Parameterisation and calibration of a grid based distributed hydrological model

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Abstract. Parameterisation of hydrological models using remote sensing is currently being studied in a European Union funded ARSGISIP project. Input to hydrological models consists of meteorological data, discharge data and spatial data (slope, soils, land-use and vegetation cover) for model parameterization. Satellite imagery has been found to be a valid data source for the purpose of hydrological modeling. However, as this data is generically in raster format its use in vector based hydrological models can be difficult. Our solution to the problem is the creation of a three-dimensional raster based hydrological model, H3mod. The model has built-in GIS functionality and includes a graphical user interface for running the model on Microsoft Windows platfroms. All relevant hydrological parameters can be set individually for each grid cell. H3mod performs quite well under northern Scandinavian conditions such as cold winters, spring flood due to snowmelt, low relief and water logged conditions in marshes and mires. Presently the model is being applied in three basins in the boreal forest of northern Finland, varying in size from 20 to 2500 km^2, and so far the results are promising. Future model enhancements will include water quality (sediment, phosphorus andnitrogen) modeling capabilities.

Introduction

This study is part of the EU funded ARSGISIP project (Applied Remote Sensing and Integrated GIS for Hydrological Parameterisation) (ARSGISIP 2000). In the project partners from Finland, Sweden, Norway, Italy, France, Austria and Germany work together to study the possibilities of remote sensing data for the parameterisation of hydrological models. The final goal of the project is to present a pool of methods for optical and microwave remote sensing techniques comprised in the Idealised European Catchment as described by Flügel and Münschen (1998). The prospects of remote sensing for hydrology have been addresses before (Kuittinen 1985). The benefits of GIS in natural resource management are obvious (Morain 1999). However the integration of GIS and remote sensing provides an entirely new dimension to hydrological modelling.

The Finnish end user of the project is the Northern Ostrobothnian Regional Environmental Centre. The local goal is to produce a system to model the environmental pressure on cold boreal river systems. The river Siuruanjoki was chosen for the project because of local problems with algae blooms during summer, a phenomena, not uncommon in lakes, but rare in rivers.

The hydrological office of the Finnish Environmental Centre presently uses the

HBV model for hydrological forecasting (Vehveläinen 1994). Another well-known model in the public domain is PRMS, (Precipitation-Runoff Modelling System) of the USGS (Leavesley et al. 1983). The HBV model is not a real distributed system, and therefore not very suitable for our purposes. PRMS is a distributed deterministic model using HRU's (hydrological response unit) as the smallest area unit. For computational reasons this is a sound solution, but is still based upon vector GIS technology. As remote sensing data is generically in raster format, we were thinking about a raster based distributed hydrological modelling system. Our system, which takes into account land use, relief and river network, is being developed in the ARSGISIP framework. The model, called H3MOD and its parameterisation shall be described below.

The model

The goal of the catchment model is to compute outflow from a modelled catchment given elevation, land use and meteorological data. The model is based on a uniform grid, which is a representatation of the catchment area by equal sized boxes. A visualisation of a grid is shown in figure 1. Typical grid box size can be (for this model) from 100x100 to 1000x1000 meters, box size being a compromise between desired accuracy and computation time.

The model consists of three main components shown in figure 2. These components are surface/unsaturated layer component, ground water component and river flow component. The surface/unsaturated layer component simulates ground surface energy balance, unsaturated layer flow, recharge to the ground water and overflow to rivers from daily weather data separately for each grid box. The ground water component computes two dimensional saturated layer ground water flows in the model grid, and includes a river-ground water interaction component. The river component simulates river flow in a two

