# Two different approaches of LULC and their impact to rainfall-runoff modelling

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**Abstract.** Land use and land cover (further in the text as LULC or LC) determine hydrological transformation of the atmospheric precipitation to a catchment. There are two ways how land use and land cover take part in a rainfall-runoff process (further in the text as RR process). The first, it is direct land use and land cover participation in RR relationship, such as interception and evapotranspiration. The second, more significant, represents land use and land cover as a protecting function of soil cover, a factor, where the essential part of precipitation transformation plays role.

There are many research activities, historical and ongoing, in the field of LULC and its relationship to rainfall-runoff modelling; e.g. for the Czech Republic there are works of researchers such as Kantor, Zeleny, Jarabac, Chlebek, for Europe Benecke, Heuveldop, for Russia Rajev, Bitjukov. In the Czech Republic there are small experimental catchments (e.g. Cervik and Mala Raztoka in Beskydy mountains). Mostly, they are devoted to analysis of forest cover impact (especially differences between Spruce and Beech trees) to RR process.

These issues appreciate geoinformation technology capabilities, especially integration of Geographical Information System (GIS), Remote Sensing (RS), and Hydrological Modelling (HM) tools, where such connection allows comprehensive insight into these matters. GIS supports pre- and post- processing, RS provides actual/historical information, and HM allows description of investigated phenomena.

There are many aspects, which can influence the outputs of RR model: interpolation methods, snow melting model, RR modelling methods, digital elevation model, land use and land cover, etc.

This work investigates LULC influences on RR process in a landscape. In this scope, two LULC datasets where tested; CORINE LC 2000 and LC information extracted from LANDSAT ETM+ imagery (14MAY2000, 2AUG2000, 24MAY2001, 4MAY2002, 5JUN2002) (further in the text referred as 'HYDRO LC [etm*mmyy*]'). One can admit that CORINE LC dataset sourced out LANDSAT as well, but in this case CORINE source data included also SPOT imagery and were processed differently than HYDRO LC [etm*mmyy*]. Add to that, both datasets are based on different classification system (nomenclature), yet similar at 1st class level.

As RR modelling method, the CN-curve method was used as to the fact that this method seems to be the most transparent one when it comes to relationship: CN-curve number – LC – hydrological soil group (HSG). Significant and large land cover changes signify CN-number modification and with that an alternate HM outcome can be predicted. Changes in CN numbers can track back LC changes taking place in a landscape.

The RR model was calibrated using CORINE LC 2000 as LC and HYDRO LC [etm*mmyy*] datasets were used as alternatives. As an area of interest, Bela catchment (Jeseniky) and Olse catchment (Beskydy) were used for such testing.

So then, two different datasets, one RR modelling method, two catchments, the assumption states for low changes in the modelling outcomes, some shifts are foreseen in case of selected episodes of significant precipitation. However, any differences in the outcome may signify frailty of the model, how fragile information the model provides, and add to that it means that certain parts of the LC don't overlap geographically and it leads to assumption that LC changes influence RR processes.

**Keywords:** Remote Sensing – GIS – Hydrological Modelling, CN-curve numbers, rainfall-runoff process, LULC, CORINE LC 2000

## 1 Introduction

In recent years, we have witnessed distinctive hydrometeorological events, accompanied with big variations of the temperature, which reflect changes in water regime of the landscape. Water cycle is complex phenomena and should be considered as such. To better understand hydrological processes in the landscape, hydrological and hydrogeological models have been built; some models (meteorological + hydrological + hydrogeological + LULC change) have been integrated to pursue the complexity of the research.

Institute of Geoinformatics (VSB- Technical University of Ostrava) was involved in a project of the Grant agency of the Czech Republic „Application of Geoinformation Technologies for Improvement of Rainfall-Runoff Relationships“ (205/06/1037). The project main objective encompassed improvement of RR models using geoinformation technology, diverse data sources and differences in their processing; add to that, it dealt with verification of the applicability of particular models combination and integration. In the scope of the project, the tasks researched aspects, which influence model’s outcomes: interpolation method (precipitation data, as input to the model, could be biased/influenced), RR modelling method, snow model (accumulation, spring snow melt), digital terrain model (influences catchment schematisation), LULC (see chapter 1.1).

