

# IMPROVEMENT OF RAINFALL-RUNOFF MODELS USING OPTICAL AND RADAR REMOTE SENSING DATA

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## Commission VIII, WG VIII /7

**KEYWORDS:** ERS Data, Soil Moisture, Rainfall, Land Cover, Rainfall-run off Modeling, GIS

### ABSTRACT:

GIS are used for the rainfall-runoff model development and determining its parameters. GIS data comprise soil layer, topography including three dimensional data, and land cover data. Rainfall estimations from remote sensing radar measurements and historical records of rainfall measurement are applied together with hydrometeorological ground station measurements which are collected in several places of each catchment. It is aimed at evaluating precipitation data from point measurements by kriging and conditional stochastic simulation to get the precipitation information layer. Basic hydrological model is extended and combined with other models representing behavior of individual parts of the water balance. More concretely, quasi two-dimensional hydrological model HELP, snow melting model (degree/day) and locally hydrogeological model are used. The Bela and Olse Rivers are pilot study areas in the northern Moravia in the Czech Republic. The water balance is in prevailing part influenced there by the forest stand and agriculture areas. Forest areas and forest soil determine surface water runoff – its time delay and peak, interception, evapotranspiration, accumulation and retention. The forest function depends on forest species, its age, and health. SPOT and ETM+ data were used for land cover determination and a pair of SPOT data for land cover changes. The land cover is a feature class for GIS modeling; land cover changes show the necessity to verify regularly the phenomenon even in areas with relatively constant land cover state in the mountainous Moravia region of the Bela River spring area in the Czech Republic. The ERS-2 data pair enabled us to study changes in the catchment that occurred in the August 10 and September 14 2002 period. The GIS analysis took into account natural conditions of the area, precipitation course measured in point hydrometeorological points, and the ERS changes.

## 1. INTRODUCTION

### 1.1 Objective of the Project

The main objective of the project which is financed by the Czech Grant Agency is to improve rainfall-runoff models with utilization of geographic information systems (GIS), various sources of data (including remote sensing) and processing methods, and to verify suitability of linking and combination of individual hydrological models in selected pilot areas of river catchments. The part of the project is to propose the way of application of these models in practice through the web based system and web services. The practical usage of the final model is a quick processing of the immediate rainfall and the water stream discharge situation, deciding if the state is in fact a flood state which should be managed as the real flood situation including all warranty activities.

### 1.2 Rainfall-Runoff Modeling

Similar demands to rainfall – runoff condition assessment and more accurate weather predictions are required not only for extreme events but also for ecological and water management reasons.

This modeling and weather predictions issuing are performed by CHMI (Czech Hydrometeorological Institute) and watershed managers in the Czech Republic. Modelling is also performed by other authors on individual catchment scale with more

research orientation. Eichler, Kulhavy, Dolezal and Soukup study drainage runoff, agriculture impact and hydrological balance models (Kulhavy 2000), including simulation approaches for drainage runoff assessment (Dolezal 2000). Neruda (2002) used artificial intelligence network approach for the rainfall – runoff modeling, predicting the following day flow using historical flow and precipitation data .

Relations between anthropogeneous landscape changes and flood intensity were assessed by Langhammer (as a result of Evaluation of natural environment changes impact to flood development grant project), methodology of rainfall – runoff conditions in urbanized and industrial areas assessment using combination of classical hydrological methods, mathematical simulations and GIS processing and visualization were studied by Rapantova (2004). Usage of GIS for watershed models, ecological aspects, erosion impacts and sediment transport modeling were studied by Vozenilek (1999). Runoff conditions are affected by various factors, above all by geomorphologic characteristics, soil profile character and condition, cover type, evapotranspiration level and snow cover condition. Evaluation of these factors error prone (error could reach tens of per cent, i.e. snow cover or evapotranspiration). Individual factors are inter-related and cannot be evaluated individually. For example, snowmelt modeling can be performed by various methods (mostly used is degree/day method) (Beven 2001, Chow 1964, Hradek 2002) and Anderson's method (Anderson 1968), whose results are influenced by altitude, terrain morphology, exposure and vegetation cover.

