Impact of Arable Land to Grassland Conversion on the Vegetation-period Water Balance of a Small Agricultural Catchment (Němčický Stream)

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Abstract: This paper presents results of decadal (10-day) water balance simulations for the vegetation periods (April to October) of 2001 (normal year), 2002 (wet year) and 2003 (dry year) in the Němčický Stream experimental catchment (3.52 km^2). The catchment is a typical agricultural area with a large extent of arable land. This paper shows that the model used (WBCM) is capable of reliably simulating decadal water balance components for the actual land use. The same model is then used to estimate water balance changes brought about when 10% of arable land has been transformed into permanent grassland. It is shown that this land use change results in a pronounced reduction of surface runoff and an increase in subsurface storage over the vegetation periods of all three years. The vegetation period groundwater runoff was only enhanced in the wet year, while the total runoff was reduced in all three years.

Keywords: hydrological extremes; hydrological modelling; land use change; water balance

One of important agricultural policy issues in the Czech Republic and elsewhere is the reduction of area of arable land in favour of permanent grassland or forest, in order to implement the principles of landscape protection guidelined by the Common Agricultural and Rural Policy of the European Union. The reasons for the reduction are often also economic. However, it is no less important to envisage the changes of the landscape water dynamics brought about by this extensive change of land use. Therefore, the expected water balance changes should be estimated and evaluated within the context of the EU Water Framework Directive (2000) implementation.

The aim of this study is to quantify water balance components of the experimental Němčický Stream catchment in its present state and to investigate how these components may be affected by non-structural measures, such as the change of land use. The land use change is likely to be associated with some uncertainty as to its impacts. However, it is more often deterministic models, rather than stochastic ones (Beven 2006), that are used for modelling of hydrological process induced by land use changes. Such were the first rainfall-runoff models as early as in the 1970s, e.g. HYROM (Anderson & Burt 1985), SACRAMENTO (Burnash *et al.* 1973), IHDM (Calver & Wood 1989) and others (e.g., SSARR cf. Rockwood 1982; HBV cf. Bergström 1992). In parallel, several catchment water balance models have been developed, focused on evapotranspiration, interception, soil moisture dynamics and runoff volumes over longer time steps (DT ≥ 1 day) (cf. Chow *et al.* 1988; Beven 2006). Two groups of the latter models are represented by SVAT (Soil-vegetation-atmosphere transfer; e.g. Dickinson & Henderson-Sellers 1988) on the one hand and SWAT (Soil-water-atmosphere; e.g. Arnold *et al.* 1998) on the other hand. The models of both

Supported by the Ministry of Agriculture of the Czech Republic, Project No. QH 92091.

groups are based on simplified representations of the actual interactions between soil, biosphere and atmosphere. The SVAT models have usually a large number of parameters for each of the soil and vegetation layers, which are difficult to estimate. The second group, the SWAT models, have usually a simpler structure with an easier-to-calculate runoff generation components. The latter group comprises, e.g., EPIC, SWAT and SWRRB (Arnold & Williams 1995). The WBCM model used in this paper also belongs to this group.

MATERIALS AND METHODS

The Němčický Stream catchment is located in the central part of Moravia, Czech Republic, with the average annual temperature 6°C and the annual precipitation average 652 mm (Uhlířová 2007). The soils in the catchment are mostly loamy Cambisols, while the valley bottom is covered by less permeable clayey Gleysols (according to the WRB 2006 classification system, cf. Němeček *et al.* 2004). The geological substrate in the experimental catchment is created by Culm sedimentary rocks, especially graywacke strata, and acid Pleistocene colluvial deposits. The corresponding distribution of Soil Hydrological Groups (USDA SCS 1985, 1986) are shown in Table 2. The catchment is covered by soil hydrological groups B, C and D. The actual values of soil hydraulic parameters were measured along three transects (Kovář & Štibinger 2006) and were found to vary within the following limits:
– field capacity FC (33.3 to 41.8%),
– total porosity P (44.3 to 49.9%),
– saturated hydraulic conductivity K_s (0.025 to 0.081 mm/min),
– sorptivity S (0.41 to 14.69 mm·min$^{-1/2}$).

The Curve Number methodology (USDA SCS 1985, 1986; Janeček *et al.* 2002), based on the soil hydrological groups, the land use & management and the antecedent moisture conditions (AMC), was applied to the catchment. The areal distribution of the medium AMC Curve Number values CN_{II}, characterizing the runoff aptitude of the Němčický Stream catchment, is shown in Figure 1.