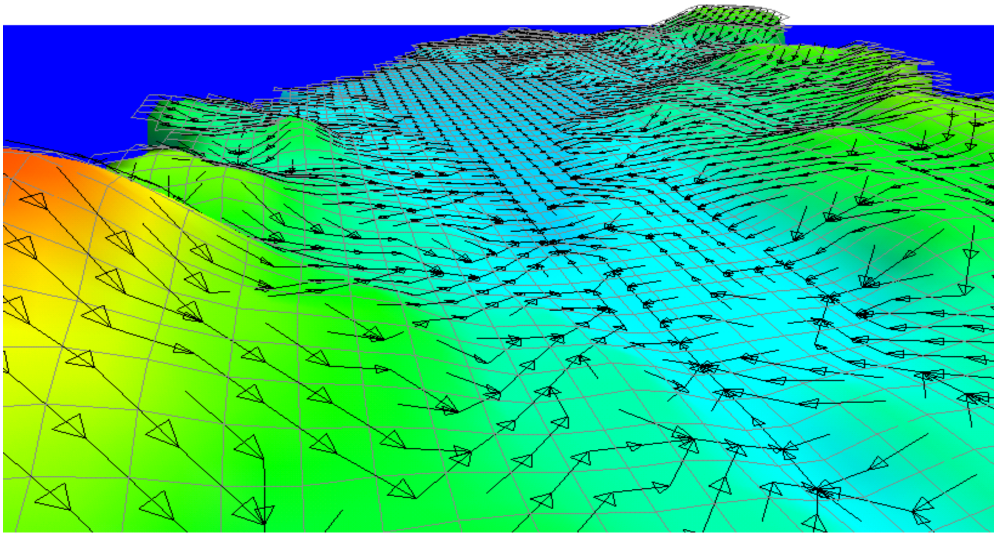


Figure 1. Model grid, where ground elevation is shown with shadowing and down slope flow directions with arrows.

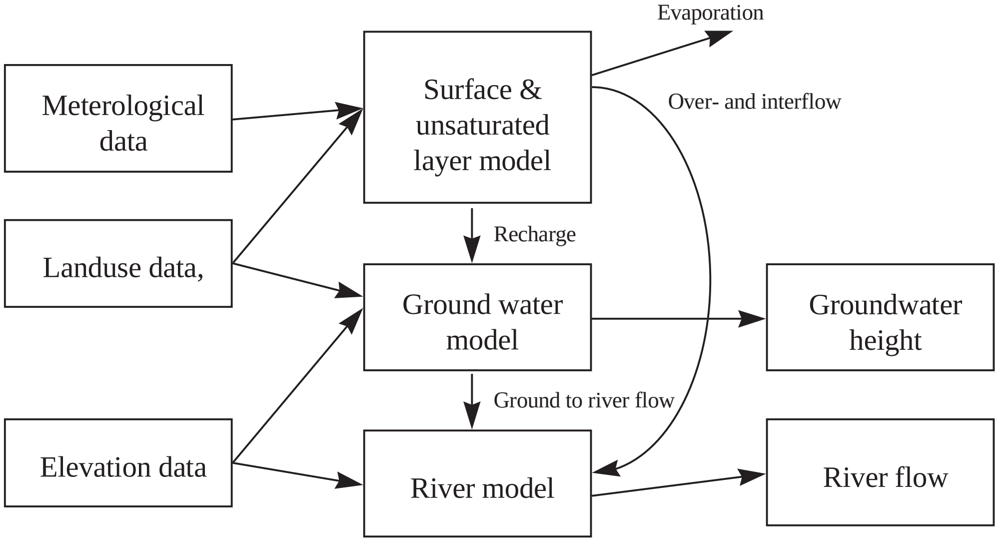


Figure 2. Model components.

dimensional river network that is based on the digital elevation model. For a more detailed description of the model see Lauri (2000, unpublished).

The surface/unsaturated layer component simulates water behaviour in the ground surface layer separately for each model grid box. It includes a snow model for wintertime conditions and a simplified unsaturated layer model. The overall structure of the component is shown in figure 3. Any number of weather stations can be used, the computations for every grid cell will use the data from the closest station.

The study area

For this study three watershed areas were chosen, one large and two smaller (fig. 4). The Siuruanjoki watershed is 2387 km^2 large and the main subject of the ARSGISIP project. The two smaller areas, Kotioja (18.10 km^2) and Vääräjoki (19.30 km^2), were added to get better understanding of the H3MOD model for calibration (Polojärvi 2001).

The Siuruanjoki and Kotioja basins are situated in the middle Boreal vegetation zone, the Vääräjoki basin lies in the northern Boreal vegetation zone. Main vegetation types are pine and spruce forests, and mixed forests with pine, spruce and birch.