This work has focused into LULC as one of the influencing assets to RR processes in the landscape.
The possibility of GIS, RS and HM integration enhances a complex study of the researched subject. Within this union,

- hydrological modelling stands for a tool supporting the connection of LULC & RR process through CN value method. The method allows direct and transparent tracking of CN-LC-HSG association (CN value – Land Cover – Hydrological Soil Group);
- GIS proposes variety of tools for pre- and post- processing, as well as analyses carried out under the LULC influence assessment;
- and remote sensing is an efficient source of actual data providing land cover information.

LULC data together with other data (e.g. precipitation, DTM, snow cover) create information base for hydrological models.
Nowadays, we use several well-known data sources such as CORINE Land Cover (CLC00, CLC2000, CLC2006). The component “land cover” of the CORINE program (Co-ordination of Information on the Environment) aims to gather information related to environment on certain priority topics for the European Community (other programs are: Corine Air, Corine Coastal Erosion, Corine Biotopes, etc). The smallest surfaces mapped (mapping units) correspond to 25 hectares. Linear features less than 100 m in width are not considered. The scale of the output product was fixed at 1:100.000. Thus, the location precision of the CLC database is 100 m. CLC was elaborated based on the visual interpretation of satellite images (SPOT, LANDSAT TM and MSS). Ancillary data (aerial photographs, topographic or vegetation maps, statistics, local knowledge) were used to refine interpretation and the assignment of the territory into the categories of the CORINE Land Cover nomenclature. the CORINE LC inventory is composed of 44 classes covering the agricultural as well as the urban and natural sector. The hierarchical structure of the CLC nomenclature allows the original information to be combined in various ways in order to perform specific analyses in different thematic fields. [13]

For the purpose of the above mentioned project, nomenclature (HYDRO LC), suitable for investigating hydrological issues related to land cover, was produced. The designed schema (HYDRO LC) states of four levels, each dedicated to spatial scale, first level copies CORINE LC nomenclature, second level contains 8 classes and follow usage of high resolution Earth Observation (EO) data (e.g. LANDSAT, ASTER), so as third level (17 classes), fourth level includes 39 classes and is used for more detailed study using very high resolution EO data. Level four needs further ancillary data such as field investigation (mostly for Land use determination).

The investigated issue is based on the assumption of the LULC influence on RR processes. The influence has been analysed based on a method, which analyses two different LC data sources used for CN value generation; CORINE LC as original one (used for model calibration) and alternative ones. The alternative datasets (HYDRO LC [etm*mmyy*]) were derived from LANDSAT ETM+ imagery. For comparison phase, HYDRO LC (etm0800) was used (LAMDSAT ETM+ from 2 August 2000) to follow the CORINE LC 2000 database reference year.

Two investigated areas were selected; Bela catchment (the Jeseniky Mountains) and Olse catchment (the Beskydy Mountains). Both catchments are the transboundary ones (national border with Poland). The Bela River leaves Czech Republic in Mikulovice and it is a tributary of the Nysa Klodzka River in Poland. The Olse River is tributary of the Odra River that flows to Poland. Both rivers drain water from the Czech Republic through Poland to the Baltic Sea.

