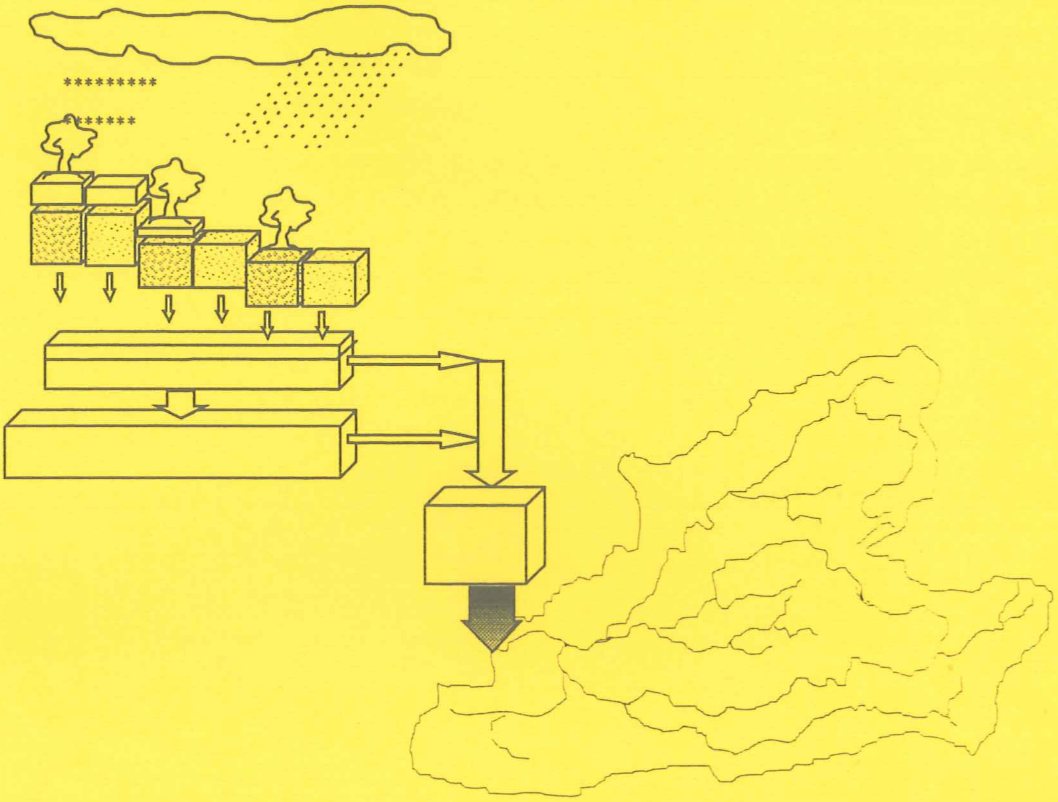
Lunds Universitets Naturgeografiska Institution

Seminarieuppsatser Nr. 49

Evaluation of a conceptual, semi-distributed hydrological model

-A case study of Hörbyån



Susanne Kolmert

Department of Physical Geography,
Lund University
Sölvegatan 13, S-221 00 Lund,
Sweden

1998

Abstract

Research in hydrological modelling has been directed towards the development of more complex models that may consider the spatial and temporal variations of meteorological and physical characteristics of a drainage basin.

The aim with this study was to evaluate the HBV-model (Hydrologiska Byråns Vattenavdelning), a conceptual, semi-distributed hydrological model. This model is able to take the spatial distribution of meteorological and physical factors in a drainage basin into consideration. An attempt to investigate the possibilities to improve the calibration and validation results from the HBV-model were made by increasing the spatial resolution of physical and meteorological characteristics of Hörbyån's drainage basin (located in Skåne, the southern part of Sweden). Hörbyån's drainage basin was partitioned into five and ten sub basins. Area values of the precipitation, elevation and vegetation types (forest/open land) were calculated in every basin. Distributed information of soil types (sand/clay) was also considered with parameters for the soil moisture zone. The results were compared with calibrations and validations of Hörbyån's drainage basin used as a single basin.

The calibration and validation results in the HBV-model were improved when the spatial distribution of vegetation and precipitation were taken into account. The calibration results were slightly improved when elevation zones and soil types were considered in the model. However, to run the HBV-model when increasing the spatial resolution of physical and meteorological characteristics in a drainage basin was time consuming and the requirements of input data were large.

1. INTRODUCTION 2

1.1 BACKGROUND 2
1.2 HYDROLOGY AND RUNOFF PROCESSES 3
1.2.1 From precipitation to runoff (A, B, C, D, E, F, G, H) 3
1.2.2 Drainage basin 4
1.2.3 Physical factors that affect runoff 4
1.3 TYPES OF HYDROLOGICAL MODELS 5
1.3.1 Empirical models 5
1.3.2 Lumped conceptual models 6
1.3.3 Distributed models 6
1.3.4 Examples of conventional hydrological modelling systems 7

2. AIM OF THE STUDY 8

3. DESCRIPTION OF STUDY AREA 9

3.1 DRAINAGE BASIN 9
3.2 GEOLOGY AND LAND COVER 9
3.3 TOPOGRAPHY 9

4. MATERIALS AND METHODS 11

4.1 HBV, A MODEL DESCRIPTION 11
4.1.1 Structure of the HBV-model 12
4.1.2 Calibration 14
4.1.3 A hydrological year 15
4.2 MATERIALS 16
4.2.1 Geographical data 16
4.2.2 Meteorological data 17
4.2.3 Computer software 17
4.3 PRE-PROCESSING INPUT DATA FOR THE HBV-MODEL 18
4.3.1 Precipitation 18
4.3.2 Temperature 19
4.3.3 Discharge 19
4.3.4 Potential Evapotranspiration 19
4.3.4.1 Penman 20
4.3.4.2 Thornthwaite 20
4.3.5 Drainage basin 21
4.3.6 Vegetation zones 22
4.3.7 Elevation zones 23
4.3.8 Sub basins 24
4.3.9 Soil types 26

5. RESULTS 27

5.1 CALIBRATION 27
5.2 VALIDATION 30

6. DISCUSSION 31

6.1 SOURCE OF ERRORS AND PROBLEMS DURING THE CALIBRATION AND VALIDATION PERIOD 31
6.2 EXAMPLES OF POOR CORRELATION ON A HYDROGRAPH CURVE 33
6.3 SCENARIOS- A PRACTICAL APPLICATION 33

7. CONCLUSIONS 35

8. REFERENCES 36

9. APPENDICES 38

1. Introduction

1.1 Background

Hydrological models are useful in water resource management. They give a more or less simplified and representative image of complex hydrological systems and are widely used in fields as hydrology, land use, soil science and geomorphology. Examples of water resource studies are hydrological effects of land cover changes, estimations of discharge in areas without recording stations, estimations of the risk for floods and studies of the water balance (Refsgaard et al. 1996).

Different types of hydrological modes have been developed through the years. Many improvements and progress in the development of rainfall-runoff relationship were made during the 1950s and 1960s despite the fact that the computer capacity still was limited. Research within hydrological computer applications was first developed in the mid 1960s (Ward et al. 1995). It was fairly simple hydrological models that were developed at this time. These more traditional models have been dominating among hydrologists so far and have proven to be rather successful for hydrological simulations (Kirkby et al. 1992). One major drawback is that the parameters in the models are not directly related to the land surface characteristics (such as land cover, vegetation and elevation) and hydrological processes (such as vegetation influence on the hydrological system).

In recent years, efforts within research in this field have been directed towards the development of more complex hydrological models. These models try to describe several processes in the hydrological cycle better than the old traditional models do. The spatial variations of land surface properties in a landscape, such as land cover, topography and soil types are considered in many of these models (Donald 1995). During the last year, advances in data acquisition techniques have made it possible to provide detailed hydrological information and this provides a better understanding of the hydrological system (Shaw 1994). Applications of geographical information systems (GIS) and remote sensing are valuable techniques for providing data to these types of hydrological modelling (Ward et al. 1995). GIS, for example are useful for supplying information of land cover changes, terrain characteristics and physical processes. Land cover classifications and estimation of the snow cover can be achieved from remotely sensed data.

Recently advances in the hydrological model types that consider land surface-atmosphere interactions is made (Flerchinger et al. 1996, Sellers et al. 1997). These model types include for example the influence of vegetation in a more mechanistic way through fluxes of water and energy. They are a major improvement over the traditional models. These models have proven to be successful and are for example used to asses the effects of land cover changes. However, a number of research themes exist where knowledge is not yet adequate as for example the relationship between land management and the water infiltration rate.

A hydrological conceptual, semi-distributed model that falls in between a traditional and a distributed model type is the HBV-model (Hydrologiska Byråns Vattenavdelning). This model was used in this study where an attempt to improve the hydrological modelling when considering the spatial variability of physical and meteorological characteristics in a drainage basin was made.

1.2 Hydrology and runoff processes

Complex hydrological processes control the relationship between precipitation and the resulting discharge where soils and vegetation cover are two of the key factors for water balance (Andersson 1989). This section contains a brief description of meteorological variables in the hydrological cycle and the main runoff processes that are considered in hydrological models. The illustration in figure 1.1 is used when describing the processes.

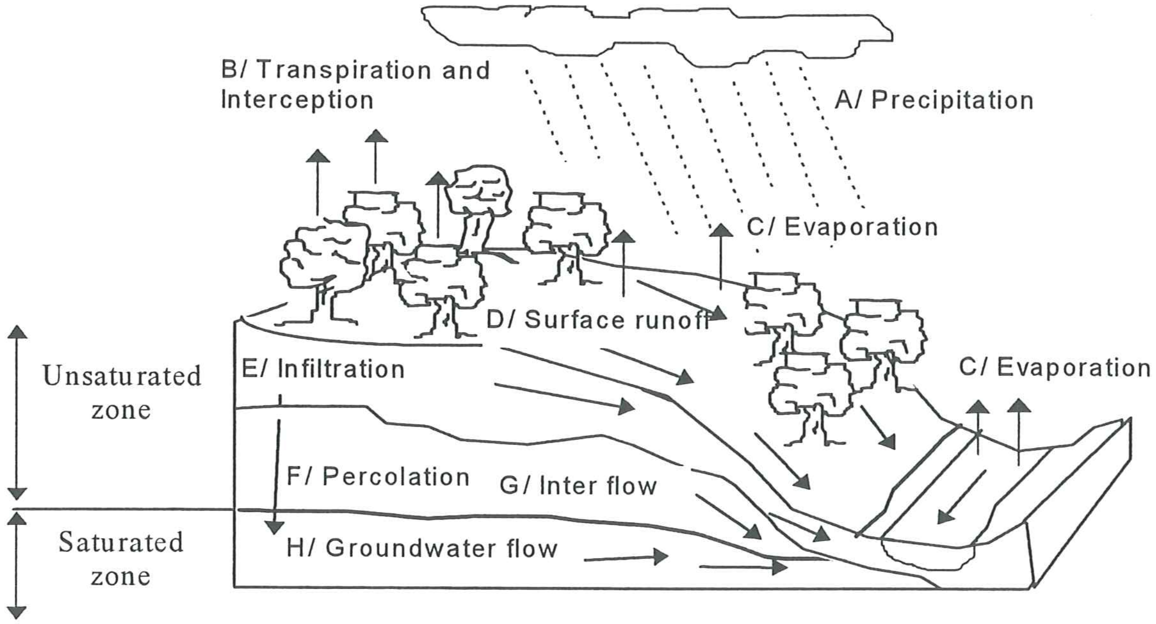


Figure 1.1 *An illustration of the hydrological cycle with its main runoff processes.*

1.2.1 From precipitation to runoff (A, B, C, D, E, F, G, H)

Much of the precipitation (A) that reaches the ground evaporates (C) from the surface of water, snow or soil and return to the atmosphere. Precipitation that falls in vegetated areas can be intercepted (B) by vegetation and also lost by evaporation. Transpiration (B), a process where water is released as vapour from the stomata of vegetation, is another process where water in the hydrological cycle is returned to the atmosphere. Those two processes, evaporation from the soil surface and transpiration from the plant surface are difficult to differentiate. Often the joint effect is considered instead as one process called evapotranspiration (Ward et al. 1995, Quick 1992).

The remaining amount of precipitation after evapotranspiration continues as surface runoff (D) or begins to infiltrate (E) into the ground. Surface runoff occurs if there is an intense rain fall period, a powerful snow melt period or whenever the water rate exceeds the infiltration rate. In the southern part of Sweden almost all water infiltrates though, due to slow rainfall intensity and moderate snow melt periods (Knutsson et al. 1993, Grip et al. 1988).
The infiltrated water percolates (F) by gravity through unsaturated soil layers to the fully saturated layers, the groundwater (H).

A horizontal water transport in the unsaturated soil moisture zone called inter flow (G) might occur if the rain is heavy. Furthermore, surface runoff occur instead of inter flow if the soil moisture zone is filled (Ward et al. 1995, Quick 1992).

The saturated layers, i.e the groundwater (H), are joined together with surface flow and inter flow and transported in river channels (Shaw 1994). Altogether, the portions of water from precipitation, snow melt and irrigated areas that includes surface runoff, inter flow and base flow is called runoff.

1.2.2 Drainage basin

Hydrological models refer to drainage basins. A drainage basin is defined as the topographic area that provides runoff to a selected point usually along a stream system. All precipitation within the drainage basin will distribute runoff to the outlet of the basin (Ward et al. 1995).

1.2.3 Physical factors that affect runoff

Main physical factors that affect the runoff in a drainage basin are for example topography, shape, soil type and land cover.
The topography delimits the size of a drainage basin through ridges (Grip et al. 1988). The shape influences the velocity of the runoff transport to the outlet. A drainage basin with a circular shape has high rates of runoff that persist for short time in the outlet. The higher rates of runoff are slower and persist for a longer time in the outlet of an elongate drainage basin (Figure 1.2). It is caused by the runoff from different areas in a circular shaped basin that are likely to reach the outlet at almost the same time. In an elongated shaped basin flow rate from the tributaries near the outlet passes the outlet before flows from the upper tributaries arrive.

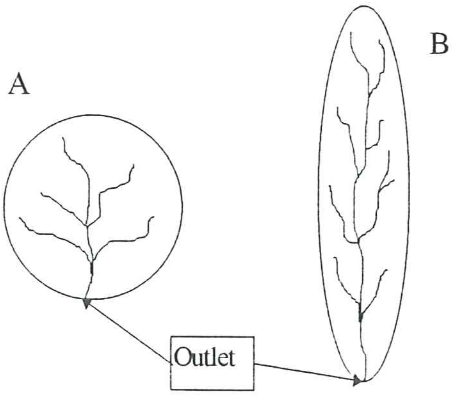


Figure 1.2 *The shape of drainage basins A: circular with fast runoff, B: elongated with slower runoff that persist longer than A.*

The type of soil is a third physical factor to describe. This factor regulates the water transport in a drainage basin. On a fine textured clayey soil where the infiltration rate is low much water is transported as surface runoff. A coarse textured, permeable sandy soil transports most water through infiltration.

There are two important terms for soils which also affect the water transport (Shaw 1994). These are field capacity (FC) and wilting point (WP) (Figure 1.3).

