Medieval terraced fields in the catchments with forest and grassland land cover

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Abstract Several permanent grassland sites in similar natural conditions (in the foothill zones of Brdy and Šumava mountains) were investigated and compared from the viewpoints of the soil water balance, the conditions for growth and development of plants, the functioning of retardation elements in tile drains and the role of historical retention elements in the landscape, namely, the medieval terraced fields.

The soil water balance dynamics was investigated with the help of tensiometers or resistance soil moisture sensors. Each site was described by phytocenological relevés. The soil hydraulic properties were also measured.

On all sites, the soil water dynamics is quasi-cyclical. There are differences among sites in terms of the soil profile retention capacity and the dynamics of percolation and evapotranspiration. The soil retention capacity is enhanced in the profiles on the medieval terraced fields with a well-developed interpedal structure. The grass stands on terraced fields was green even in the dry year 2003 when the other ones were covered by dead biomass.

The soil water storage at the terraced fields remained sufficient even during the extremely hot weather in June 2006. In 2006, the volume of infiltration at the terraced fields corresponded to the volume of precipitation, i.e., the overland flow was negligible. In comparison with an analogous forest site without terraces (Tesař, 2006), the time of soil water residence at the terraced fields is longer.

Key words: *medieval field complex, agricultural terraces, askant-arranged fields, soil water balance, soil water defficiency*

1 Introduction

This paper reflects the increasing trend of climatic extremes. At most, we appear from the trend of linearly increasing soil water defficiency (see eq. 4) and current knowledge about retention capability of soil that has been significantly influenced by human settlement starting in the Central Europe with top-medieval collonisation. The medieval agricultural technology had been characterised by humic topsoil translocation. This land management had created specific landscape elements (e.g. agrar terraces or small fields hardened by stony balks). This is typical in almost all highland regions in the Central Europe. This sites are typical with specific water retention properties, too. We have observed selected grassland in catchment area with large tile drainage. These stands have been compared in the sense of soil water balance, vegetation cover conditions, functionality of runoff retardation barriers in the drains and of comparison with the medieval terraced fields. Soil water balance was measured using soil water tensiometers or resistance soil moisture sensors (watermark).

At all these places, soil hydraulic properties was measured at all ones. Land cover of the grassland has been characterised by phytocoenological relevés, too.

2 Soil water balance

Soil water storage Z^i_j (m) in the diagnostic soil horizon i at the day j is described by equation (1).

$$Z^i_j = \Theta(h^i_j)\, l_i \tag{1}$$

where $\Theta(h^i_j)$ means soil moisture in horizon i at day j calculated from the suction head along the retention curve h_{ij} . Soil horizon thickness is marked as l_i (m). Soil water storage in the whole profile Z_j (m) composed of n horizont is defined as (2).

$$Z^i_j = \Theta(h^i_j)\, l_i \tag{2}$$

Soil water storage change in the soil profile in two following days $\Delta Z_{j-1;j}$ (m) is defined as (3).

$$\Delta Z_{j-1;j} = Z_j - Z_{j-1} \tag{3}$$

Soil water defficiency D_j (m) at the day j is defined by equation (4).

$$D_j = \Delta Z_{j-1;j} - P_{j-1}; \tag{4}$$

where P_{j-1} (m) is the precpitation daily total for the day $j-1$. The accumulated soil water residual K_j (m) for the time since start of balance computing till the day j is defined by equation (5).

$$K_j = \sum_{i=1}^{j} P_i - \sum_{i=1}^{j} E_i - \Delta Z_{1;j} \tag{5}$$

In this equation, $\Delta Z_{1,j}$ is the soil water storage change between the day j and the first one when balance started (Šír, Tesař 1998). Identification of the single days when the percolative stage occured, appears from comparison of soil water defficiency (4) and transpiration. If the defficiency is negative and higher than transpiration total of the previous day, the percolative runoff occured. The amount of daily runoff total O_j (m) can be roughly estimated by the relation

$$\text{pro } D_j<0:\ O_j=D_j-E_{j-1} \qquad (6)$$

To complay to the convention of physics, the value of runoff is negative. The events when the observed soil horizon can be supplied by the capillary rise from the lower ones, is recognizable by comparison of defficiency (4) and transpiration at the days when defficiency has positive value. The daily supply D_j (m) is approximately described by relation (7).

$$\text{pro } D_j>0:\ S_j=D_j-E_{j-1} \qquad (7)$$

The value of soil water refill is positive.

3 Evaluation using programme BIL

The numerical tool BIL has been created primarily for empirical data analysis.

The inputs are:

- Time series of suction heads in the horizons.
- Soil hydraulic parameters described as van Genuchten's equation parameters (α, n, m, Θ_a, Θ_m, Θ_r and Θ_s).
- Saturated hydraulic conductivity.
- Amount and width of soil diagnostic horizons.
- Depth of the lower boundary of active root zone to distinguish the soil water dynamics in- and below the root zone; this is graphically distinguished at the pictures starting the page 16.
- Suction heads depths and their allocation to soil hydraulic properties of each horizon.

The first outputs are cumulative frequency curves of suction heads and moisture (more Tesař 1990), the second one is the soil water storage in each diagnostic hroizon and whole profile according to eqs (1) a (2). The soil water change along the (2) is the main input for the quantification of defficiency and daily supply according to eqs (4) and (7). More informaton in Tesař et al. (2001).