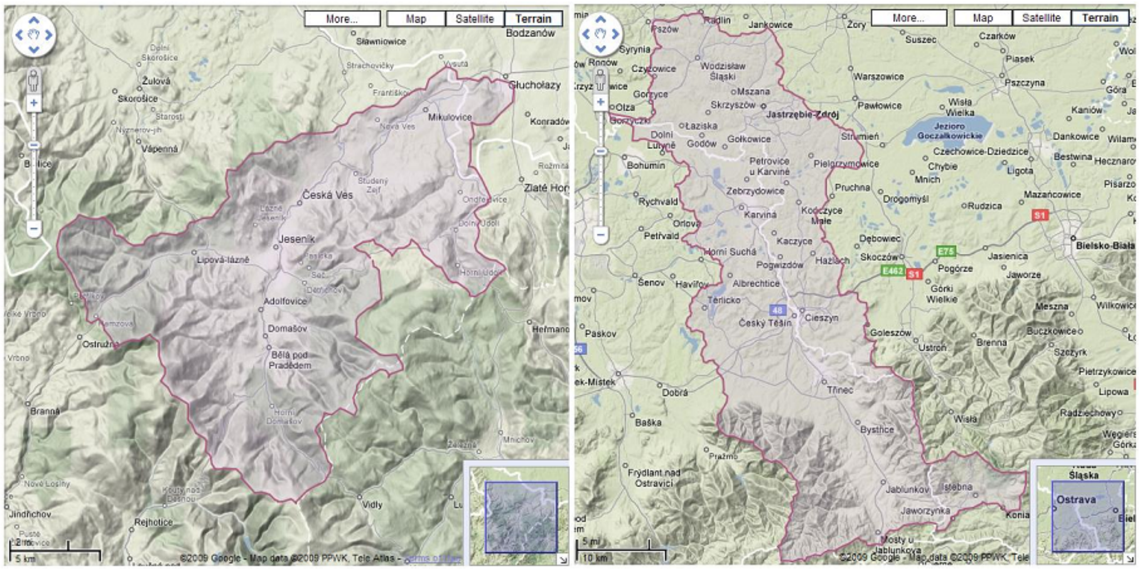



**Fig. 1** Bela (left) and Olse (right) catchment area [background/reference map's source: © Google Maps, 2009]

## 2 Land use and land cover & rainfall-runoff process

Before diving into the analysis method and the results, it is necessary to explain LULC & RR process relationship. Land cover type to be considered here includes forest stand, grass lands, agricultural areas, and urban areas.

Within a frame of the LC & RR process, several research studies have been carried out. As regards Czech research realm, the studies' interest is mostly directed towards forest land cover, especially diverse influence of beech and spruce trees, and it is usually bound with small experimental forested catchments; e.g. Valek, Zeleny, Jarabac, Chlebek, Kulhavy, Kovar, Maran and Lhota, Cernohous, as mentioned in [5]; Recent studies involve authors such as Unucka and Adamec [10, 11], Langhammer [7, 8]. The world research field holds many other studies, as Kantor and Sach [5] summarize, probably the first classical study represents Engler in [5], followed by Brechtel, Hoyningen-Huene, Benecke, van der Ploeg, Mitscherlich, Schmaltz, Rajev, Bitjukov and others.
Considering the documented findings, Kantor and Sach [5] summarize following statements:

- Surface runoff and subsequent erosion in forested areas are irrelevant (high infiltration ability, etc.), thus forest play significant attenuating mean of flood events in the landscape.
- From the point of view of ecological sustainability and safe production, there is high priority of forest management to maintain mixed forest areas (thus the fact of deciduous trees and their less ability of maintain precipitation during non-vegetative season).
- The forest soil body has its capacity and as the findings revealed the threshold seems to be 150-200 mm precipitation.

The function of the forest during RR process is dependent on the age, structure, and health of the forest stand.
As Langhammer [7] states, the basic LULC changes, which influence RR process, include:

- Deforestation (especially in spring areas where interception plays important role)
- Intensive agricultural management (e.g. meadow, pasture, forest change into cultivated land; especially into monoculture)
- Landscape urbanization (impervious paved surface where surface runoff prevails)
- Land industrialization (change of natural hydrographical network)

Grass lands, as Rychnovska [9] points out, has 10% higher porosity than arable land, which results in better retention and infiltration capabilities. Capabilities, as such, vary according to grass type and its organic matter content.

Arable lands have very unstable hydrological characteristics. It is influenced by seasonal porosity, micro-relief structure, type of cultivated crop, and agro-technical management (tillage, crop cycle, etc.). As it is stated in [12], the influence as well includes melioration, hydro-melioration, field division etc. According to [9], cereal fields and manually cultivated fields show quite high infiltration ability contrary to mechanical cultivation. The least infiltration capacity proves corn and lucerne fields together with bare soils having surface layer (crust) created after intensive rainfall.

Urban areas' main role in RR process could be related to 'very–quickly–direct–runoff' (system of roofs, canalization, and drainage). As Kulhavy and Kovar address in [6], such lands have minimal accumulation, retention and infiltration ability with a low hydraulic roughness of the surface.

