-sensors are sensitive to changing grain size distribution, (Gippel, 1989), the recordings must be calibrated against concentration of sediment measured in filtered water samples. Also silting of the lenses and growth of algae may be a problem so that calibration is needed.

To collect water samples, an ISCO water sampler is chosen. The peristaltic pumping system with a purging cycle is well suited to take the samples of sediment-loaded water. The sampler can operate in different modes, either sequential, or flow-proportional, or sample at prechosen different time intervals. The two last modes can be triggered by external devices. During the winter 1990/91 the sampler was operated in the non-uniform time mode. The sampling was started by a float-operated contact in the Borda chamber; this means that when a flow of approx. 16 ml/s was reached, the first sample was taken, the next after 1 minute and the rest of the 24 samples were distributed over 24 hours with more frequent samples in the beginning in order to describe the storm runoff hydrograph. The procedure worked quite well, but in case of storms of short duration a lot of empty bottles were collected. Furthermore, it is considered better to take samples according to the form of the actual storm hydrograph. It was therefore decided instead to collect flow-proportional samples. As the collecting tank is rectangular with vertical sides, the flow is easily monitored by measuring the stage with a pressure transducer. This is operated by the Campbell datalogger that triggers a relay connected to the flow port on the ISCO sampler every time when the stage has risen more than f.i. 2 cm.

The visual registration unit consists of a modified commercial camcorder, Canon E 60. Unfortunately, these relatively cheap recorders cannot be operated immediately by an external signal in a way that both incorporates the time into the picture and simultaneously override the autofocus function. Therefore it was necessary to build a "black box" to control the camera. The camera starts the recording sequence when the "black box" receive an external signal. In order to make the system as flexible as possible concerning the processes that start recording, the Campbell logger is chosen as source for the external signal. Presently, the signal is triggered by a certain rise in the stage in the collecting tank f.i. 2 cm as for the ISCO sampler. The signal could, however, also be triggered by rainfall intensity, or by wetting of the soil surface. In case of night, it is also possible to illuminate the measuring site. The station is powered by 12 volt ordinary car batteries.

The microtopography is measured with a reliefmeter at 1-cm intervals. If rills develop, the width and depth of the rill is recorded every meter so that the cross-section area can be computed. The length of rill between cross-sections is measured too and the total volume eroded by rills is computed. Together with bulk density this gives the gross weight of sediment removed from the plot by rilling - the net weight collected in the tank depends on the amount of sedimentation in the lower end of the plot which is not measured. By simultaneous visual registration and recording of sediment transport, the rill-forming processes should be elucidated.

BASIN SCALE

The requirements to a sediment transport monitoring station in order to interpret impact of erosion at a basin outlet are stated below:

1. Better time resolution of discharge than at ordinary gaging stations which often only record daily mean values.
2. Continuous, or more frequent recording of sediment concentration. Very often only weekly samples are available.
3. Measurements of bed load.
4. Registration of erosion features and areas of sedimentation (sinks).

The monitoring system described below has been developed within the Danish NPO-project, (Hasholt, 1989). The station at the basin outlet is shown on Fig. 3.

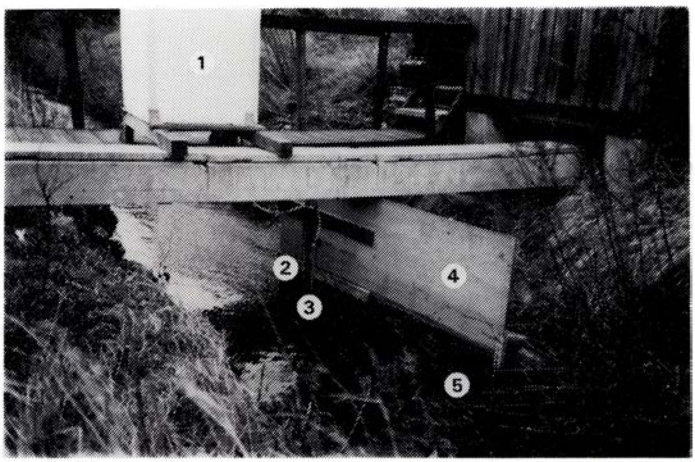

FIG. 3 1. Datalogger and batteries 2. ISCO intake tube
3. IR-sensor shield 4 Stream contractor
5. Flowmeter sensor on bottom.

Stage is recorded by an ordinary OttXX stage recorder, and a stage versus discharge relationship is established. In Denmark the stage/discharge curve is rather unstable due to growth of weeds. Because of this, parallel measurements of velocity and stage were carried out by a pressure transducer and a Doppler velocity sensor manufactured by Montedoro-Whitney. Given a measured cross section an internal programme computes the discharge every quarter of an hour and acts as a flowmeter.

Sediment samples are collected twice a day with an ISCO automatic water sampler. During the winter, when floods occur, a second ISCO sampler is operated by the flowmeter in order to get a better description of the sediment concentration during peak flows.

An indirect measure of the concentration is obtained with an IR sensor manufactured by Partech, the light-transmission is measured every second minute.