These analysis outputs starting at page 16 are shown as two-dimensional graphs where the total soil water storage in the whole profile is drawn as the black line. The defficiency or supply in the active root zone are coloured as green and the same below the active root zone as red. Therefore, the green course shows infiltration, transpiration or redistribution while the red one is according to leakage or water redistribution in the subsoil.

4 Location

4.1 Cerhovice stream basin

This watershed is located in the central Bohemia in the middle altitudes. Originally, it is a spring zone where great part of this catchment is drained by tile drainage except to land protected area "Cerhovice springs" where the soil water balance is measured, too. The draineed part of this cathment is relatively uniform with decreased retention properties. Therefore, a part of drained area has been selected for runoff retardation expriment where drain barrage is installed.

4.2 Medieval field complexes

Two localities of medieval field complexes were selected. The first one is the extravilane of řepeˇsín village with radially oriented field strips with fields divided by askant-arranged balks hardened by stone edges with the small fields in the extremely steep slopes at the cross-point of askant-arranged balks.

The second locality is Hnojnice hill near Bavorov in the south Bohemia where the isohypse-oriented field strips at the north slope of this hill are segmented to terraces created by one-dimensional tillage causing topsoil translocation. These pedons with accumulated humic topsoil have very well developed structure because of high content of soil oranic matter. Beacuse of macrozooedaphon activity, thay are typical with well-developed interpedal pore structure, too. Both sites are shown at page 15. These sites are located in the Blanice river basin in the south Bohemia which reached in the year 2006 to the to the middle flood emergency. Therefore, we can compare this runoff episode shown at page 17 with the soil water dynamics has been analysed as described in the section 3.

5 Phytocoenological relevés

5.1 Cerhovice, May 30, 2005

5.1.1 Drained meadow in the extravilane, total vegetation cover 98%.

Poa pratensis 4, Dactylis glomerata 3, Alopecurus pratensis 3, Arrhenatherum elatius 1, Trifolium pratense 2, Taraxacum officinale 2, Ranunculus acris 1, Alchemilla vulgaris 1, Lotus corniculatus +, Galium album 1, Veronica chamaedrys +, Trifolium dubium +, Achillea millefolium +, Leontodon hispidus +, Plantago lanceolatum +, Lathyrus pratensis r

5.1.2 Stand near intercepting ditch, convex slope, south-east orientation, cover 80%

Poa pratensis 4, Arrhenatherum elatius 4, Festuca glauca 2, Dactylis glomerata 1, Alopecurus pratensis 1, Taraxacum officinale 1, Plantago lanceolatum +, Trifolium dubium 1, Galium album +, Cerastium arvense +

5.1.3 Measurement point in the drained meadow near the landscape protected area; covered by 90%.

Arrhenatherum elatius 3, *Holcus lanatus* 3, *Alopecurus pratensis* 1, *Poa pratensis* 2, *Dactylis glomerata* 1, *Galium album* 1, *Leucanthemum vulgare* 1, *Campanula patula* +, *Urtica dioica* +, *Rumex crispus* +, *Lychnis flos-cuculi* +, *Achillea millefolium* +, *Vicia sepium* +

5.2 Cerhovice May 31, 2005

5.2.1 Mesophilic meadow near the railway, 90% total cover

Dactylis glomerata 3, Holcus lanatus 3, Alopecurus pratensis 1, Arrhenatherum elatius 2, Leucanthemum vulgare 3 Ranunculus acris 2, Vicia cracca 1, Alchemilla vulgaris 2, Cirsium arvense 1, Lychnis flos-cuculi 2, Taraxacum officinale 1, Myosotis arvensis +, Rosa canina agg. juv. r, Tanacetum vulgare +, Hypericum perforatum r, Campanula patula +, Potentilla anserina r

5.2.2 Drain with runoff retardation, total cover 95%

Holcus lanatus 3, Alopecurus pratensis 3, Poa pratensis 4, Festuca rubra 2,Dactylis glomerata 1, Galium verum 3, Cirsium arvense 1, Potentilla anserina 2, Vicia cracca +, Leucanthemum vulgare r, Alchemilla vulgaris 1,Taraxacum officinale 1, Ranunculus acris r, Lychnis flos-cuculi r, Triforium pratense r

5.3 Grasslands at the former medieval terraced fields

5.3.1 Hnojnice hill

Field strip bordered by terrace (H2, hkor), relevé taken at 1995. 100% cover.

Poa pratensis 3, Holcus lanatus 2, Phleum pratense 1, Alopecurus pratensis 1, Trisetum flavescens 2, Dactylis glomerata 1, Plantago lanceolatum 2, Taraxacum officinale 2, Achillea millefolium 2, Trifolium repens 1, Anthoxanthum odoratum +, Stellaria graminea 1, Cerastium vulgatum 1, Triforium dubium +, Veronica chamaedrys +, Veronica agrestis r, Campanula patula r, Pimpinella saxifraga 1, Leontodon autumnalis +, Leontodon hispidus r, Alchemilla vulgaris +, Luzula campestris +, Rumex crispus r, Hypericum perforatum +, Artemisia vulgaris +

E0: Rhytidiadelphus squarrosus 4

Analogous, near top of the hill, convex slope:

Poa pratensis 3, Dactylis glomerata 2, Veronica agrestis 1, Veronica chamaedrys +, Cerastium vulgatum 2, Plantago lanceolatum 1, Achillea millefolium 1, Elythrigia repens 1, Campanula patula +, Trisetum flavescens 1, Holcus lanatus 1, Arrhenatherum elatius 1, Trifolium pratense +, Arabidopsis thaliana +, Taraxacum officinale 1, Heracleum sphondylium +, Acetosa pratensis +, Alchemilla vulgaris +, Pimpinella saxifraga r, Trifoliumrepens +, Luzula campestris +, Anthriscus silvestris +, Populus tremula juv. +

