A Survey of Discharge and Suspension in the Landscape Ecology of a Swiss Alpine Catchment Area

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Abstract

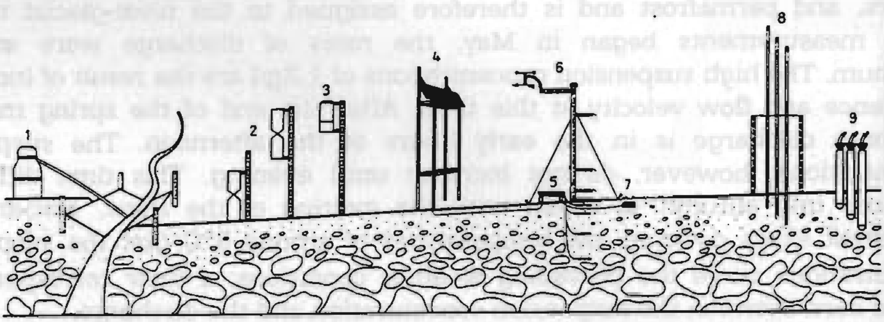
The discharge from the Lämmeren-Dala is marked by the melting of snow, glaciers, and permafrost and is therefore assigned to the nival-glacial regime. When measurements began in May, the rates of discharge were at their maximum. The high suspension concentrations of 1.2g/l are the result of increased turbulence and flow velocity at this time. After the end of the spring melt the maximum discharge is in the early hours of the afternoon. The suspension concentrations, however, do not increase until evening. This time difference continues into autumn. It is not until the melting of the snow, glaciers, and permafrost slows down at low temperatures of around 3°C that the suspension concentrations curve the prevailing weather conditions; a clear correspondence may be seen between the suspension concentration and the discharge.

Introduction

Many external environmental factors influence the human habitat and change it in the course of time. Flood events, for example, force us to take measures to keep damage to a minimum. It is important, therefore, to have information about the discharge dynamics of mountain streams and of their concentrations of suspended material. In the context of landscape ecology investigations, surface discharge and suspension are very important. When snow, glaciers, and permafrost melt, large amounts of water are released, and this can have a critical impact on the ecological system when the rate of discharge is high. In addition, the material removed as suspension is lost for possible soil development. As well as enabling statements to be made about surface discharge and suspension concentration, analysis of balances provides important indications concerning the dynamic events in the catchment area of the Gemmi. With regard to the balance of suspension, lateral material transport is of primary interest, as this spreads material over surfaces which may significantly influence the suspension concentration by acting either as a source or a sink (Leser 1991). The water balance is dependent upon discharge, precipitation, evapotranspiration, retention, and depletion. Because of its complexity the whole Gemmi system is treated as a black box. Input and output quantities will here be limited to those of surface discharge and suspension concentration. These are parameters which are measurable virtually continuously over the entire spectrum of hydrological events. The internal processes of the black box will not be discussed. Special attention is given to the study of the relationship between discharge and suspension concentration.

Investigation under the Concept of Landscape Ecology

Discharge and suspension depend on temperature, solar radiation, wind, and precipitation. Over a three-year period, these elements were recorded from July to October at four test sites, i.e., Tesserea (Leser 1991) (Fig. 1). The aim of a landscape ecological investigation is to determine and to elucidate the functional connections between the abiotic and the biotic parameters (precipitation, temperature, soil hydrology, soil respiration). An attempt will be made to extrapolate the localised measurements to the whole catchment area. The information gathered in the main river (amount of water, concentration of suspended matter) together with the parameters measured at the test sites provides important data regarding the discharge dynamics in the catchment area.



1. ISCO-Sampler (model 2700). - 2. MUENDEN-raingauge (h=1.50 m und 40 cm). 3. HELLMANN-raingauge (h=1.50 m). - 4. Solar energy collecting device for SQUIRRELS. - 5. SQUIRREL-Dataloggers (in weather-proof housing). 6. Thermistors with radiation shield (at heights above ground of 1, 10, 50, 120 cm), wind strength and direction monitor, solar radiation monitor (h=2 m) and buried thermistors (at depths of -2, -10, -30, -50 cm). - 7. Heat flux plate (d=-5 cm). - 8. Field of Tensiometer (3 in -10, -20, -30 cm d). - 9. Field of suction cops (3 in -10, -20, -30 cm d).