- *Field capacity (FC)* is the water content of the soil after the saturated soil has drained under gravity to equilibrium.

- *Wilting point (WP)* is the volume of water content of the drying soil beyond which wilting plants will not recover even if humid conditions are re-stabilised

A clayey soil has minute pores that hold water with high tension. It drains slowly and contains (by volume) a significant amount of water at the field capacity (FC). A sandy soil drains quickly and much less water is available at FC (Figure 1.3). The difference between FC and wilting point (WP) is called the available water for plants. It is the volume of water that the plants are able to use under dry periods. All water above field capacity is drained.

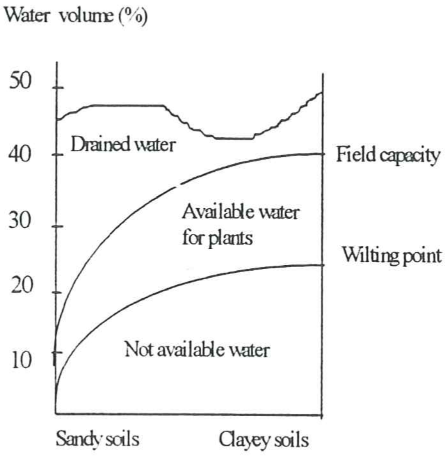


Figure 1.3 *A principal illustration of field capacity (FC) and wilting point (WP) for clayey and sandy soils.*

The last main physical factor to describe is how vegetation affects the runoff in a drainage basin. Vegetation improves the soil structure and taps the soil water. This leads to more infiltration and less surface runoff in vegetated areas. Furthermore runoff is reduced in vegetated areas due to transpiration and interception losses. Bare soils, that is an unprotected land surface, has more surface runoff and lower infiltration rates than vegetated areas.

1.3 Types of hydrological models

Hydrological models are traditionally classified into three main groups, the empirical, the lumped conceptual and the distributed physically based models (Refsgaard et al., 1996).

1.3.1 Empirical models

Empirical models are based on analysis of a large set of data where statistical relationships are developed between the inputs and output (Ward et al 1995). The most simple empirical models are called black box or input/output models. Black box models are functional and effective in areas where hydrological processes are poorly understood because of the limited number of input variables needed (Kirkby et al. 1992, Knutsson et al. 1993).

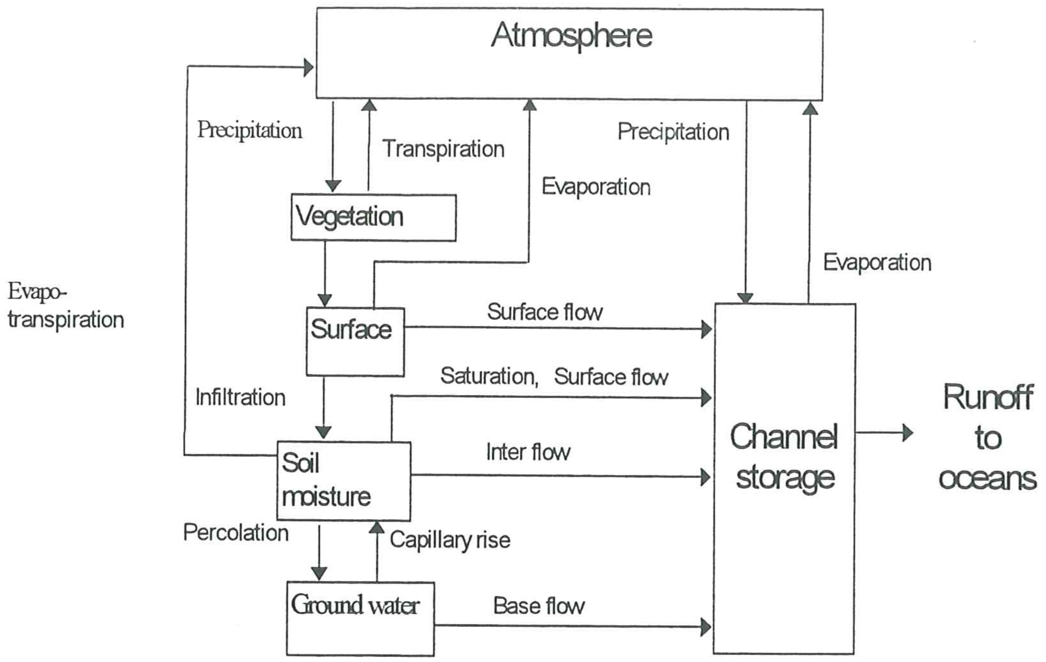


Figure 1.4 *Components of the hydrological cycle viewed as series of flows and storages in a model (Kirkby et al. 1987).*

1.3.2 Lumped conceptual models

Lumped conceptual models are more sophisticated and describe the hydrological processes better than empirical models do. In a lumped conceptual model the hydrology is studied through series of interrelated processes and storages (boxes in Figure 1.4). Each box corresponds to a water store (for example ground water or soil moisture) and the connections between the boxes correspond to flow processes (such as base flow and surface flow) (Donald et al. 1995). The processes being modelled in a drainage basin are described mathematically in a lumped conceptual model. The advantages of the empirical and the lumped conceptual models are the simplicity and limited requirements of input data (Knutsson et al. 1993). The data requirements are for example several years of daily rainfall, evaporation and runoff data. One drawback is that the parameters are not directly related to the distribution of physical characteristics in a drainage basin. These cause problems if for example the characteristics in a drainage basin change much during a period due to urbanisation or deforestation. Despite their simplicity, the empirical and lumped conceptual models have proven to be quite successful (Reefsgard et al.,1996).

1.3.3 Distributed models

The third types of models, the distributed, resemble reality better than the empirical models and the lumped conceptual models (Kirkby 1987). Distributed models are also more complex and take into account the spatial variability of both physical characteristics and meteorological conditions. Distributed models are partitioned into hydrological units (Figure 1.5) and each process (infiltration or surface flow for example) is computed independently in each of the units (Donald et al. 1995). Implementing these models is time consuming and the requirements of data and parameters are large. Distributed models are therefore restricted to use in certain areas. They are most suited for process studies in a smaller scale (Refsgaard et al. 1996).

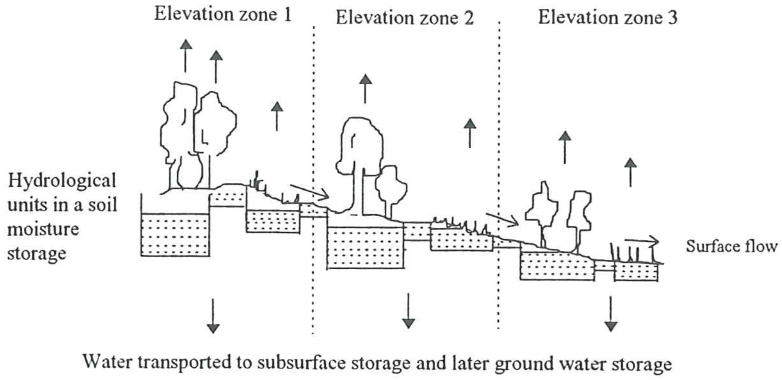


Figure 1.5 *An illustration of a distributed soil moisture zone. The soil moisture storage is partitioned into hydrological units. Elevation, vegetation and soil types are considered in each hydrological unit.*

1.3.4 Examples of conventional hydrological modelling systems

Model	Type of model	
Topmodel	A distributed model	developed in United Kingdom (Beven & Kirkby 1979)
SHE (Système Hydrologique Européen)	A distributed and physically based model	jointly developed by the Danish Hydraulic Institute, Sorgeah (France) and the UK Institute of Hydrology (Abbott et al., 1996)
HBV -model (Hydrologiska Byråns Vattenavdelning)	A conceptual and semi-distributed model	developed at SMHI, Sveriges Meteorologiska och Hydrologiska Institut.

2. Aim of the study

The aim of this thesis is to evaluate the HBV-model, a conceptual, semi-distributed hydrological model. It will include an investigation of the possibilities to improve the calibration and validation results from the HBV-model by considering the spatial variability of land surface properties and of meteorological conditions in a drainage basin.

The HBV-model will be implemented on the drainage basin of Hörbyån in Skåne, the southern part of Sweden. The drainage basin will be partitioned into 5 and 10 sub basins. The spatial distribution (areal description) of elevation, vegetation, soil types and precipitation will be described in each sub basin and used as input data in the HBV-model. The results will be compared with calibrations and validations of Hörbyån's drainage basin used as a single basin.

3. Description of study area

3.1 Drainage basin

In this project, the drainage basin of Hörbyån (located in Skåne, the southern part of Sweden) is studied (Figure 3.1). The size of the drainage basin is about 150 km^2. Water from the drainage basin is transported from east to west. The water runs into Östra Ringsjön, continues to Västra Ringsjön, through Rönne å and discharge finally in Skälderviken (Kattegatt). The precipitation in the region has an annual average of about 710 mm and the approximate annual loss by evapotranspiration is 450 to 500 mm (Ekologgruppen 1995).

3.2 Geology and land cover

Hörbyån's drainage basin is dominated by sedimentary rocks, mainly shale, in the south and western parts and by primary rocks, gneiss and granite, in the northern and eastern parts. The soils are influenced by the underlying rocks. A smooth plain country with nutritious clayey moraines dominates the south-west areas where farmlands are most common. Small groves of planted coniferous trees and deciduous forest are found among the fields (Figure 4.5). Forest dominates on the poor coarse textured moraines in the northern and eastern parts. Small areas of fields and grazing land are also found in these regions.

There are no lakes in the drainage area but a large area, mainly in the eastern part, is taken up by wetlands. Those are fairly uninfluenced of the drainage though. Hörby is the largest urban area in the study area with 14 000 (1996) inhabitants (Ekologgruppen 1995).

3.3 Topography

The altitude range from 68-192 meters above sea level in the area that makes the maximum difference in altitude to 120 meters. The altitude reaches 180 meter above sea level in the north and the discharge gauging station Heåkra, near Ringsjön is located 68 meters above sea level (Ekologgruppen 1995).

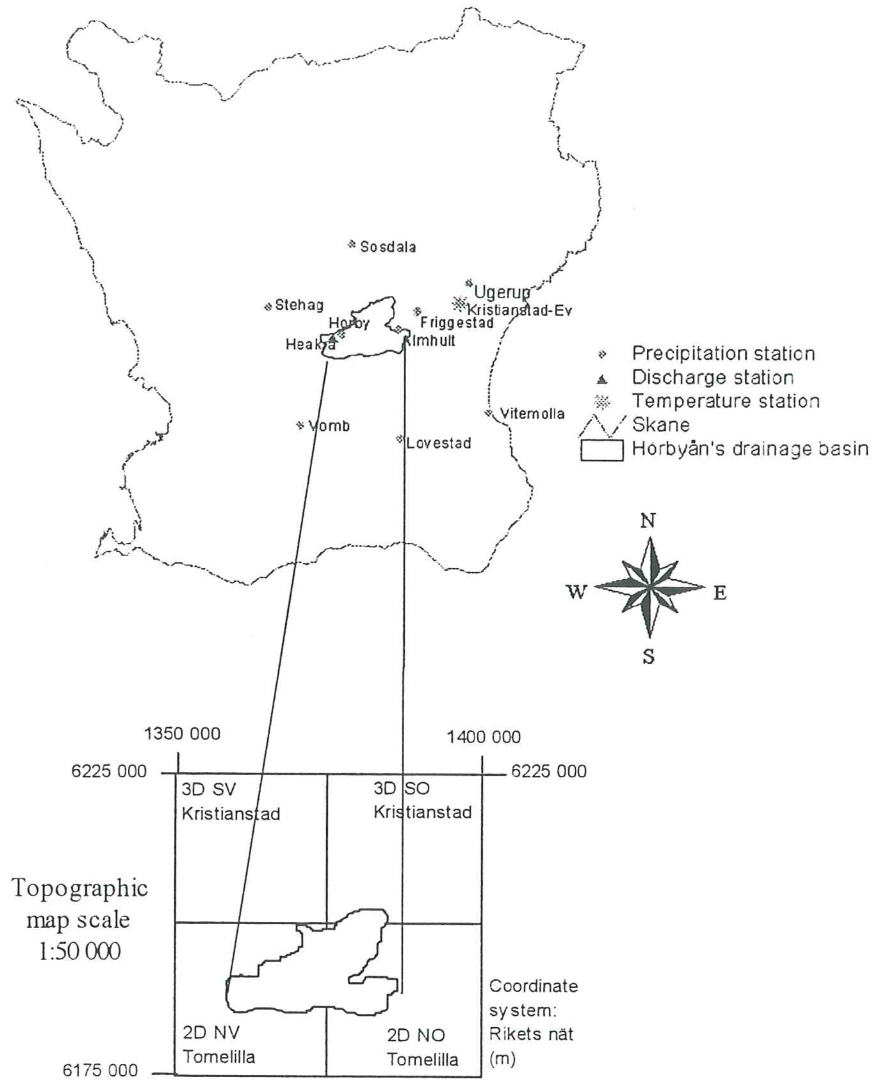


Figure 3.1 *Illustration of the location of Hörbyån's drainage basin and the four topographic maps that were used.*

4. Materials and methods

This chapter begins with a description of the conceptual, semi-distributed run off model, HBV.

