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# Comparison of saturated areas mapping methods in the Jizera Mountains, Czech Republic

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**Abstract:** Understanding and modelling the processes of flood runoff generation is still a challenge in catchment hydrology. In particular, there are issues about how best to represent the effects of the antecedent state of saturation of a catchment on runoff formation and flood hydrographs. This paper reports on the experience of mapping saturated areas using measured water table by piezometers and more qualitative assessments of the state of the moisture at soil surface or immediately under it to provide information that can usefully condition model predictions. Vegetation patterns can also provide useful indicators of runoff source areas, but integrated over much longer periods of time. In this way, it might be more likely that models will get the right predictions for the right reasons.

**Keywords:** Mapping variable source areas; Boot method; Piezometers; Vegetation mapping.

## INTRODUCTION

Let us go a bit back into the history of catchment science and into studies of small catchment with moderate topography in a humid climate in particular. There have been many studies of hydrological processes in such catchments with two main aims. The first is to understand flood runoff generation with a view to improving flood prediction; the second is to understand the flow pathways that control water quality in stream channels. Here, we will concentrate on the flood prediction problem and, in particular, understanding the controls on runoff contributing areas.

Flood prediction has been a problem for a long time and still is. One of the very first quantitative attempts to predict flood hydrographs actually made use of a semi-distributed model of snowmelt and runoff generation in the Durance basin in France (Imbeaux, 1892). Similar methods were developed (apparently independently) by Ross (1921) in the United States, trying to improve on the simple rational method of predicting flow peaks proposed by Mulvaney (1851) in Ireland (see Beven, 2012 for a more detailed review of early modelling studies). These studies did not, however, seek to understand the real nature of runoff generation processes.

For a long time, understanding of runoff generation was dominated by the idea that the bulk of an event hydrograph was made up of event water. Horton's (1933) concept of the soil as a separating surface between rainwater that ran off as overland flow and formed the hydrograph and infiltrating water that was either lost slowly to evapotranspiration or drained as baseflow was the dominant concept of runoff generation, even though Horton would not have seen overland flow on his own experimental catchment very often (Beven, 2004) and, at the same time as Horton, Hursh (1936) was discussing subsurface stormflows.

In 1960, Cappus published in Houille Blanche an excellent study where he discussed the antecedent conditions before important flood events (partly reproduced in Beven, 2006). Working in the small Alrance (3.15 km$^2$) catchment in France, he demonstrated a strong dependence of event runoff coefficient on the (shallow) ground water levels and also to a certain degree on the volume of precipitation. It was almost independent of all other factors on which it might depend such as the state of the vegetation, evaporation, intensity of the precipitation and soil moisture in the surface layers above the water table. Cappus concluded that effective runoff generation was limited to a dynamic area of the catchment that became saturated during an event (see Fig. 1). Independently in the US, the theory of variable saturated contributing areas came into being ten years later (Dunne, 1978; Dunne and Black, 1970; Dunne et al., 1976). We also now know, from the environmental isotope work of Crouzet et al. (1970), Dinçer et al. (1970), Sklash and Farvolden (1979) and others, that runoff generation may not be simply surface runoff of event water on such areas, but stored water that is displaced onto the surface or into the channel by the event inputs (see Sklash, 1990 for a review). Detailed tracer work shows that local circulation patterns can be complex even on saturated soil (e.g. Reeves et al., 1996). Some of these classic papers are reproduced in Beven (2006).

Most of the processes research has been done on experimental catchments. The paper by Robinson et al. (2013), written to commemorate the 40 years of the Plynlimon in Wales, not only goes through the important scientific results (e.g. Blackie and Robinson, 2007; Brandt et al., 2004; Calder, 1977; Kirby et al., 1991; Marc and Robinson, 2007; Robinson and Dupeyrat, 2005) but also describes the academic controversy and stakeholder pressures which brought about the existence of the catchments. On Plynlimon data a number of rainfall – runoff models have been tested, including TOPMODEL (see below) and SHE (Kirby et al., 1991).

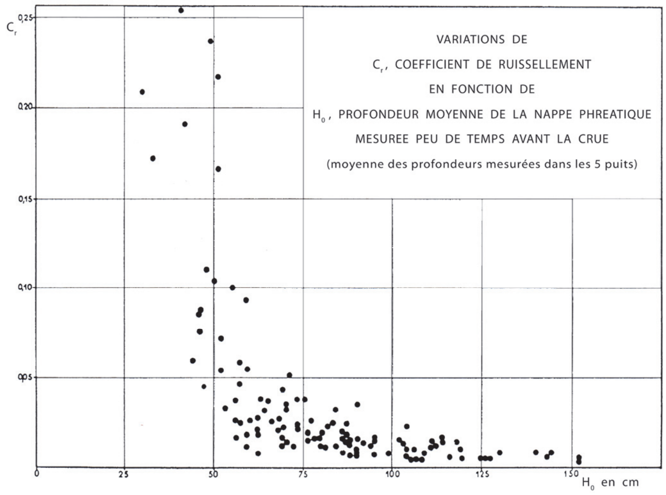


**Fig. 1.** Event runoff coefficients ($C_r$) as a function of the average depth of the water table ($H_0$ (cm) from 5 wells) – observed shortly before the flood (after Cappus, 1960, La Houille Blanche, reproduced with permission).