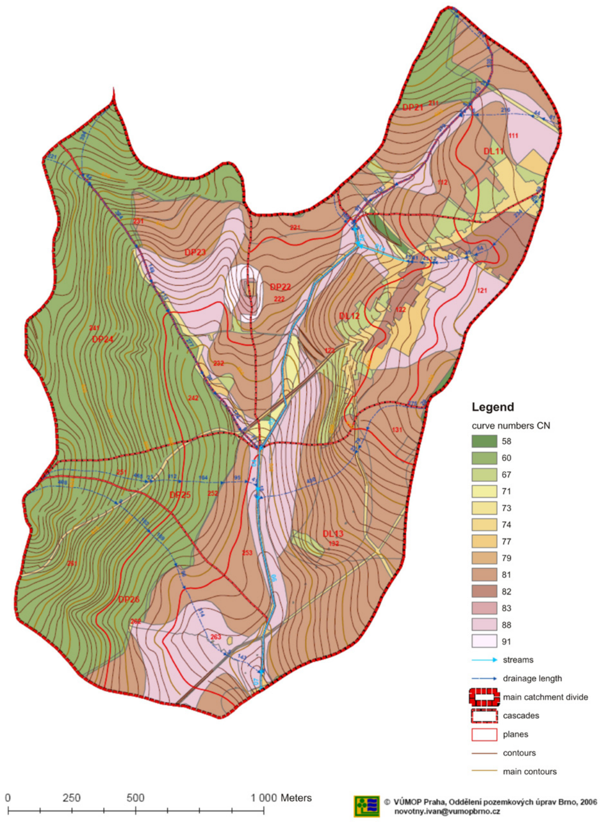

Figure 1. Curve numbers (CN) in the Němčický Stream catchment

Almost 53% of the total catchment area is presently used as arable land, on which mostly cereals and oil rape are grown. The other important catchment characteristics are given in Tables 1 and 2. The daily data on rainfall and free water evaporation were taken from the climatologic station at Protivanov (630 m a.s.l.), located at the distance 9.5 km from the

Table 1. Němčický Stream catchment characteristics and land use

Catchment characteristics		Land use (%)	
Catchment area (km^2)	3.52	arable land	52.90
River length (km^2)	1.90	permanent grassland	0.86
Average channel slope (%)	2.09	forest	35.04
Average catchment slope (%)	4.15	urbanised area	4.73
Average catchment altitude (m a.s.l.)	600	other area	6.47

Table 2. SCS hydrological soil groups and the average wetness Curve Numbers (CN) in the Němčický Stream catchment

Land use	Soil group									CN – weighted mean (–)
	B			C			D			
	area		CN (–)	area		CN (–)	area		CN (–)	
	(ha)	(%)		(ha)	(%)		(ha)	(%)		
Existing status										
Arable land	127.94	36.4	81	56.41	16.0	88	1.74	0.5	91	74.8
Permanent grassland	1.14	0.3	58	1.87	0.5	71	–	–	–	
Forest	121.56	34.6	60	1.48	0.4	73	0.20	0.1	79	
Urbanized area	8.30	2.4	74	8.35	2.4	82	–	–	–	
Other area*	11.06	3.1	67	10.82	3.1	77	0.89	0.2	83	
In total	270.00	76.8	–	78.93	22.4	–	2.83	0.8	–	
Scenario status										
Arable land	127.94	36.4	81	22.92	6.5	88	–	–	–	73.0
Permanent grassland	1.14	0.3	58	35.36	10.1	71	1.74	0.5	78	
Forest	121.56	34.6	60	1.48	0.4	73	0.20	0.1	79	
Urbanized area	8.30	2.4	74	8.35	2.4	82	–	–	–	
Other area*	11.06	3.1	67	10.82	3.1	77	0.89	0.2	83	
In total	270.00	76.8	–	78.93	22.4	–	2.83	0.8	–	

*Greenary spots

catchment. All daily data were then converted to decadal (10-day) sums. The WBCM model (Water Balance Conceptual Model; Kulhavý & Kovář 2000; Kovář *et al.* 2004; Kovář 2006) is a lumped model with a linear or non-linear storage probability distribution over the catchment area (Bultot & Dupriez 1976). It is based on the integrated storage approach, assuming that each storage element of the model represents the cumulative storage capacity (of a particular store) for the entire catchment. Individual storage elements mimic the effects of interception, soil surface storage, root zone (or active zone), the whole unsaturated zone and the groundwater zone (if the latter is not very deep). The model was developed for simulation of water balance at daily steps over the whole vegetation period, which is a critical time for water scarcity occurrence (Tallaksen & van Lanen 2004). Relevant interactions between the zones listed above are taken into account.