5.3.2 Řepešín

Pasture land under askant-arranged balk; relevé was taken May 14, 2001

Poa pratensis 4, Dactylis glomerata 1, Plantago lanceolatum 3, Alchemilla vulgaris 1, Luzula campestris 3, Hypericum perforatum 1, Trifolium pratense 1, Veronica chamaedrys 1, Veronica agrestis r, Festuca rubra 1, Acetosa pratensis +, Achillea millefolium 1, Taraxacum officinale 1, Leontodon autumnalis 1, Leontodon hispidus +, Arrhenatherum elatius 1, Leucanthemum vulgare +, Knautia arvensis r, Medicago lupulina +, Pimpinella saxifraga +, Lotus corniculatus r, Anthriscus silvestris +, Stellaria media +,Vicia cracca r, Viola silvatica r

Similar pasture land; both sites 100% covered

Poa pratensis 2, Festuca rubra 3, Holcus lanatus 1, Arrhenatherum elatius +,Plantago lanceolatum 3, Luzula campestris 3, Dactylis glomerata 1, Cynosurus cristatus +, Achillea millefolium 2, Leontodon autumnalis 3, Taraxacum officinale 2, Acetosa pratensis +, Ranunculus acris 2, Leontodon autumnalis 3, Leontodon hispidus +, Trifolium pratense 1, Veronica chamaedrys 1, Trifolium hybridum r, Alchemilla vulgaris 1

6 Results and discussion

In the year 2006, the drained sites at the Cerhovice stream catchment show no dynamics. Even in the half of June 2006, small transpiration event occured as it is shown at the page 16. Small redistribution events can be visible at the site with retarded drainage runoff. In the stabilised stage of high profile saturation, we can see a short and small transpiration event antecedent to the greatest runoff event from the watershed. This event was accompanied with no reaction in the soil profile, therefore, the most of the runoff episode comes from surface runoff.

The terraced field on the Hnojnice Hill shows at 2002 response to two extreme precipitation totals as soil water storage decrease in th active root zone. Considering the soil thickness (2,5 m), it is at most redistribution. In this site, soil water balance model showed surface runoff decrease about 50 8 – 70 mm. As this hill was during the flood at 2002 unavailable, we have no direct empirical verification, we can only compare the empirical time series with model output. The comparison is shown at page 18.

To evaluate the rule of terraced fields, we can compare with checking stand without terraces. It is shown at page 19. Soil water storage dynamics is lower than in the model output. This is caused by overestimating of potential evapotranspiration using data from the nearest global radiation measurement point located at lower altitude. Nevertheless, the surface runoff daily total caused by the causal rainfall August 13, 2002, is comparable in the model output so as in the empirical soil water balance analysis.

On the other hand, the askant-arranged stony terraces behave as collective drains. They are typical by quick percolation of infiltrated water shown as the quick response to the rainfall event. It is shown at page 21.

In the year 2006 when the Blanice river reached to middle flood emergency after long defficiency during previous month (see pg. 17), we can see conspicuous coincidence of the causal precipitation daily total (28 mm) and soil water supply (26 mm, see pg. 23). This is the padon described in the section 4.2 with the well-devloped interpedal pore network. The graph at the page 23 shows high water retention capacity enabling sufficient transpiration of vegetation cover by the higher soil water defficiency. Together with the accumulative stage enhancement when the surface runoff is negligible and hydraulic capacity is sufficient to absorb the water amount coming with the causal rainfall, the medieval terraced fields serve as buffers mitigating the climate extremes. This is in coincidence with their function in the late-medieval climatic optimum typical by higer temperatures in the Central Europe .

7 Conclusion

Soil water balance at the medieval terraced fields is typical with longer accumulative stage and longer delay for percolative reponse to the rainfall event. These sites with the enhanced humic horizons createed by topsoil translocation caused by one-dimensional tillage continual since the top Middle-ages till the early-modern soil management technology start, behave as water accumulators decreasing the infleuence of climatic extremes to the vegetation cover. The accumulative stage prolongation is more visible than at another sites without microrelief changes.

The grasslands at the former medieval fields have stabilised soil water regime. Therfore, in the comparison with the drained areas, they have mesophilic character and biodiversity of grass ecosystem is higher. On all sites, the soil water dynamics is quasi-cyclical. There are differences among sites in terms of the soil profile retention capacity and the dynamics of percolation and evapotranspiration. The soil retention capacity is enhanced in the profiles on the medieval terraced fields with a well-developed interpedal structure. The grass stands on terraced fields was green even in the dry year 2003 when the other sites were covered by dead biomass. The soil water storage in the terraced fields remained sufficient even during the extremely hot weather in July 2006. In 2006, the volume of infiltration on the terraced fields corresponded to the volume of precipitation, i.e., the overland flow was negligible. In comparison with an analogous site without terraces (Tesař, 2006), the time of soil water residence at the terraced fields is longer.

