# 4 STREAM MORPHOLOGY

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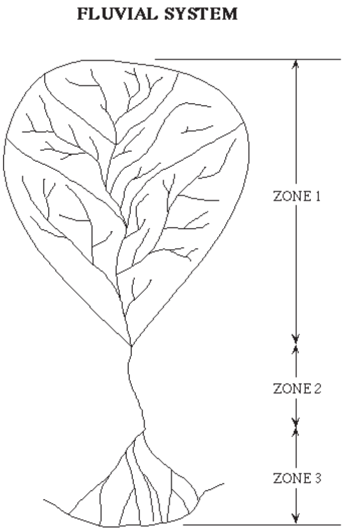
## 4.1 Introduction

Streams carry water and sediment out of drainage basins and therefore reflect the nature of the hillslope and drainage basin processes and of course also the climatic forces that drive the hydrological cycle. To develop an understanding of the potential and actual changes that might occur as a result of climate change, the relevant fluvial processes should be identified. The following outline of the fluvial system is designed to provide a basic model by which the fluvial processes can be ordered. The uppermost part of the fluvial system is the drainage basin, watershed, or sediment-source area (Zone 1 in Figure 4.1). This is the area from which water and sediment are derived. It is primarily the zone of sediment production, although sediment storage does occur there too in many ways. Zone 2 is the transfer zone; for a stable channel the inflow and outflow of sediment are balanced. Zone 3 is the area of deposition, where various types of alluvial or coastal deposits can occur.

Certain aspects of fluvial systems are reasonably constant through time; for example, the length of a stream or the area of a drainage basin change only very slowly. The factors that are not constant in time or do not occur in the same way at regular intervals can consist of rare (extreme) events or of structural changes in the driving forces of the system.

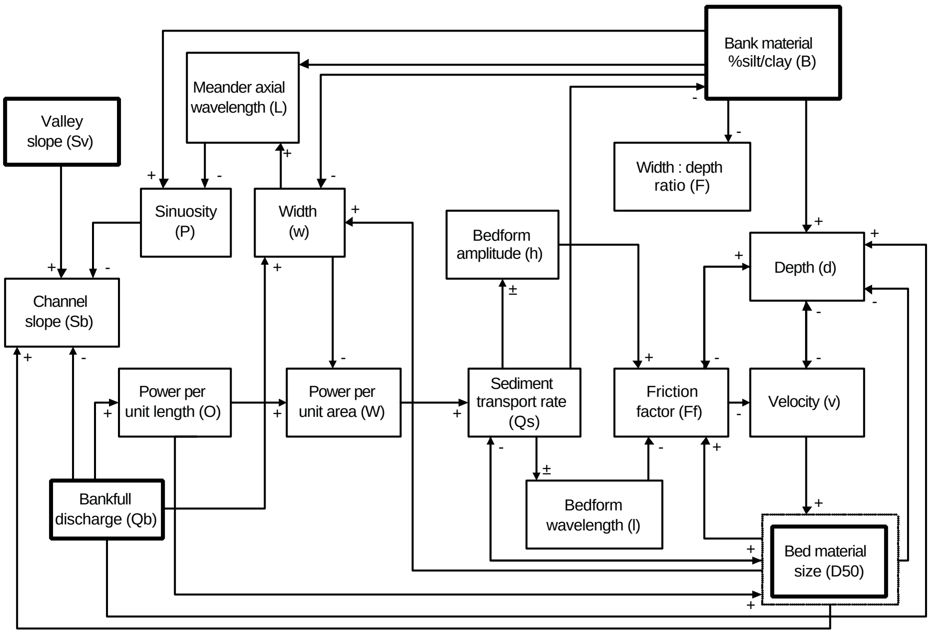
Figure 4.1 Idealized fluvial system (After Schumm 1977), with upper reaches in Zone 1, middle reaches in Zone 2, and lower reaches in Zone 3.