### 1.3 Aim of the Project

Project objective is an improvement of accuracy of rainfall – runoff models with GIS usage, various data sources and its processing procedures and to verify convenience of interconnecting and combinations of individual models in the pilot areas. Project also includes proposal of practical usage of these models performed by web system, offering results of modeling to expert and public administration.

## 2. INPUT DATA

### 2.1 The Study Areas

The project is focused on two catchments – the Bela River and the Olse River.

The Bela River (Biela in Polish) spring is in the northern part of the Hruby Jeseník Mountain 925 m above sea level. It continues through Mikulovice to Poland – to the Głebinowskie Lake, from which outflows into the Nysa Kłodzka River forming a tributary of the Odra River near Lewin Brzanski town.

From the geomorphological view, the area belongs to the Eastern Sudeten, from the climatic point of view it is a slightly warm region. Total annual precipitation is 850 mm, average annual temperature is 7.1°C. The catchment is drained northward to the Baltic Sea.

The Olse River flows from Itebný in Poland into the Odra River in the flat Ostrava region forming the frontier between Poland and the Czech Republic after leaving Poland.

River Catchment		Bela	Olse
Length	all	99 km	56 km
	Czech Republic	83 km	32 km
	Poland	16 km	24 km
Area	all	1118 km <sup>2</sup>	284 km <sup>2</sup>
	Czech Republic	639 km <sup>2</sup>	270 km <sup>2</sup>
	Poland	479 km <sup>2</sup>	14 km <sup>2</sup>

Table 1. Geographical characteristics of the Olse and Bela Rivers

### 2.2 Meteorological Data

The meteorological data were measured by 6 rain gauges (Bílý Kříž, Jablunkov, Lučina, Hradiště, Třinec, Lysá hora) in one hour time intervals. The other precipitation data were derived from meteorological radar. The data were calculated for 14 places from one sq km grid.

### 2.3 Land Cover of the Catchment

Land cover of the catchment is formed by 3 main areas: urban (12,8/72) sq km, agricultural (71,9/318,6 sq km) and forest (185,3/241,4 sq km) according to the land use/land cover CORINE data from 1990 in the Bela/Olse Rivers.

### 2.4 Soil Types

The map of soil classes from different regions of the Czech Republic are in BPEJ codes. The data comprise a map of used homogenous areas; the BPEJ data form a feature class in GIS. The feature class attributes are embedded in 8-numbered code characterizing climate region, main soil unit, gradient of slope, soil skeleton, boulderity (mostly 0) and soil depth. They are processed in 1 : 5000 scale. Four “soil” type areas have different 3-number coding - bare land, water, quarry, and forest.

### 2.5 DEM of both Catchment

Digital elevation model was derived from 1 : 25 000 scale contour lines using TIN and processed into the grid form.

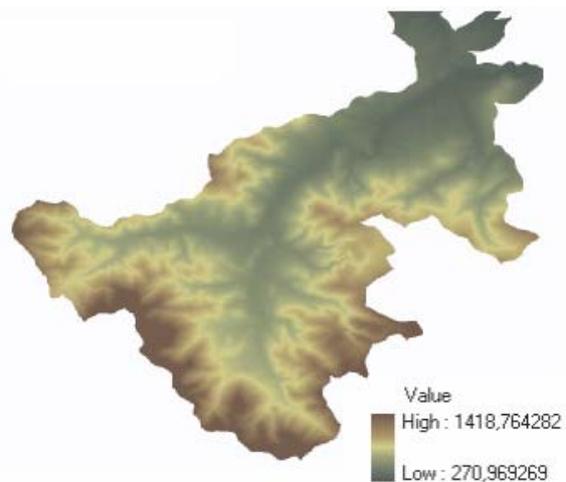


Figure. 1. Digital elevation model in 25 x 25 m grid of the Bělá River Catchment.