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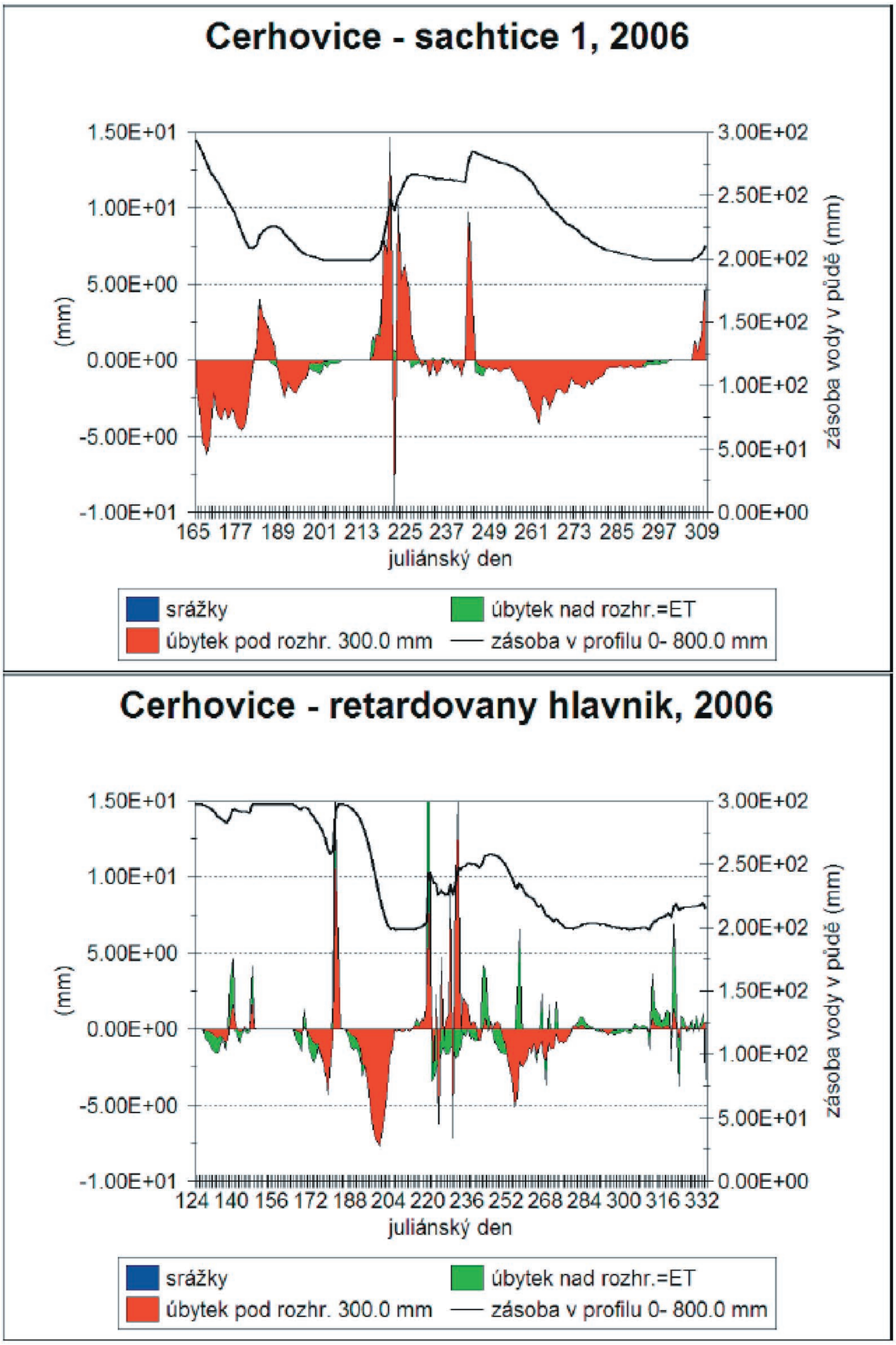
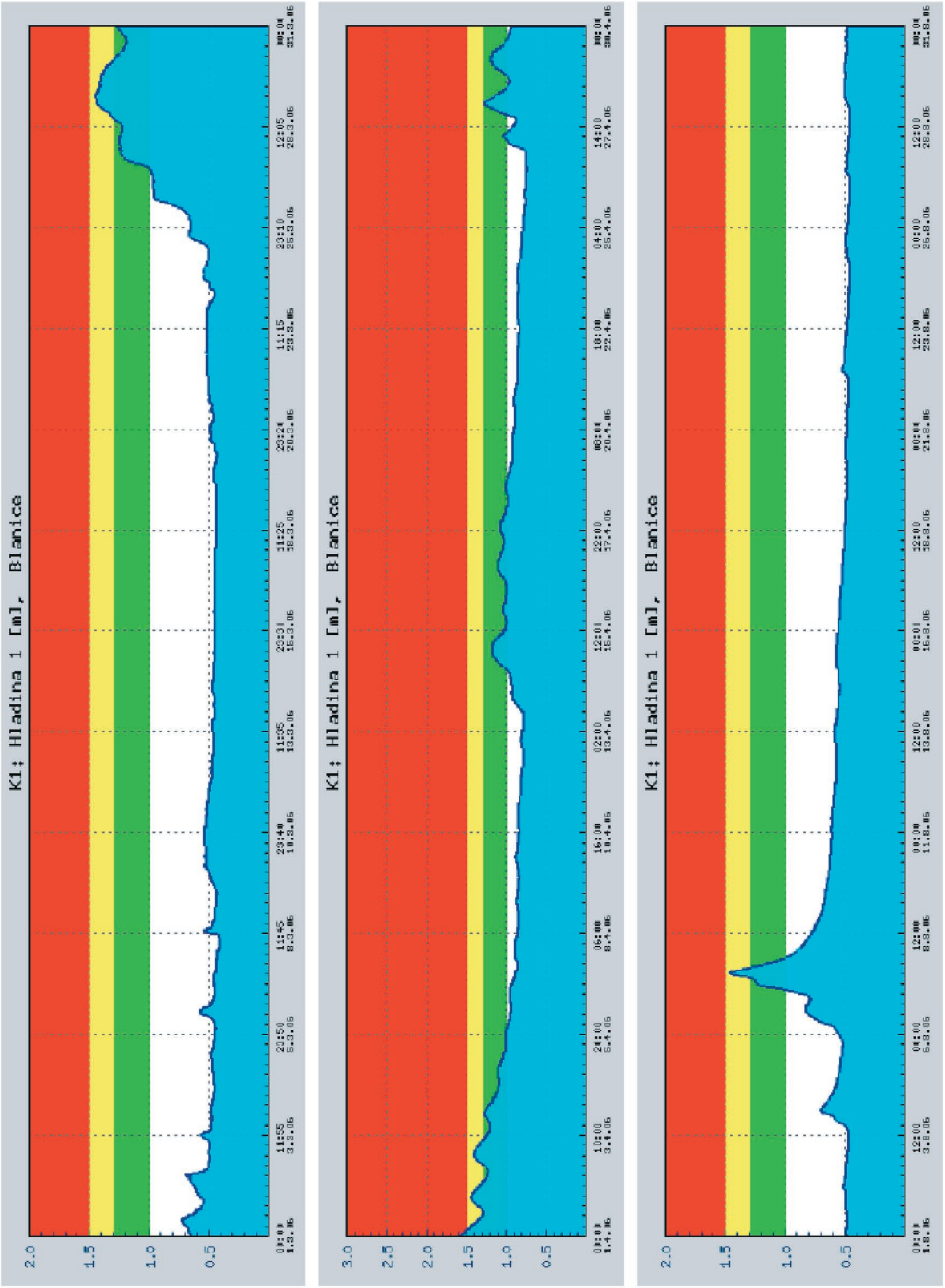
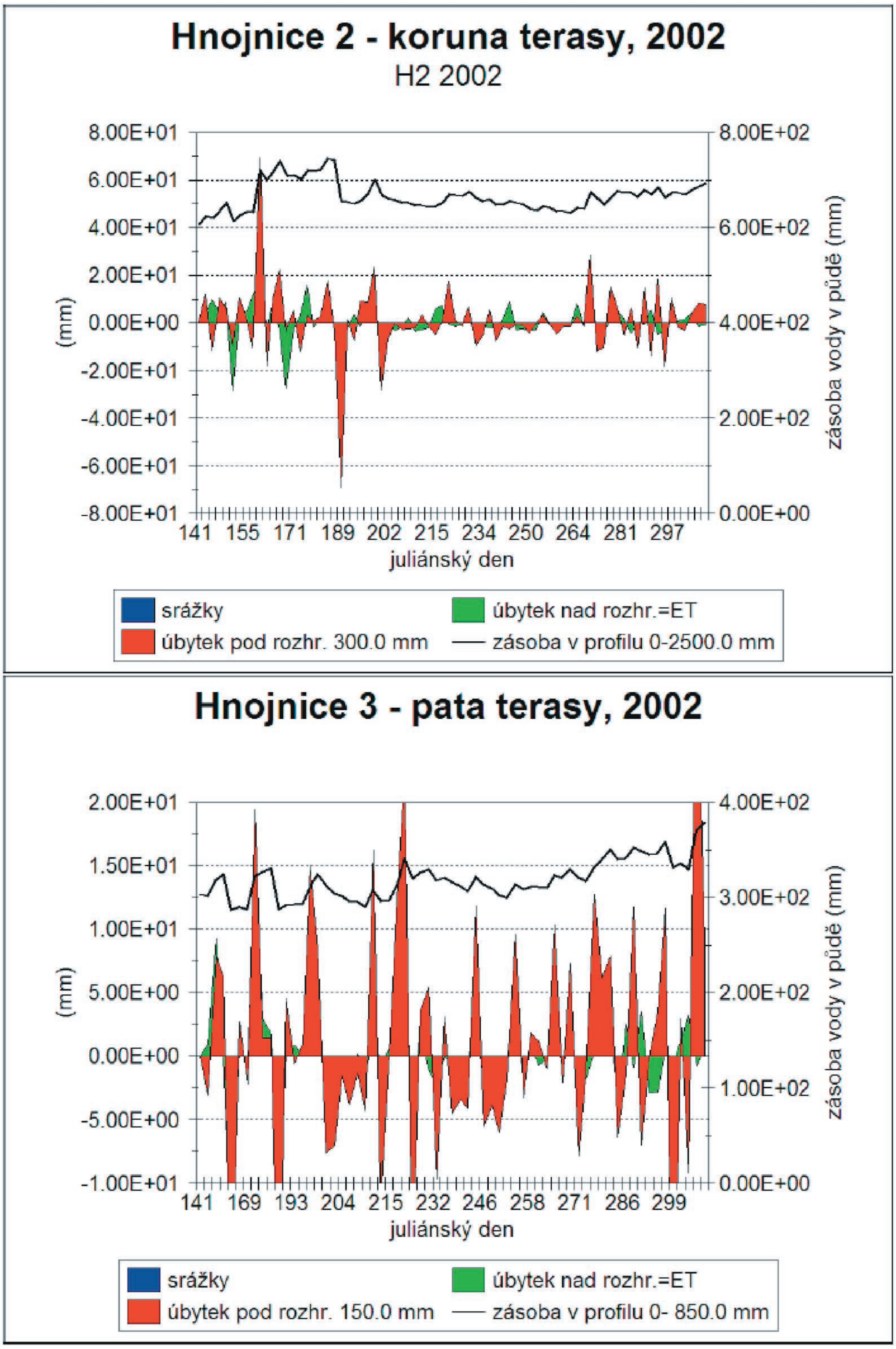
Aerial photographs - Hnojnice Hill (top) and Řepešín field complex (bottom).



