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Distributed Element Water Balance Model System

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4
2008

REPORT

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Norwegian Water Resources and Energy Directorate
2008

Report no. 4 - 2008

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Published by: Norwegian Water Resources and Energy Directorate

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Printed by: Norwegian Water Resources and Energy Directorate

Cover photo: View from Kongens utsikt. Photo by Stein Beldring

ISBN: 978-82-410-0670-8

Key words: Distributed hydrological model, water balance

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June 2008

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Preface

Precipitation-runoff models are used for applications which require simulation of the dynamic water balance of a selected area of the land surface, e.g. a watershed. They provide a capability to predict hydrological state variables and fluxes from atmospheric data, with the purpose of for example hydrological forecasts, hydrological impact simulations or management of water resources. Mathematical models simplify the physical processes and replace them by a set of equations, whose solutions are programmed as a computer code. The results of simulations with the mathematical model are interpreted in terms of the physical system. The structure of models vary in their level of complexity, however, the major mechanisms involved in conversion of precipitation to discharge at the catchment outlet are usually considered in one way or another. In order to be used as a tool for examining spatially distributed hydrological processes and their interactions, both vertical and lateral flow paths should be incorporated in a model. Models to be used for operationally applicable simulation systems often have a simpler structure than required by models used as research tools. In addition to describe the physical processes which govern storage and flow of water as subsurface and overland flow through a catchment, precipitation-runoff models must include the various hydrological and radiative processes at the land surface-atmosphere interface; interception storage, glacier mass balance, snow accumulation and snowmelt, soil evaporation and transpiration. The spatially distributed hydrological model described in this document is used for modelling the water balance and lateral transport of water in the land phase of the hydrological cycle. The model allows different algorithms to be used for hydrological process descriptions. The spatial distribution and shape of discrete landscape elements and the time steps of the model may be selected according to the problem to be solved. The requirements for running the model and the procedures for setting up the model definition files are described. The Distributed Element Water balance model system (DEW model system) is not a hydrological model *per se*, but a model interface that can be used to combine algorithms from different hydrological model structures.

Oslo, June 2008

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Symbols

file.dta	data file
file.asc	ascii/grid import/export format file

1 Introduction

The spatially distributed hydrological model described in this document is used for modelling the water balance and lateral transport of water in the land phase of the hydrological cycle. The model allows different algorithms to be used for hydrological process descriptions. The spatial distribution and shape of discrete landscape elements and the time steps of the model may be selected according to the problem to be solved. The requirements for running the model and the procedures for setting up the model definition files are described. The Distributed Element Water balance model system (DEW model system) is not a hydrological model *per se*, but a model interface that can be used to combine algorithms from different hydrological model structures. Currently, the HBV (Bergström, 1995; Lindström et al., 1997) and the KiWa (Beldring et al., 2000; Beldring, 2002) model structures are implemented in the DEW model. The mathematical and logical expressions used to describe the hydrological system are described, as well as the variables and parameters used for hydrological process simulations. Model parameters remain constant over time or vary in a manner which may be described using physical principles or empirical relationships. Parameters either represent physically measurable properties of a watershed, or are used to describe hydrological processes. A variable may represent: (i) the state of the different storages in the hydrological system as approximated by the forecasting model; (ii) the input signal which drives the model; or (iii) the output from the model. Variables vary with time.

Precipitation-runoff models are used for applications which require simulation of the dynamic water balance of a selected area of the land surface, e.g. a watershed. They provide a capability to predict hydrological state variables and fluxes from atmospheric data, with the purpose of for example hydrological forecasts, hydrological impact simulations or management of water resources (DeVries and Hromadka, 1993). Mathematical models simplify the physical processes and replace them by a set of equations, whose solutions are programmed as a computer code. The results of simulations with the mathematical model are interpreted in terms of the physical system (Freeze, 1978). The structure of the models vary in their level of complexity, however, the major mechanisms involved in conversion of precipitation to discharge at the catchment outlet are usually considered in one way or another. In order to be used as a tool for examining spatially distributed hydrological processes and their interactions, both vertical and lateral flow paths should be incorporated in a model. Models to be used for operationally applicable simulation systems often have a simpler structure than required by models used as research tools (Bronstert, 1999). In addition to describe the physical processes which govern storage and flow of water as subsurface and overland flow through a catchment, precipitation-runoff models must include the various hydrological and radiative processes at the land surface-atmosphere interface; interception storage, glacier mass balance, snow accumulation and snowmelt, soil evaporation and transpiration (DeVries and Hromadka, 1993).

In spite of the variability of catchment properties, storm hydrographs are relatively well-behaved, implying a smoothing effect at the catchment scale which overrides the effect at smaller scales (Grayson et al., 1992b). Similar conclusions can be drawn from the temporal variablity of conservative tracers (Bonell, 1993). In small catchments and on hillslopes the effect of this integration will be less pronounced (Grayson et al., 1995). If the purpose of hydrological modeling is to simulate runoff and evapotranspiration from catchments, it may not be necessary to describe exact patterns of catchment properties and hydrological responses at small scale, however, the distribution of characteristics within the catchments may still be important (Wood et al., 1988, 1990; Seyfried and Wilcox, 1995).

For consideration of runoff generation in small catchments (less than 10 km^2) the channel phase may usually be neglected. Small catchments are dominated by the land phase, and are highly sensitive to intense rainfalls with short duration (Singh, 1995). Kirkby (1988) suggested that satisfactory hydrological models of small catchments could be developed by considering vertical unsaturated flow and downslope saturated subsurface flow and saturation overland flow on two-dimensional hillslope strips which interact negligibly with neighbouring strips. The most general way to develop a model of the land phase of runoff generation is to use the complete equations of saturated and unsaturated subsurface flow and overland flow (Freeze, 1978). However, most models apply an approach based on a simplified representation of the appropriate mechanisms (Dingman, 1994).

If the time of concentration of the catchment is influenced by the transport of the flood wave through the channel system, hydrological models must include procedures for routing of flows down the river channel including lakes and reservoirs. This is the situation for large river systems such as the River Glomma and its major tributaries. River routing models may be classified as either hydraulic (distributed) or hydrological (lumped). In hydraulic routing models the flows and water levels are computed as a function of time simultaneously at several cross sections along the watercourse using the hydrodynamic equations of unsteady flow (the Saint Venant equations) or their dynamic wave or kinematic wave approximations. Hydrological routing is based on continuity considerations for storage of water in reservoirs or river reaches and require less data than hydraulic routing. (Lettenmaier and Wood, 1993).

The majority of hydrological simulation models in use are conceptual models based on a simplified representation of the real system. These models approximate catchment processes by a series of linked storages, which are usually modeled using linear reservoirs (Shaw, 1994). Although conceptual models do not describe in detail the mechanisms by which runoff is generated during rain or snowmelt events, these models are in frequent use due to their low data demand, and the fact that they have proved quite successful when used for operational forecasts of runoff (Bergström, 1991). The HBV model (Bergström, 1995; Lindström et al., 1997) has been used in Scandinavia and other regions of the world for several decades. It is a semi-distributed conceptual precipitation-runoff model which uses subcatchments as the primary hydrological units, and within these an area-elevation distribution and a crude classification of land use (forest, open, lakes) are applied. The model is run with daily time steps, using rainfall data and air temperature and monthly estimates of potential evaporation as input. It consists of three main components; (i) snow accumulation and snowmelt; (ii) soil moisture and evapotranspiration accounting; and (iii) groundwater reservoir, runoff response and river routing. Groundwater recharge depends on water content in the the soil moisture store. The model has a number of free parameters, whose values are determined by calibration. There are also parameters describing the characteristics of the catchment and its climate. The model exists in several versions.