One of the first attempts to incorporate the saturated area concepts into a predictive model was that of Kirkby (1975) who introduced the concept of the topographic index as a means of identifying those areas with the greatest propensity to saturate. These concepts were later incorporated into TOPMODEL (Beven and Kirkby, 1979). One of the most significant features of TOPMODEL is that, despite being simple in concept and requiring minimal computing resources, the predictions can be mapped back into the space of the catchment for comparison with field observations (e.g. Beven and Kirkby, 1979; Blažková et al., 2002a, b; Franks et al., 1998; Güntner et al., 1999; Lamb et al., 1997, 1998). Such comparisons are not always successful (e.g. Barling et al., 1994; Seibert et al., 1997) but this can then be used to make modifications to the modelling strategy (Beven, 1997; Freer et al., 1997; Quinn et al., 1991). A study which actually used saturated area mapping for evaluation and modification of TOPMODEL was done by Ambroise et al. (1996) on the Ringelbach catchment (0.36 $km^2$) in France.

Shanley et al. (2002) investigated old and new water contributions to stream flow at nested catchments (41 to 11 125 ha) in Vermont using two-component isotopic hydrograph separations, organic carbon and relative alkalinity. They found multiple processes including topographically controlled increase in surface-saturated area with increasing catchment size; direct runoff over frozen ground; low infiltration in agriculturally compacted soil and differences in soil transmissivity.

Balin Talamba et al. (2003) used for their modelling, with a modified TOPMODEL information from point soil moisture measurement (TDR), hillslope scale dye tracing and catchment scale environmental tracing (calcium, silica and $^{18}O$).

Kostka and Holko (2001) carried out a sensitivity study and validation of TOPMODEL in Jalovecky Creek in Western Tatry Mountains, especially with regard to the dynamics of saturated areas. On two events, deuterium has been used for hydrograph separation. Later, they used $^{18}O$ to find out mean transit time of water in the Jalovecky Creek which for the period 1991 to 2002 was estimated as 13 months (Holko and Kostka, 2006).

Using $^{18}O$, $^{2}H$ and silica, Sanda et al. (2009) estimated in the Uhlirska catchment in the Jizera Mountains on one rainfall runoff event that up to 75% is pre-event water of which about 50% had been stored in the shallow soil subsurface on the hillslopes. On the same catchment, an experimental hillslope transect has been equipped with subsurface trench (with large tipping buckets monitoring continuously subsurface flow) and with a number of tensiometers from several (shallow) depths. 25 significant rainfall-runoff events have been recorded during 7-years monitoring. The authors found that instant moisture in the soil profile depends on the history of filling the pore space. Soil profile is close to saturation in the periods of subsurface flow during the events. In the area of shallow soils on the hillslope, the flow is controlled by the soil suction in the subsurface (Sanda et al., 2006). For the functioning of Uhlirska catchment, see also the mapping of saturated areas using the boot method and piezometers described in Blažková et al. (2002a, b) and below in this paper.

In the study of Vogel et al. (2010), $^{18}O$ was used as a natural tracer to study subsurface hillslope runoff. Sanda et al. (2013) applied a combined hydrological, hydrochemical and isotopic approach on the Uhlirska catchment.

McGlynn and McDonnell (2003) mapped in the field stream heads and riparian width on the 280 ha Maimai research catchment in New Zealand using morphological indicators in order to be able to distinguish between riparian and hillslope inputs into the stream network.

Latron and Gallart (2007, 2008) investigated runoff generation, both using the depth of water table and contributing areas on the (Mediterranean) Can Vila catchment (0.56 $km^2$). They found infiltration excess runoff on bare areas. They distinguished two types of saturation excess areas: an A-type on those areas linked to groundwater rising to the surface and a B-type where saturation was restricted to the upper soil layer (as a result of perched water tables).

Rinderer et al. (2012) have shown, by comparison with gravimetric sampling and time domain reflectometry, that a qualitative method of mapping saturated areas in wet environment can give reasonable result.

Pfister et al. (2010) have used a FLIR b50 infrared camera to produce thermal images (study site 5 x 3 m; camera is sensitive to 0.1 mm of water column). It was possible to discriminate between snow cover, snow melt, soil seepage and stream water and to find out where variably saturated areas are active and if connectivity exists between the hillslope and the riparian area.

In order to identify critical source areas of phosphorus pollution, Srinivasan and McDowell (2009) monitored shallow water table (< 1 m from surface) in Glenomaru subcatchment in New Zealand. There appeared to be an active subsurface (shallow) flow system transferring flows from land to streams while infiltration excess overland flow occurred on semi-pervious areas like fence lines, animal tracks and gateways.

Molenat et al. (2008) describe the results obtained from monitoring nitrates and shallow and deep groundwater table in three headwater catchments (0.1 to 5 $km^2$) in Brittany. They had to distinguish winter (high concentration due to nitrate rich groundwater) and summer (denitrification in the riparian zone) regime. The shift between winter and summer depends on the connectivity between the upland nitrate rich groundwater and the stream. The upland water table works as a trigger.