Figure 1: The Test Site (Tessera) for Analysing Ecodynamical Process-Elements (Modified according to Leser 1991)

The Area under Investigation

The Gemmi area of six square kilometres lies at 2,350masl at a latitude of 46°N in the Valais Alps (Switzerland). Glacial and melt streams feed the Lämmeren-Dala mountain stream, which subsequently flows into Dauben Lake (Fig. 2). This periglacial alpine region is assigned to the nival-glacial regime. Certain surface structures, such as rock glaciers or hummocks, indicate the existence of permafrost. The geological limestone layers of the Helvetian Plates (Jurassic-Tertiary: 210-30 million years old) have been exposed to climatic influences, and karst development characterises the Gemmi landscape. The average yearly precipitation lies between 1,500 and 2,000mm (Lämmerengrat weather station, approximately one kilometre away from the investigated area).

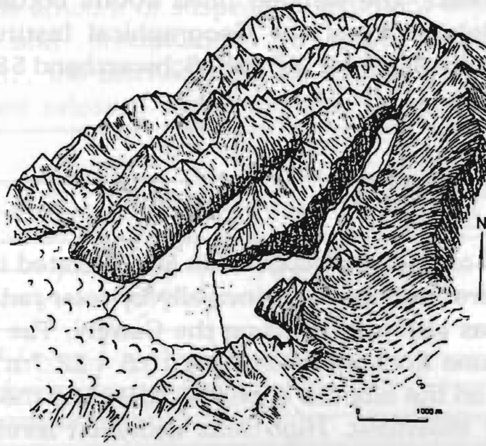


Figure 2: The Gemmi Catchment Area

Measurement Methods

Investigation of the Discharge Dynamics

Discharge measurements on the Gemmi have been carried out since 1991 with a water-level gauge. At a particular point on the Lämmeren-Dala, the riverbed was paved and a sill constructed, thus creating a discharge zone as free of turbulence as possible. Unfortunately the author had no influence on the reading of the electronic gauge in 1994 and 1995, and long periods of time elapsed during which the gauge did not react to water-level variations and no data could be recorded. Therefore, at particular times only, approximate estimates of the amount of discharge can be given. The range of fluctuation is based on the measurements of discharge from the previous years, 1991-1994. To keep data loss as low as possible, current meters for measuring water velocity were employed at certain times. In a cross-section of the stream, velocity and discharge measurements were made at two depths (two-point system) at each of three different points (Working Group for Operational Hydrology 1987). From the sum of the individual measurements the total discharge was obtained. Because of time constraints, these measurements could only be made on particular days. Thus, these results must be considered to be sample values of possible discharge patterns.

Investigation of Suspension

A considerable part of the sediment is transported as suspension, which is defined as undissolved, suspended, or floating solids transported in water (Schrott 1994). The suspended solids originate from soil erosion, braided channel erosion, or permafrost regions in the catchment area. It was possible to measure both the suspension and the discharge in the artificial channel. For continuous sampling of the suspension, an ISCO sampler (model 2700) was installed at a fixed point next to the level gauge. The inlet filter of the suction line was fixed 15cm above the stream bed. In this way, influence of stream-bed material on the suspension concentration was excluded. The sampler filled 500ml bottles, and 446 of these were analysed in the laboratory of the Geographical Institute in Basel. Round filters (110mm) of the (pore diameter 7.2mm) Schwarzband 589.1 type were used.