Building a physically based precipitation-runoff model of a hillslope or small catchment involves specification of the governing laws of mathematical physics, the geometry of the system, sources and sinks and initial and boundary conditions. For a wide range of surface and subsurface flow processes the governing equations are law of conservation of mass (continuity equation) and a flux law (Singh and Prasana, 1999). Overland flow is modeled as broad sheet flow using the Saint-Venant equations or their kinematic wave approximations (Moore and Foster, 1990). However, natural surfaces have several small and large irregularities causing water to occur as anastomosing flow with a great variety of flow depths (Kirkby, 1988). Descriptions of overland flow assuming sheet flow over smooth surfaces are therefore at best viewed as parametric prediction models (Freeze, 1974). Both saturated and unsaturated flow within porous media are described as potential flow using Darcy's law and the continuity equation, which combine to the Richards equation. However, Darcy's law is not valid when boundary layer effects and viscous resistance retard the flow, e.g. in macropore systems (Dingman, 1984, 1994). Since water in macropores moves only under the influence of gravity, the flow can be approximated by kinematic wave theory in this case (Germann et al., 1986). Concerning infiltration and percolation through an unsaturated soil matrix, Philip's or Green and Ampt's approaches may suffice, although the underlying assumptions may be violated if large structural pores are present (Youngs, 1991). As undisturbed forest soils in general have a surface layer which can accept all rainfall or snowmelt, development of ponded infiltration theory has been ignored in most forest hydrology studies (Bonell, 1993).

The KiWa model structure (Beldring et al., 2000; Beldring 2002) applies kinematic wave approximations to saturated subsurface and overland flows for describing the spatial distribution of soil moisture and groundwater conditions and their significance for runoff and evapotranspiration fluxes at the hillslope scale. These physically based descriptions of saturated subsurface flow and saturation overland flow have been included in a precipitation-runoff model structure which has proved able to simulate the interactions between snow storage, subsurface moisture conditions, runoff and evapotranspiration fluxes in catchments in humid, temperate environments. The most general way to model a catchment's response to rainfall or snowmelt events is to use the complete equations of saturated and unsaturated subsurface flows, overland flow and open channel flow. This involves specification of the governing laws of mathematical physics, the geometry of the system, sources and sinks and initial and boundary conditions. In general, for any water resources system the governing equations are the law of conservation of mass and a flux law (Singh, 1996). In addition, a description of the various hydrological and radiative processes at the land surface-atmosphere interface is necessary in order to include evapotranspiration fluexes and snow storage in the model. Kirkby (1988) suggested that satisfactory event models of small catchments could be developed by considering vertical unsaturated flow and downslope saturated subsurface flow and saturation overland flow on a two-dimensional hillslope strip. The KiWa model is based on these simplifications; flow processes in hillslopes with a shallow layer of permeable deposits overlying a relatively impermeable bedrock were described by kinematic wave approximations. Kinematic wave theory is based on a one-dimensional approximation to the flow problem: whenever a functional relation exists at each point in a medium between the flux and the concentration of a continously distributed material, the wave motion follows from the equation of continuity (Whitham, 1974). Propagation of material in the medium is described as a a distinctive type of wave motion, exclusive of the influence of mass and force, i.e. without acceleration effects due to the characteristics of the flow itself (Dingman, 1994). The friction slope equals the slope of the impermeable bed (Moore and Foster, 1990). The governing equations of saturated subsurface flow and saturation overland flow were solved using the method of characteristics (Singh, 1996). The displacement of points on the groundwater table or the overland flow profile due to spatially uniform water input are described along characteristic curves in the three-dimensional space of length coordinate, time and saturated depth. The KiWa model structure combines the kinematic wave approximations to saturated subsurface flow and saturation overland flow with descriptions of snow storage, interception storage, soil moisture and evapotranspiration processes. Runoff from the hillslope is given as the sum of saturated subsurface flow and saturation overland flow. Assuming that moisture and runoff conditions at the hillslope scale are representative for conditions at larger scale and that flow changes are transported rapidly through the stream channel network to the outlet of a computational element, the precipitation-runoff model converts calculated water balance elements from hillslope to area values for the computational elements. The model assumes that water infiltrating through the soil surface reaches the groundwater table as soon as the soil moisture deficit in the root zone is replenished, saturated subsurface flow occurs as potential flow parallel to the sloping bed, while saturation overland flow develops due to water input from precipitation or snowmelt when the entire soil profile is saturated. Preferential and return flows are not considered, neither is downslope unsaturated flow.

Advances in computer technology and improved observational capabilities providing spatially distributed data have led to the development of physically based, distributed models which describe state variables and flow of water in three dimensions using realistic, process-based equations (Grayson et al., 1992a, 1992b; Sorooshian, 1997). Examples of these models are the Institute of Hydrology Distributed Model (IHDM) (Calver and Wood, 1995), the Système Hydrologique Européen (SHE) model (Abbot et al., 1985a, 1985b) and the ECOMAG model (Motovilov et al., 1999). Theoretically, the main advantage of physically based, distributed models is that they represent accurately the heterogeneities in space and time of various hydrological processes. However, this comes at the expense of a large number of parameters, most of which are related to a better representation of the physics involved (Sorooshian, 1997), and a high demand for data describing spatially distributed catchment characteristics and climatic input (Seyfried and Wilcox, 1995). A critique expressed against these models concerns the description of integrated areal response at the grid scale using effective parameters and equations derived from an understandig of physics at the point scale. As there is no satisfactory theory for aggregating the behaviour of hydrological processes, state variables or parameters from the point scale to the size of the selected grid elements, models which are claimed to be distributed, physically based are in reality lumped conceptual models, just with many more parameters (Blöschl and Sivapalan, 1995). Distributed models which operate on computational elements much larger than the spatial scale of the processes dominating runoff production cannot be expected to produce accurate predictions of discharge in heterogeneous terrain. In order to provide accurate descriptions of the mechanisms controlling event response within small catchments using physically based, distributed models, the size of computational elements must be small enough to represent the relevant hydrological processes and their interactions (Bronstert, 1999).

Topographical gradients control the spatial extent of runoff producing areas in the landscape through lateral fluxes and spatial redistribution of water. This has led to the development of physically based hydrological models using digital elevation models for providing an accurate representation of topographical characteristics which are fundamental for flow processes (Moore et al., 1991; Grayson et al., 1992a). These models describe saturated subsurface flow, saturation overland flow and infiltration excess overland flow, and can also account for differences in soil characteristics or vegetation (O'Loughlin, 1986). Grayson et al. (1992b) argued that topographically driven, spatially distributed process models hold the greatest potential for application to various forest land management problems related to small or medium size (less than 10 km2) headwater catchments.

2 Spatial discretisation

2.1 Model domain

If the model is to be run on a regular grid, the programs *stationMask* and *preDew* may be used for defining the model domain and the characteristics of the landscape elements used as computational elements in the model. This requires that data defining watercourses, catchments and land surface characteristics are available as ascii/grid import/export format files used by most geographical information systems (GIS). These two programs generate a set of files which are necessary for running program *dew* with the spatially distributed DEW model.

If the model is to be run with irregularly shaped computational elements, the files defining the model domain and the characteristics of landscape elements must be produced with a text editor.

2.2 Meteorological input data

If the model is run on a regular grid, meteorological input data may also be defined on a regular grid. In this case the meteorological data are read from binary files, one file per time step for precipitation and temperature, respectively. Regardless of the spatial discretisation of the model domain, time series of meteorological input data from station points may be used for driving the model. In this case, the meteorological data are read from a text file.

2.3 Hierarchy of landscape and watercourse elements

The model can describe flow of water through the hierarchy of landscape elements, subcatchments and the river/lake network in two ways. The implicit approach assumes that runoff is sendt from all landscape elements within a subcatchment directly to the outlet for every timestep. Water is then routed through a simplified river/lake network where each subcatchment corresponds to one branch in the watercourse network.

The second approach describes flow of water between landscape elements and within the river/lake network explicitly. This requires that flow directions within the hierarchy of landscape elements, between landscape elements and watercourse elements, and within the hierarchy of watercourse elements are supplied to the model.

The requirements for using the simple, or implicit, approach are presented first. Chapter 5 describes additional requirements for using an explicit hierarchy of landscape and watercourse elements.

3 Program *stationMask*

Program *stationMask* defines the model domain.