Investigations at more detailed scale than the hillslope, partly with soil samples from the Jizera Mountains, has been carried out e.g. in Cislerova (1999), Cislerova and Votrubova (2002), Hrncir et al. (2010), Jelinkova et al. (2011), Sanda and Cislerova (2009), Votrubova et al. (2000, 2003). This research was aimed at the elucidation of the preferential flow phenomena and the role of air entrapped in the soil which is conducted using computer tomography and magnetic resonance visualisation together with more conventional measurements on small and large soil samples (Snehota and Cislerova, 2005; Snehota et al., 2008).

An example of a study which connects the occurrence of plant assemblages with detailed study of flow pathways is reported in Ostendorf et al. (1996) and Quinn et al. (1998) from permafrost soils in Alaska. Another example is the article of Sala and Tenhunen (1994) from the Mediterranean region where plants of the same species in less favourable conditions at the top of hillslopes normally minimise their transpiration while those at the bottom do not and therefore suffer greater damage in the case of a prolonged drought.

The extent of saturation of the catchment is important for determining the functioning of the catchment, i.e. routes along which the water flows in various hydrological situations. We need to know these routes to form a concept and properly model more extreme situations than those that were observed and in order for it to also be possible to model the water quality which can change by passing through various layers in the catchment, especially in extremely wet and extremely dry periods.

## USING THE TOPOGRAPHIC INDEX AS AN INDICATOR OF POTENTIAL SATURATED AREAS

Modelling the saturation of the catchment is done on the basis of the topographic index (Kirkby, 1975) $\ln(a/\tan\beta)$ (ATB), where a is the area of the catchment drained to a certain point and $\beta$ is the local slope of the hillside. The pattern of the topographic index can be mapped in a catchment (see e.g. Jezdecka in Fig. 2). The water courses are clearly visible in a map of the topographic index (they have a high index value, e.g. 18). Slopes close to the catchment divide have low values (e.g. 5). There might be also flat places at the divide. The near to zero slope would make the ATB rather large. The average value of the index on a catchment is usually about 7.

The topographic index was extended by Beven (1986) to a soil and topographic index in the form $\ln(a/(T_0 \tan\beta)$, where $T_0$ is the local transmissivity of the soil when it is just saturated to the surface. This allows for the variability of soil characteristics in the catchment to be taken into account in assessing potential contributing areas. Points (usually cells in a raster elevation grid) with the same soil-topographic index respond in a hydrologically similar way. It is not therefore necessary to make calculations for every point in the catchment, only for representative values of the soil-topographic index. Thus, the basic TOPMODEL version is a semi-distributed hydrological model.

While it is relatively simple to prepare a map of the topographic index – this can be performed on the basis of topographic maps – this is not the case with the soil transmissivity. Patterns of soil type are often available, but it is known that the values of soil saturated hydraulic conductivity and transmissivity can vary significantly within a soil class. It is simplest therefore to assume that an effective soil transmissivity is homogeneously constant within a catchment. The effective value can then be calibrated along with the other model parameters by matching discharges. This, however, will compromise the accuracy of local predictions of saturation if, as we expect, the transmissivity is varying in space.

One way to avoid this assumption of homogeneity is to match transmissivities to local observations of soil saturation or water table depths (e.g. Ambroise et al., 1996; Blažková et al., 2002a, b; Lamb et al., 1997, 1998). Given such local information, local transmissivity values can be back-calculated, at least at those points where the measurements are available. However, mapping the way in which saturated areas change over time in a catchment involves demanding work in the field, which can be performed only in very small catchments (several hectares). In larger catchments, it is necessary, where possible, to choose representative places for mapping. The literature contains very few examples of such mapping because of these difficulties.

Information from mapping is extremely valuable because this can be better compared with the behaviour of the catchment. The runoff in the outlet profile is the integrated response of the catchment. In contrast, for example, measuring the moisture content in the individual probes yields point data which is thus rather variable and suction pressure is variable by orders of magnitude. Mapping saturated areas yields information on areas with dimensions of tens of square metres. This is an appropriate scale for comparison with the predictions of distributed or semi-distributed models such as TOPMODEL. It is then possible to evaluate a model run, not only in terms of the reproduction of discharge observations, but also of the internal dynamics of the catchment. This will be a more rigorous test of whether a model is reproducing storm runoff by the right mechanisms. TOPMODEL has the advantage of the possibility of physical interpretation in this way (Beven, 1993, 1997, 2012).