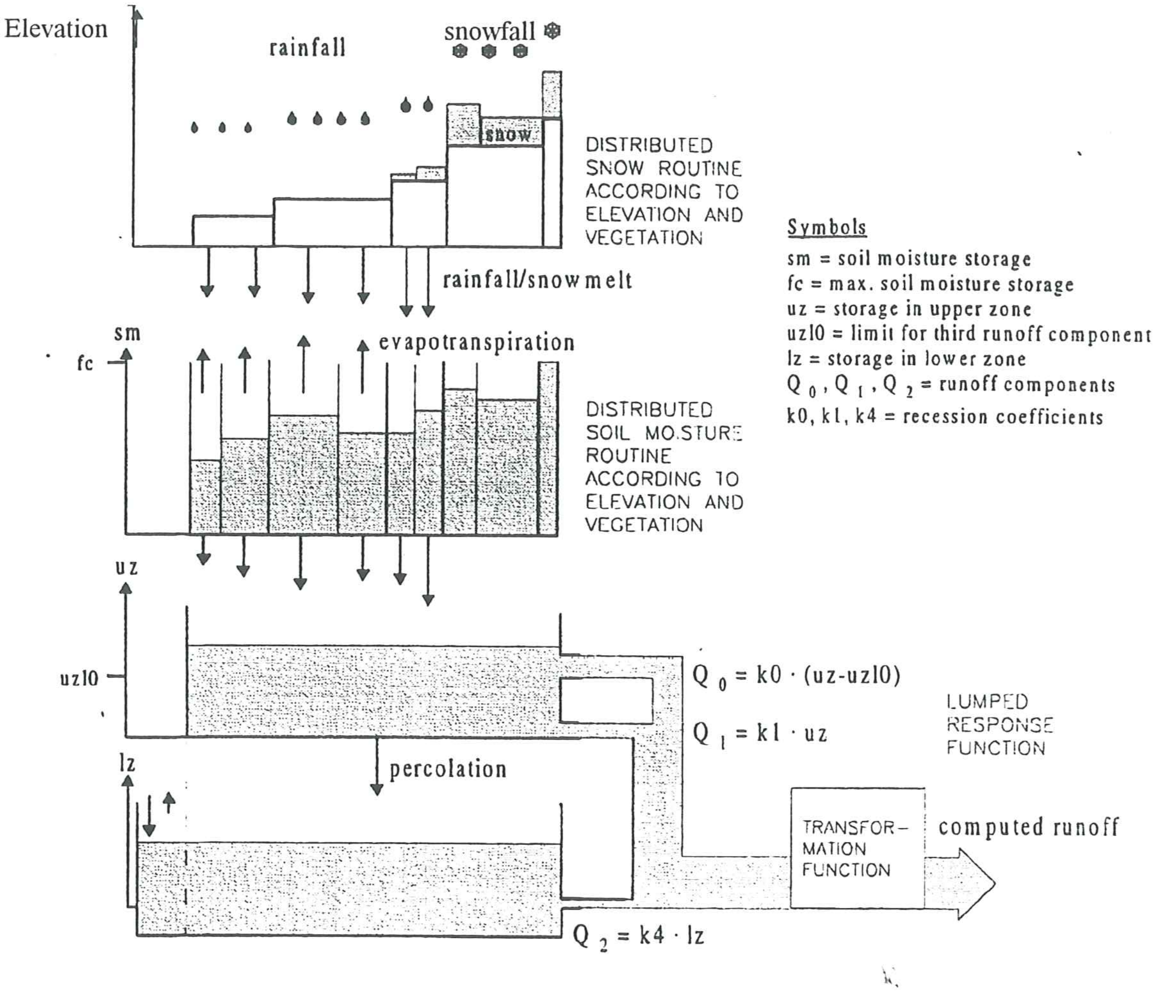


Figure 4.1 *Illustration of the general structure of the HBV-model applied to one sub basin (IHMS Manual version 4.0)*

4.1 HBV, a model description

The HBV-model (Hydrologiska byråns vattenavdelning) is a runoff model developed by S. Bergström (1976) at Sveriges meteorologiska och hydrologiska institut (SMHI) (Figure 4.1). Since 1976 the model is used for regular inflow forecasting to hydropower reservoirs in Swedish drainage basins. Main fields of applications for the HBV-model today are hydrological forecasting, estimating the risk for floods, studying the water balance and for estimating the discharge in areas without discharge-stations.

The Integrated Hydrological Modelling System, IHMS, (Lindström et al. 1996) is the computerised system for hydrological model computations based on the HBV-model. A revision of the HBV-model was carried out during 1993-1996. This new version is called HBV-96 and it is included in the IHMS that is used for this thesis. HBV-96 may describe more physical parameters (for example capillary flow and interception). Also the temporal and spatial resolution could be described better in HBV-96 than in the earlier HBV-model (Lindström et al. 1996).

The aim of the HBV-model is to reproduce the main hydrological processes in a defined area. It is semi-distributed which means that it takes into account variations in hydrological conditions through hydrological units and areal description of a basin (sub basins, vegetation zones and elevation zones). Because of inherent empirical components the HBV-model must be calibrated and compared with an observed series of measured meteorological data during 5 to 10 years to obtain a number of parameters that can be used for runoff prediction. This calibration is made by process of trial and error either manually or automatic by use of computer routines. The number of parameters to be calibrated depends on the number of sub basins, vegetation zones and elevation zones that are used in the model. Parameters as field capacity, snow melt rate and percolation are examples of parameters that need to be obtained through calibrations.

The obtained parameter values from the calibration should be controlled by a validation period, which is an independent test period directly after the calibration period. A validation period is used to test the accuracy of the calibration. After this period it is possible to run a hydrological forecasting, a short range (<30 days) or a long range (months) forecasting.

Both the calibration period (1985-10-01 until 1991-12-31) and the validation period (1992-01-01 until 1993-12-31) were examined. The calibrations were optimised and compared with the recorded discharge. Later the accuracy of the calibration periods was evaluated with a validation.

4.1.1 Structure of the HBV-model

The HBV-model consist of three subroutines (Figure 4.1), one for snow accumulation and melt, one for soil moisture and one response routine. A transformation function is included in the response routine. The subdivision of a basin into sub basins (distributed information) is considered in both the snow and soil moisture routines.

- **Snow routine**

The snow melt rate and snow accumulation are calculated in the snow routine. Both the temperature and precipitation differences due to elevation, and differences for snow melt in forest and open land due to vegetation types are considered in this routine. It is based on a simple degree-day factor (a melting factor) and a threshold temperature.

$$Snowmelt = CFMAX * (T - TT) \quad \text{(mm/day)}$$

where CFMAX is the degree-day factor (mm/day °C), T is the actual temperature in the elevation zone and TT is the threshold temperature (normally close to 0 °C). TT determines if the precipitation falls as snow or rain. The snow melt starts at temperatures above the threshold temperature.

- **Soil moisture routine**

The soil moisture routine is the main part of the runoff formation. This routine takes into account elevation and vegetation in the same manner as the snow routine. The soil moisture routine is based on two functions (Figure 4.2) and three parameters (FC, LP and BETA) must be calibrated in this routine.

Function A/

The actual evapotranspiration (EA) increases as the soil becomes wetter (SM). The EA is highest when the actual evapotranspiration (EA)/potential evapotranspiration (EP) = 1. This is called limit for potential evapotranspiration (LP) and EA is almost constant when the soil moisture reaches this level. EA remains constant until the maximum soil moisture storage is reached, field capacity (FC) (Figure 4.2 A).

Function B/

The contribution to runoff from snow melt and rain will be large when the soil is wet (high soil moisture values) and small at dry conditions (low soil moisture values). All precipitation contributes to runoff when the field capacity (FC) is reached (Figure 4.2).

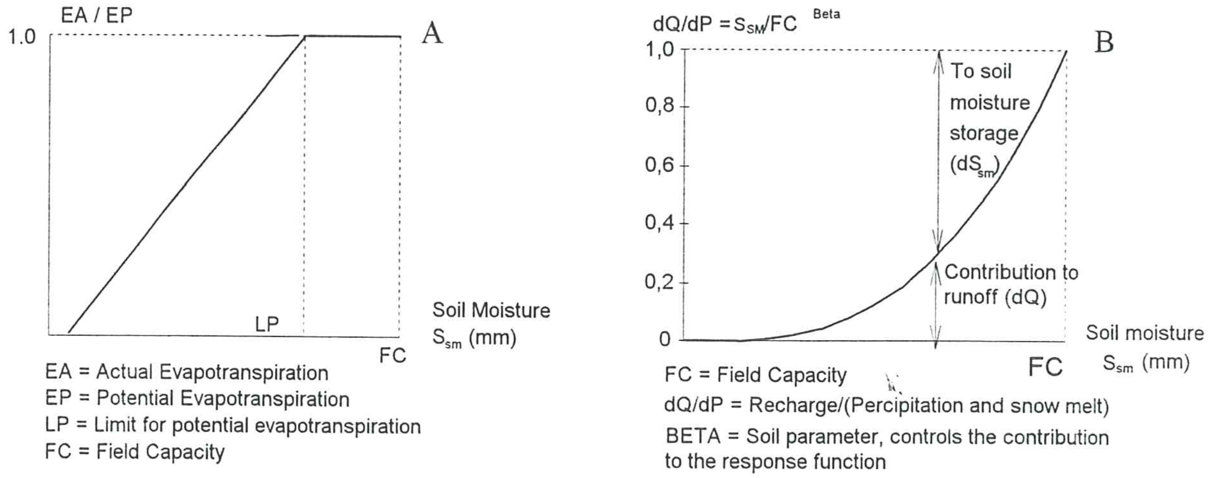


Figure 4.2 *Summary presentation of the soil moisture routine, A: Actual evapotranspiration (EA)/ Potential evapotranspiration (EP) as a function of the soil moisture (SM) content , B :Contribution to runoff (dQ) from precipitation and snow melt (dP) as a function of soil moisture (SM) (Bergström 1992, Bengtsson 1997).*

- **Groundwater routine** (the response routine)

  This routine transforms excess water from the soil moisture routine to runoff. This part of the model generates the runoff over time during a flow transport through storage in groundwater, aquifers and lakes.

  The routine is divided into two reservoirs, one upper and one lower zone. The lower zone represents the drainage from the base flow, a slow [1]recession. The upper zone, represents a drainage through more superficial channels, a faster recession (Figure 4.3 B). As long as the

---

[1] Recession is the amount of water that contributes to runoff from each magazine.

upper reservoir contains water it will percolate down to the lower reservoir (Figure 4.3 A). Water will begin to flow out from the upper reservoir when the lower reservoir is filled.

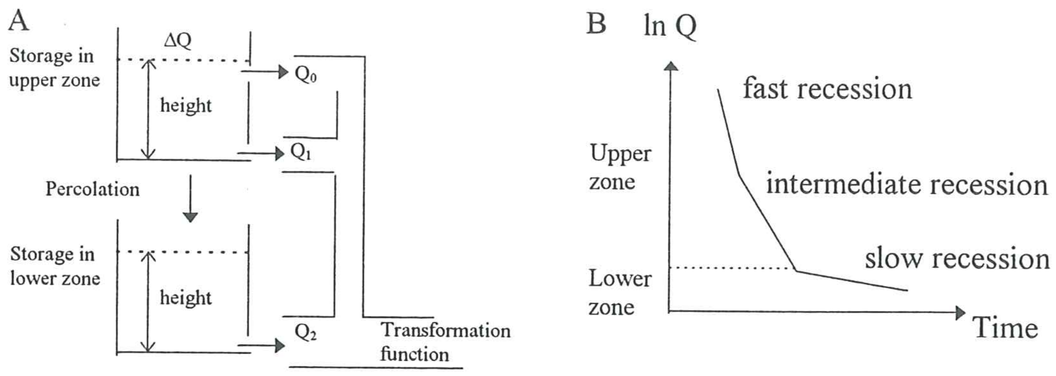


Figure 4.3: A: *The outflow of a reservoir is a function of the amount of water (height) in the reservoirs (Bengtsson 1997). B Illustration of how fast runoff from different zones declines.*

- **Routing procedure**
  This is a transformation function that evaluates the effects of water storage in reservoirs (e.g. lakes and aquifers) and stream channels. The runoff will for example decrease and become delayed if there are lakes in a drainage basin. It takes longer time for runoff in the beginning of a flow channel (sub basin 2 in Figure 4.4) than for the water in the main stream close to the outlet (sub basin 3 in Figure 4.4) to reach the outlet. Travel time is therefore also required on the estimated runoff due to the length of the river. A filter is used in the procedure to smoothen the generated flow (daily runoff, through flow, mm/day) in order to get a proper shape of the hydrograph due to travel time.

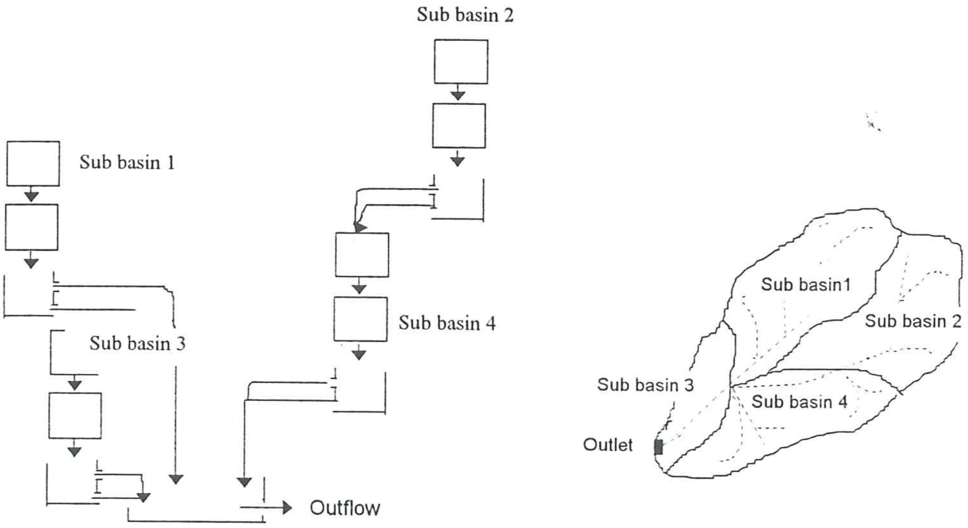


Figure 4.4 *Illustration of a drainage basin with four sub basins. The travel time for the runoff in sub basin 1 and sub basin 2 is longer than for sub basin 3 and sub basin 4 (Bergström 1993).*

4.1.2 Calibration

The HBV-model must be calibrated to obtain a number of parameters. The hydrograph curve of the recorded (measured) discharge is compared with a hydrograph curve of the computed discharge during the calibration. The discharge is calibrated with trial and error techniques until an agreement of the curves are found. Three criteria are used when the discharge is calibrated in HBV (IHMS, manual version 4.0). These are:

1/ Visual inspection, a comparison of the computed and the measured discharge in the hydrograph curves.

2 a/ The Accumulated Difference (AD) which is a measure of the volume error in mm expressed as

$$\text{AD (t)} = \sum_{i=1}^{t} Qcom(i) - Qrec(i)$$

Qcom(i)= computed discharge for each day , Qrec(i) = observed discharge for each day, t = time, i = total period (number of days)

2 b/ Also the Relative Accumulated Difference (RAD) which is a measure of the relative mean volume error in % is used, $\text{RAD (t)} = \sum_{i=1}^{t} \frac{Qcom(i) - Qrec(i)}{\sum_{i=1}^{t} Qrec(i)}$

The volume error should be as close to 0 as possible. The computed discharge is overestimated when the volume error is positive and vice versa.

3/ The explained variance around mean expressed as

$$R^2 = \frac{\sum Qrec - Qrec_{mean})^2 - \sum (Qcomp - Qrec)^2}{\sum (Qrec - Qrec_{mean})^2}$$

The hydrographs of the computed and observed discharge would agree completely if the explained variance $R^2 = 1$. Normally R^2 values end up among 0.80 to 0.95 if the observed meteorological input data are recorded without homogeneity breaks (IHMS, manual version 4.0).

4.1.3 A hydrological year

The HBV-model should be run at least one year before the calibration to adapt and fill the water magazines in all routines. This period should begin the first of October when a so called hydrological year (Grip et al. 1988, Bergström 1993) begins in the southern part of Sweden. The water magazines (upper and lower reservoirs) are, at this time of the year, almost empty due to high evapotranspiration rates during the summer. The soil moisture is 90% of the maximum soil moisture storage and there is no snow at this time (Figure 4.5). Water in the magazines begins to fill again after the first of October when the evapotranspiration rate decreases and when the precipitation rates are fairly high.