Climate change represents a structural shift of independent variables and affects the discharge of streams, the amount of sediment they can carry, and the amount of sediment being produced on hillslopes and transported to streams. However, within any given climatic regime, there will be very rare or infrequent events, such as a catastrophic storm, which also may play an important role in the operation of the fluvial system. There is an interplay between those aspects of drainage basins that do not change with time, and those variables that do.

For the purpose of predicting effects of climate change on the morphology of stream channels the model StreaMES (Stream Morphological Evaluation System) has been set up. Richards (1982) made a speculative representation of the alluvial channel system (Figure 4.2a). This conceptual model was implemented and adapted for the Dutch situation. The general scheme of the model StreaMES is given in Figure 4.2b. In the scheme the distinction is made between the exogenous factors (outside of the frame, at the top side) and the endogenous mechanisms

Figure 4.2a Richards conception of the alluvial channel system. Independent variables have heavy outlines; bed material size, though ultimately controlled by lithology, is semi-independent as it is effected by sediment transport. Direct relations are shown by +, inverse by -; arrows show direction of influence. Some links are reversible; as for example as friction.

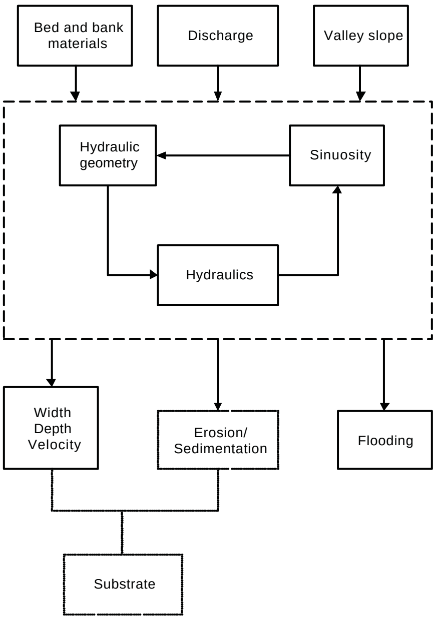


governing the channel system itself. The following exogenous factors are considered:

- substrate properties
- discharge
- valley slope

For the endogenous mechanisms free meandering of a stream is assumed. In the case study this is limited to the main arteries of the Reusel and Beerze. The model makes use of both physical and empirical relationships. In the following description the exogenous factors are illlustrated by data from the study region.

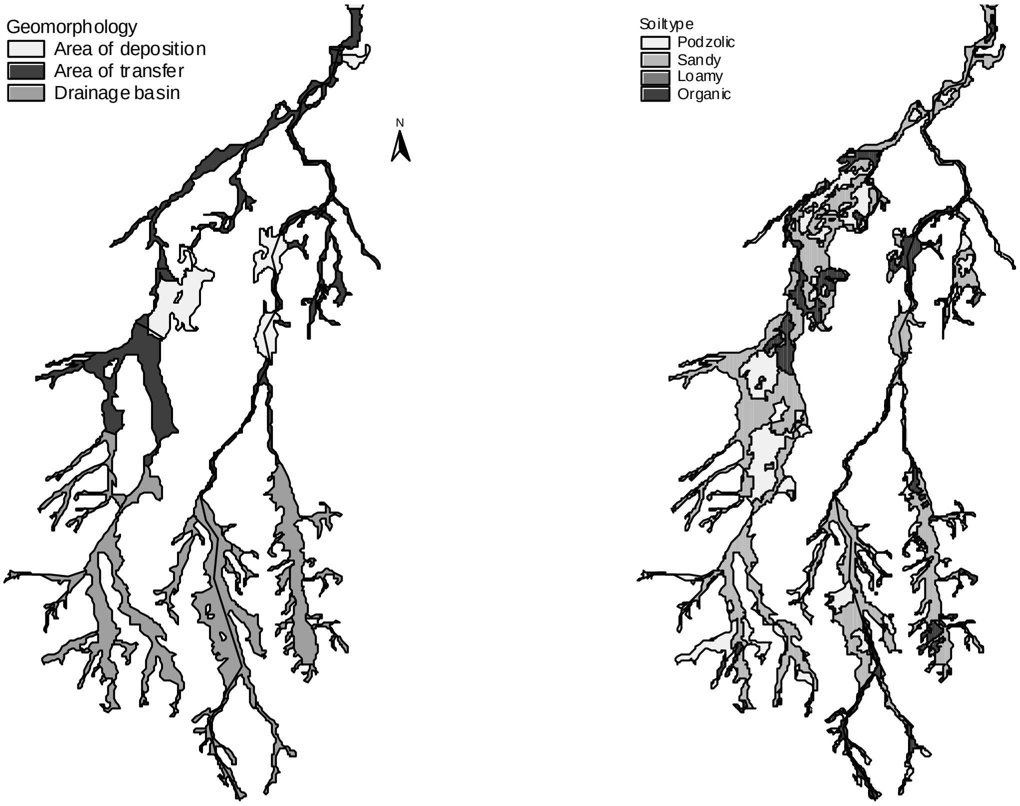
Figure 4.2b Outline of morphological prediction model StreaMES.