The model considers actual storage depths in individual zones and assesses their daily values and the corresponding input and output rates in accordance with the underlying physical principles. Mathematically, the simulation consists in the recurrent solution of a system of finite difference equations together with a set of algebraic equations balancing the following processes (Kulhavý & Kovář 2000):

- potential evapotranspiration, interception and throughfall,
- surface runoff and infiltration,
- active zone soil moisture dynamics,
- soil moisture content and actual evapotranspiration,
- groundwater dynamics, base flow and total runoff.

There are 13 parameters in the WBCM model:

AREA – catchment area (km^2),
FC – parameter characterising the “average” value of the root zone field capacity (–),
POR – parameter characterising the average value of the root zone porosity (–),
DROT – parameter of the root zone depth (mm),
WIC – the upper limit of interception capacity (mm),
SMAX – parameter representing the maximum capacity of the unsaturated zone (mm),
ALPHA – parameter describing the non-linear progress of filling of the unsaturated zone (–),
CN – SCS Runoff Curve Number (–),

P1, P2, P7 – parameters affecting the unsaturated zone dynamics, namely, its filling (P2) and exhausting (P1 and P7) (–),

GWM – parameter expressing the maximum active capacity of the saturated zone in the neighbourhood of the water stream (mm),

BK – parameter transforming groundwater recharge into base flow (days).

Three of them, SMAX, GWM and BK, were calibrated for the normal year 2001 within the reconstruction phase of our study.

The linear distribution of local interception capacities over the catchment area is assumed, which results in a catchment-wide estimate of actual interception and throughfall. The US Soil Conservation Service method based on the runoff curve number (CN) assessment is used to quantify surface runoff (US SCS 1986; Hjelmfelt 1991). Both the recharge of the active zone and its depletion depend, in addition to the atmospheric boundary condition, on soil parameters (field capacity, porosity, hydraulic conductivity) and on the previous soil moisture content, being principally controlled by the field capacity parameter. The finite-difference form of the one-dimensional Richards equation is used to model these processes (Kulhavý & Kovář 2000).

The rate of depletion of the root zone storage by actual evapotranspiration is estimated as an appropriate fraction of the potential evapotranspiration, depending on the soil moisture content and related to the physical properties of the particular soil (Greenwood *et al.* 2009). The saturated zone is assumed to fill via groundwater recharge and to get depleted via base flow (groundwater runoff) only. The above-mentioned three parameters of the

Table 3. Decadal water balance: April–October 2001 (normal year) in mm per decade

Decade	Rainfall SP	Actual evapotranspiration SAE	Change of storage			Total runoff		Imbalance SP-SAE-STF-DW
			unsaturated ASM	saturated GWS	total storage DW	calculated STF	observed SQM	
1	37.20	11.55	–0.84	11.18	10.34	15.61	16.34	–0.30
2	11.30	8.61	–2.20	–7.37	–9.57	10.37	11.10	1.89
3	3.80	18.06	–13.46	1.81	–11.65	4.16	4.26	–6.77
4	8.20	29.60	–24.34	1.51	–22.83	1.44	1.23	–0.01
5	25.80	28.24	–20.05	6.48	–13.57	1.12	1.44	10.01
6	10.40	30.79	–25.33	1.54	–23.79	1.39	1.38	2.01
7	18.80	17.66	–5.39	3.47	–1.92	0.77	0.54	2.29
8	20.80	18.41	–5.17	4.99	–0.18	0.86	0.85	1.71
9	6.40	29.56	–24.58	1.04	–23.54	0.37	0.12	0.01
10	19.50	26.64	–13.54	3.58	–9.96	0.82	0.01	2.00
11	30.70	26.70	–6.00	5.29	–0.71	0.65	0.01	4.06
12	48.80	19.15	8.79	7.05	15.84	3.87	3.91	9.94
13	38.60	28.50	–3.57	4.58	1.01	1.09	1.00	8.00
14	11.40	24.60	–17.23	1.33	–15.90	2.69	2.16	0.01
15	20.40	21.69	–9.51	4.09	–5.42	4.13	3.44	0.00
16	31.80	11.71	8.55	5.58	14.13	1.95	2.11	4.01
17	65.90	7.43	39.24	27.04	66.28	4.80	4.36	–12.61
18	26.50	6.54	11.20	16.58	27.78	18.14	18.73	–25.96
19	3.50	7.47	–4.35	3.03	–1.32	7.40	7.99	–10.05
20	1.30	5.43	–4.13	1.37	–2.76	3.37	3.52	–4.74
21	4.80	2.93	0.07	0.11	0.18	0.78	1.06	0.91
22	11.90	1.44	–4.71	0.43	–4.28	1.50	1.15	13.24
Period totals	457.80	382.71	–116.55	104.71	–11.84	87.28	86.71	–0.35

model (SMAX, GWM and BK) were optimised by minimising the sum of squared differences between the computed and observed 10-day runoff depths. The water balance equation for the catchment reads (Lal 2002):

$$SP = SAE + SOF + SBF + (ASM + GWS) \quad (1)$$

where:
SP – rainfall depth (mm)
SAE – actual evapotranspiration (mm)
SOF – direct runoff depth (mm)
SBF – base flow depth (mm)
ASM – change in unsaturated zone (mm)
GWS – change in groundwater storage (mm)

Together, SOF and SBF create the total runoff depth STF (mm), while ASM and GWS create together the total storage change DW (mm).