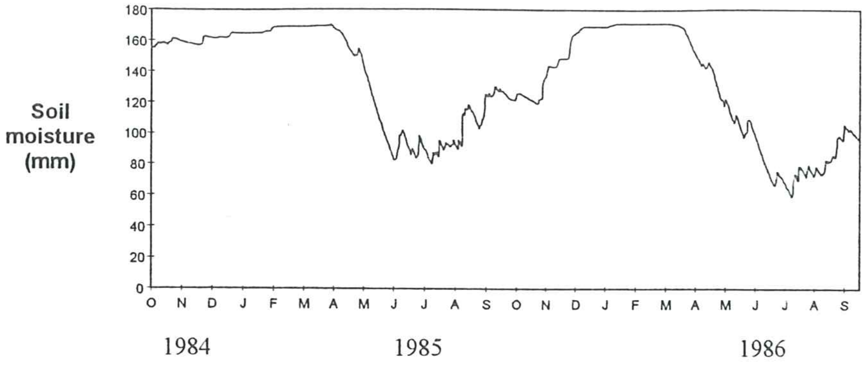


Figure 4.5 *Illustration of the soil moisture zone during two years, the first year (1984/1985) illustrates when the water magazine is filled (Feb. to April), a year before the calibration period begins. The second year (1985/1986) illustrates how water in the soil moisture zone fluctuates during the first calibrated year.*

4.2 Materials

Three different types of input data were used in the HBV-model. These were the digital elevation model (DEM), the remotely sensed data and the meteorological data. The data types and computer software used in this project are described in this section.

4.2.1 Geographical data

One Satellite image, Landsat TM (Thematic Mapper) scene (pixel size 30*30 meter) from August 1994, spectral bands (2. 0.52-0.60 µm (green) 3. 0.63-0.69 µm (red) and 4. 0.76-0.90 µm (near - IR)) were used as remotely sensed cover data for land cover classifications. Three land cover classes were derived (forest, open land and lakes) because HBV accept a maximum of three classes. This was further described in 4.3.6.

The satellite image was corrected both radiometrically in IDRISI (4.2.3) and geometrically using the EASI/PACE (GCP works 4.2.3) programs before the image processing. A radiometric correction compensates for atmospheric effects (reflection, the angle of the sun). A geometric correction compensates for distortion due to for example variations in altitude, velocity and attitude of the sensor platform and for the curvature of the earth (Lillesand et al. 1994). The Nearest Neighbour interpolation algorithm (Richards 1995) that relocate original image pixels to geometrically corrected map grid was used as transformation function for the geometric correction. This algorithm was chosen since the pixel size on the input data was the same as for the output data. About 30 well-distributed ground control points (GCP) were used for the re-sampling to the topographic maps (the geometrically corrected maps) (Figure 3.1). The root mean square (RMS) (Richards 1995) error was less than 0.5 pixels.

Sixteen digital elevation models (DEM) from Lantmäteriverket (LMV) with pixel size 50 * 50 m in x and y direction were merged to one DEM. Resolution in y direction (the height) was 1 decimetre. The function of the DEM was to estimate boundaries for the main drainage basin using the EASI/PACE programs (4.2.3), and also to define the elevation zones (4.3.7).

Topographic maps (Figure 3.1) were used for the manual estimation of Hörbyån's drainage basin (4.3.5) and also for the estimation of sub basins (4.3.8).

4.2.2 Meteorological data

All the meteorological data, obtained from SMHI, were used as input data for the HBV-model. Daily recorded values from 10 precipitation stations, one temperature station and one discharge station from the period of 1984-10-01 until 1993-12-31 were used (Figure 3.1, Table 4.1).

Input data required for calculations of the potential evapotranspiration (PE) (4.3.4) were also obtained from SMHI (daily values of wind speed, vapour pressure, sunlight hours and temperature). Other data required for the calculations as possible sunlight hours and black body radiation was taken from tabulated values (Ministry of Agriculture, Fisheries and Food (1967) (Appendix 1)).

4.2.3 Computer software

Computer software in the Microsoft Windows and DOS environment were used in this project. The geometrical corrections, image classifications and DEM processes were made using the EASI/PACE programs, in the packages GCP-works, X-pace and Image works. The image processing program IDRISI was used for interpretation, image processing and map production. Calculations and graphs were produced using MICROSOFT EXCEL 6.0. The digitising of Hörbyån drainage basin was made using ARC/ INFO and maps were produced using ArcView 3.0. Finally the IHMS 4.1 was used for the runoff modelling of the HBV-model.

Table 4.1 *Meteorological stations that were used in this study.*

	Meteorological Stations	Altitude (m)
Precipitation	1 Friggestad	150
	2 Hörby	65
	3 Kristianstad-Everöd	17
	4 Stehag	60
	5 Sösdala	87
	6 Ugerup	20
	7 Vinslöv	27
	8 Vitemölla	15
	9 Vomb	25
	10 Älmhult	180
Temperature	1 Kristanstad Everöd	17
Discharge	1 Heåkra	68
Calculations of PE		
Radiation	Lund	
Wind speed	Kristianstad Everöd	17
Humidity	Kristianstad Everöd	17
Temperature	Kristianstad Everöd	17

4.3 Pre-processing input data for the HBV-model

How the input data was captured and applied to Hörbyån's drainage basin is described in this section. Meteorological input data requirements of the HBV-model, for the calibration and verification period are daily values of precipitation, air temperature, estimates of monthly mean values of the potential evapotranspiration and daily values of observed discharge. The estimated discharge is compared and calibrated against the observed discharge. Other input data needed to HBV are the total area of a drainage basin, sub basins, elevation zones and vegetation zones. These type of input data serve as land surface parameters in the HBV-model.

4.3.1 Precipitation

HBV uses an average description of each basin as input data. One value for every meteorological input data (precipitation, temperature, potential evapotranspiration and discharge) represents a basin (either the whole drainage basin or a sub basin).

The central point (x- and y- co-ordinates) was chosen for representing the precipitation for the total area in each basin of Hörbyån's drainage basin. Co-ordinates for these points were estimated in the image processing program IDRISI.

Spatial patterns of precipitation, in both the drainage basin and in each sub basin, were obtained through interpolation in this study. Ten precipitation stations, located like a network in and near Hörbyån's drainage basin were used for the interpolation (figure 3.1). The Symap interpolation algorithm, an algorithm which is able to calculate point values, was used for the computation. This algorithm calculates a weighted average of values from nearby precipitation stations. The weights are based on the inverse square of distances to the stations. The Symap interpolation algorithm is described in the following equation.

$$Z_P = \frac{\sum_{i=1}^{n} \frac{1}{(P_i)^2} Z_i}{\sum_{i=1}^{n} \frac{1}{(P_i)^2}} = \frac{\frac{1}{(P_1)^2} Z_1 + \frac{1}{(P_2)^2} Z_2 + \ldots + \frac{1}{(P_n)^2} Z_n}{\frac{1}{(P_1)^2} + \frac{1}{(P_2)^2} + \ldots + \frac{1}{(P_n)^2}}$$

P was the central point in a basin, P_i were the distances from P to the precipitation stations in (1,2,...,n) and Z_P was a weighted average of the precipitation values Z_i in the precipitation stations (1,2,...,n) (Figure 4.6) (Shepard 1984).

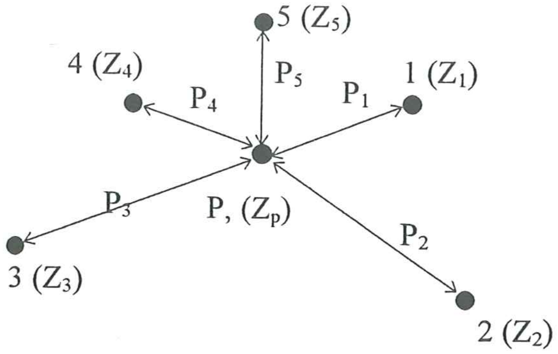


Figure 4.6: *Illustration of the Symap interpolation algorithm.*

All precipitation stations which are included in the calculations will receive a weight. If the distance from P to P_1 is short comparing to P_2, the weight will then become larger for $\frac{1}{(\overline{P_1})^2}$ than for $\frac{1}{(\overline{P_2})^2}$.

To decide that the central point in each sub basin is representative for the whole area is a simplification but probably adequate for small basins. The elevation was not considered in the interpolation in this study according to the low elevation range in the drainage area. It is a deficit that should be considered.

4.3.2 Temperature

Temperature data were used for calculations of ablation and accumulation in the snow routine of the HBV-model. No interpolation was made for the temperature data due to lack of recording stations with regular temperature measurements, close to or in the drainage basin. Instead the available meteorological station, Kristianstad Everöd, was representing the temperature for the whole drainage basin (table 4.1)

4.3.3 Discharge

Measured discharge at Heåkra (Figure 3.1) was compared with computed discharge during the calibration and validation period in the HBV-model. The outlet for Hörbyån in this study was Heåkra since the discharge was measured from this station, even though the actual outlet of Hörbyån is next to Östra Ringsjön

4.3.4 Potential Evapotranspiration

The HBV-model allows an average input of the potential evapotranspiration (PE) for the whole drainage basin.

PE was defined by Penman in 1956 as *"the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water"* (Ward et al. 1995). The PE is a complex function depending on many factors in the atmosphere, the soil and the vegetation (1.2). The PE is both complicated and expensive to measure and is instead common to approximate. A number of formulas exist to approximate the potential evapotranspiration such as Penman's formula (4.3.4.1) and Thornthwaite's formula (4.3.4.2). Both equations were used for calculation of PE and compared in this study.

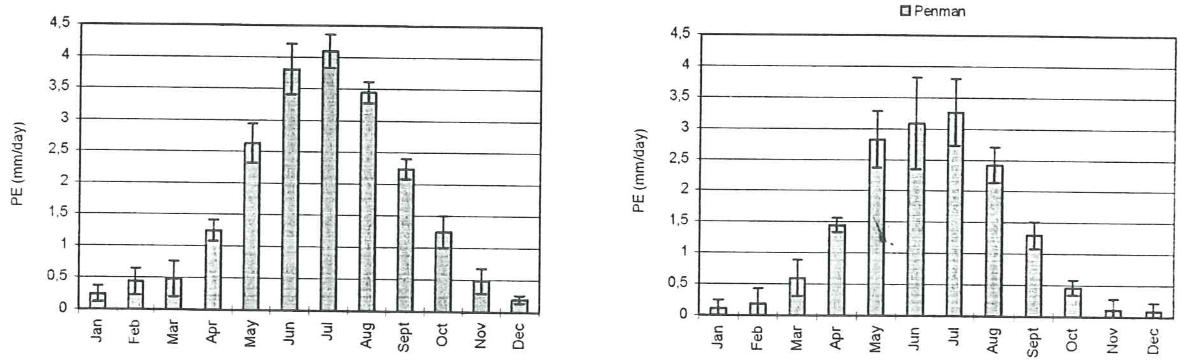
4.3.4.1 Penman

Penman's equation (Eq 1. Appendix 1) provides a method of calculating the mean daily potential evapotranspiration (PE_d) or mean monthly potential evapotranspiration (PE_m) from a vegetated surface. Penman's formula considers the atmospheric disturbance through radiation (albedo) and the wind energy. However, it does not account for neither interception losses nor night-time losses. Required weather data for the equation are: daily values of air temperature, wind speed, radiation and relative humidity (Shaw 1988, Ward 1995).

4.3.4.2 Thornthwaite

Thornthwite's equation (Eq 2. Appendix 1) provides a method of calculating the potential evapotranspiration on mean monthly basis (PE_m). The equation accounts for very simple atmospheric effects only and gives representative values mainly in humid climates similar to Eastern United States where the equation was developed. Influences of vegetation, interception and night-time losses are not considered in the equation. Thornthwaite's method requires therefore less weather data compared to Penman's method. Required input data are the mean monthly air temperature and the latitude of the study area for making an adjustment of the number of daylight hours (Ward et al., 1995, Shaw 1988).

The PE was calculated using Penman's and Thornthwaite's equations for each month from 1984 until 1995. Mean monthly values for 11 years are given in Figure 4.7. Due to lack of recording stations for the required input data, PE is calculated with average values for the whole drainage basin.



A: PE calculated with Thornthwaite's equation. B: PE calculated with Penman's equation

Figure 4.7 *The differences in potential evapotranspiration (PE) using Thornthwaite's and Penman's equation based on monthly mean meteorological data. The results are divided by the number of days month. Mean meteorological data from the period May 1984-October 1995 are used. Albedo = 25% (grass) was used in Penman's formula.*

The reason for calculating the PE twice using two different equations was to investigate how the results from a simplified equation with less input data requirement differed from an equation that consider more parameters. There might be difficulties in finding enough meteorological data required by Penman's formula in a study area and a more simple equation as Thornthwaite's equation must be used instead.

In the southern part of Sweden the mean annual PE is measured to approximately 550-600 mm (Knutsson et al. 1993). The mean annual PE calculated by Penman's equation (480 mm) in this study was lower than the approximations while the calculations by Thornthwaite's equation (629 mm) were higher.

High temperatures have a large effect in Thornthwaite's equation and the PE tends therefore to be exaggerated, specially during the summers (Figure 4.7). Penman's equation considers other meteorological factors and does not exaggerate that much. As seen in Figure 4.7 the distribution of the standard deviation was larger when using Penman's equation compared to Thornthwaite's equation. This depends on that more meteorological factors were considered. The albedo for grass sites (0,25) was used when estimating the PE by Penman's formula in this study. The albedo for forest sites, with higher evapotranspiration, is (0,18). The PE used in forest sites were therefore somewhat underestimated in this study. Except for these more meteorological factors were considered in Penman's equation and the results from this equation were used as input data in the HBV-model.

4.3.5 Drainage basin

Two methods, a manual and computer based[2] determination, were used when estimating the size of Hörbyån's drainage basin. The reason for using two methods was to compare the results and study advantages and drawbacks with both methods.

The topographic maps (Figure 3.1) were used for the manual estimation of Hörbyån's drainage basin. High peaks and ridges in the terrain around Hörbyån, upstream from the outlet (Heåkra), were detected and defined as the boundary of the drainage basin. Hörbyån and the manually defined drainage basin were afterwards digitised in ARC/INFO. A DEM was used for the second method where Hörbyån's drainage directions were estimated with a simulation algorithm in the EASI/PACE programs to define the drainage boundary. Results from both the methods were compared in Figure 4.8

Hörbyån's Drainage basin	Area (km^2)
digitised	148,98
simulated	162,48

Area difference

$$\frac{(162{,}48 - 148{,}98)}{148{,}98} *100 = 9{,}08\%$$

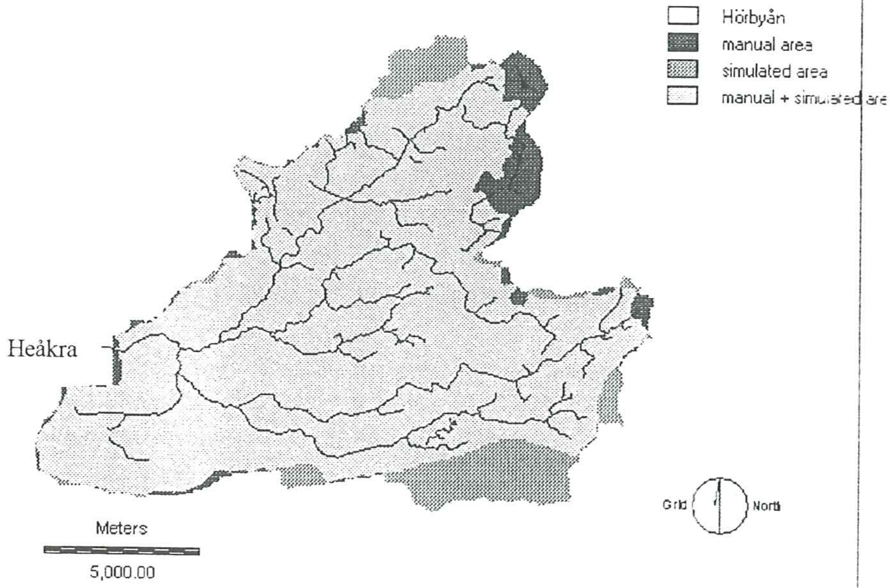


Figure 4.8 *Difference between the simulated and the manually defined drainage area for Hörbyån.*

---

[2] Simulated by PCI:s TERRAIN ANALYSIS PACKAGE.