### 2.6 Remote Sensing Data

Three remote sensing data types were used for. The first detailed data processing was performed from ETM+ Landsat data, a pair of SPOT data and a pair of ERS-2 data formed the whole group of remote sensing data for both catchments.

**2.6.1 ETM+ Landsat data:** The data (FRAME 25, TRACK 189) from June 2000 and July 2002 were preprocessed and classified. The list of classes was adapted from classes defined by the European standard – CORINE classes. The classes are split into the 3 level classification. The CORINE information level available for the whole Europe is less detailed than the classification.

The land cover classes were agriculture areas, pastures, discontinuous urban fabric, peat bogs, moors, mixed forests, broad-leaved forests, coniferous forests, water streams, water basins.

	Acquisition date	scene	MS/P
the Bela River	07/09/02	072 - 249	Spot 4, MS - HRV1
	07/21/02	071 - 249	Spot 5, MS -HRG2
	07/21/02	071 - 249	Spot 5, P-HRG2
	08/21/02	068 - 248	Spot 5, MS -HRG2
	08/21/02	068 - 248	Spot 5, P-HRG2
the Olse river	04/04/04	070 - 249	Spot 5, MS -HRG1
	07/21/02	071 - 249	Spot 5, MS-HRG2
	07/21/02	071 - 249	Spot 5, P-HRG2

Table 2. List of SPOT image data used for the and cover change detection (P – panchromatic, MS – multispectral data. HRV1, HRG1, HRG2 – SPOT scanners)

**2.6.2 SPOT image data:** The data list is in table 2. After preprocessing, the data were georeferenced and used for the land cover change detection between 2002 and 2004.

**2.6.3 ERS-2 image data:** List and details of the ERS -2 data are in table 3. The radar data were used for the moisture change detection, which occurred between two time layers – before the flood and after it with a 34 days’ interval.

**2.7 Flood events and radar data**

The regular water level measurements showed individually the following dates with floods on both rivers. The ERS-2 data were selected to cover the period of these events (see table 4); three floods are imaged by a pre- and post imagery. One (shadowed in table 3) is described only by two post-data.

river	flood date	ERS -2	ERS -2
Bela	08/12/2002	8/10/2002	9/14/2002
	04/25/2004	5/1/2004	6/5/2004
Olse	07/19/2002	7/22/2002	8/26/2002
	08/24/2005	7/27/2005	8/31/2005

Table 3 . Flood events in both river catchments and appropriate ERS-2 image data

**3. METHODOLOGY**

The methodology was focused on rainfall-runoff characteristics of both catchments important for determination of their influence on water capacity/runoff after precipitation. The data recognizing these characteristics are or are not temporarily constant. There are only persistent data which can be implemented into GIS for analyzed areas as a constant part of the model. The other data - “non-stationary” - have to be regularly updated.

The change detection is based on the principle that radar data with steep incidence angles are sensitive to the moisture content of the surface layer and less sensitive to other physical features – surface roughness. The 34 days’ period is short enough to be regarded as relatively unchanged in the vegetation cover. The idea is more reliable in forest areas than in agricultural areas. Therefore the changes especially in the forest cover can be supposed to be an impact of the soil moisture change. No ground measurements were performed for the analyzed areas.

**3.1 Preparation of Data temporarily varying**

Non-stationarity can be found at land cover data (months’ scale) and hydrological data.(hours’scale)

**3.1.1 Preparation of Land Cover data:** The hydrological data are measured and collected everyday from many places in the country. However, the land cover data updating is performed in years’ intervals.

The first step to analyze the land cover change development was to compare two data sources for land cover:

- o GIS vector data of Land Use & Land Cover (LU/LC) CORINE database being a European standardized layer – with around 10 years’ updating period in 1:100 000 scale
- o Land cover evaluated from the latest remote sensing data.

The land cover development was analyzed from two time levels of LU/LC CORINE data. It was found using GIS tool for overlaying that changes in the Olse River reached 0,8 % of the catchment area and 0,1 % in the Bela River Catchment area from CORINE 1990 to CORINE 2000.