Bed load is difficult to measure. In some water courses only a small amount of the sediment load is transported as bed load and measurements can be neglected. In other water courses the measuring site can be placed where the bed load is suspended so that total load can be sampled. In larger streams in Western Jutland, it is necessary to measure the bed load (Bartholdy et al., 1991). Two methods are used, either sampling with a pressure difference sampler or, measuring the dimensions of bed forms and their velocity.

In order to interpret the time variations in the recorded sediment transport supplementary and detailed investigations are needed of the drainage system, both water courses, ditches and drains. Also measurements of bed- and bank erosion and sedimentation should be made.

EXPERIENCES AND DISCUSSION

Testing of a prototype erosion site station took place on the erosion plot in Foulum where it was used for monitoring sediment transport caused by a thawbreak in February 1991. The soil was frozen and covered by snow with a water equivalent of 25 mm. Melting started the 20 February and was followed by approx. 5 mm rain the 23 February. The runoff began at 1400 h on the 20, and the specific runoff was less than 240 l/s/km² until the 21 when the ISCO sampler was triggered. Maximum specific runoff was 572 l/s/km² at 0430 h on the 23. Analysis of the water samples shows that the concentration varies from 2 mg/l to 126 mg/l in the period from 1300 h on the 21 to 0900 h the 22; the mean value is 14 mg/l. The low concentration during this period is confirmed by the IR sensor recordings; these exceed the measuring range 0240 h on the 23 indicating concentrations larger than approx. 1500 mg/l. At this time the Borda bucket is filled with sediment.

The results show that, due to the frozen soil, approx. 60% of the melted snow ran off without causing erosion . Later, when the uper soil layer was thawed, concentrations larger than 1500 mg/l were found, indicating erosion, but now the amount of water is limiting. The small amount of eroded sediment produced by this thawbreak was also confirmed by the rill measurements that showed no significant increase in rill volume. Nearly 90% of the snow and rain ran off as surface runoff.

The pressure transducer worked quite well, and it was possible to compute the time when the flow triggered the ISCO sampler within ± 10 min; it is, however, better to register the exact sampling time - either by logging the contact closure directly or, as now, to operate the sampler by a flowmeter. The IR-sensors and the Borda bucket can only operate at moderate sediment transport rates, therefore the pumping tube should be separated from this system. Probably it is necessary to design a weighing system for monitoring of large sediment concentrations. The results clearly demonstrate the need for detailed studies to interpret the effect of thawbreak on erosion.

The same thawbreak was monitored at the Langvad basin (Hasholt, 1989) roughly 200 km SE of Foulum. Here the snow was also lying on frozen soil, the water equivalent was 14 mm. Melting started slowly the 20 February and 6 mm rain fell on the 23. A sharp increase in the runoff from an erosion plot in the upper part of the basin was recorded 0600 h on the 23. Here, the maximum runoff is reached 1400 h on the 23. Maximum specific runoff was 100 $l/s/km^2$. The runoff was also recorded at the basin outlet; here, the peak occurs 2315 h on the 24. The maximum specific runoff was 35 $l/s/km^2$ and the recession lasted about a week.

The sediment concentration in the runoff from the erosion plot was 27-92 mg/l. The concentration measured by the ISCO samplers at the basin outlet has a maximum of 172 mg/l at 1500 h on the 23, which clearly demonstrates a hysteresis in the concentrations discharge relationship. The rude graph of concentration versus time, based on the water samples, is confirmed by the IR-sensor recordings that show a more differentiated pattern with a maximum around 1800 h on the 23 and a lower maximum around 1800 h on the 24.

The sharp increase of the discharge and the first maximum in the sediment concentration at the gaging station is probably caused by moderately sediment-ladden meltwater running on the surface, the later recession is caused by water infiltrated into the groundwater. This is partly confirmed by the fact that only approx. 15% of the snow and rain at the plot ran off at the surface.

Simultaneous measurements of discharge and recordings with the flowmeter showed that this was correct within $\pm$ 10%. Problems occur because of ice - this is, however, also the case with ordinary stage-discharge relationships. Security and control is obtained by operating two independent systems.

The two ISCO samplers worked quite well except during periods with severe frost where the intake tube was frozen. The flow-operated sampler should have been operated with a minimum level in order to get more samples during peaks. This is difficult, however, because a good knowledge of the peak pattern at the station is needed to select flow pulse and minimum level.

The IR-sensor readings were only out of range for shorter periods, indicating that the concentration is below 250-300 mg/l most of the time. A calibration curve for the IR-sensor was established by use of 14 ISCO and manual water samples. The relationship was not linear, it was fitted to a power function:

$C\ (mg/l) = 78.4\ (S(volts) - 0.6)^{0.795}$, $r^2 = 0.91$. The sensitivity was $\pm$ 1 - 3 mg/l and maximum range value was 255 mg/l for 5 volts. This relationship was used together with the flowmeter recordings to compute daily load: 1380 (890) kg 23 February, 2660 (2650) 24 February, and 980 (1090) 25 February. The figures in brackets have been computed using daily mean discharge and concentration values from water samples, which is ordinary practice. It is clearly demonstrated that large differences may occur at the steep parts of the hydrograph and that ordinary measurements are not sufficient to test erosion- and sediment transport models with sophisticated routing procedures, or to interpret the runoff and sediment transport in a basin.

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