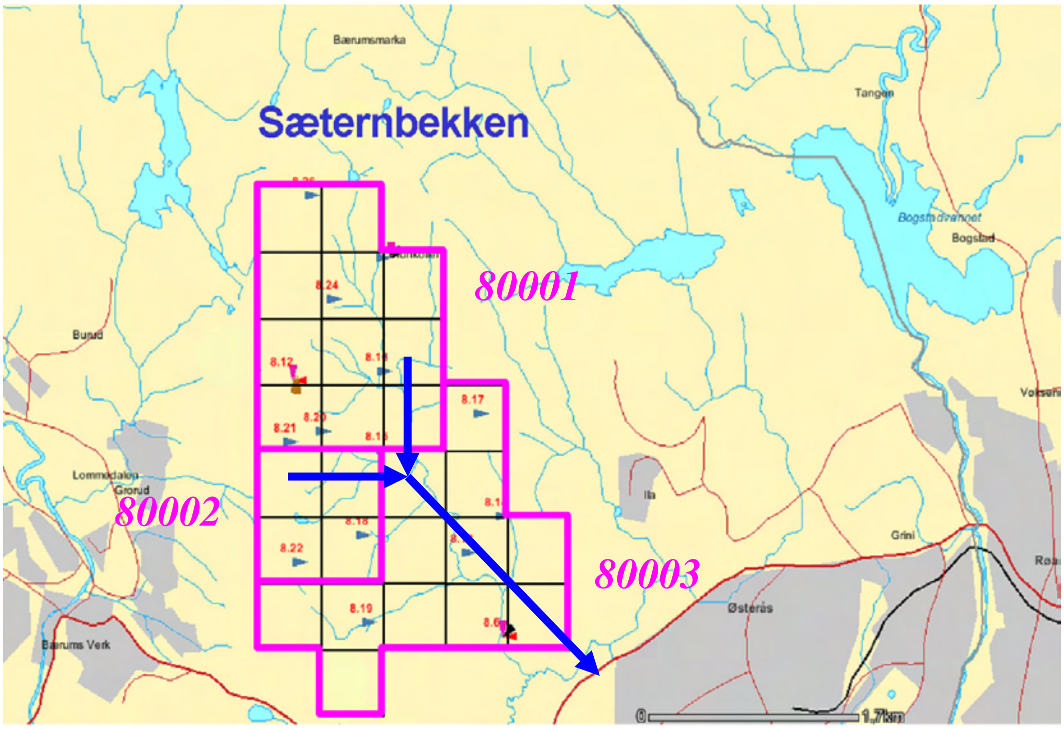
3.1 Input

Program *stationMask* requires two input files.

- Watercourse/subcatchment hierarchy description
- Landscape elements located within each watercourse/subcatchment

3.2 Watercourse/subcatchment hierarchy description

The discretisation of watercourses/subcatchments use a unique number for identifying the different elements. In the example below, these numbers are 80001, 80002 and 80003. The watercourses/subcatchments 80001 and 80002 discharge into watercourse/subcatchment 80003. The outlet from the model domain is located in watercourse/subcatchment 80003. Several outlets are possible.



The watercourse/subcatchment hierarchy is defined using a file named *watercourse.dta* in this example:

```
# Number of watercourses: 3
0 :  80001    1.0
1 :  80002    1.0
2 :  80003    1.0
# Number of watercourse outlets: 1
2
# Hierarchy of watercourses
2 2 :  0 1
```

```
# Number of watercourses: <no. of watercourses/subcatchments>
<index> : <watercourse/subcatchment id.> <scale factor>
<index> : <watercourse/subcatchment id.> <scale factor>
...
# Number of watercourse outlets: <no. of outlets>
<index of outlet watercourse/subcatchment>
<index of outlet watercourse/subcatchment>
...
# Hierarchy of watercourses
<index of downstream>  <no. of upstreams> : <indices of upstreams>
<index of downstream>  <no. of upstreams> : <indices of upstreams>
...
```

#Number of watercourses

Number of watercourses/subcatchments.

The watercourses/subcatchments indices start from 0. For each watercourse/subcatchment:

- Watercourse/subcatchment index
- Watercourse/subcatchment identification
- Scale factor for modelled watercourse/subcatchment discharge

#Number of watercourse outlets

The watercourse/subcatchment index of each outlet must be provided.

#Hierarchy of watercourses/subcatchments

- Watercourse/subcatchment index
- Number of upstream watercourses/subcatchments
- Upstream watercourses/subcatchments indices

3.3 Landscape elements within each watercourse/subcatchment

The landscape elements within the regular grid are identified by an ascii/grid import/export format file. This file has grid cell identifiers that connect landscape elements to watercourse/subcatchments identifiers as shown in the file named *watercourse_id.*asc in the example below. Grid cells with nodata value (-9999) will not be included in the model domain. The file *watercourse_id.asc* may include grid cells with watercourse/subcatchments identifiers which are not included in the model domain.

```
ncols         5
nrows         8
xllcorner     0
yllcorner     0
cellsize      500
NODATA_value  -9999
80001  80001  -9999  -9999  -9999
80001  80001  80001  -9999  -9999
80001  80001  80001  -9999  -9999
80001  80001  80001  80003  -9999
80002  80002  80003  80003  -9999
80002  80002  80003  80003  80003
80003  80003  80003  80003  80003
-9999  80003  -9999  -9999  -9999
```

3.4 Output

Program *stationMask* produces one output file in ascii/grid import/export format with information about the model domain. The name of the output-file must be provided when running the model. In the example below this file is called *stations.asc*. Program *stationMask* writes the data in one column.

```
ncols         5
nrows         8                       ...
xllcorner     0                       80002
yllcorner     0                       80002
cellsize      500                     80003
NODATA_value  -9999                   80003
80001                                 -9999
80001                                 80002
-9999                                 80002
-9999                                 80003
-9999                                 80003
80001                                 80003
80001                                 80003
80001                                 80003
-9999                                 80003
-9999                                 80003
80001                                 80003
80001                                 -9999
80001                                 80003
-9999                                 -9999
-9999                                 -9999
80001                                 -9999
80001
80001
80003
-9999
...
```

3.5 Running ***stationMask***

When *stationMask* is run on a Linux system or using a Windows console interface it is possible to read the information necessary for running the program from a text file. In the example below, the text file is called *control_mask.txt*. The model is started from the command prompt with the command:

stationMask < *control_mask.txt*

If the executable file *stationMask* is not located in a directory in the search path of the computer session, the full or relative path to *stationMask* must be provided.

File *control_mask.txt* contains the information to be supplied to the user interface of program *stationMask*.

```
watershed.dta                 Watercourse/subcatchment hierarchy
watercourse_id.asc            Landscape elements
stations.asc                  Output file with model domain
```

4 Program *predew*

Program *predew* determines the characteristics of each landscape element based on ascii/grid import/export format files with information about land surface characteristics, e.g. elevation, topographical characteristics, land use, lakes, glaciers. The program also connects landscape elements to watercourse/subcatchment elements.

4.1 Input

Program *predew* requires 14 input-files.