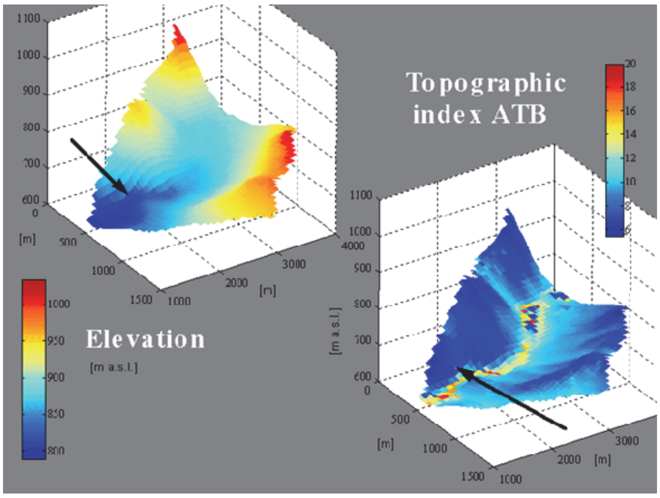


**Fig. 2.** Elevation map and map of topographic index for the Jezdecka catchment (4.75 km$^2$). The arrow shows the position of the saturation mapping site (see Fig. 6).

## OBSERVATIONS OF SATURATED CONTRIBUTING AREAS IN THE CZECH REPUBLIC

Estimation of the antecedent saturation of a catchment in the modelling of floods remains one of the most difficult problems encountered in hydrological modelling. Some 15 years ago, work was started in the Jizera Mountains in the Czech Republic with the aim of using TOPMODEL on our experimental catchments (from 1.87 to 4.75 km$^2$). Information has been provided by CHMI (the Czech Hydrometeorological Institute) and in the theses of Sanda (1999) and Tacheci (2002).

The Uhlirska and Jezdecka catchments have been described in the paper of Blažková and Beven (1997), the Uhlirska also in Blažková and Beven (1995) and Blažková et al. (2002a, b, c). Recently we have studied saturated areas in Smrzovsky Brook, a catchment at the foothills of the Jizera Mountains where we have used the same methods as in Uhlirska and Jezdecka and beside that a mapping based on vegetation. The location of the catchments is in Fig. 3.

In Fig. 4 we provide an ATB map of Uhlirska (1.87 km$^2$) with observation sites. Tacheci installed there more than 60 piezometers (Tacheci, 2002) and carried out surveys of water table levels while Kulasova carried out surveys of the state of surface saturation by a more subjective "boot method" (Blažková et al., 2002a). Both observations and topographic index maps suggest that there will be a continuous area near the stream which, once the catchment is wetted, is nearly all the time at or close to saturation while the propensity to saturation will decrease as we climb up the slopes of the catchment away from the stream.

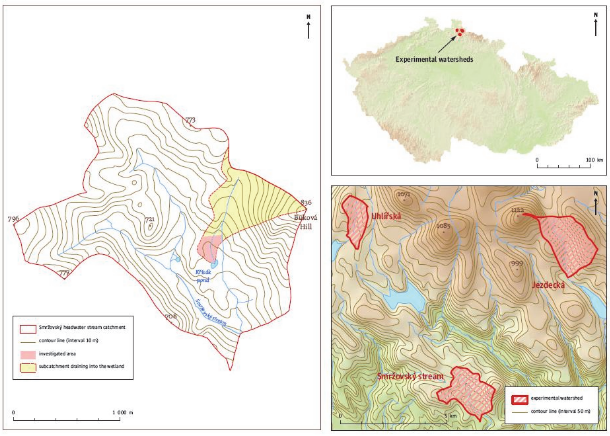

**Fig. 3**. Map of sites in the Jizera Mountains described in this paper.

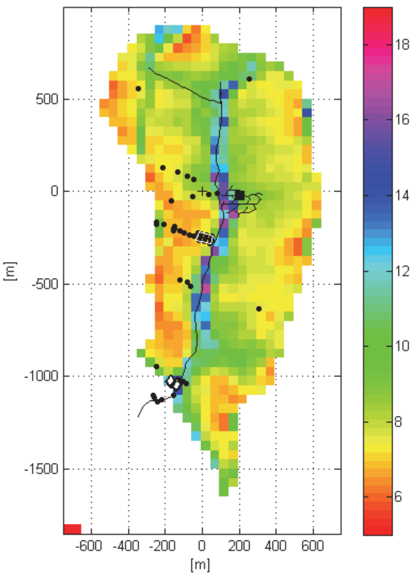


**Fig. 4.** Topographic index in the Uhlirska catchment; black points – piezometers; black square – piezometer 30; diamonds with white face colour and black edge colour – old ditch, + beginning of coordinates; black full lines – stream and observed ditches; white lines – location of the transect. Remark: The watershed divide at the south of the map is affected by the presence of road.

On the Uhlirska catchment we mapped the transect on the right-hand bank of the Černá Nisa and an old (filled-in) drainage ditch near the outlet. A picture of how the catchment becomes gradually saturated can be formed on the basis of the cumulative expression of the topographic index (Fig. 5a, b).

The old ditch at the outlet provided a representative site in that the distribution of topographic index values along its length corresponded to the middle range of distribution of the topographic index in the catchment as a whole (Fig. 5b).

Mapping the transect was rather complicated in the Uhlirska catchment because of the particular geological conditions – as was later discovered in piezometric evaluation, artesian water was present at the transect site. This complicated the picture of the saturated area. Nevertheless, the saturation of the individual points within the transect could be mapped and, for each mapping, could be classified into classes of surface state. In this study, five classes were used (dry/moist/wet under foot/water at the surface/overland flow).