## 3 Classification system HYDRO LC

A land cover classification scheme was created to support the investigation of LC effects on RR process. Designed schema (Hydro LC) states of four levels, each dedicated to spatial scale, first level copies CORINE LC nomenclature, second level contains 8 classes and follow usage of high resolution EO data (e.g. LANDSAT, ASTER) so as third level (17 classes), fourth level includes 39 classes and is used for more detailed study using very high resolution EO data. Level four needs further ancillary data such as field investigation (mostly for Land use determination).
The schema was designed to provide as direct link as possible to CN values. The link is established through hydrological soil types expressing second dimension to land cover (see Fig. 2) as an example of HYDRO LC level 2 link with CN values.

| u2 | u2_code | HSG | HSGL2 | CN |
|---|---|---|---|---|
| Zástavba a městská prostranství | 11 | A | A11 | 64 |
| Zástavba a městská prostranství | 11 | B | B11 | 77 |
| Zástavba a městská prostranství | 11 | C | C11 | 84 |
| Zástavba a městská prostranství | 11 | D | D11 | 87 |
| Komunikace | 12 | A | A12 | 82 |
| Komunikace | 12 | B | B12 | 88 |
| Komunikace | 12 | C | C12 | 91 |
| Komunikace | 12 | D | D12 | 93 |
| Holá půda, pastviny, louky, sady | 21 | A | A21 | 56 |
| Holá půda, pastviny, louky, sady | 21 | B | B21 | 73 |
| Holá půda, pastviny, louky, sady | 21 | C | C21 | 82 |
| Holá půda, pastviny, louky, sady | 21 | D | D21 | 86 |
| Řádkové plodiny a pícniny | 22 | A | A22 | 63 |
| Řádkové plodiny a pícniny | 22 | B | B22 | 74 |
| Řádkové plodiny a pícniny | 22 | C | C22 | 81 |
| Řádkové plodiny a pícniny | 22 | D | D22 | 84 |
| Lesy | 31 | A | A31 | 30 |
| Lesy | 31 | B | B31 | 55 |
| Lesy | 31 | C | C31 | 70 |
| Lesy | 31 | D | D31 | 77 |
| Křoviny | 32 | A | A32 | 35 |
| Křoviny | 32 | B | B32 | 56 |
| Křoviny | 32 | C | C32 | 70 |
| Křoviny | 32 | D | D32 | 77 |
| Vodní toky | 51 | W | W51 | 100 |
| Vodní plochy | 52 | W | W52 | 100 |

| u2 | u2_code | A | B | C | D |
|---|---|---|---|---|---|
| Zástavba a městská prostranství | **11** | 64 | 77 | 84 | 87 |
| Komunikace | **12** | 82 | 88 | 91 | 93 |
| Holá půda, pastviny, louky, sady | **21** | 56 | 73 | 82 | 86 |
| Řádkové plodiny a pícniny | **22** | 63 | 74 | 81 | 84 |
| Lesy | **31** | 30 | 55 | 70 | 77 |
| Křoviny | **32** | 35 | 56 | 70 | 77 |

| | |
|---|---|
| u2 | level 2 |
| u2_code | level 2 code |
| HSG | hydrological soil group |
| HSGL2 | HSG and LC level 2 combination |
| CN | CN value |

**Fig. 2** HYDRO LC level 2 and the CN link through Hydrological Soil Group (HSG)

## 4 Analysis method

The analysis was carried out with the idea compare two LULC data sources as HM inputs for CN value determination: CORINE LC 2000 and classified LANDSAT ETM+ based on HYDRO LC classification

schema. The LC-HSG association with CN value was done using LULC data, hydrological soil group data, sub-catchment delineation, and a look-up table with CN – LC – HSG combination.
CORINE LC 2000 was used for model calibration for original calculations, HYDRO LC [etm0800] served for alternative CN values generation and their use for simulated calculations in RR model of Bela and Olse.
Regarding transboundary catchments character, HSG information was extracted from two sources (Czech and Polish), which needed to be harmonized (graphic and attribute parts). Czech HSG data were drawn from the Estimated Pedologic-Ecological Units (EPEU, in Czech 'BPEJ'). Polish HSG data were provided by the Institute of Soil Science and Plant Cultivation (IUNG, http://www.iung.pulawy.pl).
Subcatchments were produced during catchment schematization process. Both catchments resulted in 47 subcatchments (see Fig.3). RR models are calibrated for precipitation episodes September 2007 (Olse) and August 2002 (Bela); they were generated within the framework of the project „Application of Geoinformation Technologies for Improvement of Rainfall-Runoff Relationships“ (205/06/1037) at the Institute of geological engineering at VSB – Technical University. The episode from August 2002 is the closest one to the reference date of the both LULC sources. Although Olse episodes (September 2007) is 5 years off the date, the investigation is worth pursuing as it is based on comparison of HYDRO LC [etm0800] to original CORINE input.
The look-up tables with CN – LC – HSG combination were produced based on the information given by Hradek&Kurik [3] and HEC-HMS guide book [2].