- File with meteorological stations information
- Parameter file common for all land cover and soil/bedrock classes
- Output file from program *stationMask* with information about the model domain.
- Elevation of grid cells
- Slope length of grid cells
- Slope angle of grid cells
- Aspect of grid cells
- Percentage of grid cells areas covered by lakes
- Percentage of grid cells areas covered by forest
- Percentage of grid cells areas covered by bogs
- Percentage of grid cells areas covered by glaciers
- Potential tree line of grid cells
- Watercourse/subcatchment hierarchy description (used by program *stationMask*)
- Landscape elements located within each watercourse/subcatchment (used by program *stationMask*)

4.2 Meteorological stations information

Program *predew* determines the meteorological stations to be used for modelling precipitation and temperature in each grid cell. A file with information about the type and location of each meteorological station must be supplied. This file is called *met_stations.dta* in the example below.

```
Number of precipitation stations : 4
Number of temperature stations   : 4
P   5608       0.0        0.0  205.0        SAETERNBEKKEN
P   5608    2500.0        0.0  205.0        SAETERNBEKKEN
P   5608       0.0     4000.0  205.0        SAETERNBEKKEN
P   5608    2500.0     4000.0  205.0        SAETERNBEKKEN
T   5608       0.0        0.0  205.0        SAETERNBEKKEN
T   5608    2500.0        0.0  205.0        SAETERNBEKKEN
T   5608       0.0     4000.0  205.0        SAETERNBEKKEN
T   5608    2500.0     4000.0  205.0        SAETERNBEKKEN
```

```
Number of precipitation stations : <no. of precipitation stations>
Number of temperature stations   : <no. of temperature stations>
<station type>  <station id.>  <east coord.>  <north coord.>
         <elevation>  <station name>
<station type>  <station id.>  <east coord.>  <north coord.>
         <elevation>  <station name>
...
```

This file must be provided even in the case that meteorological data are to be read from binary grid files. In this case, the information is only to be considered as dummy information and the file *met_stations.dta* should contain the following data:

```
Number of precipitation stations : 1
Number of temperature stations   : 1
P   -9999  -9999  -9999  -9999
T   -9999  -9999  -9999  -9999
```

4.3 Parameter file common for all land cover and soil/bedrock classes

The file *dew_common_parameters.dta* in the example below provides parameter values and other characteristics common to all land cover and soil/bedrock classes which are necessary for running the model. Model parameters are defined in Chapter 7.

```
Number of seconds per time step    SECONDS_TIMESTEP    : 3600
Number of precipitation series     NUM_PREC_SERIES     : 1
Number of temperature series       NUM_TEMP_SERIES     : 1
Prec. grad. low  per 100 m         PREC_GRAD_LOW       : 1.05
Prec. grad. high per 100 m         PREC_GRAD_HIGH      : 1.0
Altitude for 50 % reduction        GRAD_CHANGE_ALT     : 0
Prec. correction for rain          PREC_CORR_RAIN      : 1.0
Additional prec. corr. for snow    PREC_CORR_SNOW      : 1.0
Temp. lapse rate dry time steps    LAPSE_DRY           : -.21
Temp. lapse rate wet time stes     LAPSE_WET           : -.21
Lake temperature memory (days)     DAY_TEMP_MEMORY     : 30.0
Lake evaporation constant          LAKE_EPOT_PAR       : 1.0E-4
Rating curve constant              KLAKE               : .0025
Rating curve saddle point          DELTA_LEVEL         : 0.0
Rating curve exponent              NLAKE               : 1.0
Initial soil moisture        INITIAL_SOIL_MOISTURE     : 0.1
Initial upper zone           INITIAL_UPPER_ZONE        : 0.0
Initial lower zone           INITIAL_LOWER_ZONE        : .05
Initial saturated fraction one  INTITIAL_SATURATED_ONE : 0.0
Initial saturated fraction two  INTITIAL_SATURATED_TWO : 0.2
Initial lake temperature     INITIAL_LAKE_TEMP         : 0.0
Initial lake level           INITIAL_LAKE_LEVEL        : 0.0
Initial snow storage         INITIAL_SNOW_STORAGE      : 0.0
Initial total reservoir      INITIAL_TOTAL_RESERVOIR   : 0.0
Day no. for zero snow storage      DAY_SNOW_ZERO       : 0
```

- Number of seconds per time step is the temporal resolution of model simulations
- Number of precipitation series and number of temperature series defines the number of for stations to be used for determination of meteorological input data for each grid cell. Program *predew* determines weights for inverse distance interpolation of meteorological data to each model grid cell using the nearest precipitation and temperature stations.
- Gradients for precipitation increase per 100 m elevation change above and below altitude `GRAD_CHANGE_ALT` must be supplied. A value of 1.0 means no change. `PREC_GRAD_HIGH` will not be used if `GRAD_CHANGE_ALT` = 0.
- Precipitation correction for rain adjusts data for gauge losses. An additional precipitation correction for snow may also be provided.
- Temperature lapse rates for dry and wet time steps (no rain or rain).
- Lake temperature memory and lake evaporation constant provide information used in a simple method for modelling lake temperature and lake evaporation.
- Rating curve parameters are used for modelling lake outflow.

- Initial value for soil moisture content in HBV elements.
- Initial values for upper and lower saturated zone water content in HBV elements.
- Initial values for saturated zone water content in KiWa elements.
- Initial values for lake temperature and lake water level.
- Initial value for total volume of water stored in lakes.
- Snow storage may be reduced to zero at a specified day number each year. If `DAY_SNOW_ZERO` = 0 the snow storage is not altered.

4.4 Land surface characteristics of grid cells

Program *predew* reads input files with land surface characteristics of the grid cells within the model domain. The information is supplied as ascii/grid import/export format files with information about elevation (metres above sea level), slope length (metres), slope angle (degrees), aspect (degrees), percentage of grid cells areas covered by lakes, percentage of grid cells areas covered by forest, percentage of grid cells areas covered by bogs, percentage of grid cells areas covered by glaciers and finally, potential tree line of grid cells (metres above sea level). The potential tree line defines the upper margin of the subalpine forest where trees become dwarfed or are absent. All these files have the same format. An example is provided for grid cell elevations in file *altitude.asc*.

```
ncols         5
nrows         8
xllcorner     0
yllcorner     0
cellsize      500
NODATA_value  -9999
  410    400  -9999  -9999  -9999
  400    360    380  -9999  -9999
  300    280    300  -9999  -9999
  240    220    200    230  -9999
  280    220    200    210  -9999
  270    240    200    170    160
  280    250    210    160    120
-9999    240  -9999  -9999  -9999
```

4.5 Output

Program *predew* produces three output files.

- A file with control information used during model development. The name of this file must be supplied when running the model. In the example below this file is called *pre_out.txt*.
- File with information about grid cell characteristics
- File with information about landscape elements within each watercourse/subcatchment

4.6 File with information about grid cell characteristics

The file with information about characteristics for each grid cell produced by program *predew* describes the coordinates of each grid cell and the model structure/algorithm used for modelling hydrological processes. Two model structures are possible: HBV model and Kinematic Wave (KiWa) model structure. These two model structures differ in the algorithms used for describing subsurface processes.

Furthermore, elevation, slope properties, lake and glacier percentage, land cover type, soil type and other land surface characteristics are described. Information about the meteorological stations and the weights to be used for interpolation of meteorological data are also provided. The file *dew_landscape.dta* shown below presents the first lines of an output file with information about grid cell characteristics.

```
ncols         5
nrows         8
xllcorner     0
yllcorner     0
cellsize      500
NODATA_value  -9999
# Number of landscape elements :  27
0 0 1 250000. 410. 300.0 3.4 180. 0.0 0.0 2 2 100.0 0 0 0.0
     2 1.0 2 1.0
```

The first six lines provide information necessary for describing the coordinates of a regular grid.
Line 7 gives information about the number of landscape elements.
Starting from line 8, there is one line for each landscape element (grid cell) in the model domain with the following information.

```
Element index
Coordinate index
Model structure (0 = HBV, 1 = KiWa)
Area (m²)
Elevation (m)
Slope length (m)
Slope angle (degrees)
Aspect (degrees)
Lake percentage (%)
Glacier percentage (%)
Land surface class 1; land cover class
Land surface class 1; soil type
Percentage of area covered by land surface class 1 (%)
Land surface class 2; land cover class
Land surface class 2; soil type
Percentage of area covered by land surface class 2 (%)
For all precipitation series:
     Precipitation station number
     Precipitation station weight
For all temperature series:
     Temperature station number
     Temperature station weight
```