To verify the results, changes between 05/14/2000 and 8/2/2002 Thematic Mapper data were determined. The two years’ period test showed 18,9 % of changes in the Bela River Catchment area. The main difference is caused in prevailing part by a certain generation of mapped areas in the CORINE database.

Recommendations:

- o Remote sensing data are the best tool for the land cover change detection
- o Land cover updating should be performed several times per year – at least in spring, summer and autumn to detect not only seasonal changes in agricultural regions but also other ones.

The problem is that the decision to perform land cover updating is more or less a personal decision – there is no systematic tool, or measurements.

**3.1.2 Preparation of Hydrological Data:** Hydrological data are measured continuously and were processed with one hour time resolution in meteorological stations. However, the number of them is not sufficient. The precipitation and temperature data for the Bela River (269,9 sq km) and the Olse River (635,6 sq km) catchments are collected in 6 meteorological stations. The other data for the precipitation were from the ground radar measurements processed to a regular grid form.

The data from six stations interpolated to cover each catchment have insufficient density and therefore a meteorological model especially for the temperature behavior related to the terrain morphology will be processed to improve the temperature interpolation.

Recommendations:

- o In case of low density measured hydrological data another data source should be found to improve the input data quality – other measurements (ground data in our case), or modeled data (temperature data in our case).

### 3.2 Preparation of Time Independent Data

Soil and DEM data can be regarded as data with constant state for modeled regions.

**3.2.1 Preparation of Soil Data:** Soil maps are used as vector GIS layers ready for any immediate usage. However, the soils are classified into 78 detailed soil classes. For the first GIS evaluation, only aggregated classes according to their skeleton content and soil depth were used. The classifications derived from these characteristics are in tables 4 and 5. The skeleton definition depends on gravel content with 4 – 30 mm size and rock content with size greater than 30 mm.

Class	description
0	Without skeleton, with skeleton less than 10 %
1	Low skeleton less than 25 %
2	Mid skeleton less than 50 %
3	High skeleton higher than 50%

Table 4. Soil type classification according to the skeleton content

class	Soil depth
0	Deep – depth more then 60 cm
1	Mid – depth 30 – 60 cm
2	Shallow – depth less than 30 cm

Table 5. Soil type coding according to the soil depth

The soil classes were created by real combinations of the soil depth and skeleton content yielding 10 classes (see table 6).

class	skeleton category	depth category
0	0	0
1	0-1	0-1
2	1	0
3	2	0
4	2	0-1
5	1	2
6	2	2
7	0-1	0-1
8	2-3	0-2
9	0-3	0-2

Table 6. Soil classes created from skeleton content and soil depth categories

**3.2.2 Processing of DEM data:** DEM data were processed from contour maps using TIN to define areas with predetermined slope ranges to study relations among individual characteristics and changes found in ERS – 2 data. The GIS slope classes were aggregated into 4 ones: 0 – 5°, 5 – 15°, 15 – 30°, 30 – 90°.

### 3.3 SPOT data processing

SPOT data were used for the soil moisture change detection. A pair formed by 07/09/02 and 07/21/02 multispectral SPOT data was used for the analysis. Band subtractions for three band pairs (with the same wave length ranges) were calculated.

The changes were analyzed individually for land cover classes. The land cover classes were adapted from LU/LC CORINE and are in table 7.

class number	class name
1.1	Industrial and Urban areas
1.2	Roads
1.3	Rail networks
2.1	Permanent crops
2.2	Growing crops
2.3	Fruits trees and berry plantations
2.4	Non-irrigated arable land
2.5	Complex cultivation patterns
3.1	Coniferous forest
3.2	Mixed forest
4.1	Inland Marshes
5.1	Water bodies
6.1	Clouds
6.2	Clouds shadow

Table 7. List of final land cover classes determined for the change detection between 07/09/2002 and 07/21/2002

The detailed analysis was performed for change determinations. Complex cultivation patterns comprising more sparse vegetation showed changes in subtraction channels. The rest classes were not suitable to for the changes to be found. Their vegetation cover has not changed during the 12 days.