The simulated drainage basin was 9,08 % (13,50 km^2) larger than the digitised, manually defined, drainage basin (Figure 4.8). Topographic maps (Figure 3.1) showed that the simulated drainage basin intersects with other drainage basins next to Hörbyån both in the North and in the South. The reasons for the intersections probably depend on sinks (depressions) and flat areas in these parts of the drainage basin. There were sinks in the DEM that are defined as pixels with lower values than all their eight adjacent neighbouring pixels (Pilesjö 1992). Sinks disturb the flow pattern and the simulation algorithm for estimation of drainage basins in EASI/PACE can not handle sinks (PCI 1994). All sinks were therefore filled, by another algorithm in the EASI/PACE programs, before the simulation to allow a continuos flow across the DEM surface. Problems arise if all sinks are not filled. Furthermore some regions were flat (the same pixel value as for the eight adjacent neighbouring pixels) and those areas are difficult to handle by the simulation algorithm. A drainage direction is assumed in every pixel by the simulation algorithm even if the area is flat. A drainage basin could therefore be underestimated or overestimated in flat areas. The area in the north eastern part of Hörbyån was not included as drainage area by the simulation. Hörbyån was ditched in a part of this region and the simulation algorithm can not detect ditched area. All together these problems assumed to make the area of the simulated drainage basin too large.

To estimate the drainage area boundaries manually was time consuming and small variations were not possible to consider. The manually estimation of Hörbyån's drainage basin seems to contain fewer total area errors though and this drainage area was finally used in the calibrations.

4.3.6 Vegetation zones

The HBV-model is semi-distributed and can account for hydrological conditions through hydrological units. An area description of a drainage basin may be considered with for example vegetation zones.

The hydrological model, HBV, is able to accept a maximum of three vegetation types. Those are open land, forest and lakes (IHMS, manual version 4.0). A remotely sensed satellite image. Landsat TM, August 1994, were used to obtain the spatial distribution of land cover in Hörbyån's drainage basin. The topographic maps (Figure 3.1) were used to identify training fields for forest, open land and lakes visually on the Landsat scene. 10 to 15 training area polygons (10 to 40 pixels per polygon) for each of the three land cover classes were created manually. Polygons for forest included forests and wetlands, open lands included farmland and urban areas and finally lakes included just lakes.

Spectral signatures were generated based on the training fields to check the separability[3] for each land cover class. The separability between open land and lakes were complete (2,0). The separability between lakes and forest, forest and open land areas were fairly good (Table 4.2).

---

[3] Separability = A measurement of how distinct classes are separated from each other.

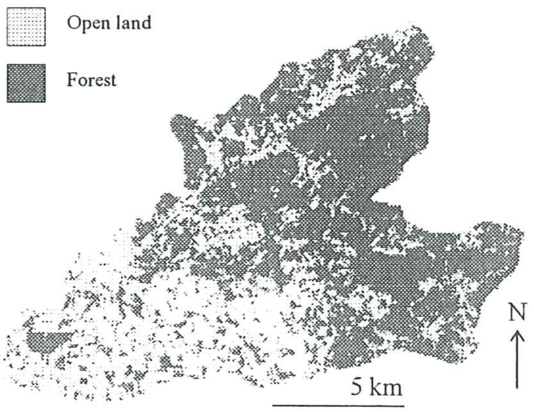
Table 4.2 *The separability measure: Bhattacharrya Distance (supervised*) (PCI 1994), for the spectral signatures in the TM-94 scene.*

	lakes	open land
Open land	2,0	
forest	1,87	1,88

- 2.0 complete separability

These spectral signatures were used to classify the land cover in Hörbyån's drainage basin with a Maximum Likelihood classification algorithm (Burrough, 1986). This classification algorithm assumes that the training data is normally distributed and evaluates for both the variance and correlation in the distribution of response. Probability functions are used in the algorithm when classifying which category unidentified pixels should belong to. Unidentified pixels are assigned to the category with highest probability value.

The result from the Maximum Likelihood classification with the Landsat scene (band 2,3,4) was used as input data of vegetation zones in the HBV-model. All pixels in the drainage basin assigned a land cover class during the classification either as forest, open land or lakes. The three land cover classes by area are given in Figure 4.9. Forest areas (57 %) dominated in the drainage basin. Further the classification confirms that there are no lakes in Hörbyån's drainage basin (Figure 4.9)



Land cover classification of Hörbyån's drainage basin

Land cover	Area %
Lake	0
Forest	57
Open land	43

Figure 4.9 *Result of the Maximum Likelihood classification algorithm in Hörbyån's drainage area with the Landsat TM-94 scene*

4.3.7 Elevation zones

The HBV-model may also account for the correlation between precipitation and altitude (IHMS, manual version 4.0). This is particularly essential in mountainous regions where the elevation range is considerable. However, precipitation increases, temperature and evapotranspiration decrease with heights (Figure 4.10).

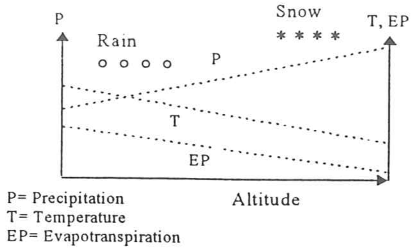


Figure 4.10 *A principle illustration of temperature, precipitation and evapotranspiration dependence due to the altitude.*

The altitude difference in Hörbyån's drainage basin is moderate, 124 meters. Three elevation zones (Figure 4.11) with the intervals 51-100, 101-150 and 151-200 meter were created with the DEM and used as input data during some of the calibrations.

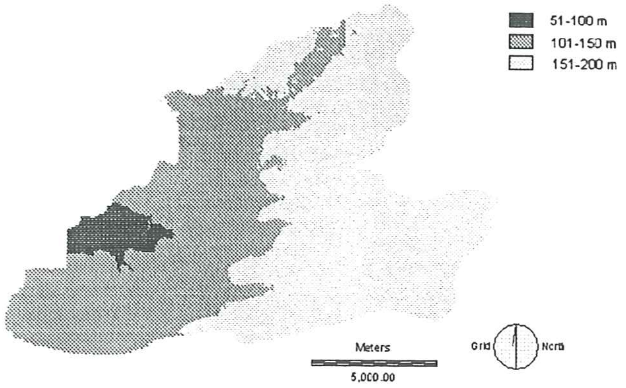


Figure 4.11 *Three elevation zones in Hörbyån's drainage basin.*

4.3.8 Sub basins

To improve the spatial distribution of a drainage basin further, HBV may also take into account for sub basins. Each sub basin is first considered separately and the contribution of runoff from all sub basins is interconnected (added) in the end when using several sub basins in HBV.

The manually defined drainage basin was partitioned into sub basins by using Strahler's stream network method (Skinner et al. 1987). The flowpaths are partitioned into a number of pathways (Figure 4.12) with this method. Minor flowpaths without tributaries are classified as first order stream, those streams with only first order tributaries are classified as second order streams. Third order has first and second order tributaries. Only one main stream remains in the end that are close to the outlet and get the highest order (Skinner et al. 1987).

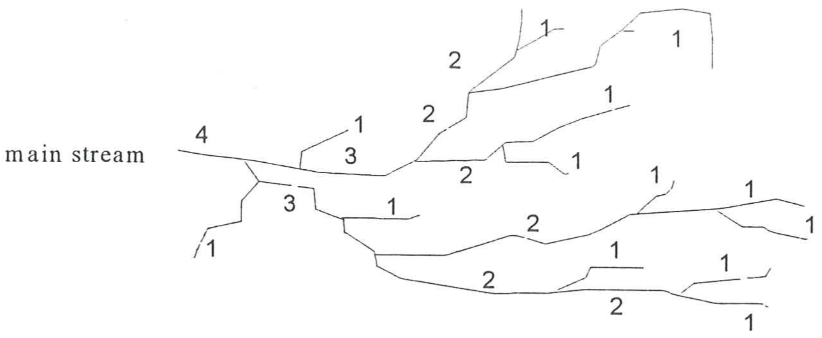


Figure 4.12. *Illustration of Strahler stream ordering system (Strahler1952) (Skinner et al. 1987).*

The sub basins were estimated manually since the manually defined drainage basin was used in this study (4.3.5). Both the topography maps (Figure 3.1) for the drainage area and the stream tributaries for Hörbyån were used as tools when partitioning the basin into sub basins. The drainage basin was first partitioned into five sub basins, one sub basin close to the outlet on the main stream and four sub basins on the third and second order tributaries. The areas of each sub basin differed among 16 km^2 to 46 km^2 (Figure 4.13). The drainage basin was further partitioned into ten sub basins also by using Strahler's method. The size of the drainage basins then varied among 4 km^2 to 24 km^2 (Figure 4.14).

A supervised land cover classification with the Landsat scene was made in each sub basin in the same manner as for the whole drainage basin in 4.3.6.

Result from each land cover classification for five and ten sub basins is shown in Figure 4.13 and Figure 4.14. Three sub basins (1,2,3) were dominated by forest (>50%) and two (4,5) by open land (>50%) (Figure 4.13) when the drainage basin was partitioned into five sub basins.

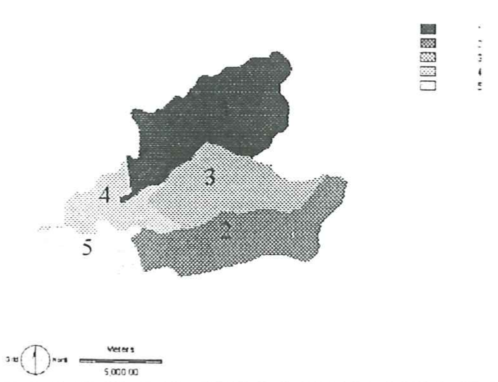
Subbasin	Area (km^2)	Forest (%)	Open land (%)	
1	45,57	**76**	24	
2	36,45	**54**	46	
3	29,36	**72**	28	
4	15,90	27	**73**	
5	20,33	23	**77**	

Figure 4.13 *The area, land cover and boundaries when Hörbyån's drainage basin was partitioned into five sub basins.*

Five sub basins (1,2,3,5,6) were dominated by forest and five (4,7,8,9,10) by open land in Hörbyån's drainage basin that was partitioned into 10 sub basins (Figure 4.14).

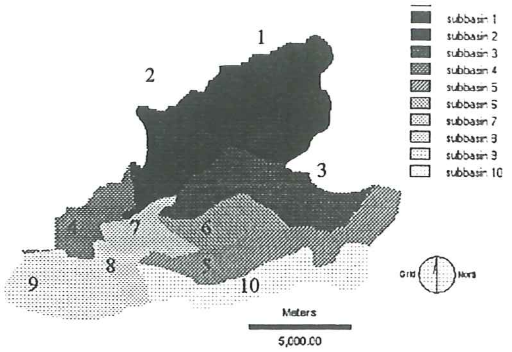
Sub basin	Area (km^2)	Forest (%)	Open land (%)	
1	23,20	78	22	
2	22,37	73	27	
3	20,62	79	21	
4	8,97	27	73	
5	19,90	57	43	
6	8,74	57	43	
7	6,93	26	74	
8	4,34	22	78	
9	16,01	23	78	
10	16,55	50	50	

Figure 4.14 *The area and land cover in each sub basin when Hörbyån's drainage basin was partitioned into ten sub basins.*

Each sub basin was finally partitioned into three elevation zones in the same manner as for the whole drainage basin in 4.3.7. A land cover classification was made in each elevation zone. The results are seen in Appendix 2.

4.3.9 Soil types

There is no parameter for soil types in the HBV-model. However, it is possible to account for soil types through the parameters in the soil moisture routine, the limits for the potential evaporation (LP), the field capacity (FC) and BETA. This is made through different setting on the three parameters depending on what kind of soil type to describe.

Sub basins in Hörbyån's drainage basin dominated by forest assumed to consist of sandy soils and sub basins dominated by open land assumed to consist of clayey soils in Hörbyån's drainage basin (figure 4.2). Parameter values for LP and FC in sub basins that dominated by forest were given lower values than sub basins dominated by open land (Figure 1.3).

5. Results

The calibration of the model started with a set of standard parameters for Skåne provided by SMHI (Bergström 1990). The calibration was made by trial and error adjustment to optimise parameter values during the period 1985-10-01 until 1991-12-31. Three to six parameters in each basin were varied during the calibration of each sub-routine (4.1), about 15 parameters altogether in every basin. Ten types of calibrations were made altogether. The results from five calibrations with an acceptable agreement on the hydrograph curves for each type of calibration are presented in figures 5.1-5.3 where the relative accumulated difference (RAD) is plotted versus the explained variance (R^2). Vegetation and precipitation were considered for all types of calibration. Elevation zones were considered in five calibration types (figure 5.1 B, 5.2 B,D and 5.3 B,D) and soil types were considered in four calibration types (figure 5.2 C,D and figure 5.3 C,D)

5.1 Calibration

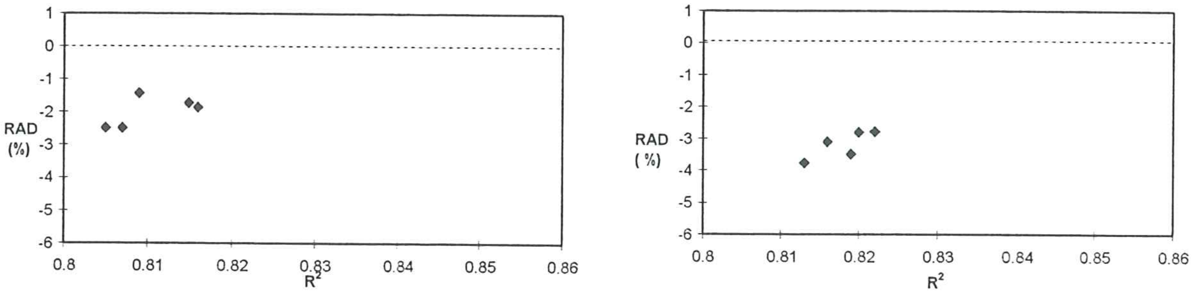


Figure 5.1

A. *Calibration results for the whole drainage basin. RAD = the relative accumulated difference (volume error), R^2 = the explained variance around mean.*

B. *Calibration results for the whole drainage basin. Three elevation zones were considered.*

R^2 varied among 0,80 and 0,82 when calibrating the whole drainage basin without a spatial distribution of sub basins and elevation zones (Figure 5.1). The agreement for inter annual variations between the recorded and the simulated discharge was difficult to bring in line during these calibrations. R^2 was somewhat improved when elevation zones were included in the calibrations (Figure 5.1B). R^2 then varied among 0,81 to 0,82.