4.7 File with information about landscape elements within each watercourse/subcatchment

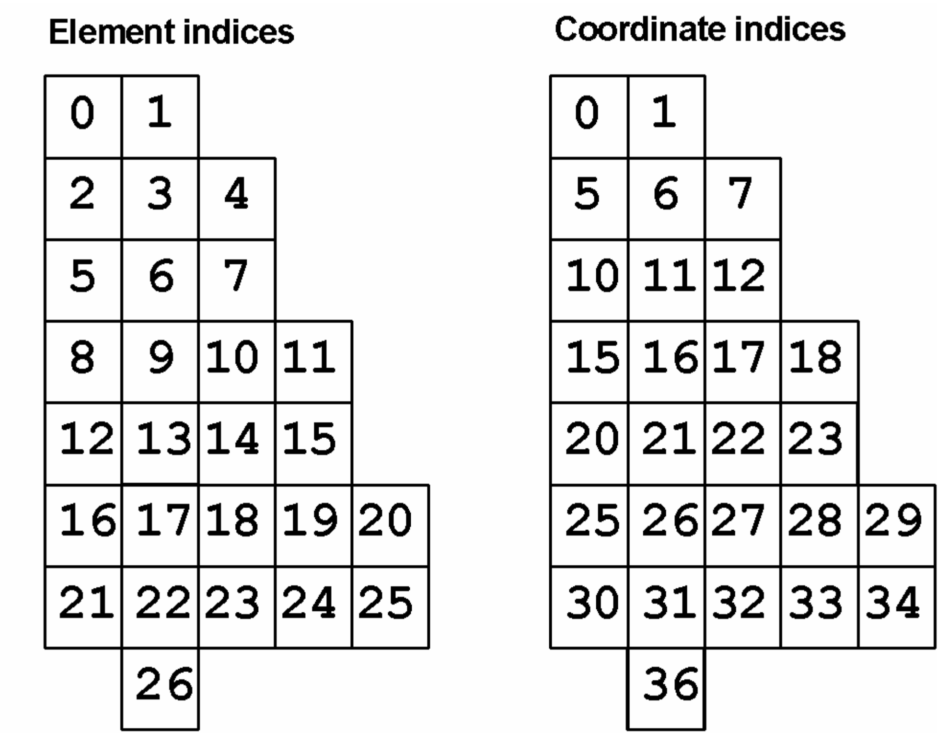
The landscape elements discharging to each watercourse or located within each subcatchment are listed in file *dew_waterland.dta* presented below.

```
#  80001  #  11
0  0
1  1
2  5
3  6
4  7
5  10
6  11
7  12
8  15
9  16
10  17
#  80002  #  4
12  20
13  21
16  25
17  26
#  80003  #  12
11  18
14  22
15  23
18  27
19  28
20  29
21  30
22  31
23  32
24  33
25  34
26  36
```

The information provided for each watercourse/subcatchment is:

```
#  <watercourse/subcathment index>  #  <no. of landscape elements>
<element index of element 1> <coordinate index of element 1>
<element index of element 2> <coordinate index of element 2>
...
```

Element indices start from 0, coordinate indices are starting from 0 in the upper left corner of the regular grid. The example below shows element indices and coordinate indices for the regular grid used for landscape elements in catchment Sæternbekken.



4.8 Running *predew*

When *predew* is run on a Linux system or using a Windows console interface it is possible to read the information necessary for running the program from a text file. In the example below, the text file is called *control_pre.txt*. The model is started from the command prompt with the command:

predew < control_pre.txt

If the executable file *predew* is not located in a directory in the search path of the computer session, the full or relative path to *predew* must be provided.

File *control_pre.txt* contains the information to be supplied to the user interface of program *predew*.

```
0 / 1                       Model structure: 0 = HBV, 1 = KiWa
C                      Watercourse hierarchy: Subcatchments (C)
pre_out.txt                 Program development output file
met_stations.dta            Meteorological stations
dew_common_parameters.dta   Parameters for all classes
stations.asc                Model domain file
altitude.asc                Elevation
length.asc                  Slope length
slope.asc                   Slope angle
aspect.asc                  Aspect
lake_per.asc                Lake percentage
forest_per.asc              Forest percentage
bog_per.asc                 Bog percentage
glacier_per.asc             Glacier percentage
tree_level.asc              Potential tree line
watershed.dta               Watercourse/subcatchment hierarchy
watercourse_id.asc          Landscape elements
```

5 Program *dew*

The hydrological modelling is performed by program *dew*. Program *dew* can be run in calibration mode or simulation mode. When the program is being run in calibration mode, a file with observed streamflow data for the calibration period is required. Program *dew* will not perform optimization of model parameters; the only difference between the two modes is that the sum all model simulated streamflow values is written to the end of the model results files *dew_<watercourse/subcatchment>.var* (Chapter 6). Only model results for time steps where observed data are available will be included in this sum.

5.1 Input

Input files to program *dew* may be generated by programs *stationMask* and *predew* or be produced using a text editor. When the model domain is not a regular grid, input files must be produced by a text editor. In addition to the files that may be generated by programs *stationMask* and *predew* or be produced using a text editor, program *dew* requires files with information about parameter values of land cover/vegetation classes and soil/bedrock classes, watercourse elements and meteorological input data. The structure of the input files is described below, or in Chaper 3. Model parameters are defined in Chapter 7.

Program *dew* requires 10 or 11 input-files.

- File with meteorological stations information
- Parameter file common for all land cover and soil/bedrock classes
- Land cover classes parameters
- Soil/bedrock classes parameters HBV model
- Soil/bedrock classes parameters KiWa model
- Landscape elements selected for time series output
- Landscape elements characteristics (may be generated by program *predew*)
- Watercourse/subcatchment hierarchy description (used by programs *stationMask* and *predew*)
- Landscape elements located within each watercourse/subcatchment (used by programs *stationMask* and *predew*)
- Correction of meteorological data
- Meteorological time series (only for input data in time series format)
- File with observed streamflow data named *obs_streamflow.var*. This file is required in calibration mode, but not in simulation mode. If it does not exist, model results will not be compared to observations. An example is provided in file *obs_streamflow.var* below.

```
#dew_00080003.var
19960920/0000      0.011248
19960920/0100      0.011248
19960920/0200      0.011248
19960920/0300      0.011248
19960920/0400      0.011248
19960920/0500      0.011248
19960920/0600      0.011248
...
```

The first line gives the name of the model output file which observed data are to be compared to. The next lines contain observed streamflow data. This information can be repeated for each model output file which is to be compared to observed data.

5.2 When the model domain is not a regular grid

If the model domain is not a regular grid, the information in the first six lines of the file *dew_landscape.dta* is to be considered as dummy information. It must be provided, but it will not be used by the program *dew*.

The landscape elements discharging to each watercourse or located within each subcatchment are read from file *dew_waterland.dta*. In the case that the model domain is a regular grid, this file may be generated by program *predew*. If irregularly shaped landscape elements are used, this file must be produced using a text editor. The coordinate indices may then no longer be used for finding the location of landscape elements, and should be assigned the value of the element indices. The landscape elements discharging to each watercourse or located within each subcatchment should then be listed as in the example below. The watercourse/subcatchment element 80003 receives water from 10 landscape elements with indices from 0 to 9.

```
#  80003  #  10
0  0
1  1
2  2
3  3
4  4
5  5
6  6
7  7
8  8
9  9
```

5.3 Land cover classes parameters

The following land cover classes are used by program *dew*.

- Open land: Non-forested areas below the tree line (agricultural fields, meadows etc.)
- Bog: Bogs and wetland areas
- Forest: Lowland areas with coniferous or deciduous forests
- Alpine: Areas below the tree line with subalpine forests
- Heather: Areas above the tree line with grass, heather, shrubs or dwarfed trees
- Bedrock: Areas above the tree line with extremely sparse vegetation
- Glacier: Glaciated areas covered by snow and ice

The tree line is the upper margin of the subalpine forest where trees become dwarfed or are absent.