### 3.4 ERS – 2 data processing

The changes were analyzed from ERS – 2 also by band subtraction. The subtraction channel values depicted important differences. Ten classes were created from them where the first up to the sixth classes represented negative values (change) and the eighth and ninth positive ones. The pixel with values around zero formed the seventh class. Ten classes covered the whole pixel value range in the subtraction channel split into the same value range groups.

Relations between the classes and natural conditions serve for the future detailed analysis of moisture change detection.

The changes were analyzed from the point of view of two main land cover classes – forest and agricultural area where the slope, soil type and distance to a water stream are shown.

## 4. RESULTS

The following two graphs compare forest and agricultural areas with slope classes.

Figure 2 shows that three slope classes (0 – 5°, 5 – 15° and 15 – 30°) are present in similar area sizes in all change classes and the fourth class (slope higher than 30 %) forms less than 2 % of area in all change classes of forests. However, the 1<sup>st</sup> slope class (0 – 5°) forms nearly 75 % of all change classes in agricultural areas.

The ratio of the 1<sup>st</sup> to 2<sup>nd</sup> and 3<sup>rd</sup> classes for forest is a constant value for all change classes (equal to 1). The ratio of the 1<sup>st</sup> to

the 2<sup>nd</sup> classes is also a constant value for all change classes in agriculture areas. .

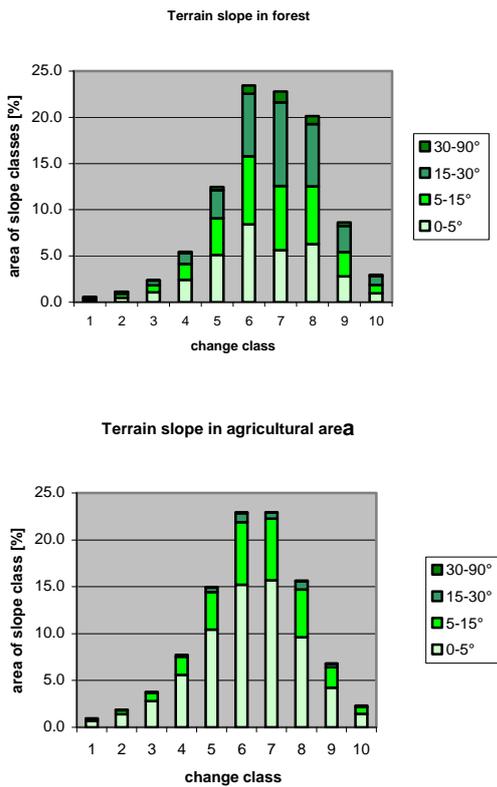


Figure.2. Comparison of slopes in forest and agricultural areas in individual change classes

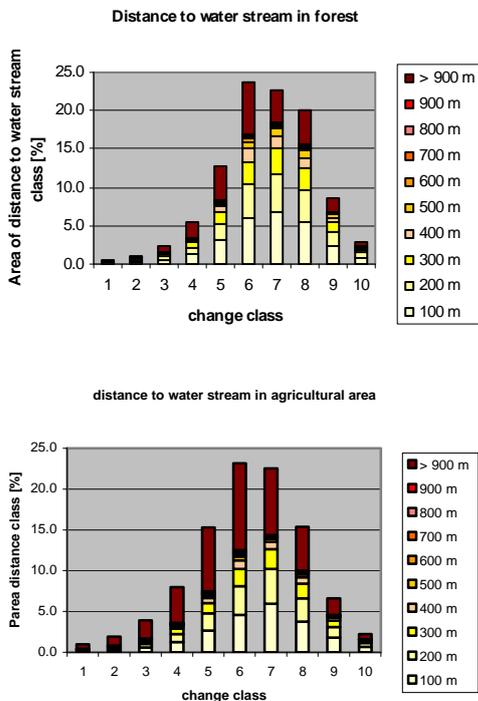


Figure.3. Graphs of distances to water streams for the change classes

The distance to water stream influence is shown in figure 3. The graphs in figure 3 show that the distance to water streams does not play any important role in the change classes. The mutual ratios of the distant classes within the change ones are similar; in negative change classes (1<sup>st</sup> to 6<sup>th</sup>), the longest distance seems to be a signature showing a certain value due to having the largest areas in the 1<sup>st</sup> – 6<sup>th</sup> classes.