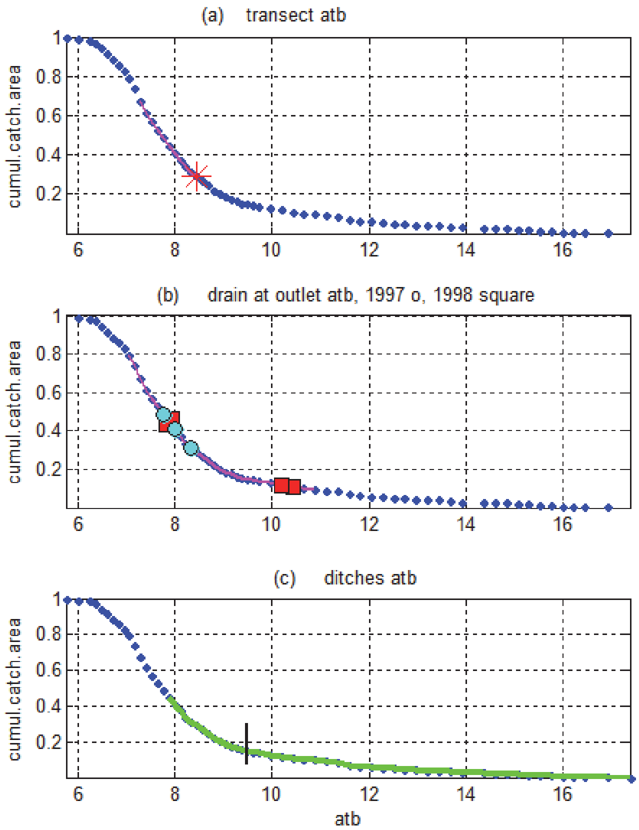


**Fig. 5.** Cumulative distribution of topographic index (ATB) for the whole Uhlirska catchment (1.87 km$^2$) – blue dots; Y axis shows fraction of the catchment area (dimensionless) starting from the largest values of ATB (the cells with the large values of ATB occupy the smallest areas in the catchment, usually those with the stream); (a) – transect (Blažková et al., 2002a), (b) – old drainage ditch at the outlet (Blažková et al., 2002a), (c) – ditches; full lines in all three plots represent the possible range in which the particular method enables the mapping. The * marker in the plot (a) is the lowest value of the topographic index in the transect i.e. the transect did not contain cells with ATB larger than 8.25; the marks o and square in the (b) plot denote the dynamics in the year 1997 and 1998, respectively, and the corresponding area of the catchment, in which the saturation occurred. The green line in plot (c) shows the mapping range of the ditches; the short black vertical line in (c) denotes the ATB of piezometer 30.

A later study was carried out in the Jezdecka catchment (4.75 km$^2$). Fig. 2 shows the position of the mapped area in the maps of elevation and topographic index. This site appeared to be less complicated in its response than in the Uhlirska catchment, although the transect slope was rather steep relative to other parts of the catchment. On this catchment we were able to get mapping data for the exceptional flood of 2002 which happened after a rather dry summer. A heavy rain had fallen on large parts of Bohemia (11$^{th}$ to 13$^{th}$ August). The largest daily total in the Jizera Mountains (278 mm) was recorded at the Knajpa rainfall station on the 13$^{th}$ August 2002. The daily totals exceeded 200 mm in another 6 stations (Strachota, 2002). It is possible to compare to the largest still non-exceeded daily record total

345.1 mm which occurred at Nova Louka in the Jizera Mountains in 1897. For comparison, the probable maximum precipitation in the Jizera Mountains can be estimated at about 400 to 450 mm while in most stations in the Czech Republic it could be about 150 to 300 mm (Rezacova et al., 2005).

The flood of 2002 is exceptional because in other places of Bohemia, especially on the south of Bohemia, a heavy antecedent rainfall happened on 6th to 8th August, so that the flood waves had the return periods of the order of 500 to 1000 years there.

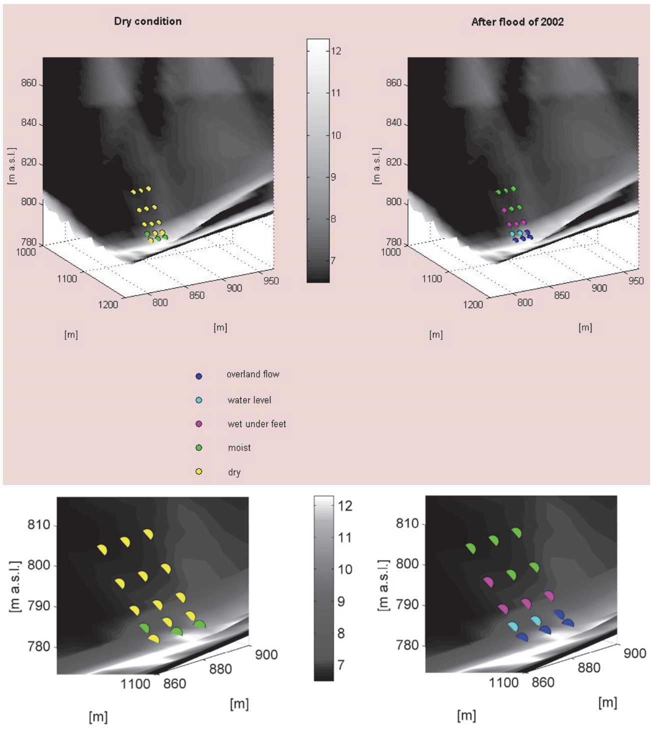


**Fig. 6.** Mapping of saturation classes in the Jezdecka catchment. See Fig. 2 for location of the mapping site within the catchment; grey scale is the topographic index (ATB); lower plot is zoom in the monitored points.