Land cover classes parameters are read from file *dew_landsurface_parameters.dta* below. The file has one line per land cover class, but has been divided into three parts in this example.

```
Type     no.    INTER_MAX     EPOT_PAR      WET_PER_CORR
OPEN      0     1.0E-4        9.2E-5        0.8
BOG       1     1.0E-4        0.000020      0.8
FOREST    2     1.0E-4        0.000020      0.8
ALPINE    3     0.0           0.0           0.0
HEATHER   4     1.0E-4        9.2E-5        0.8
BEDROCK   5     1.0E-4        9.2E-5        0.8
GLACIER   6     1.0E-4        9.2E-5        0.8
```

```
ACC_TEMP     MELT_TEMP    SNOW_MELT_RATE    ICE_MELT_RATE
0.0          -0.03        0.01              1.12
0.0          -0.03        0.01              1.12
0.0          -0.03        0.01              1.12
0.0          -0.03        0.01              1.12
0.0          -0.03        0.01              1.12
0.0          -0.03        0.01              1.12
0.0          -0.03        0.01              1.12
```

```
FREEZE_EFF   MAX_REL     ALBEDO     CV_SNOW
0.01         0.08        0.90       0.0
0.01         0.08        0.90       0.0
0.01         0.08        0.90       0.0
0.01         0.08        0.90       0.3
0.01         0.08        0.90       0.5
0.01         0.08        0.90       0.75
0.01         0.08        0.90       1.0
```

5.4 Soil/bedrock classes parameters

There is one soil/bedrock class corresponding to each land cover class. There is one set of soil/bedrock classes parameters for the HBV model structure, and one set of soil/bedrock classes parameters for the KiWa model structure.

Soil/bedrock classes parameters for the HBV model structure are read from file *hbv_soil_parameters.dta* below. The file has one line per soil/bedrock class, but has been divided into two parts in this example.

```
Type     no.      FC         BETA       FCDEL       INFMAX
OPEN      0       0.38       2.0        1.0         50.0
BOG       1       0.38       2.0        1.0         50.0
FOREST    2       0.38       2.0        1.0         50.0
ALPINE    3       0.38       2.0        1.0         50.0
HEATHER   4       0.38       2.0        1.0         50.0
BEDROCK   5       0.38       2.0        1.0         50.0
GLACIER   6       0.38       2.0        1.0         50.0
```

```
KUZ         ALFA       PERC        KLZ          DRAW
1.0         1.87       1.0E-4      0.013        0.0
1.0         1.87       1.0E-4      0.013        0.0
1.0         1.87       1.0E-4      0.013        0.0
1.0         1.87       1.0E-4      0.013        0.0
1.0         1.87       1.0E-4      0.013        0.0
1.0         1.87       1.0E-4      0.013        0.0
1.0         1.87       1.0E-4      0.013        0.0
```

Soil/bedrock classes parameters for the KiWa model structure are read from file *kiwa_soil_parameters.dta* below. The file has one line per soil/bedrock class, but has been divided into three parts in this example.

```
Type       no.    SOIL_DEPTH  OV_PAR_1    OV_PAR_2
OPEN        0     0.8         45.2        1.24
BOG         1     0.8         45.2        1.24
FOREST      2     0.8         45.2        1.24
ALPINE      3     0.8         45.2        1.24
HEATHER     4     0.8         45.2        1.24
BEDROCK     5     0.8         45.2        1.24
GLACIER     6     0.8         45.2        1.24
```

```
TSAT_0      EFF_POR      KSAT_0      A         DELTA
0.7         0.074        16.6       -8.20     -15.51
0.7         0.074        16.6       -8.20     -15.51
0.7         0.074        16.6       -8.20     -15.51
0.7         0.074        16.6       -8.20     -15.51
0.7         0.074        16.6       -8.20     -15.51
0.7         0.074        16.6       -8.20     -15.51
0.7         0.074        16.6       -8.20     -15.51
```

```
LAMBDA_KW      ROOT_DEPTH   WILT_POINT    EACT_PAR
-1.415         0.40         0.06          0.9
-1.415         0.40         0.06          0.9
-1.415         0.40         0.06          0.9
-1.415         0.40         0.06          0.9
-1.415         0.40         0.06          0.9
-1.415         0.40         0.06          0.9
-1.415         0.40         0.06          0.9
```

5.5 Landscape elements selected for time series output

State variables and fluxes for selected landscape/model elements may be written to files. The numbers of the selected landscape elements must be specified. File *hbv_elements.dta* below shows an example.

```
# Number of landscape elements selected for time series output: 3
*no.*  *groundwater reference level*  *groundwater eff. por.*
 0    -1.5    0.1
12    -1.5    0.15
25    -2.0    0.1
```

Presently, the model will only output the groundwater table depth (*m*) of HBV model elements.

5.6 Correction of meteorological data

Meteorological time series are corrected for gauge losses and elevation gradients using information in the file with parameter values and other characteristics common to all land cover and soil/bedrock classes. However, these corrections will not be applied when gridded meteorological input data are used. Instead, it is possible to apply corrections to all grid cells within a subcatchment. File *catchment_correction.dta* below shows an example.

```
Catchment id.  Precipitation correction  Temperature correction
80001          1.0                       0.0
80002          1.0                       0.0
80003          1.0                       0.0
```

These corrections apply to all landscape elements discharging to a watercourse or contained within a subcatchment. All precipitation values read from the grid file are multiplied by the precipitation correction, whereas the temperature correction is added to all temperature values read from the grid file. These corrections can also be applied in the case that meteorological time series are used. In this case, the precipitation and temperature corrections will be applied to the input data for all computation element of the model located within a subcatchment.

5.7 Meteorological time series input data

Meteorological time series data are supplied in a file with one column per time series. File *input_data.dta*. below is an example.

```
*Time*         *Precip* *Precip* *Precip* *Precip* *Temp* *Temp* *Temp* *Temp*
Saeternbekken
19960820/0000  0        0        0        0        13.8   13.8   13.8   13.8
19960820/0100  0        0        0        0        13.45  13.45  13.45  13.45
19960820/0200  0        0        0        0        13.2   13.2   13.2   13.2
19960820/0300  0        0        0        0        13.65  13.65  13.65  13.65
19960820/0400  0        0        0        0        13.45  13.45  13.45  13.45
19960820/0500  0        0        0        0        13.55  13.55  13.55  13.55
19960820/0600  0.25     0.25     0.25     0.25     13.65  13.65  13.65  13.65
19960820/0700  0        0        0        0        14.1   14.1   14.1   14.1
19960820/0800  0        0        0        0        14.7   14.7   14.7   14.7
19960820/0900  0.1      0.1      0.1      0.1      17.4   17.4   17.4   17.4
19960820/1000  0        0        0        0        20.55  20.55  20.55  20.55
19960820/1100  0        0        0        0        22.6   22.6   22.6   22.6
19960820/1200  0        0        0        0        23.85  23.85  23.85  23.85
19960820/1300  0        0        0        0        24.2   24.2   24.2   24.2
19960820/1400  0        0        0        0        24.15  24.15  24.15  24.15
19960820/1500  0        0        0        0        23.65  23.65  23.65  23.65
19960820/1600  0        0        0        0        23.15  23.15  23.15  23.15
19960820/1700  0        0        0        0        21.05  21.05  21.05  21.05
19960820/1800  0        0        0        0        19.5   19.5   19.5   19.5
19960820/1900  0        0        0        0        17.7   17.7   17.7   17.7
19960820/2000  0        0        0        0        16.4   16.4   16.4   16.4
19960820/2100  0        0        0        0        15.8   15.8   15.8   15.8
19960820/2200  0        0        0        0        15.3   15.3   15.3   15.3
19960820/2300  0        0        0        0        14.55  14.55  14.55  14.55
```

Each precipitation and temperature station in file *met_stations.dta* corresponds to a column in file *input_data.dta*. Precipitation date have unit *mm/time* step and temperature data have unit ° *C*. The two first lines on the file are used for comments. Meteorological time series are corrected for gauge losses and elevation gradients using information in the file with parameter values and other characteristics common to all land cover and soil/bedrock classes.

5.8 Running *dew*

When *dew* is run on a Linux system or using a Windows console interface it is possible to read the information necessary for running the program from a text file. In the example below, the text file is called *control_dew.txt*. The model is started from the command prompt with the command:

dew < control_dew.txt

If the executable file *dew* is not located in a directory in the search path of the computer session, the full or relative path to *dew* must be provided.