## 4.2 Exogenous factors

The (main) streams have been divided into a limited number of reaches, based on the geomorphology, soil and valley slope. The reaches provide the spatial resolution for attributing values of exogenous factors. Actual predictions for the channel reaches are, however, done for the (smaller) surface water subtrajectories of the regional hydrologic model SIMGRO. So a reach in StreaMES can cover more than one subtrajectory of the hydrologic model.

<u>Figure 4.3</u> Geomorphological classification of main streams (left) and soil classification (right).



The first step is to make a subdivision based on the geomorphological map, which shows whether a reach belongs to the upper, middle, or lower reaches of a stream system (Figure 4.3, left). Then the reaches are further subdivided based on the soil map (Figure 4.3, right).

From Figure 4.3 it is apparent that the soil map closely correlates with the geomorphological map, and that most of the soils are sandy and podzolic. So at first glance it is not necessary to further subdivide the reaches using the soil map. However, the loam fraction of the soil does differ within the geomorphological classes,  and is also an important factor for determining the erodibility of the substrate. So a further subdivision of reaches was based on the loam fraction.

In general the valleys of the main streams follow a smooth logarithmic profile. At a more detailed scale sharp changes in slope can be found. These sharp changes on a local scale appear to take place concurrently with changes in the soil characteristics. So the variation of the valley slope was not used for further subdividing the reaches. In total 16 reaches are distinguished for a total stream length of about 80 km (Reusel and Beerze).

The following parameters have been coupled to the substrate:

- the side-slope of the stream
- the hydraulic geometry
- the hydraulic conductivity

For the side-slope of the stream the empirical data given in Table 4.1 have been used (taken from Cultuurtechnisch Vademecum 1988). For the hydraulic geometry in relation to the substrate a distinction has been made between deep, medium deep, and shallow profiles. This distinction is based upon the stability of the soil layers. In Cultuurtechnisch Vademecum (1988) the following empirical relationships are given between the bottom width B and the depth of the cross-profile h:

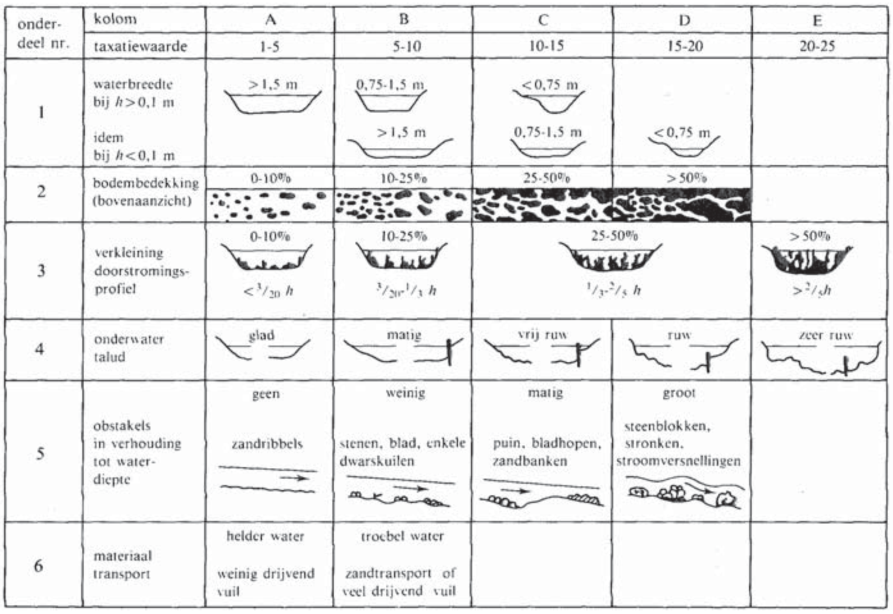
- $B= 2.00\ h^{5/4}$ for deep profiles (4.1a)
- $B= 2.75\ h^{3/2}$ for medium profiles (4.1b)
- $B= 5.00\ h^{5/2}$ for shallow profiles (4.1c)

The hydraulic conductivity is in this study quantified in terms of the Manning coefficent $k_M$. The $k_M$–value is very much determined by the amount of vegetation that is present in the waterway. A method developed by Bon (1967) has been used for classifying the streams in terms of their ‘degree of maintenance’. Determination of the degree of maintenance is done by using an estimation scheme (Figure 4.4). For six aspects, which have an influence on the hydraulic conductivity, a rating has been given. The average value of the six ratings is an indication for the degree of maintenance. For the streams in this study this is usually about ‘4’ on a scale from 1 (most maintenance) to 9 (least maintenance). Then the empirical information given in Cultuurtechnisch Vademecum (1988) was used for the relationship between the $k_M$ and the mean stream velocity (Figure 4.5).

Table 4.1 Side-slope of stream, depending on soil type (Werkgroep Herziening Cultuurtechnisch Vademecum 1988).

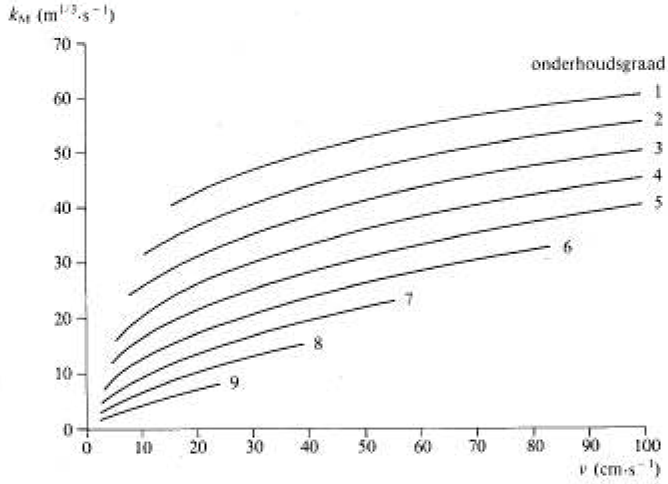
| Soil type | Side-slope (width/height) |
|---|---|
| Clay, loam, loss, hard peat | 1 – 2 |
| Zavel, hard sand | 1.5 – 2.5 |
| Coarse sand | 1.5 – 3 |
| Fine sand, loose peat | 2 – 4 |

Figure 4.4 Estimation scheme for the degree of maintenance.