RAD was negative for both types of calibration results. This means that the total volume of the simulated discharge was underestimated. The underestimation was moderate (<4%) for all calibrations though.

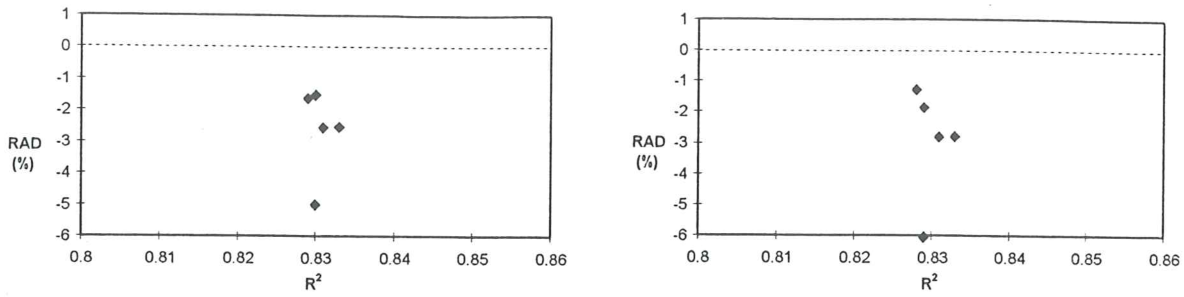
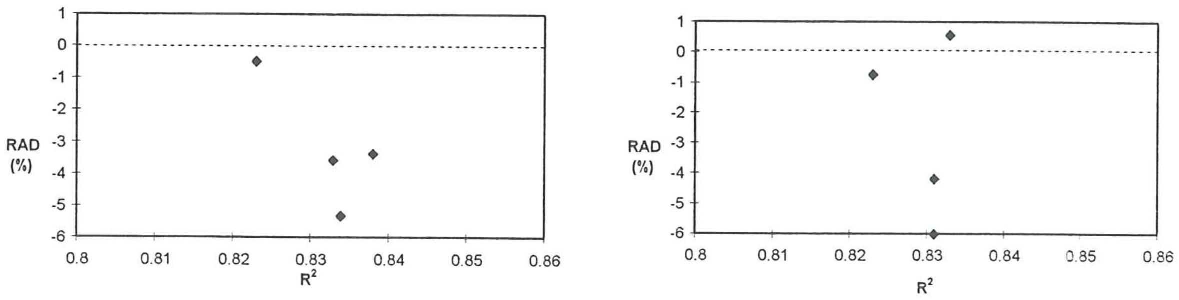


Figure 5.2 **A** *Calibration results of Hörbyån's drainage basin partitioned into 5 sub basin.*

B. *Calibration result of Hörbyån's drainage basin partitioned into 5 sub basins. Three elevation zones were considered in each basin.*



C. *Calibration results of Hörbyån's drainage basin partitioned into 5 sub basins. Two soil types were considered in each basin.*

D. *Calibration results of Hörbyån's drainage basin partitioned into 5 sub basins. Two soil types and three elevation zones were considered in each basin.*

Further improvements on the calibration results were achieved when Hörbyån's drainage basin was partitioned into 5 sub basins (figure 5.2 A-D). R^2 then varied among 0,82 and 0,84. R^2 increased somewhat in some calibrations (figure 5.2 C) when considering soil types, clayey or sandy soils, (figure 5.2 C-D). There were no improvements on R^2 when the elevation zones were included in the calibrations (figure 5.2 B, D). Overall the hydrograph curves of the simulated and measured discharge agreed better for the whole calibration period when using 5 sub basins instead of the whole drainage basin without sub basins (figure 5.1 A-B). It was difficult to find out which type of calibration in figure 5.2 A-D that was better than the other though.

The relative accumulated difference (RAD) was negative (underestimated) for all calibrations except for one (figure 5.2 D). However, the volume errors were moderate (between +1-(-6)%).

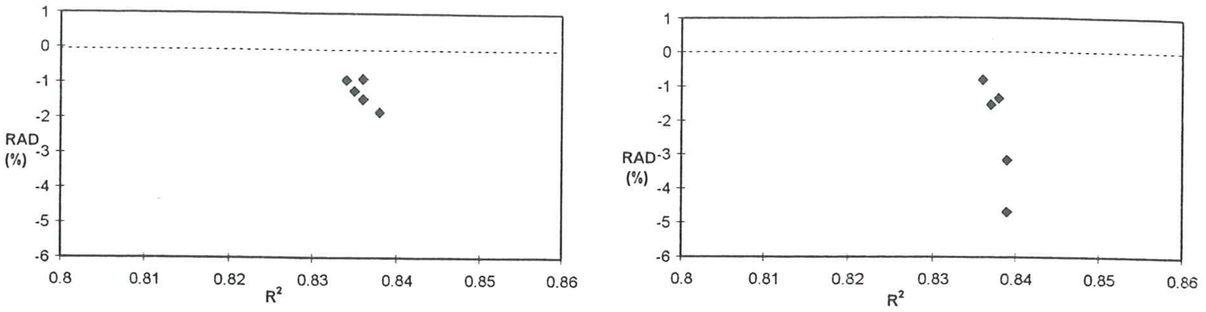
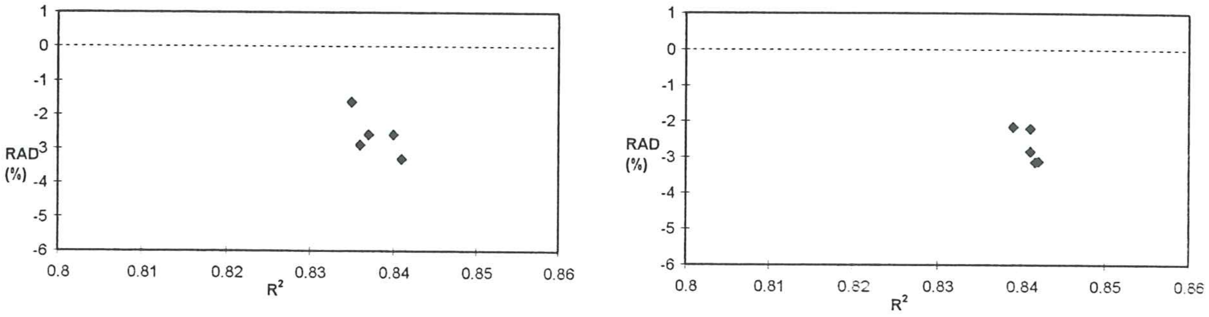


Figure 5.3

A. *Calibration results of Hörbyån's drainage basin partitioned into 10 sub basins.*

B. *Calibration results of Hörbyån's drainage basin partitioned into 10 sub basins. Three elevation zones were considered in each basin.*



C. *Calibration results of Hörbyån's drainage basin partitioned into 10 sub basins. Two soil types were considered in each basin..*

D. *Calibration results of Hörbyån's drainage basin partitioned into 10 sub basins. Two soil types and three elevation zones were considered in each basin.*

Calibrations were also performed with Hörbyån partitioned into 10 sub basins. These calibration results are seen in figure 5.3 A-D and they were slightly better than the results for 5 sub basins (figure 5.2 A-D). R^2 varied among 0,83 and 0,85 during all four calibration types (figure 5.3 A-D). R^2 was somewhat better in those calibrations that considered soil types, sand or clay, (figure 5.3 C-D) compared to those types of calibrations that did not consider soil types (figure 5.3 A-B). R^2 were slightly better when elevation zones were included in the calibrations. These calibration types where elevation zones were included (figure 5.3 B, D) were to prefer when using 10 sub basins since they performed the highest R^2-values.

RAD was negative for all calibrations. However the underestimation was moderate (-1 to -5 %) for all calibrations.

A hydrograph curve for one of the calibrations in figure 5.3 D is presented in Appendix 3 and discussed further in 6.2.

5.2 Validation

A validation period (1992-01-01 to 1993-12-31), based on data from an independent period was used as an accuracy analysis. The performance was somewhat reduced with the HBV-model during this period compared to the calibration periods. RAD increased (-10 to -15 %) while R^2 (0,83 to 0,85) were almost the same as during the calibrations. Exceptions of these results were validation periods for the drainage basin without any sub basins. Both R^2 (about 0,70) and RAD (-15 to -20%) were strongly reduced then.

6. Discussion

The results of the calibration showed a better correlation when Hörbyån's drainage basin was partitioned into five or ten sub basins and the spatial resolution of the precipitation, elevation, soil types and vegetation were increased compared to when the whole basin was calibrated without sub basins. However, it was complicated and time-consuming to prepare input data and to obtain correct parameter values for the calibrations when using more than one sub basin. The required number of parameters to calibrate was large especially when using 10 sub basins. The uncertainties of these calibrations were substantial since all parameters within a sub basin interact with each other.

The results were only slightly improved when three elevation zones were included in a calibration. The elevation range in Hörbyån's drainage basin is modest and the temperature, precipitation and evapotranspiration dependence due to the altitude are therefore low. This was probably the major reason for such small improvements of the calibration results when using three elevation zones.

The results improved slightly when soil types were considered in the calibrations. Many parameters had to be calibrated in these investigations and it was difficult to understand their combined effects. One should interpret such results from calibrations with caution. Thus, this kind of study is not to prefer in the HBV-model.

The validation period in this study showed high values on the RAD after almost every calibration. However, it was difficult to determine if the calibration period was stable with the short validation period used. The validation period had an extremely high precipitation rate, 900 mm during one of the years. A normal annual precipitation rate is about 700 millimetres. This could be one reason for the high accumulated difference during the validation period.

6.1 Source of errors and problems during the calibration and validation period

In order to optimise the result, all the calibration criteria has to be used, i.e R^2, RAD and the visual inspection. The calibration procedure was difficult and time- consuming since many parameters had to be calibrated in the model. The judgement of a calibration (for example to decide when to stop a calibration) is also very subjective, since two different combinations of two or more parameters might yield the same results. Another problem with the calibrations is that one set of parameter values may carry out small volume errors and a poor explained variance compared to another set of parameters where the volume errors could be high as well as the explained variance. It was sometimes difficult to decide which combinations of parameters to use according to this. Due to these factors many compromises must be done during optimisation of a calibration.

The accuracy of the results was rather uncertain due to uncertainties in the parameters. To predict the accuracy of the calibrations a sensitivity analysis should be made for all parameter combinations. This type of analysis investigate how sensitive the calibration is to each parameter. A sensitive parameter have a major effect on the output data (Kirkby et al. 1992). The parameters in the soil moisture routine (FC, LP, BETA) that regulate the volume error are sensitive in the HBV-model. Those parameters are therefore important to calibrate. A sensitive analysis are very time consuming though and it was not possible to make in this thesis.

The calibration in this study was based on one discharge station only. This was not considered to be enough when calibrating Hörbyån's drainage basin, particularly not when the basin was partitioned into 5 and 10 sub basins. It was almost impossible to calibrate the model with different parameter settings in every sub basin since all sub basins must be calibrated at the same time. The parameter settings were instead the same for all sub basins except when considering travel time and soil types. A better coverage of discharge stations used for input data would be desirable . To use stations with measured discharge in the outlet of every sub basin or at least in more than one sub basin would be preferred but Heåkra is unfortunately the only discharge station in Hörbyån's drainage basin.

Furthermore, meteorological recording stations for temperature, wind speed and precipitation in the drainage area were a limitation when estimating the discharge. There are for example ten meteorological stations in Skåne with regular temperature measurements during a long period (>10 years), and most of the stations are located on the west coast. Kristanstad Everöd, outside the basin, was closest to Hörbyån. Temperature data from this point represented the temperature for the entire drainage area. Due to these limitations hydrological details are hard to discern in the HBV-model.

Another factor to consider is if there is discontinuity in the climate series. However, the SYMAP interpolation algorithm compensate for lack of data. Thus, the precipitation series were continuous in this study. Furthermore, the temperature and discharge series were continuous. These factor was therefore not a source of errors in this study.

The HBV-model does not consider the accuracy of the measured discharge data. The simulated discharge can never reproduce reality better than the measured discharge data. Thus a poor accuracy in the measured data yields poor results in the simulated discharge.

The construction of the model itself is a problem. As an example, the HBV-model does not consider the hydrological effect due to land cover changes. This is a deficiencie since land cover might change during a calibration and validation period.

Furthermore, a more mechanistic treatment of the role of vegetation would be desirable instead. The influences of vegetation would then be better described with fluxes of water and energy through the plant roots and leaves (Flerchinger 1996). In such a model, land cover could be implemented. Furthermore, vegetation types could be considered since the transpiration is computed separately from evaporation in these types of models.

A better improvement of the results was expected with an increase of the spatial resolution of a drainage basin. But since the parameters are obtained empirically they do not have any direct links to the characteristics of a drainage basin and this is probably one of the main reasons for such limited improvements.

6.2 Examples of poor correlation on a hydrograph curve

A hydrograph curve from one of the calibrations when Hörbyån's drainage basin was partitioned into 10 sub basins and three elevation zones is presented in Appendix 3. The entire calibration period from 1985-10-01 until 1991-12-31 is presented in this curve. The hydrograph curves from the recorded and computed discharge during this period agreed fairly well. The correlation (R^2) was 0,845. However, there were exceptions, periods where the hydrograph curves did not agree well. These periods are marked with a number in Appendix 3 and are discussed below.

1/ The snow melt periods in Hörbyån's drainage basin were difficult to calibrate due to high fluctuations. Peaks of the recorded discharge during February in 1986 and 1987 depended on spring floods due to ice and snow melt periods. The computed discharge was underestimated during these periods since it is complicated to obtain good estimates of the total amount of snow accumulation and to calculate how the snow melt rate occurs in the HBV-model.

2/ The simulated discharge tended to be overestimated during the autumn flow during the period October until December in 1987, 1989, 1990 and 1991. The water magazines of the model were probably filled too rapidly during these years. This is caused by the field capacity (FC) in the soil moisture routine that might be underestimated. An increase of either the field capacity parameter or the evapotranspiration parameter in the calibration could solve this problem. The total volume error would increase further if for example the field capacity increased. This is not desirable though and a compromise was instead used in the calibration.

3/ The recorded discharge fluctuates rapidly during the summer in 1987. It was a summer with a long precipitation period and high evapotranspiration rates. It was difficult for the computed discharge to bring out these fluctuations. Instead the curve falls as an average discharge value for the whole period. The total volume error during this period therefore neither increases nor decreases but the explained variance (R^2) is poor during this period. The reason for a poor correlation could be that the lower reservoirs in the HBV-model are filled due to a long precipitation period. Thus, much of the drainage comes from more superficial channels with fast recession instead. The parameter steering the fast recession is then underestimated for these conditions.