The bedrock is part of the Precambrian Fennoscandian shield, a peneplain with a gently undulating relief, lacking pronounced peaks. Several glaciations left an abundance of fluvio-glacial material behind, moraines, drumlins, eskers and kames. Poor drainage has created many lakes, mires and fens. For example mires and fens cover 35 % of the Siuruanjoki basin.

The climate is characterised by a long cold winter and a short summer. Precipitation falls during all seasons, although slightly more during summer and autumn. Total precipitation is about 600 mm, of which 250 mm during winter as snow. Aproximately 30 % of all precipitation evaporates

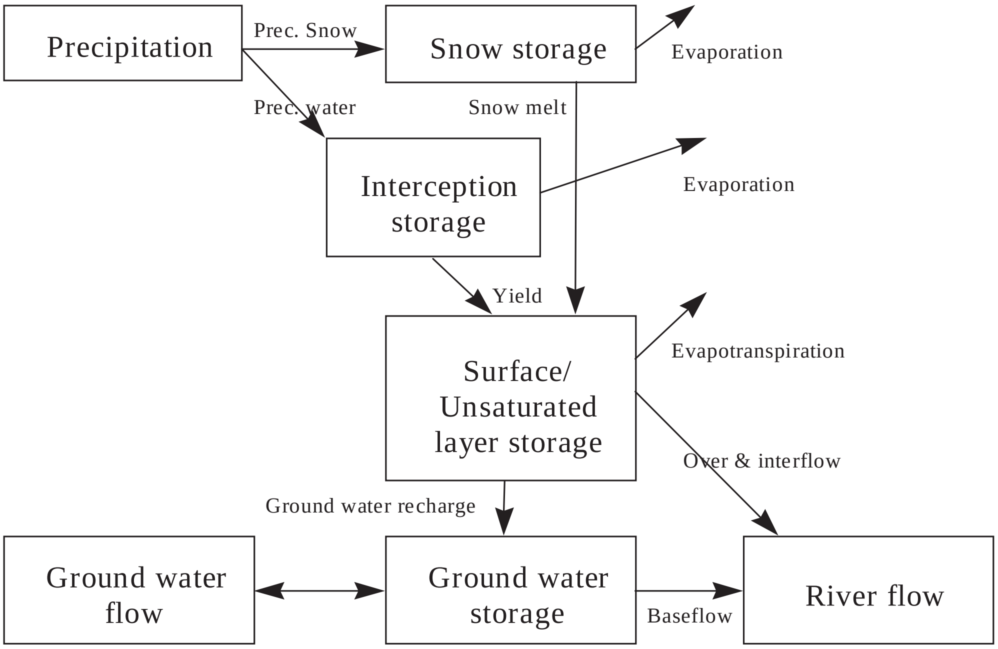


Figure 3. Surface/unsaturated flow component structure.

directly. The length of the growing season is about 150 days. A permanent snow cover is present beteen five to six months of the year (November–April). Temperatures during winter vary form 0 to –30 °C, summers can be rather warm with temperatures between 15 and 25 °C.

Materials and methods

The model constitutes of two main modules, the database generation module or FLD, and the actual model, the VIV module. Basically there are two kinds of input, environmental data and meteorological data, hydrological data is used for calibration and validation. Most important environmental data are land use and relief. The digital elevation model (DEM) is obtained from the Finnish national land survey, the DEM has a horizontal resolution of 25 meter and vertical accuracy of one decimetre. Land use data was derived from Landsat 5 TM images. The Landsat images were processed using the ERMapper 5.2 image processing software. The images were classified using a supervised maximum likelihood classifier, using ground truth data. The resulting image was rectified to the Finnish co-ordinate system and exported to the Arc/Info 8.0 GIS system (Lehtola 1999). Also the river network and watershed boundary were digitised from topographic maps scale 1:20 000, and put in the GIS system.