| onder-deel nr. | kolom | A | B | C | D | E |
|---|---|---|---|---|---|---|
| | taxatiewaarde | 1-5 | 5-10 | 10-15 | 15-20 | 20-25 |
| 1 | waterbreedte bij $h > 0{,}1$ m | > 1,5 m | 0,75-1,5 m | < 0,75 m | | |
| | idem bij $h < 0{,}1$ m | | > 1,5 m | 0,75-1,5 m | < 0,75 m | |
| 2 | bodembedekking (bovenaanzicht) | 0-10% | 10-25% | 25-50% | > 50% | |
| 3 | verkleining doorstromings-profiel | 0-10%<br>$< {}^3/_{20}\ h$ | 10-25%<br>${}^3/_{20}$-${}^1/_3\ h$ | 25-50%<br>${}^1/_3$-${}^2/_5\ h$ | | > 50%<br>$> {}^2/_5 h$ |
| 4 | onderwater talud | glad | matig | vrij ruw | ruw | zeer ruw |
| 5 | obstakels in verhouding tot water-diepte | geen<br>zandribbels | weinig<br>stenen, blad, enkele dwarskuilen | matig<br>puin, bladhopen, zandbanken | groot<br>steenblokken, stronken, stroomversnellingen | |
| 6 | materiaal transport | helder water<br>weinig drijvend vuil | troebel water<br>zandtransport of veel drijvend vuil | | | |

Figure 4.5 Relationships between the Manning coefficient $k_M$ for the hydraulic conductivity and the mean stream velocity, for varying degrees of maintenance (*onderhoudsgraad*) of the stream (1 = most maintenance, 9 = least maintenance).



The so-called bank-full discharge is thought to determine the stream profile, as is generally assumed. Richards (1982) defines the bank-full discharge as the discharge with a mean recurrence interval of 1.6 years. The regional hydrologic model supplies these discharges for each of the surface water subtrajectories.

The mean valley slopes of the surface water subtrajectories have been determined using a Digital Terrain Model (DTM) of the study region.

## 4.3 Endogenous system relationships

For the flow resistance the Manning-equation for steady state flow in a conduit has been used:

$$Q_{bf} = k_M \; A \, R^{2/3} \sqrt{S_b} \tag{4.2}$$

in which:

- $Q_{bf}$ : bank-full discharge (m$^3$/s)
- $k_M$ : Manning coefficient (m$^{1/3}$/s)
- $A$ : wetted cross section (m$^2$)
- $R$ : hydraulic radius (m)
- $S_b$ : gradient along the stream bed (-)

The hydraulic radius is the wetted cross section divided by the wetted perimeter.

The second system relationship concerns the sinuosity of the stream. The sinuosity is the ratio between the length of the stream and the distance (‘as the crow flies’) along the valley bottom: the higher the value, the more the stream meanders. The sinuosity mainly depends on the soil material, the valley slope and the width/depth ratio of the stream. The following relationship given by Chitale(1970) has been used:

$$\xi = 1.429 \, (\frac{D_{50}}{h})^{\,0.077} \, S_v^{\,-0.052} \, (\frac{W_{top}}{h})^{\,-0.065} \tag{4.3}$$

in which:

- $\xi$ : sinuosity (-)
- $D_{50}$ : median grain size of substrate (m)
- $S_v$ : valley slope (-)
- $W_{top}$ : width of stream at the top of the cross-profile (m)
- $h$ : water depth (m)

## 4.4 Calculation method

There are three unknown parameters in the equations:

- the bottom width $B$
- the water depth $h$
- the sinuosity $\xi$

The width $W_{top}$ at the top of the profile is also an unknown parameter, but it follows directly from the bottom width $B$, the side-slope (Table 4.1) and the water depth. And the slope along the streambed $S_b$ is equal to the valley slope $S_v$ divided by the sinuosity ?. For the remaining three unknowns given above there are also three equations, so a solution can be found. For finding the solution an iterative procedure has been programmed and linked to a spreadsheet. The model was used to calculate the hydraulic geometry and sinuosity of the subtrajectories of the streams. Changes in the hydraulic geometry and sinuosity will result in changes in stream length, stream slope, stream depth and storage in the SIMGRO-model. By re-running the SIMGRO model a number of times, each time with an update of the channel dimensions, the equilibrium state of the channel geometry can be obtained.