4/ Another exception when the hydrograph curves did not agree was during 1991. The computed discharge tended to be underestimated several times during this year. Peaks of the computed discharge were sometimes half the of the peaks of the recorded discharge. This lead to an increase of the total volume error and it might be an evidence of a too short calibration period.

6.3 Scenarios- a practical application

Human influence can be detected in the hydrological response. Changes in land cover, for example influence of surface runoff and ground-water storage, can be detected. The water balance, the travel time for run off and also the water quality are all affected due to land cover changes (Bergström 1993). Hydrological models can be applied for analysis of these hydrological impacts due to human influence. However, this analysis is not possible to perform in the HBV-model since all parameter values are obtained empirically in the model. A more mechanistic modelling approach would be needed to carry out this kind of scenario analysis. However, since the HBV-model is used, a short discussion is made instead to describe the scenarios in Hörbyån's drainage basin due to land cover changes.

Assuming that 15 % of the forest in Hörbyån's drainage basin will be removed and replaced by fields and urban areas in the next 10 years. This will affect Hörbyån through an increase of the discharge. This depends on a decrease of evapotranspiration and interception losses. A more intense snow melt will also occur. These effects increase the soil moisture and run off in a drainage basin particularly during summers and autumns. The hydrological response will also become quicker in the drainage basin after deforestation.

Assuming that 15 % of the open areas is planted with forest during the next 10 years. This will increase the transpiration rates and interception in the drainage basin. The runoff will decrease but since forest growth is very limited these processes are much slower than for deforestation.

7. Conclusions

The general conclusions can be summarised as follows

- To use an increased spatial resolution of physical and meteorological characteristics in Hörbyån's drainage basin was to prefer in this study. The HBV-model resulted in better R^2-values during the calibration and validation periods when the drainage basin was partitioned into five or ten sub basins. R^2 increased from 0.80- 0,81 (Hörbyån's drainage basin as a single basin) to 0,84 (Hörbyån's drainage basin partitioned into 5 or 10 sub basins) during the calibrations. However, it was time-consuming to prepare and to run the HBV-model when increasing the spatial variability of the drainage basin.

- The calibration results were about the same when using 10 sub basins instead of 5 sub basins in the HBV-model. Since many parameters must be calibrated and all parameters within a sub basin interact, it was complicated and time consuming to evaluate the results of these calibrations. The uncertainties were also substantial, particularly when using 10 sub basins.

- The temperature, precipitation and evapotranspiration dependence due to the altitude are low in Hörbyån's drainage basin since the elevation range is modest. The results were therefore only slightly improved when three elevation zones were included in the calibrations.

- The results improved somewhat when physical interpretations on the soil types were considered in the calibrations. Many parameters had to be calibrated in this investigation and since all parameters in a sub basin interact in the HBV-model one should interpret such results with caution.

Acknowledgement

My supervisor Lennart Olsson is acknowledged for introducing me and supporting me through this Master thesis. I would also like to thank Maud Nilsson at SMHI for support of the HBV model and Maj-Lena Linderson at the department of Physical Geography, Lund university, who provided some of the meteorological data used in this project. Finally, thank you Jonas for being patient and for great support.

8. References

1. Abbott B.M. et al.,1996. *Distributed hydrological modelling*, Water Science and Technology Library, Netherlands.
2. Andeberg L,1994. Kort introduktion till hydrologi, kompendium, KFS i Lund AB.
3. Andersson L., 1989. *Ecohydrological Flow Analysis of a Swedish Landscape in a 100 Year Perspective*, Linköping
4. Bengtsson L., 1997. Hydrologi- teori och processer, KFS i Lund AB.
5. Bergström S., *Sveriges hydrologi - grundläggande hydrologiska förhållanden*, SMHI, Maj 1993.
6. Bergström S., *The HBV Model- its structure and applications*, SMHI NO4, April 1992.
7. Bergström S.1990, *Parametervärden för HBV-modellen i Sverige*, SMHI nr 28.
8. Burrough P.A.,1986. *Principles of Geographical Information Systems for Land Resources Assessment*. Butler & Tanner, Great Britain..
9. Donald R.J., 1995. *A land cover -based snow cover representation for distributed hydrologic models, Water resources research*, VOL. 31, NO. 4 pp 995-1009.
10. Ekologgruppen, 1995. *Vattenvårdande åtgärder för Hörbyån*, Miljö- och Hälsoskyddsnämnden i Hörby kommun.
11. Flerchinger G. N., 1996. Modeling evapotrnspiratioin and surface energy budgets across a watershed, Water Resources Research, VOL. 32, NO.8 2539-2548
12. Grip H., Rohde A., 1988. *Vattnets väg från regn till bäck*, Lagerblads tryckeri AB, Karlshamn
13. IHMS Integrated hydrological modelling system, manual Version 4.0, SMHI.
14. Kirkby M.J. et al.,1993. *Computer simulation in physical geography*, second edition, John Wiley & Sons.
15. Knutsson G., Morfeldt C-O., 1993. *Grundvatten- teori och tillämpning*, Svensk trycktjänst AB
16. Lillesand, T.M. and Kiefer, R.W., 1994. *Remote Sensing and image interpretation*, Third Edition, John Wiley & Sons, Inc
17. Lindström G et al., *HBV-96- En areellt fördelad modell för vattenkrafthydrologin*, SMHI Nr 12, April 1996.
18. Ministry of Agriculture, Fisheries and Food (MAFF), 1967. Potential transpiration, Tech Bull. 16., HMSO.
19. PCI, 1994. *Using PCI Software*, Version 5.3, EASI/PACE, Richmond Hill, PCI Inc.
20. Pilesjö P., 1992. *GIS and Remote Sensing for Soil Erosion Studies in Semi-arid Environments, Estimation of Soil Erosion Parameters at Different Scales*, Wallin & Dalholm Boktr. AB Lund.
21. Quinn M.C.,1992. *Encyclopedia of environmental science and engineering*, Third edition
22. Refsgaard et al. 1996. Operational validation and intercomparison of different types of hydrological models, Water resources research, VOL. 32, NO.7 p2189-2202
23. Richards, J.A., 1995. *Remote Sensing Digital Image Analysis - An introduction*, second edition, Springer-Verlag Berlin Heidelberg.
24. Sellers P.J., 1997. Modeling the exchanges of Energy, Water, and Carbon Between Continents and the Atmosphere, Science VOL 257, 24 January 1997.
25. Shaw E.M., 1988. *Hydrology in Practice*, second edition. Chapman and Hall, London.
26. Shepard D.S., 1984. *Spatial Statistics and models*. VOLUME 40 Reidel Publishing company Holland
27. Skinner B.J. et al.,1987. Physical Geology, John Wiley & Sons, Inc .

28. Straggler, A.N.,1957. *Quantitative analysis of watershed geomorphology.*; EOM Trans. AGU 38, 913-92
29. Ward A.D., Elliot W. J.,1995. *Environmental Hydrology*, CRC Press United States of America.

Appendix1.

Process	Equation	Terms
Penman's equation (1948) (equation 1) Requirements for input data: daily values of radiation, temperature, wind speed and actual vapour pressure	$PE = \frac{(\Delta / \gamma) * H_T + E_{at}}{(\Delta / \gamma) + 1}$	PE = potential evapotranspiration [mm/day] γ =Psychrometric constant (mbar*°C^{-1})^1 Δ= represent the slope of the curve of saturated vapour pressure plotted against temperature.^{1} H_T = the available heat E_{at}= added wind energy [mm/day]
	$H_T = R_{in}(1 - \alpha) - R_{out}$ $R_{in}(1 - \alpha) = R_a \underset{1}{(0.18 + 0.55 \frac{n}{N})}$ 1: Clarity of the sky $R_{out} = 0.95 \underset{1}{\sigma T^4} \underset{2}{(0.56 - 0.092 \sqrt{e})} \underset{3}{(0.10 + 0.90 \frac{n}{N})}$ 1: black body radiation 2: humidity of the air 3: cloudiness	R_{in} = incoming radiation [mm/day] α = albedo, reflection (grass 0,25, forest 0,18) R_{out} = outgoing radiation [mm/day] R_a= Angots number [mm/day] ^{1} n = daylight hours [h] N = Length of day [h] ^{1} n/N ratio of maximum possible sunshine duration. 0.95 vegetation does not work as perfect body σ = Stefan Boltzman's constant [W/m^2* K^4] T = temperature [K] σ T^4 = black body radiation [mm/day] ^{1}
	$E_{at} = 0.35(e_s - e)(1 + 0.537u)$	e_s = saturated vapour pressure [mm Hg] table values e = actual vapour pressure [mm Hg] 1= roughness in wind speed u = wind speed [m/s] **Source: Shaw 1988, Andersson 1989, Andeberg 1994** ^{1} Table values from : Ministry of agriculture, Fisheries and Food (MAFF 1967).
Thornthwaite's equation (1957) (equation 2) Requirements for input data: mean temperature, possible daylight hours	$PE_m = \frac{4}{3} N (\frac{10 T_m}{I})^a$	PE_m = monthly potential evapotranspiration [mm/month] N = possible daylight hours (h)^1 T_m = mean monthly temperature (° C) I = heat index $I = \sum (\frac{Tm}{5})^{\frac{3}{2}}$ for m = 1,2,...12. a = $6.75*10^{-7}*I^3 - 7.71*10^5*I^2 + 1.792*10^{-2}*I + 0.49239$ Source: Shaw 1988, Ward et al. 1995

Appendix2.

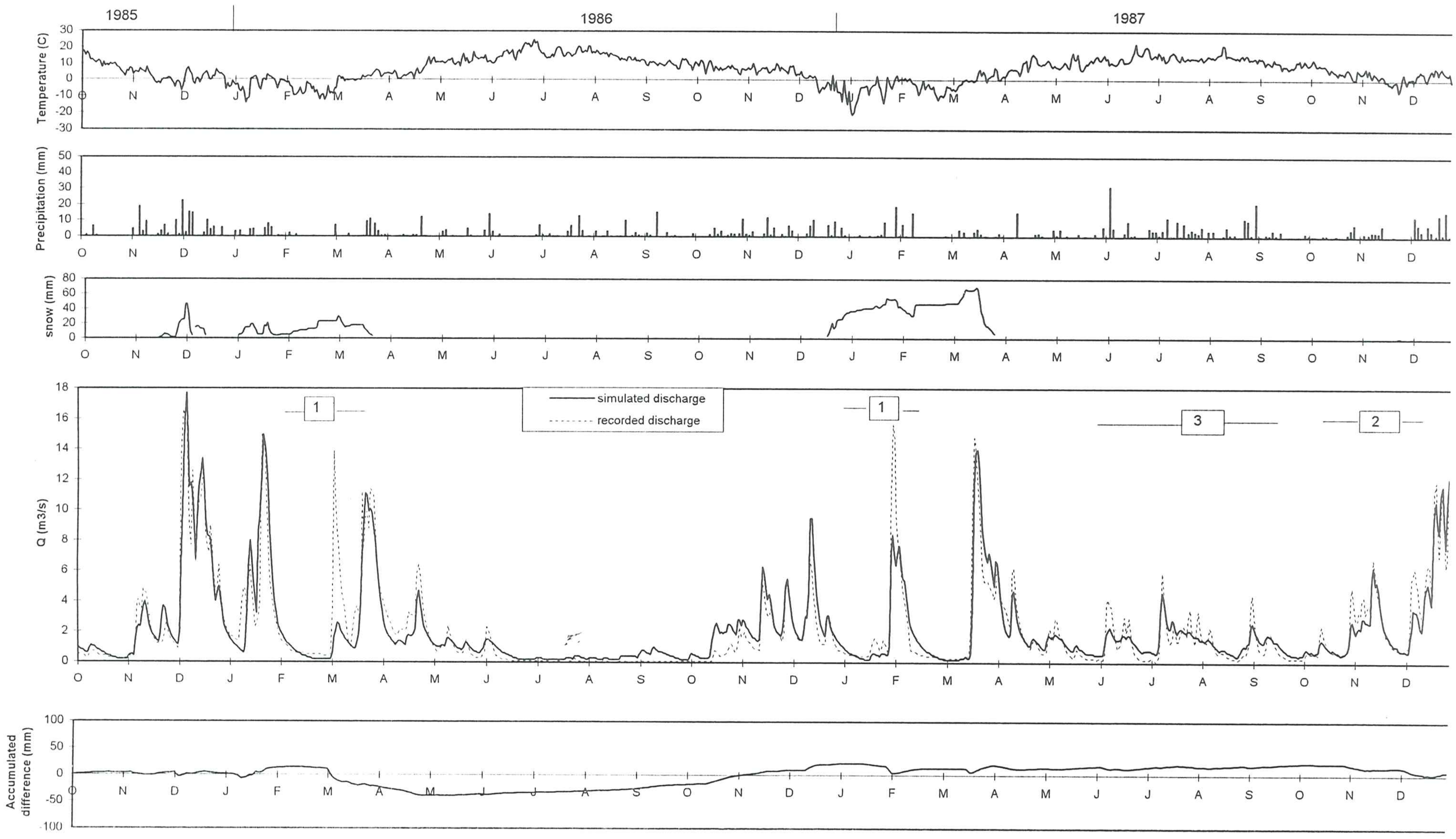
Area of elevation zones and vegetation zones in 5 sub basins