Meteorological data was obtained from the Finnish meteorological service. For the Siuruanjoki basin we have a temperature (minimum and maximum) and precipitation daily time series for the years 1963 – 1999. The hydrological discharge data for the same period was obtained from the

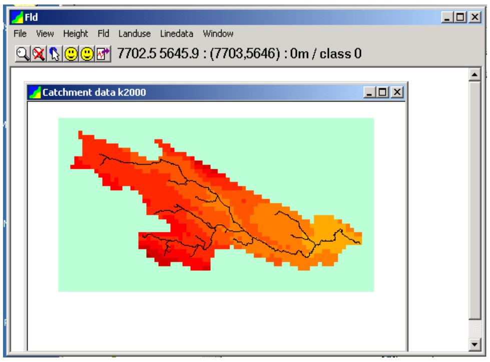
Figure 4. The location of the three study areas; 1 = Siuruanjoki, 2 = Kotioja and 3 = Vääräjoki, and major bio-climatic zones.

Northern Ostrobothnian Regional Environmental Centre (NOREC). For the two smaller basins meteorological data was available only for the years 1990–1999.

After creation of the GIS database, the spatial and non-spatial data had to be imported in the H3MOD hydrological model. As the resolution of the land use data is 30 meter the data had to be resampled. For the Siuruanjoki river a grid resolution of 900 meter was chosen, and for the smaller basins 150 meter. Also the elevation data had to be resampled to the same resolution. As the model at present is not geo-referenced all spatial data is relative and must be of exact the same size. To import the river network and catchment boundary scaling and shifting had to be applied.

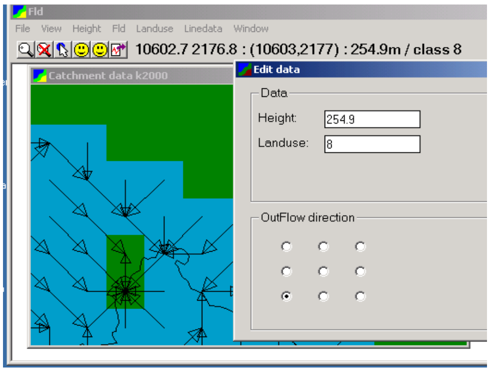
When the land use, elevation and river network are imported correctly the flow of water from every grid cell can be calculated (FLD) (fig. 5). In very flat terrain some manual intervention is needed, this is however relatively easy with the tools provided in the program (fig. 6).

The third step is to get the meteorological and hydrological data in the right format, which is a simple text file with header information, and is easy to do by exporting the data from Microsoft Excel using the space delimited format (table 1). After this step the model is running, although calibration is still to be done to account for the different land use, vegetation and soil parameters.



7702.5 5645.9 : (7703,5646) : 0m / class 0

Figure 5. Input of DEM and river network of the Vääräjoki basin.



10602.7 2176.8 : (10603,2177) : 254.9m / class 8

Height: 254.9

Landuse: 8

○ ○ ○
○ ○ ○
● ○ ○

Figure 6. Correction of FLD network errors.

Table 1. Example of meteorological data file.

```
#name Ranua
#xpos 42000
#ypos 66000
#zpos 154
#timeformat YYYY MM DD hhmm
#var TMIN C
#var TMAX C
#var PREC mm
1963   1   1  1200   -15    -7.8   0.0
1963   1   2  1200   -20    -9.2   0.0
1963   1   3  1200  -20.5  -10.8   0.0
1963   1   4  1200  -24.6   -4.3   0.3
1963   1   5  1200  -26.7   -9.3   0.0
1963   1   6  1200  -24.1   -16    1.1
1963   1   7  1200  -17.1  -12.1   3.4
```

All the spatial data import and manipulation is done in the FLD module of the program, the resulting data is stored in an ASCII file. Running of the actual model is done in the VIV module. Calibration of the land use classes is done in a simple spreadsheet like table. The model has also an optimisation mode, which however is rather slow.

Results

The results of the model are satisfactory, autumn storm runoff, winter base flow and spring floods are predicted well, although intensities of floods are not always correct (R^2 values vary from 0.5 to 0.8). Figures 7 and 8 show the hydrographs for the Siuruanjoki and Vääräjoki basins. The model can predict discharge in any chosen