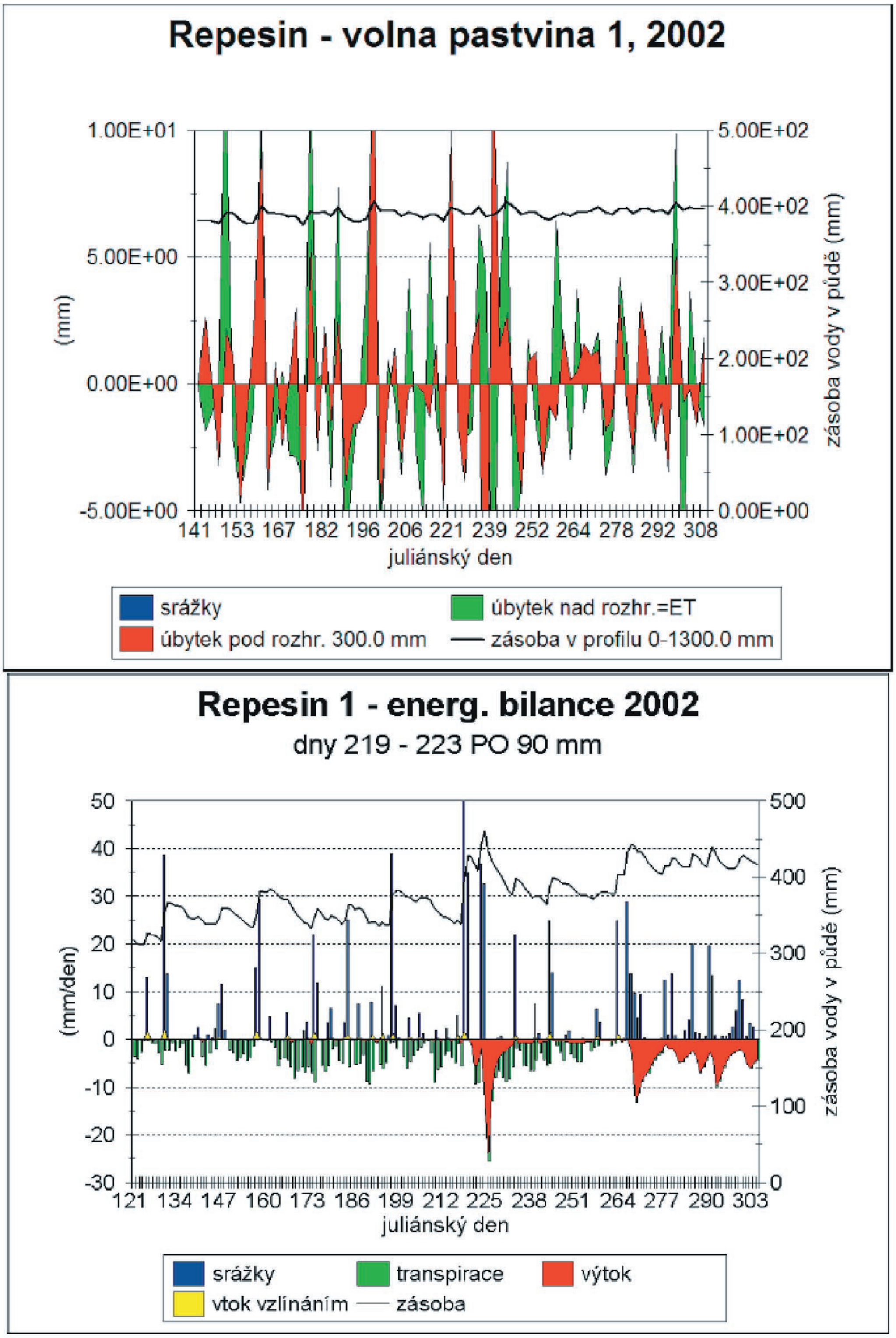
Cerhovice stream, soil water dynamics at the drained site (top) and retarded tile runoff (bottom).