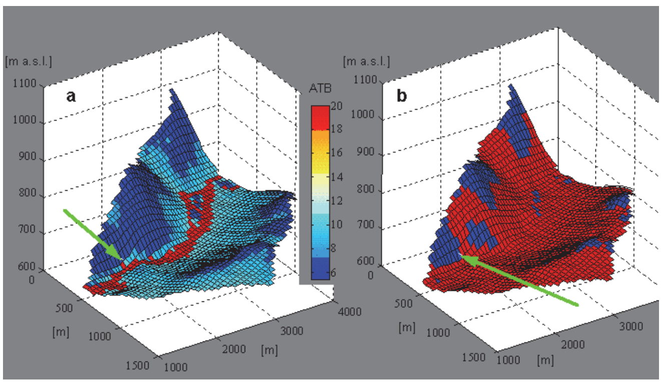


**Fig. 7.** TOPMODEL predictions of saturated areas (red color) on (a) dry catchment before the major flood 2002 and (b) wet catchment several days after the flood; Jezdecka catchment (4.75km$^2$); unsaturated cells show the topographic index ATB; predictions conditioned on the mapped pattern of saturation at the site indicated by the arrows (see also Figs. 2 and 6).

Fig. 6 shows the results of mapping in this exceptional year. The experimental area was mapped as soon as it was possible to reach the site following the flood, as compared to a previously dry transect. Fig. 7 shows results of a TOPMODEL computation for the whole catchment, after conditioning the model parameters on the results of the transect mapping (wet grids are red, the others – not saturated, show the topographic index values).

## USING FIELD DRAIN SURVEYS IN ASSESSING CATCHMENT SATURATION

In work with the piezometer network in the Uhlirska catchment prior to 1998 (Blažková et al., 2002b), we found that the processes of saturation could be represented well by the response of a single representative piezometer (no. 30, in a mild slope position on the left-hand bank of the stream; see Figs. 4, 5 and 8). In 1998, however, extensive network of forestry drainage ditches was dug in the left-hand bank, so that monitoring of the groundwater level in that piezometer could be no longer considered representative.

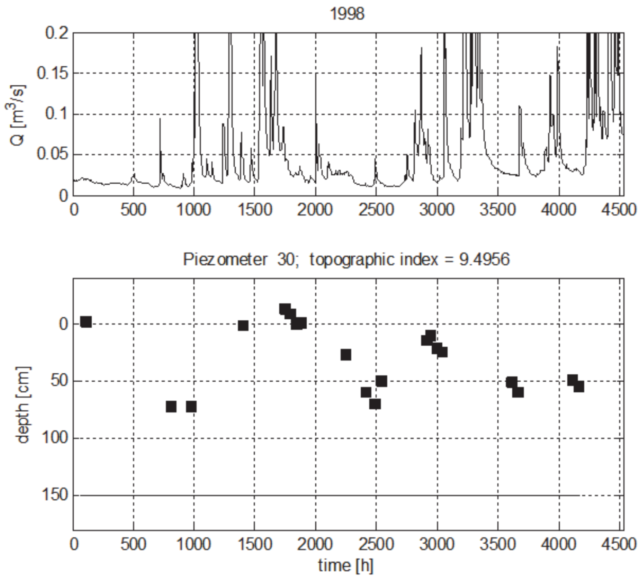


**Fig. 8.** Dynamics of water table in the piezometer 30 in 1998 before the renewal of ditches (Blažková et al., 2002b); zero on the x-axis is the beginning of May.

The map of the topographic index in Uhlirska catchment (Fig. 4) shows that the observed system of ditches on the eastern side of the catchment is located in a topographical hollow (place with higher values of the topographic index). Subsurface saturated flows are concentrated in the hollow and during some quite extraordinary rainfall they could create an ephemeral channel. The ditches are made approximately in the direction of such a channel. The forestry people renovate the ditches quite regularly because of the subsurface saturation which makes it impossible to grow spruce successfully. It does not really matter so much if the water travels to the main channel in the subsurface (more slowly) or in the ditches (quickly or very quickly with some foam).

Therefore the excavation of ditches provided an opportunity to map the saturated areas in a different manner, on the basis of the behaviour of these ditches. Fig. 5c depicts the range of values of the ATB (and the corresponding fraction of area) in the catchment within which mapping could be performed using the ditches as compared to the less extensive ranges achieved with the transect and the old ditch at the outlet. Three ditches were selected for mapping. When they were excavated in 1998, the depth of the ditches for the main branch was in the range 0.8 to

1 m, with depths of secondary branches of drains in the range 0.5 to 0.9 m.