Results

Discharge Dynamics

The discharge dynamics of the Lämmeren-Dala are indicated in Table 1. Daily and annual discharge rates are determined principally by solar radiation (Röthlisberger and Lang 1987). This was also confirmed on the Gemmi. The extreme amounts of discharge in May and June fluctuated between 10.5 - 22.7m^3/s in the years from 1991-1994 and depend on the amount of winter snow and the radiation conditions at the beginning of the snowmelt. High solar radiation levels result after a few days in an increased release rate of stored water, which either flows away underground or flows above ground and into Dauben Lake. The daily discharge is determined by the periodic melting process and also by aperiodic events such as the onset of cold weather with precipitation. Figure 3 shows a typical daily discharge pattern in August. In the course of the morning, the discharge increases markedly and reaches its maximum at about 14:00h. After the day's maximum, the level slowly sinks until the morning hours of the next day. The phase-shifted time course of solar radiation in Figure 3 shows that the discharge peak is reached a few hours later than the maximum radiation level. Short-term fluctuations in temperature, the melting of annual snowfields, the thawing of the permafrost, and precipitation events prevent a strict correlation between these two quantities. Karst development in the area results in part of the surface runoff trickling underground into a complex cave system and re-emerging at Salgesch (horizontal distance Gemmi-Salgesch: 12km; height difference: 1,500m). These results cannot therefore be interpreted as absolute values. Significant flood waves on the Gemmi can sometimes be detected at the outflow near Salgesch a few days later or sometimes not at all. For this reason a correlation between the proportions of discharge at the Gemmi and Salgesch cannot be a matter of consideration.

Table 1: Characteristics of the Discharge Dynamics in the Years 1991-1994 (Differences in winter snowfall levels and in the weather during the observation period result in different maximum values of the discharge.)

Year	flood event date	discharge (m^3/s)	discharge (m^3/s) (15.05. - 15.10.)
1991	13.06	10.5	0.67
1992	20.05	21.0	2.11
1993	28.05	14.4	1.66
1994	27.05	22.7	1.81

Suspension

According to the prevailing weather conditions on the Gemmi, 2, 4, 6, or 24 samples per 24 hours were taken from the main river during the period from 11 July - 22 September. Of interest here are the eight full daily profiles (24 samples / 24 hours) which represent the period from 11 July - 17 August. The suspended sediment concentrations on all graphs show a clear maximum between 21:00 and

23:00 hours. The peak in Figure 4 starts to rise at about 18:00 and begins to fall again after 21:00h. The amount of suspended sediment depends primarily on the radiation conditions and precipitation. In good weather conditions with approximately 750W/m^2, the discharge values increase. At such times additional sources of sediment are released which increase the concentration levels-in the

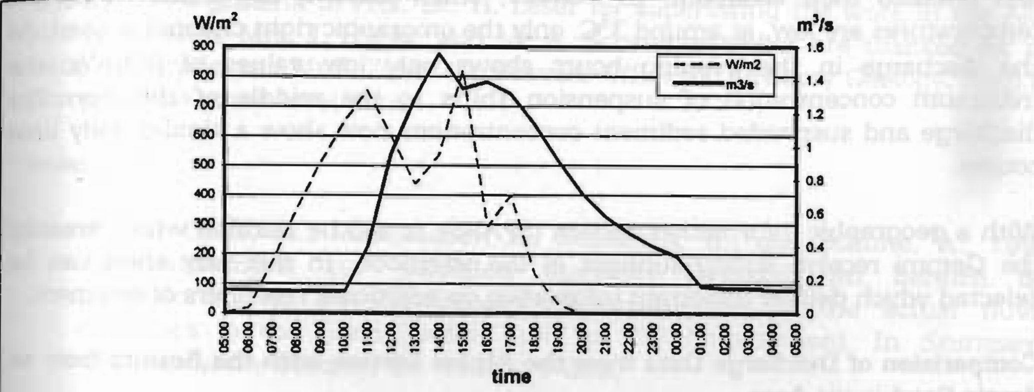


Figure 3: Typical Daily Variation of the Discharge in August Depending upon the Solar Radiation (A time lag between the two elements is clearly to be seen. The discharge starts to increase at 10:00 and decreases continuously from 14:00 to midnight.)

evening hours in particular. Precipitation events, particularly snow, temporarily refill the glacier reservoir. If the suspension concentrations are compared with the daily maximum discharge at 14:00, a marked time lag of about seven hours is seen. The accumulation of suspended sediment during the night can be explained as follows.