File *control_dew.txt* contains the information to be supplied to the user interface of program *dew*.

```
S            Type of model run: simulation(S) or calibration(C)
C            Watercourse hierarchy: nested catchments (C)
T / G        Meteorological input data format: Time series or Grid
dew_out.txt                 Program development output file
20 8 1996 0 0               Start model spin-up dd mm yyyy hh mm
20 9 1996 0 0               Start simulation dd mm yyyy hh mm
17 11 1996 23 0             End simulation dd mm yyyy hh mm
met_stations.dta                 Meteorological stations
dew_common_parameters.dta        Parameters for all classes
dew_landsurface_parameters.dta   Land cover classes parameters
hbv_soil_parameters.dta     Soil/bedrock classes parameters HBV
kiwa_soil_parameters.dta    Soil/bedrock classes parameters KiWa
dew_elements.dta        Landscape elements with time series output
dew_landscape.dta           Landscape elements characteristics
watershed.dta               Watercourse/subcatchment hierarchy
dew_waterland.dta           Landscape elements within each
                            watercourse/subcatchment
catchment_correction.dta    Correction of meteorological data
input_data.dta              Meteorological input data (only for
                            input data in time series format)
```

The watercourse hierarchy in the examples above assumes that subcatchments are nested, with no explicit description of the river/lake network.

6 Explicit hierarchy of landscape and watercourse elements

If a watercourse hierarchy with an explicit river/lake network is to be used, the landscape elements must also be assigned flow directions. These flow directions must be supplied by a file which is read by program *predew*. In this case, all landscape elements located along the river network receives water from upstream elements and discharges into the stream network. In the example below the file *watercourse_id.asc* contains information about landscape elements located along the river network.

6.1 Watercourse description within a regular grid

The watercourse hierarchy in the case of an explicit river/lake network is defined using the file *watercourse.dta* as in the previous example:

```
# Number of watercourses: 3
0 :  80001    1.0
1 :  80002    1.0
2 :  80003    1.0
# Number of watercourse outlets: 1
2
# Hierarchy of watercourses
2 2 :  0 1
```

6.2 Landscape elements within a regular grid

The landscape elements located along the river/lake network hierarchy are described using the file *watercourse_id*.asc in the example below. Note that this file may not be used for defining the model domain with program *station_mask*. This must be done using another file where grid cells with landscape elements that are to be included in the model domain have values not equal to nodata (-9999).

```
ncols         5
nrows         8
xllcorner     0
yllcorner     0
cellsize      500
NODATA_value  -9999
-9999  -9999  -9999  -9999  -9999
-9999  -9999  -9999  -9999  -9999
-9999  -9999  -9999  -9999  -9999
-9999  -9999  80001  -9999  -9999
-9999  80002  80003  -9999  -9999
-9999  -9999  -9999  80003  -9999
-9999  -9999  -9999  -9999  80003
-9999  -9999  -9999  -9999  -9999
```

The file *dew_waterland.dta* with information about landscape elements discharging to each element of the river/lake network is presented in the example below.

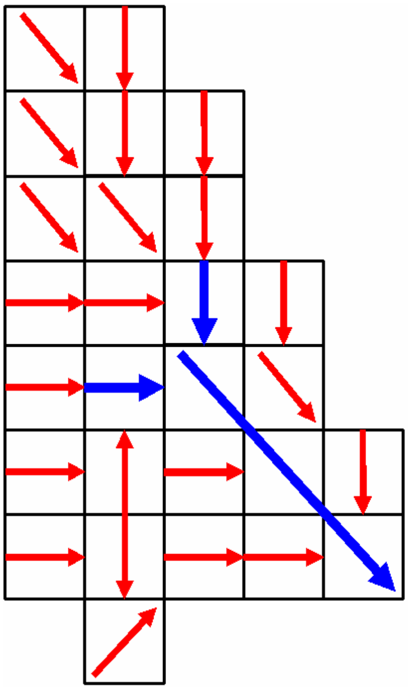
```
#  80001  #  1
10  17
#  80002  #  1
13  21
#  80003  #  3
14  22
19  28
25  34
```

6.3 Flow directions of landscape elements

Program *predew* requires an additional input file with flow directions of landscape elements/grid cells within the model domain. In case of a regular grid, water from each grid cell may discharge to one of eight downstream grid cells. The information is supplied by an ascii/grid import/export format file with information about the flow direction for each grid cell. An example is provided in file *land_flow.asc* below.

```
ncols         5
nrows         8
xllcorner     0
yllcorner     0
cellsize      500
NODATA_value  -9999
      2      4  -9999  -9999  -9999
      2      4      4  -9999  -9999
      2      2      4  -9999  -9999
      1      1      4      4  -9999
      1      1      2      2  -9999
      1     64      1      2      4
      1      4      1      1      4
  -9999    128  -9999  -9999  -9999
```

The flow directions of the hierarchy of landscape elements and river/lake network in this example is presented in the figure below:



Program *predew* writes the flow directions of all landscape elements within the model domain to file *dew_landupflow.dta* presented in the example below. Each landscape element may receive water from upstream landscape elements. Finally, water is discharged into the river/lake network from the landscape elements described in file *watercourse_id.asc* in the example above.

```
3  2 :  0  1
6  2 :  2  3
7  1 :  4
9  2 :  8  5
10  3 :  9  6  7
13  2 :  17  12
15  1 :  11
17  1 :  16
19  1 :  18
20  1 :  15
22  1 :  21
23  1 :  26
24  1 :  23
25  2 :  24  20
26  1 :  22
```

The information provided for each landscape element is:

```
<element index>  <no. of upstream elements>  :  <element indices
of upstream landscape elements>  ...
<element index>  <no. of upstream elements>  :  <element indices
of upstream landscape elements>  ...
<element index>  <no. of upstream elements>  :  <element indices
of upstream landscape elements>  ...
...
```

6.4 Running *predew* in case of an explicit hierarchy of landscape and watercourse elements

In the example below, the information necessary for running program *predew* is read from the file *control_pre.txt*. An additional input file is required as compared to the case with an implicit hierarchy of landscape and watercourse elements. The model is started from the command prompt with the command:

predew < control_pre.txt

```
0 / 1                       Model structure: 0 = HBV, 1 = KiWa
N             Watercourse hierarchy: river/lake network (N)
pre_out.txt                 Program development output file
met_stations.dta            Meteorological stations
dew_common_parameters.dta   Parameters for all classes
stations.asc                Model domain file
altitude.asc                Elevation
length.asc                  Slope length
slope.asc                   Slope angle
aspect.asc                  Aspect
lake_per.asc                Lake percentage
forest_per.asc              Forest percentage
bog_per.asc                 Bog percentage
glacier_per.asc             Glacier percentage
tree_level.asc              Potential tree line
watershed.dta               Watercourse/subcatchment hierarchy
land_flow.asc               Flow direction of landscape elements
watercourse_id.asc          Landscape elements
```

6.5 Running *dew* in case of an explicit hierarchy of landscape and watercourse elements

In the example below, the information necessary for running program *dew* is read from the file *control_dew.txt*. An additional input file is required as compared to the case with an implicit hierarchy of landscape and watercourse elements. The model is started from the command prompt with the command:

dew < control_dew.txt

```
S            Type of model run: simulation(S) or calibration(C)
N            Watercourse hierarchy: river/lake network (N)
T / G        Meteorological input data format: Time series or Grid
dew_out.txt                 Program development output file
20 8 1996 0 0               Start model spin-up dd mm yyyy hh mm
20 9 1996 0 0               Start simulation dd mm yyyy hh mm
17 11 1996 23 0             End simulation dd mm yyyy hh mm
met_stations.dta                 Meteorological stations
dew_common_parameters.dta        Parameters for all classes
dew_landsurface_parameters.dta   Land cover classes parameters
hbv_soil_parameters.dta     Soil/bedrock classes parameters HBV
kiwa_soil_parameters.dta    Soil/bedrock classes parameters KiWa
dew_elements.dta        Landscape elements with time series output
dew_landscape.dta           Landscape elements characteristics
watershed.dta               Watercourse/subcatchment hierarchy
dew_waterland.dta           Landscape elements within each
                            watercourse/subcatchment
dew_landupflow.dta          Upstream landscape elements
catchment_correction.dta    Correction of meteorological data
input_data.dta              Meteorological input data (only for
                            input data in time series format)
```

7 Model results

Program *dew* calculated input data, state variables and fluxes for each watercourse/subcatchment. The discharge from each outlet in the model domain is determined after routing water through the hierarchies of watercourses and subcatchments.