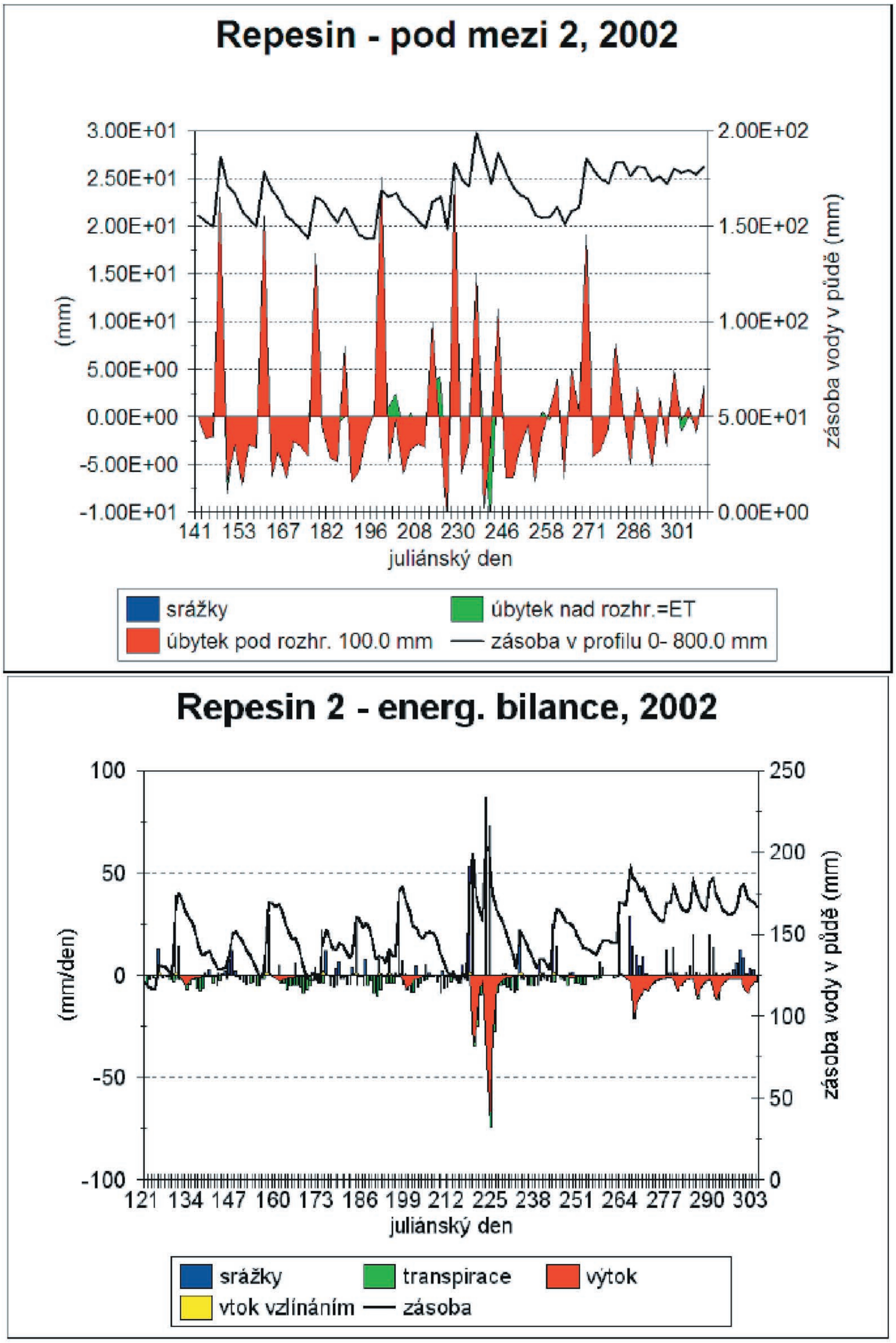
Water level at the Blanice river, limnigraph station Podedvory.