Mapping of the patterns of saturation in the selected ditches was performed several times in each summer period (i.e. in the season without snow) from 1999 to 2005. A similar qualitative classification was used as for the earlier transect study (in this case dry/moist/wet under foot/water at the surface/flowing water/fast flow with foam). In Figs. 9 and 10, these states are depicted in colour and are superimposed onto the gridded map of the topographic index which is plotted in grey scale. In the area of the monitored ditches, the topographic index was calculated in 10 x 10 m grids while the remainder of the catchment was calculated in 50 x 50 m grids. This gives a better definition of the pattern of topographic index in the vicinity of the ditches. It is known that the pattern of the index depends on the algorithm for routing flow downslope. In this case a multiple flow direction method was used (Quinn et al., 1991).

Two contrasting situations are depicted in the Figs. 9 and 10. Fig. 9 shows the extent of saturation during a dry period while Fig. 10 gives the state after the above mentioned major flood in 2002. In most of the years of mapping, the extent of saturation is usually greatest after the spring melt; however, in 2002, the greatest extent occurred after the summer flood.

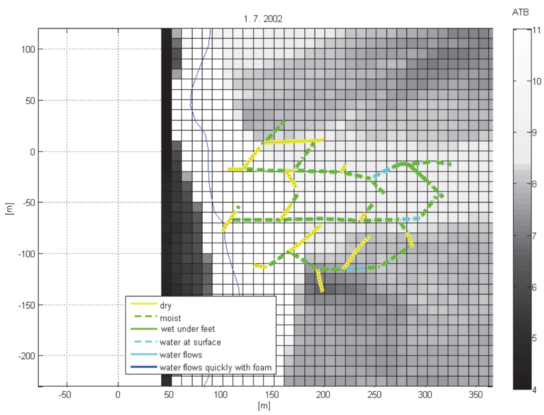


**Fig. 9.** Functioning of ditches in a dry period in 2002; grey scale is the topographic index.

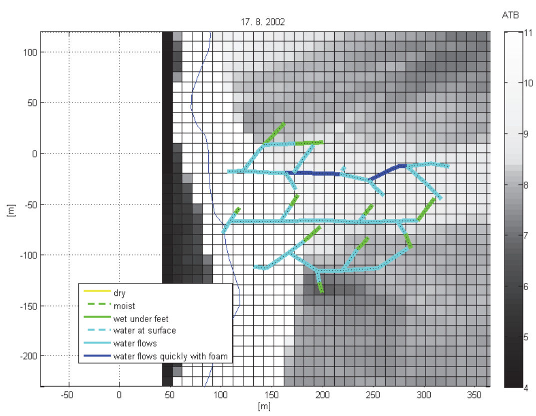


**Fig. 10**. Functioning of ditches during the catastrophic flood in 2002; grey scale is the topographic index.

On condition that the ditches are collecting overland flow and subsurface flow from a topographical hollow like in this case and that their direction is approximately perpendicular to the contour lines we would expect that using them for saturation area mapping has at least three important advantages relative to the other previously mentioned studies:

• The degree of wetness is much more readily apparent (because the flow is concentrated or, on the other hand, there is no flow in the ditch) and therefore the mapping is much less subjective (we are getting here the sum of the possible overland flow and of the shallow subsurface flow).

• The ditches run over more grids and the degree of wetness changes along the length of ditches which confirms the theoretical (and also practical in experimental catchments) finding that as one climbs the slope, the soil is drier and drier, even if after rain there may be a ground water level for a short time.

• A larger proportion of a catchment can be mapped this way in the same period of time.

A disadvantage of the technique is that saturation in a ditch is not the same as saturation of the surrounding soil when comparing the observations to model predictions. This means that the effective topographic index distribution for the application of TOPMODEL needs to reflect the role of the ditches in intercepting flows from upslope, and as indicators of saturation below the soil surface. Fig. 11 presents the ATB distribution on the whole catchment, from the area with ditches and from the rest of the area. This is the subject of continuing work to make use of the ditch information in the calibration of model parameters and evaluation of the model predictions.

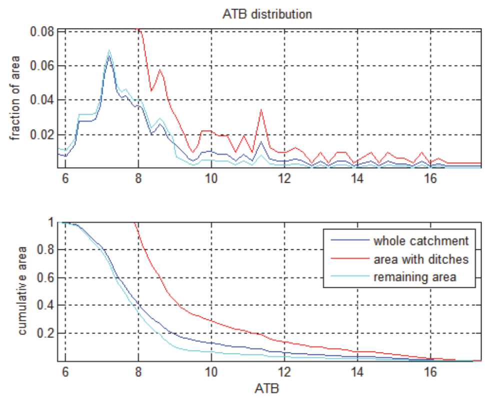


**Fig. 11.** Upper plot – distribution of topographic index in the Uhlirska catchment; lower plot – cumulative distribution of topographic index; blue – the whole catchment, red – area with ditches; cyan – remaining area.