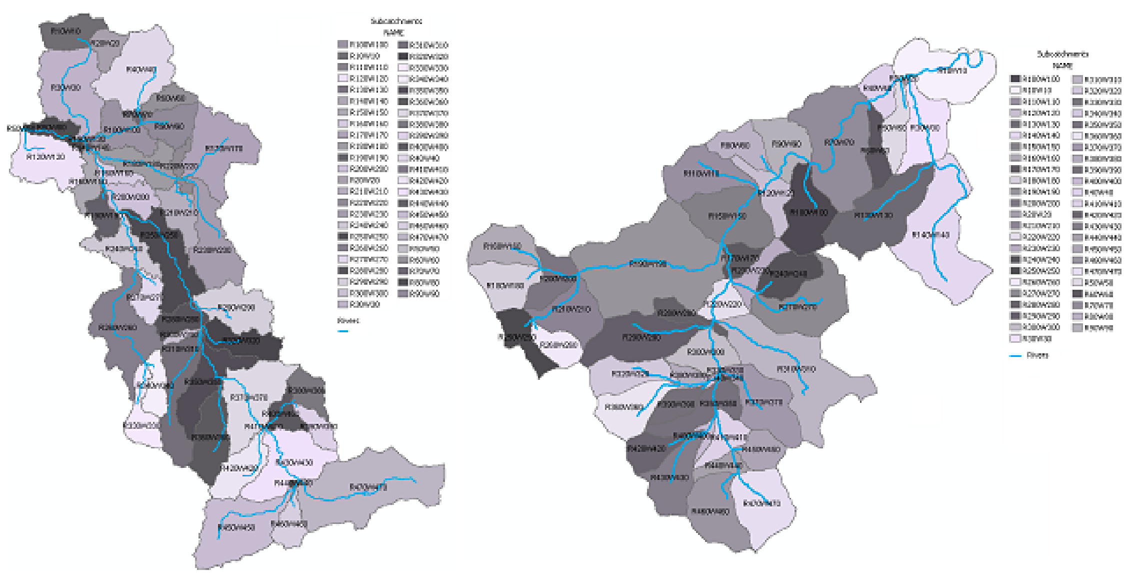


**Fig. 3** Olse and Bela catchment division – each counts 47 subcatchments

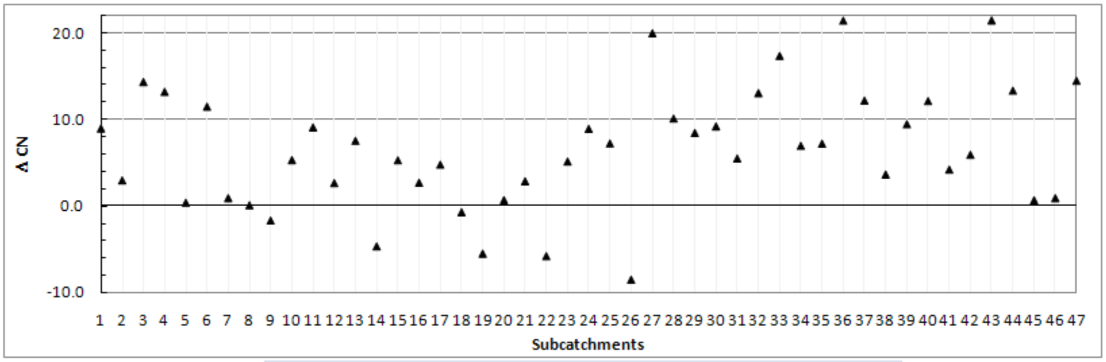
## 5 Results and conclusions

CN values express ratio of surface and hypodermic runoff; they indicate probability of the runoff type. [4]
The higher CN value, the higher probability that the surface runoff occurs. In terms of the difference in reference CN values (CORINE) and alternative CN values (HYDRO LC), it can be stated that:

- Negative change (increase of CN value) leads to a higher probability of surface runoff then in the original state and analogically it is possible to trackback land cover change and decrease of its soil hydrological condition.
- Positive change shows low probability of surface runoff.