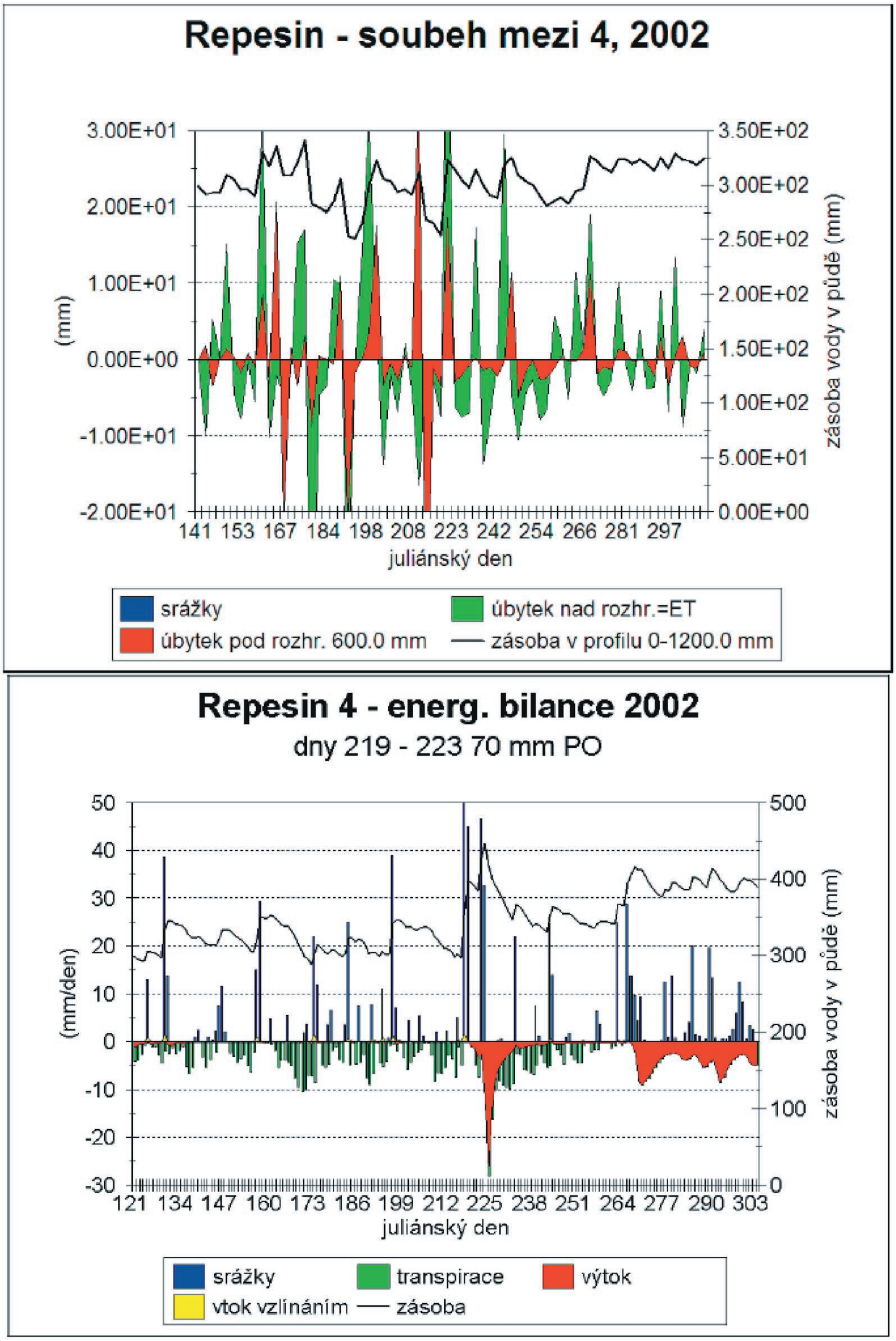
Soil water dynamics at the top and base of terrace, Hnojnice hill.