The ditches are no longer mapped as they are now filled with sediment and overgrown with vegetation. They, however, continue to lead water to the stream (albeit more slowly than before) and could be mapped with much more effort and more subjectivity – like the drainage ditch at the outlet in the earlier study. One can conclude that the fresh ditches are an excellent means for quick orientation about wetness of a catchment and can help as an important constraint on the TOPMODEL simulations.

## OTHER INDICATORS OF SATURATED CONTRIBUTING AREAS IN SMALL CATCHMENTS

Clearly the methods for mapping the saturated state in a catchment presented above can provide valuable information on the dynamics of saturation in a catchment that can be useful for calibrating and testing models. However, they require significant effort and it would be useful to have more cost effective ways of making such assessments. One more way of obtaining a rapid assessment of the potential for saturated conditions can be based on vegetation mapping. This has been tested on a tributary of the Smrzovsky brook at the foothills of the Jizera Mountains (Figs. 3 and 12). Mean air temperature is 5.5°C and annual

**Table 1.** The most important representatives of wetness groups (ATB is topographic index).

| Most important representatives of wetness groups | | Group of wetness requirements | Approximate range of ATB on the observed Krisak slope*) |
|---|---|---|---|
| Tufted Vetch | *Vicia cracca* | Edge of medow: species requiring drier site | < 6 |
| Yorkshire-fog | *Holcus millos* | | |
| Germander Speedwell | *Veronica chamaedrys* | | |
| Common Bird's-foot-trefoil | *Lotus corniculatus* | | |
| Meadow Fescue | *Festuca pratensis* | | |
| Imperforate St John's-wort | *Hypericum maculutum* | Species requiring dry to wet site | 6 to 7 |
| Ragged-robin | *Lychnis flos -cuculi* | | |
| Red Fescue | *Festuca rubra* | | |
| Meadow Foxtail | *Alopecurus pratensis* | | |
| Tufted Hair-grass | *Deschampia caespitosa* | | |
| Wood Club-rush | *Scirpus silvaticus* | Species growing in wet conditions | 7 to 8 |
| Meadowsweet | *Fillependula ulmaria* | | |
| Marsh Horsetail | *Equisetum palustre* | | |
| Common Bistort | *Bistorta major* | | |
| Carnation Sedge | *Carex panicea* | | |
| Soft-rush | *Juncus effusus* | | |
| Marsh-marigold | *Caltha palustris* | Species requiring presence of water all the time | > 8 |
| Bulrush | *Typha latifolia* | | |

*) These observations are affected by the peat mining in previous times.

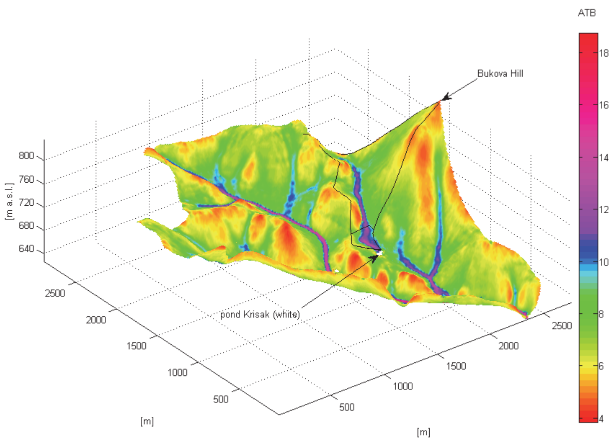


**Fig. 12.** A 3-D plot of the Smrzovsky Brook (area 3.62 km$^2$) with the catchment area of the pond Krisak (area 0.39 km$^2$ (pond is white) and the investigated area (0.04 km$^2$ wetland immediately upstream of Krisak); watershed divide – black.

average precipitation 1229 mm (1901–1950 from standard data of the Czech Hydrometeorological Institute – CHMI). We have been mapping saturation there from 2007 to 2010 using all the methods described above together with mapping of changes in the patterns of a simplified classification of plant communities based on the requirements of plants for water (Table 1 is a simplified example). One area in this small catchment upstream of a man-made pond Krisak (Gondolteich) was an extensive wetland in the past, there was peat mining there, followed by establishing the pond and drainage of meadows. However, part of the original wetland with some protected species of plants, remains. The sequence of groups of plant has quite a steep gradient which is in an approximate agreement with the topographic index. The vegetation communities, however, provide a different sort of information to direct observations of saturation since they will tend to integrate the changing hydrological conditions over a longer period of time. The results are described in Kulasová et al. (2014).

## CONCLUSIONS

Understanding and modelling the processes of flood runoff generation is still a challenge in catchment hydrology. In particular there are issues about how best to represent the effects of the antecedent state of saturation of a catchment on runoff coefficients and flood hydrographs. This paper has set out some experience of mapping of saturated areas using groundwater table information and more qualitative assessments of the state of the surface to provide information that can usefully condition model predictions. Vegetation patterns can also provide useful indicators of source areas of runoff, but integrated over much longer periods of time. In this way, it might be more likely that models will get the right predictions for the right reasons.

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