The last influence in the first step of evaluation was the skeleton content and soil depth. Their relation between skeleton content and soil depth versus the change classes is on graphs in figure 4. The mutual ratios of individual soil type classes in one change class is quite inhomogeneous and shows the highest influence on the change classes.

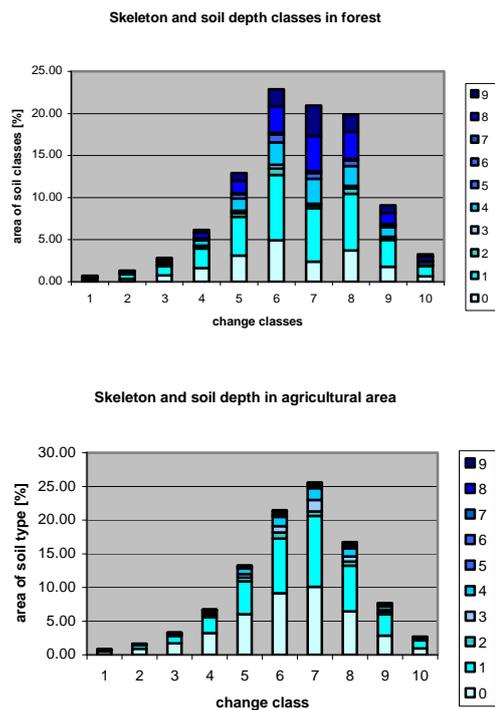


Figure. 4. Graphs of soil classes related to the change classes in forest and agriculture areas

### 5. CONCLUSION

The remote sensing data processing and GIS evaluation proved that individual characteristics have relatively small direct influence to the radar data changes calculated from 2 ERS – 2 images covering 34 days' with a flood event in between. All classes of all characteristics occur in all change classes. The distance characteristic shows that dryer areas (negative changes) are half situated in distances longer than 900 meters and their size sinks seriously in wetter change classes (positive ones).

The relation among the change and all characteristics is in fact more complex and therefore combinations of all characteristics must be taken into account. There are 10 (change classes) x 4 (slope classes) x 10 (distance to water stream classes) x 10 (soil classes) x 2 (land cover - vegetation, forest) possible theoretical states for pixel segments in our case studies. The analysis will be processed in GIS by overlaying of individual feature class. The overlaying will determine homogenous areas with more detailed information stored in all aggregated classes which will

be compared to precipitation and temperature layers where the layers comprise not only sum of all precipitations, but also their course during the analyzed period.

The discharge measurements in rivers and hydrological models will be used for the water surface outflow, water capacity and finally determined soil moisture; the following equations will be used for the final analysis:

$$\text{moist change} = \text{moist}_1 - \text{moist}_2 - \text{evapotranspiration} \quad (1)$$

$$\Delta_{\text{moist}} = f(\text{precipitation}(t), \text{temperature}, \text{soil type}, \text{land cover}, \text{distance of water stream}, \text{slope}) \quad (2)$$

where  $\text{moist}_i$  - soil moisture during the ERS measurements

$\text{precipitation}(t)$  - precipitation course between two measurements.

$\text{moist change}$  is an input parameter to water surface outflow model calibrated by a river discharge.

The model is quite complicated and fits only to the very one catchment. The final goal is not to determine the real soil moisture from radar data, but change values related to the soil water capacity. However, it is still relatively difficult to determine the evapotranspiration course for various land cover classes.

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## ACKNOWLEDGEMENT

The research is a part of the Czech Grant Agency project No.205/06/1037 „Application of Geoinformation Technologies for Improvement of Rainfall-Runoff Relationships“.