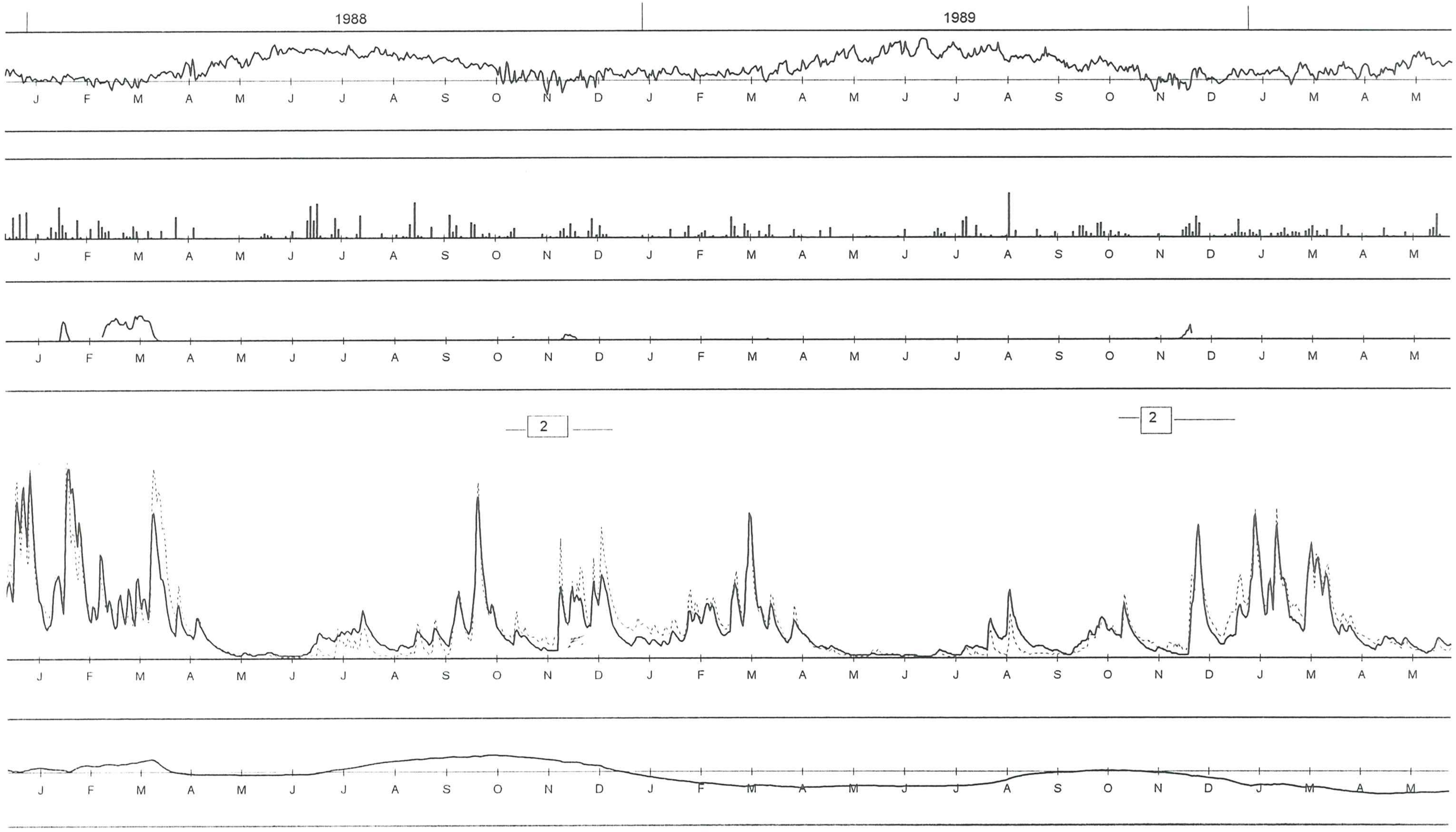
Sub basin	Elevation zone (m)	Area (%)	Forest (%)	Open land (%)
1	51-100	0	0	0
	101-150	45	29	16
	151-200	55	47	8
		100	76	24
2	51-100	-	-	-
	101-150	13	2	11
	151-200	87	52	35
		100	54	46
3	51-100	-	-	-
	101-150	29	18	11
	151-200	71	54	17
		100	72	28
4	51-100	37	9	28
	101-150	62	18	44
	151-200	1	-	1
		100	27	73
5	51-100	1	1	0
	101-150	99	22	77
	151-200	0	-	-
		100	23	77

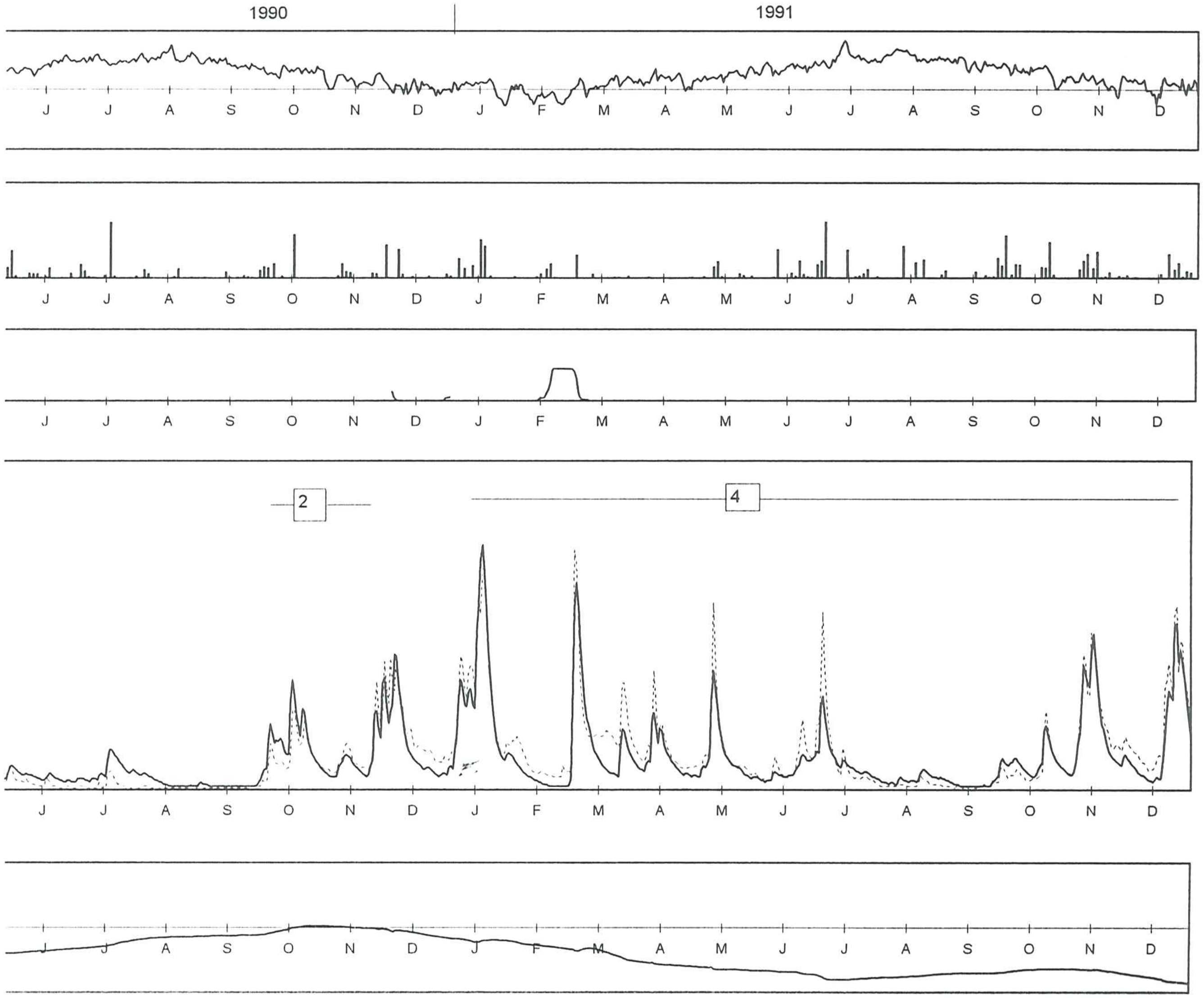
Area of elevation zones and vegetation zones in 10 sub basins

Sub basin	Elevation zone (m)	Area (%)	Forest (%)	Open land (%)
1	51-100	-	-	-
	101-150	17	8	9
	151-200	83	70	13
		100	78	22
2	51-100	1	1	-
	101-150	72	48	24
	151-200	27	24	3
		100	73	27
3	51-100	-	-	-
	101-150	23	15	8
	151-200	77	64	13
		100	79	21
4	51-100	51	9	42
	101-150	49	18	31
	151-200	-	-	-
		100	27	73
5	51-100	-	-	-
	101-150	13	3	10
	151-200	87	54	33
		100	57	43
6	51-100	-	-	-
	101-150	40	23	17
	151-200	60	34	26
		100	57	43
7	51-100	17	7	10
	101-150	80	19	61
	151-200	3	-	3
		100	26	74
8	51-100	2	1	1
	101-150	97	21	76
	151-200	1	-	1
		100	22	78
9	51-100	-	-	-
	101-150	100	23	77
	151-200	-	-	-
		100	23	77
10	51-100	-	-	-
	101-150	13	2	11
	151-200	87	48	39
		100	50	50

Hydrograph curves for Hörbyån's drainage basin when the drainage basin is partitioned into 10 sub basins (figure 4.3 D).




1988
1989
J F M A M J J A S O N D J F M A M J J A S O N D J M A M
J F M A M J J A S O N D J F M A M J J A S O N D J M A M
J F M A M J J A S O N D J F M A M J J A S O N D J M A M
2
2
J F M A M J J A S O N D J F M A M J J A S O N D J M A M
J F M A M J J A S O N D J F M A M J J A S O N D J M A M



1990
1991
J J A S O N D J F M A M J J A S O N D
J J A S O N D J F M A M J J A S O N D
J J A S O N D J F M A M J J A S O N D
2
4
J J A S O N D J F M A M J J A S O N D
J J A S O N D J F M A M J J A S O N D

Lunds Universitets Naturgeografiska institution. Seminarieuppsatser. Uppsatserna finns tillgängliga på Naturgeografiska institutionens bibliotek, Sölvegatan 13, 223 62 LUND.

The reports are available at the Geo-Library, Department of Physical Geography, University of Lund, Sölvegatan 13, S-223 62 Lund, Sweden.

1. Pilesjö, P. (1985): Metoder för morfometrisk analys av kustområden.
2. Ahlström, K. & Bergman, A. (1986): Kartering av erosionskänsliga områden i Ringsjöbygden.
3. Huseid, A. (1986): Stormfällning och dess orsakssamband, Söderåsen, Skåne.
4. Sandstedt, P. & Wällstedt, B. (1986): Krankesjön under ytan - en naturgeografisk beskrivning.
5. Johansson, K. (1986): En lokalklimatisk temperaturstudie på Kungsmarken, öster om Lund.
6. Estgren, C. (1987): Isälvsstråket Djurfälla-Flädermo, norr om Motala.
7. Lindgren, E. & Runnström, M. (1987): En objektiv metod för att bestämma läplanteringars läverkan.
8. Hansson, R. (1987): Studie av frekvensstyrd filtringsmetod för att segmentera satellitbilder, med försök på Landsat TM-data över ett skogsområde i S. Norrland.
9. Matthiesen, N. & Snäll, M. (1988): Temperatur och himmelsexponering i gator: Resultat av mätningar i Malmö.

10A. Nilsson, S. (1988): Veberöd. En beskrivning av samhällets och bygdens utbyggnad och utveckling från början av 1800-talet till vår tid.

10B. Nillson, G., 1988: Isförhållande i södra Öresund.

11. Tunving, E. (1989): Översvämning i Murciaprovinsen, sydöstra Spanien, november 1987.
12. Glave, S. (1989): Termiska studier i Malmö med värmebilder och konventionell mätutrustning.
13. Mjölbo, Y. (1989): Landskapsförändringen - hur skall den övervakas?
14. Finnander, M-L. (1989): Vädrets betydelse för snöavsmältningen i Tarfaladalen.
15. Ardö, J. (1989): Samband mellan Landsat TM-data och skogliga beståndsdata på avdelningsnivå.
16. Mikaelsson, E. (1989): Byskeälvens dalgång inom Västerbottens län. Geomorfologisk karta, beskrivning och naturvärdesbedömning.
17. Nhilen, C. (1990): Bilavgaser i gatumiljö och deras beroende av vädret. Litteraturstudier och mätning med DOAS vid motortrafikled i Umeå.
18. Brasjö, C. (1990): Geometrisk korrektion av NOAA AVHRR-data.
19. Erlandsson, R. (1991): Vägbanetemperaturer i Lund.
20. Arheimer, B. (1991): Näringsläckage från åkermark inom Bråans dräneringsområde. Lokalisering och åtgärdsförslag.
21. Andersson, G. (1991): En studie av transversalmoräner i västra Småland.

22A. Skillius, Å., (1991): Water havesting in Bakul, Senegal.

22B. Persson, P. (1991): Satellitdata för övervakning av höstsådda rapsfält i Skåne.

23. Michelson, D. (1991): Land Use Mapping of theThat Luang - Salakham Wetland, Lao PDR, Using Landsat TM-Data.
24. Malmberg, U. (1991): En jämförelse mellan SPOT- och Landsatdata för vegetationsklassning i Småland.
25. Mossberg, M. & Pettersson, G. (1991): A Study of Infiltration Capacity in a Semiarid Environment, Mberengwa District, Zimbabwe.
26. Theander, T. (1992): Avfallsupplag i Malmöhus län. Dränering och miljöpåverkan.
27. Osaengius, S. (1992): Stranderosion vid Löderups strandbad.
28. Olsson, K. (1992): Sea Ice Dynamics in Time and Space. Based on upward looking sonar, satellite images and a time series of digital ice charts.
29. Larsson, K. (1993): Gully Erosion from Road Drainage in the Kenyan Highlands. A Study of Aerial Photo Interpreted Factors.
30. Richardson, C. (1993): Nischbildningsprocesser - en fältstudie vid Passglaciären, Kebnekaise.
31. Martinsson, L. (1994): Detection of Forest Change in Sumava Mountains. Czech

Republic Using Remotely Sensed Data.
32. Klintenberg, P. (1995): The Vegetation Distribution in the Kärkevagge Valley.
33. Hese, S. (1995): Forest Damage Assessment in the Black Triangle area using Landsat TM, MSS and Forest Inventory data.
34. Josefsson, T. och Mårtensson, I. (1995). A vegetation map and a Digital Elevation Model over the Kapp Linné area, Svalbard -with analyses of the vertical and horizontal distribution of the vegetation
35. Brogaard, S och Falkenström, H. (1995). Assessing salinization, sand encroachment and expanding urban areas in the Nile Valley using Landsat MSS data.
36. Krantz, M. (1996): GIS som hjälpmedel vid växtskyddsrådgivning.
37. Lindegård, P. (1996). VINTERKLIMAT OCH VÅRBAKSLAG. Lufttemperatur och kådflödessjuka hos gran i södra Sverige.
38. Bremborg, P. (1996). Desertification mapping of Horqin Sandy Land, Inner Mongolia, by means of remote sensing.
39. Hellberg, J. (1996). Förändringsstudie av jordbrukslandskapet på Söderslätt 1938-1985.
40. Achberger, C. (1996): Quality and representability of mobile measurements for local climatological research.
41. Olsson, M. (1996): Extrema lufttryck i Europa och Skandinavien 1881-1995
42. Sundberg, D. (1997): En GIS-tillämpad studie av vattenerosion i sydsvensk jordbruksmark.
43. Liljeberg, M. (1997): Klassning och statistisk separabilitetsanalys av marktäckningsklasser i Halland, analys av multivariata data Landsat TM och ERS-1 SAR.
44. Roos, E. (1997): Temperature Variations and Landscape Heterogeneity in two Swedish Agricultural Areas. An application of mobile measurements.
45. Arvidsson, P. (1997): Regional fördelning av skogsskador i förhållande till mängd SO_2 under vegetationsperioden i norra Tjeckien.
46. Akselsson, C. (1997): Kritisk belastning av aciditet för skogsmark i norra Tjeckien.
47. Carlsson, G. (1997): Turbulens och supraglacial meandring.
48. Jönsson, C. (1998): Multitemporala vegetationsstudier i nordöstra Kenya med AVHRR NDVI
49. Kolmert, S. (1998): Evaluation of a conceptual semi-distributed hydrological model – A case study of Hörbyån.