Following pictures (Fig. 4, 6) presents CN value change for Bela and Olse subcatchments; the table in the picture depicts the subcatchments, which alternative CN value is higher then |10|. This threshold was set based on the assumption where each LC – HSG combination has minimum and maximum CN value according to soil hydrological conditions (good – min, bad – max). This interval never exceeds 10. Thus, the change value |10| and higher can prove land cover type change, independently form soil hydrological condition change.

As you can see, in case of Bela (Fig. 4), the change is positive and it is possible to conclude the obvious decrease of the surface runoff (see Fig.5) and therefore, it indicates a land cover change or mismatch of the LCs in both datasets. Such a traceable change could be, however, positive in terms of protective measures when it comes to RR process optimisation in the landscape.




Bělá

| ID in the Graph | Subcatchment | CORINE | HYDRO LC [etm0800] | Δ | Zvýšení/Snížení pravděpodobnosti povrchového odtoku | Plocha [km2] |
|---|---|---|---|---|---|---|
| 3 | R110W110 | 67.6 | 53.2 | 14.4 | Snížení | 7.078 |
| 4 | R120W120 | 75.2 | 61.9 | 13.3 | Snížení | 3.916 |
| 6 | R140W140 | 77.4 | 65.9 | 11.5 | Snížení | 15.886 |
| 27 | R330W330 | 82.6 | 62.5 | 20.1 | Snížení | 0.096 |
| 28 | R340W340 | 82.8 | 72.7 | 10.1 | Snížení | 0.287 |
| 32 | R380W380 | 73.7 | 60.6 | 13.1 | Snížení | 1.354 |
| 33 | R390W390 | 74.5 | 57.1 | 17.4 | Snížení | 2.845 |
| 36 | R410W410 | 75.2 | 53.7 | 21.5 | Snížení | 3.257 |
| 37 | R420W420 | 72.4 | 60.2 | 12.2 | Snížení | 3.671 |
| 40 | R450W450 | 70.6 | 58.4 | 12.2 | Snížení | 3.184 |
| 43 | R50W50 | 72.3 | 50.7 | 21.6 | Snížení | 3.502 |
| 44 | R60W60 | 69.7 | 56.3 | 13.4 | Snížení | 2.927 |
| 47 | R90W90 | 81.6 | 67.1 | 14.5 | Snížení | 5.419 |

**Fig. 4** CN value change (original vs. alternative) for Bela subcatchments

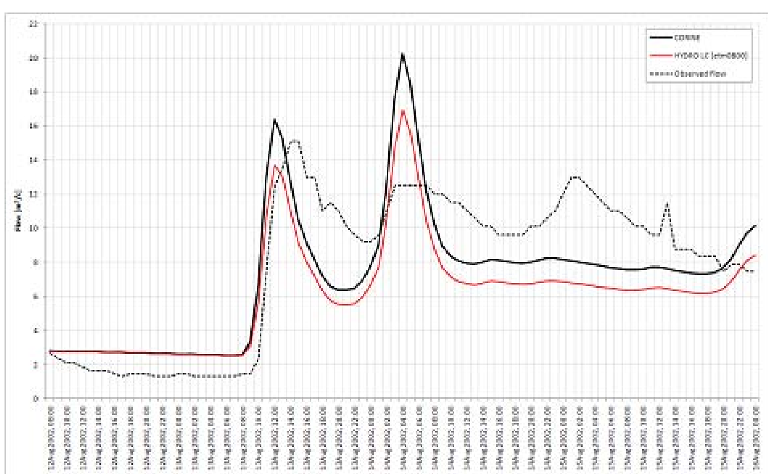
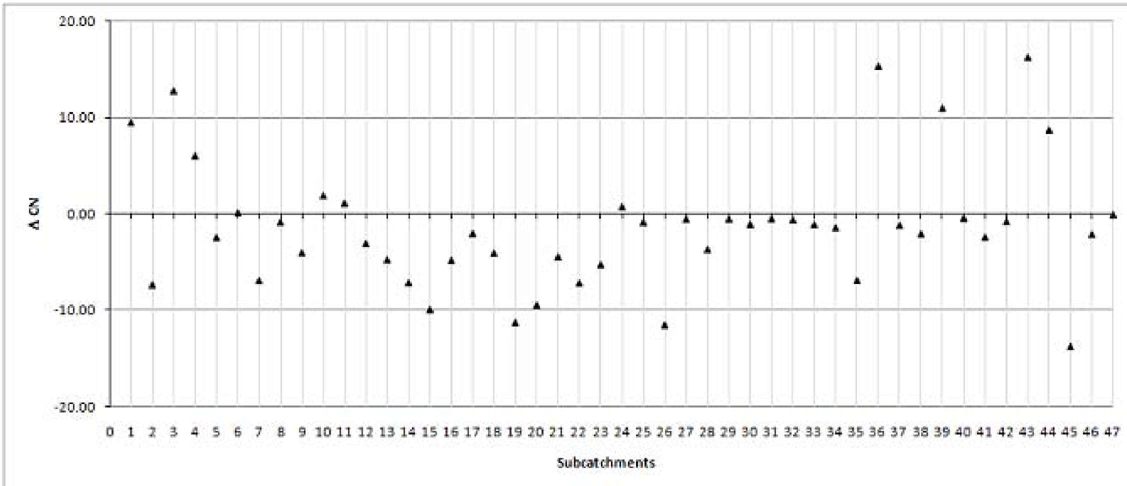