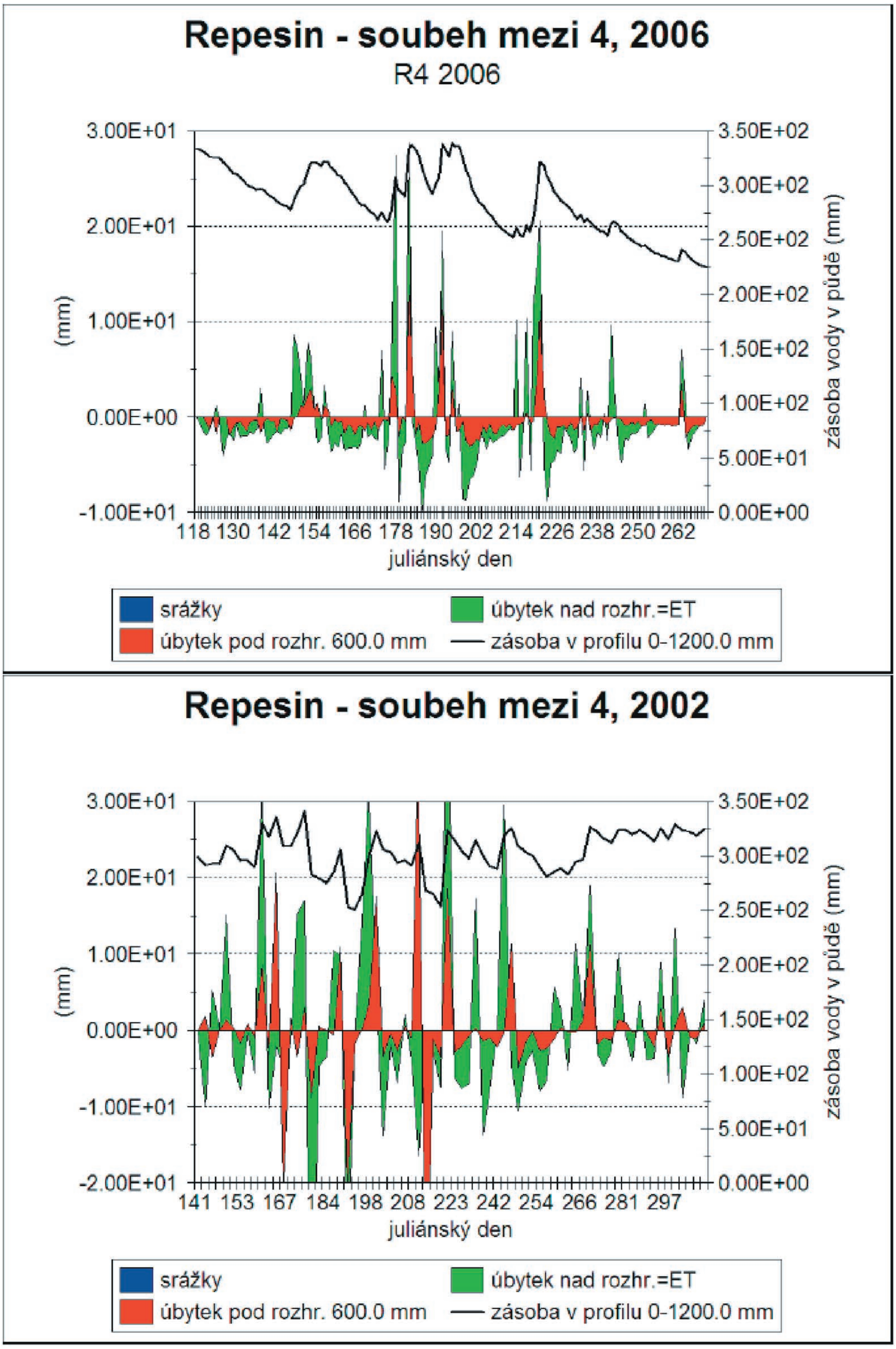
Řepešín, checkpoint without microrelief variation. Empirical soil water dynamics (top) and simulation output using balance model SWAP.



Soil water dynamics, Řepešín, base of askant-arranged balk, 2002.



Řepešín, 2002, terraced field at the cross-point of the askant-arranged balks with the enhanced humic topsoil.



Comaprison of soil water dynamics 2002 and 2006, Řepešín, terraced field at the cross-point of the askant-arranged balks with the enhanced humic topsoil.