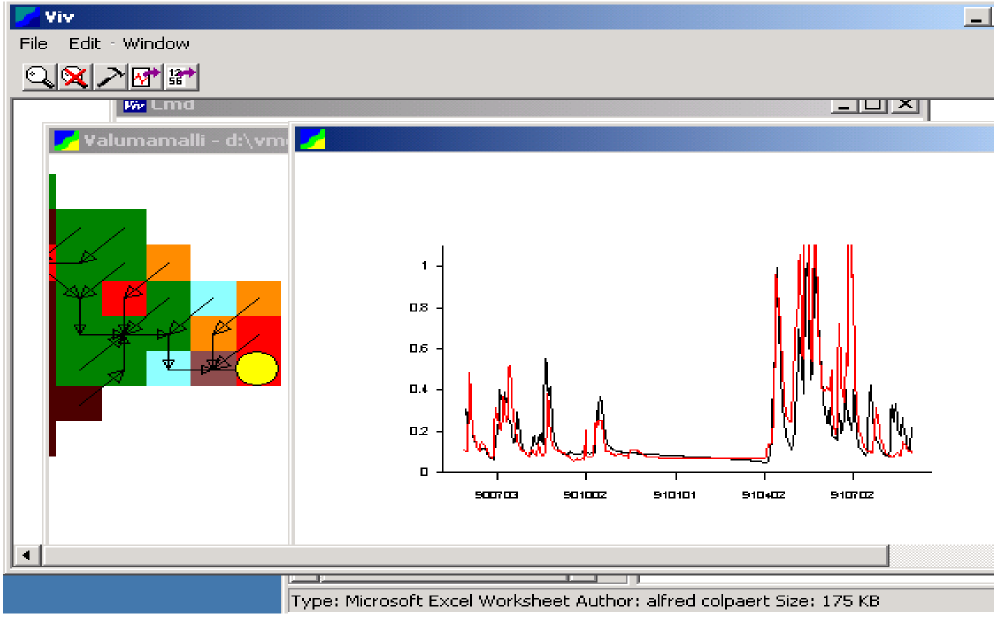


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Figure 7. Output of the model run for the Vääräjoki basin (1.6.1990 to 31.8.1991), the lines are the measured and predicted values (M^3/s). The dot in map marks the location of the point of measurement.

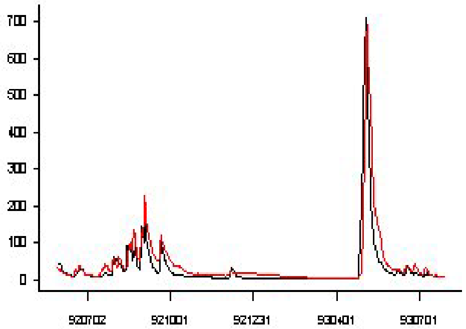

Figure 8. Siuruanjoki basin, output of the model run (1.6.1992 to 30.7.1993), the lines are the measured and predicted values (M^3/s).

Table 2. Numerical output of the model run for the Vääräjoki basin.

```
measurement data from vj9095.vir
prec  =124.691
evap  =49.4362
rflo  =76.4205
qgw   =50.5296
qover =25.4072
in  :75.2544
out :75.9368
r2 = 0.55846
```

place within the catchment area. The yellow dot in the map part of figure 7 is the main outlet of the catchment and the graph shows the discharge at this location. More of these discharge points can be added anywhere in the basin, for example to monitor tributaries. Table 2 shows the outcome of the model run in numerical form. Besides discharge the model can display a wide range of variables, like snow depth, water depth, groundwater recharge, temperature, evapotranspiration etc. From the graph in figure 7 it is seen that some rainstorms during the beginning of summer are missing from the meteorological data. This problem is however related to uncertainties regarding precipitation measurement (More 1976).

Conclusions

Parameterisation of the H3MOD model using satellite image derived land use data is simple, other data like leaf area index still have to be studied. Major factors of uncertainty are the limited number of precipitation measurement points and possible errors in discharge measurement.

The intention is to enhance the model with a water quality module (sediment, phosphorous and nitrogen). For this purpose the predicted values seem to be sufficiently reliable. At present the model is still being developed, and for example the evapotransiration module is still not perfect.

For the Siuruanjoki catchment, with a grid resolution of 900 x 900 meter, 2945 grid cells, the calculation time in a 1500 MHZ Pentium-4 (256 Mt RAM) is one minute 1.2 seconds for a one year simulation (three calculatons per day). For a 120 MHZ Pentium-1 the time for the same simulation was seven minutes 37.1 seconds (40 Mt RAM).

Acknowledgements

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