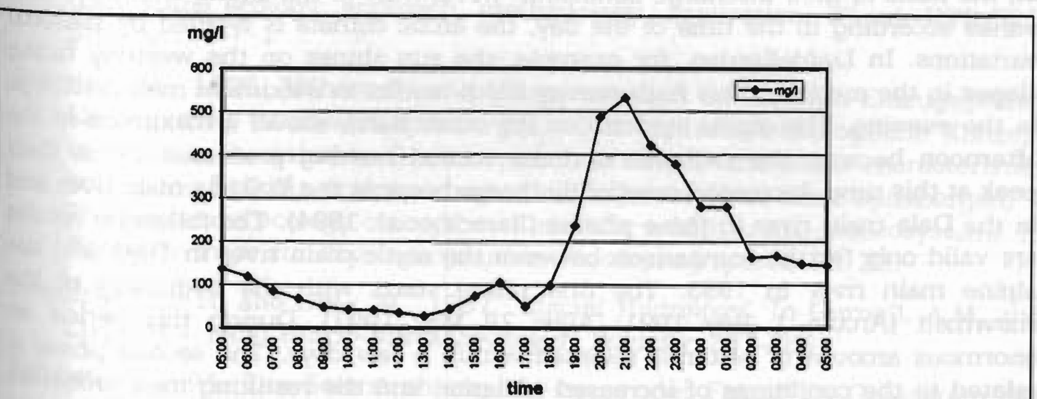


Figure 4: Profile of Suspension Concentrations on 08.08.1995 (The concentration reaches a maximum at 21:00 and then falls continuously into the early hours of the next day.)

The Lämmeren-Dala takes different routes down the glacio-fluvial gravel valley at different times of day: in the morning, on the orographic right, in the evening, in both flow systems (cf. Fig. 2). In the late afternoon the suspended sediment in the orographic left channel is also mobilised, and released towards evening. Over and above that, the processes of ice- and snowmelt and the thawing of permafrost combine to boost the removal of the suspended sediment from the catchment area. Heavy precipitation reactivates melt streams which have dried up in summer and releases their sediment. In October, when there is not much water and temperatures are low, at around 3°C, only the orographic right channel is used. As the discharge in the evening hours shows only low values of $0.3 m^3/s$, the maximum concentration of suspension shifts to the middle of the day. The discharge and suspended sediment concentrations now show a similar daily time course.

With a geographic information system (SPANS), it will be clarified which areas of the Gemmi receive strong sunlight in the afternoon. In this way areas can be selected which deliver important infomation on additional reservoirs of sediment.

Comparision of Discharge Data from the Alpine System with the Results from an Arctic Catchment Area

During the geo-scientific Spitsbergen Expedition from 1990 to 1992, data on discharge and sediment transport were collected by the Heidelberg group (Barsch et al. 1992) in Liefdefjorden (80°N). The nutrient behaviour of the arctic Kvikkåa main river and the climatic conditions in the catchment area were examined by the Basel group (Literature list of the Polar Ecology Research Group, Wüthrich, 1994). Further, Potschin (1996) describes in her work the nutrient situation in the study area as well as providing a detailed characterisation of the ecological seasons in the high Arctic. This holistic approach is being applied to the Gemmi catchment area. The differences in the two catchment areas will now be discussed on the basis of their discharge behaviour. In contrast to the alpine climate, which varies according to the time of the day, the arctic climate is typified by seasonal variations. In Liefdefjorden, for example, the sun shines on the westerly facing slopes in the evening. This high energy input results in maximum melt discharge in the evening. The alpine system, on the other hand, shows a maximum in the afternoon because the radiation and the related melting processes are at their peak at this time. Increased rates of discharge occur in the Kvikkåa main river and in the Dala main river in three phases (Barsch et al. 1994). The following results are valid only for the comparison between the arctic main river in 1991 and the alpine main river in 1993. The first phase starts with the beginning of the snowmelt (Arctic: 1 July 1991; Alps: 28 May 1993). During this period an enormous amount of water is released within a few days. The second phase is related to the conditions of increased radiation and the resulting melt processes (Arctic: 21 July 1991; Alps: 14 July 1993). The third phase is dominated by the glacial melt (Arctic: 13 August 1991; Alps: 23 September 1993). It is interesting to note that the first phase begins two months earlier in the Alps than in the Arctic. The second phase commences at approximately the same time in both systems. The third phase, however, begins six weeks earlier in the arctic main river than in the Alps. Obviously, the discharge system, based on yearly seasons, goes through the three phases in a shorter time than the daily varying alpine system. A three-phase system was also established by Kiel (1989) in central

Iceland. There the distribution is, however, a winter discharge, a nival spring discharge, and a glacial discharge in summer.

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