**Fig. 5** Hydrogram of Bela catchment




Olše

| ID in the Graph | Subcatchment | CORINE | HYDRO LC [etm0800] | Δ | Zvýšení/Snížení pravděpodobnosti | Plocha [km2] |
|---|---|---|---|---|---|---|
| 3 | R110W110 | 66 | 53.20 | 12.80 | Snížení | 0.086 |
| 19 | R260W260 | 66 | 77.25 | -11.25 | Zvýšení | 52.662 |
| 26 | R320W320 | 69 | 80.49 | -11.49 | Zvýšení | 23.101 |
| 36 | R410W410 | 69 | 53.67 | 15.33 | Snížení | 0.034 |
| 39 | R440W440 | 72 | 61.00 | 11.00 | Snížení | 0.803 |
| 43 | R50W50 | 67 | 50.74 | 16.26 | Snížení | 0.049 |
| 45 | R70W70 | 65 | 78.75 | -13.75 | Zvýšení | 2.246 |

**Fig. 6** CN value change (original vs. alternative) for Olse subcatchments

As you can see, in case of Olse (Fig. 6), the change is positive (4 subcatchments) and negative (3 subcatchments). However, the resulting hydrogram for whole catchment (see Fig.7) addresses negative change. Even if 7.7% of the catchment area shows change in the CN value, it can lead into consequences for whole catchment.

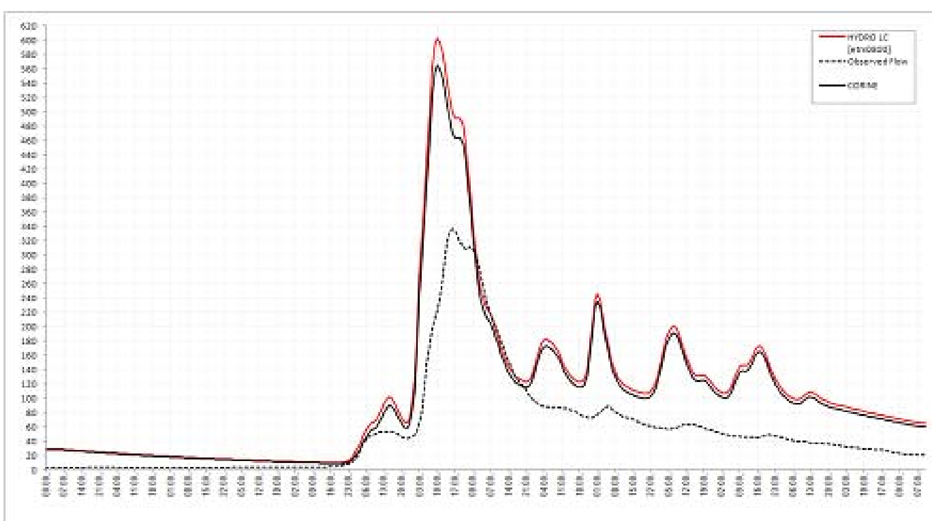


**Fig. 7** Hydrogram of Olse catchment

Next steps will follow investigations to trackback the LC change that led into CN value change. There are needed inspections and verifications of single subcatchments which different CN values exceed the given threshold |10|.

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