7.1 Model results files

Program *dew* produces the following output files.

- A file with control information used during model development. The name of this file must be supplied when running the model. In the example above this file is called *dew_out.txt*.

For each watercourse/subcatchment.

pre_<watercourse/subcatchment>.var	precipitation (*mm/time step*)
tem_<watercourse/subcatchment>.var	temperature (° *C*)
swe_<watercourse/subcatchment>.var	snow water equivalent (*mm*)
eva_<watercourse/subcatchment>.var	evaporation (*mm/time step*)
hpe_<watercourse/subcatchment>.var	percolation from soil moisture zone to upper zone (*mm/time step*)
hsm_<watercourse/subcatchment>.var	HBV soil moisture deficit (*mm*)
huz_<watercourse/subcatchment>.var	HBV upper zone (*mm*)
hlz_<watercourse/subcatchment>.var	HBV lower zone (*mm*)
hgw_<watercourse/subcatchment>.var	HBV upp. and low. zone (*mm*)
run_<watercourse/subcatchment>.var	runoff (*mm/time step*)
dew_<watercourse/subcatchment>.var	discharge (m^3/*time step*)

For each model element selected for time series output.

HBV_groundwater_<element>.var	groundwater table depth (*m*)

For all elements within the model domain.

res_totalvol.var	total volume of water stored in lakes (m^3)

8 Model parameters

The parameters of model *hbv* are used for modifying input data and calculating state variables and fluxes for all computational elements within the model domain, both landscape elements and watercourse elements.

8.1 Parameters common for all land cover and soil/bedrock classes

- **`PREC_GRAD_LOW, PREC_GRAD_HIGH:`** Gradients for precipitation increase per 100 m elevation change below and above elevation **`GRAD_CHANGE_ALT`**. A value of 1.0 means no change. A value of 1.1 means 10 % increase per 100 m elevation change. **`PREC_GRAD_HIGH`** will not be used if **`GRAD_CHANGE_ALT`** = 0.
- **`PREC_CORR_RAIN:`** Precipitation correction for rain.
- **`PREC_CORR_SNOW:`** Additional precipitation correction for snow.
- **`LAPSE_DRY, LAPSE_WET:`** Temperature lapse rates for dry and wet time steps (no rain or rain).
- **`DAY_TEMP_MEMORY:`** Temperature memory for lakes used in a simple method for modelling lake temperature.
- **`LAKE_EPOT_PAR:`** Controls lake evaporation rate.
- **`KLAKE:`** The constant of the rating curve of lakes.
- **`DELTA_LEVEL:`** The zero point of the rating curve of the lakes.
- **`NLAKE:`** Exponent of the rating curve of the lakes.
- **`INITIAL_SOIL_MOISTURE:`** Initial water content in soil moisture zone in HBV model elements (m).
- **`INITIAL_UPPER_ZONE:`** Initial water content in upper zone in HBV model elements (m).
- **`INITIAL_LOWER_ZONE:`** Initial water content in lower zone in HBV model elements (m).
- **`INITIAL_SATURATED_ONE:`** Initial fraction of soil profile covered by saturated zone in upper end of hillslope in KiWa model elements (m).
- **`INITIAL_SATURATED_TWO:`** Initial fraction of soil profile covered by saturated zone in lower end of hillslope in KiWa model elements (m).
- **`INITIAL_LAKE_TEMP:`** Initial temperature of lake elements (˚C).
- **`INITIAL_LAKE_LEVEL:`** Initial water level of lake elements (m).
- **`INITIAL_SNOW_STORAGE:`** Initial snow storage (m).
- **`INITIAL_TOTAL_RESERVOIR:`** Initial volume of water stored in lakes (m^3).

8.2 Land cover parameters

The parameters for land cover are unique for each class.

- **`INTER_MAX:`** Maximum interception storage (m).
- **`EPOT_PAR:`** Controls potential evaporation rate (m/(TimeStep·˚C)).
- **`WET_PER_CORR:`** Controls reduction of ground evapotranspiration when intercepted water is stored on vegetation..
- **`ACC_TEMP:`** Threshold temperature for snow accumulation (˚C).

- `MELT_TEMP`: Threshold temperature for snow melt (˚C).
- `SNOW_MELT_RATE`: Controls snow melt rate (m/(TimeStep·˚C)).
- `ICE_MELT_RATE`: Controls ice melt rate for glaciers by multiplication with `SNOW_MELT_RATE`.
- `FREEZE_EFF`: Controls refreeze rate of liquid meltwater in snow by multiplication with `SNOW_MELT_RATE`.
- `MAX_REL`: Meltwater is retained in the snow until the amount of liquid water reaches the relative fraction of snowpack water equivalent given by `MAX_REL`.
- `ALBEDO`: Snow surface albedo.
- `CV_SNOW`: Coefficient of variation for lognormal distribution of snowfall.

8.3 HBV soil/bedrock parameters

The parameters for soil/bedrock are unique for each class.

- `FC`: Field capacity (m).
- `BETA`: Controls distribution function of soil moisture.
- `FCDEL`: Fraction of field capacity where reduction of evapotranspiration below potential level starts.
- `INFMAX`: Maximum infiltration rate (m/TimeStep).
- `KUZ`: Upper zone response coefficient.
- `ALFA`: Controls increase of upper zone response with increasing water content.
- `PERC`: Percolation from upper to lower zone (m/TimeStep).
- `KLZ`: Lower zone response coefficient.
- `DRAW`: Rate of draw up from lower zone to soil moisture zone (m/TimeStep).

8.4 KiWa soil/bedrock parameters

The parameters for soil/bedrock are unique for each class.

- `SOIL_DEPTH`: Depth of soil profile (m).
- `OV_PAR_1`: Overland flow kinematic wave friction parameter (m/TimeStep).
- `OV_PAR_2`: Overland flow kinematic wave exponent.
- `TSAT_0`: Saturation volumetric water content at soil surface.
- `EFF_POR`: Storage coefficient of saturated zone.
- `KSAT_0`: Saturated hydraulic conductivity at soil surface (m/TimeStep).
- `A`: Determines the rate of decrease of saturated hydraulic conductivity with depth below the soil surface.
- `DELTA`: Controls partitioning of ground evapotranspiration between saturated and unsaturated zone.
- `LAMBDA_KW`: Controls relationship between equilibrium soil moisture content at the soil surface and depth to groundwater table.
- `ROOT_DEPTH`: Depth of root zone (m).
- `WILT_POINT`: Volumetric water content at the wilting point of vegetation.
- `EACT_PAR`: Controls actual evapotranspiration from the ground.

9 DEW model algorithms

The algorithms of program *hbv* are based on the Nordic HBV model (Sælthun, 1996), with some exceptions. One important difference is that the response function of the upper groundwater reservoir is based on the principle described by Lindström et al. (1997) where no threshold is applied. Runoff from the upper groundwater zone is given by:

$$Q_U = KUZ \cdot UZ^{ALFA} \qquad ; \; ALFA > 1.0$$

9.1 Vegetation

The vegetation cover is described as a lumped reservoir. Intercepted water stored on vegetation evaporates at the potential rate. As long as intercepted water is present, the fraction of the time step when actual evapotranspiration from the ground takes place is reduced according to:

$$DryPeriod = TimeStep - WetPeriod \cdot WET\_PER\_CORR$$

- *DryPeriod* is the fraction of *TimeStep* when evapotranspiration from the ground occurs.
- *TimeStep* is the time resolution of the model run.
- *WetPeriod* is the fraction of *TimeStep* when evaporation of intercepted water occurs at the potential rate.
- $0 \leq WET\_PER\_CORR \leq 1$

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