RESULTS AND DISCUSSION

First, the model WBCM was calibrated for the set of decadal data of the vegetation period 2001. The vegetation period was defined as starting April 1 and ending October 31 of each year, which approximately corresponds to the actual growing season and avoids the periods of frost and snow. Three WBCM model parameters (SMAX, GWM and BK) were satisfactorily optimised, with the result: SMAX = 280 mm, GWM = 560 mm, BK = 17.4 days.

The comparison of the observed and simulated decadal total runoff depths in all tested years is provided in Figure 2.

The same optimised parameter values were then used for water balance simulation of the 2002 and 2003 vegetation periods. The other parameters

Table 4. Decadal water balance April–October 2002 (wet year) in mm per decade

Decade	Rainfall SP	Actual evapotranspiration SAE	Change of storage			Total runoff		Imbalance SP-SAE-STF-DW
			unsaturated ASM	saturated GWS	total storage DW	calculated STF	observed SQM	
1	1.30	11.27	−9.47	−2.34	−11.81	3.64	3.83	−1.80
2	12.30	7.42	−0.74	5.14	4.41	3.99	3.90	−3.51
3	14.79	17.22	−7.80	6.35	−1.45	3.51	3.50	−4.49
4	4.50	33.44	−25.94	−1.13	−27.07	4.13	4.73	−6.00
5	64.50	26.34	−3.13	32.74	29.61	8.55	7.35	0.00
6	14.51	15.84	−4.67	5.64	0.97	3.70	3.45	−6.00
7	16.48	21.56	−10.06	4.36	−5.70	2.62	2.80	−2.00
8	22.50	29.44	−15.49	7.34	−8.15	3.21	3.08	−2.00
9	26.50	27.19	−8.83	6.31	−2.52	1.83	1.74	0.00
10	11.60	24.36	−14.34	1.33	−13.01	0.25	0.38	0.00
11	30.10	18.65	6.51	4.75	11.26	0.19	0.08	0.00
12	6.20	20.11	−14.34	0.28	−14.07	0.15	0.01	0.00
13	38.80	15.05	6.20	4.84	11.04	0.71	0.21	12.00
14	83.01	17.11	18.10	19.57	37.67	6.24	5.67	21.99
15	15.60	22.52	−11.21	5.17	−6.04	1.12	1.54	−2.00
16	56.19	16.54	18.56	17.18	35.74	3.92	3.20	−0.01
17	17.10	13.28	−1.77	2.74	0.98	2.11	1.60	0.74
18	27.61	6.21	9.31	10.67	19.99	2.10	2.13	−0.68
19	10.50	6.32	0.02	0.45	0.47	3.09	2.57	0.62
20	24.35	3.06	6.23	11.39	17.62	4.10	4.34	−0.43
21	18.60	4.02	2.68	8.03	10.71	3.09	3.02	0.78
22	4.60	1.74	7.92	1.69	9.61	1.64	1.52	−8.39
Period totals	521.64	358.70	−52.26	152.50	100.26	63.89	60.65	−1.18

(AREA, FC, POR, DROT, WIC, ALPHA, CN, P1, P2 and P7), as well as the initial conditions at the start of each vegetation period, were adjusted a priori. The balance computation went continuously throughout the whole vegetation period (from April 1 to October 31) at a daily step.

The simulated (after calibration) and observed decadal water balance components for the vegetation periods of 2001, 2002 and 2003 are presented in Tables 3–5 and are also depicted in Figure 3.

Non-negligible imbalances can be found in many decades, when the latter are considered separately. They are due to the fact that all balance components are calculated by the model independently, without forcing the balance to close at the end of each day. However, very small global imbalances found for the entire vegetation periods indicate that the model parameterisation is satisfactory. The decadal imbalances are presented in the last columns to the right of Tables 3–5. They are calculated as follows:

$$\text{Imbalance} = \text{SP} - \text{SAE} - \text{STF} - \text{DW} \quad (2)$$

The adequacy and accuracy of simulated decadal runoff sums, in comparison with the measured runoff sums, was evaluated using the Nash-Sutcliffe coefficient of determination *RE*, the residual coefficient of variation *PE* and the error in volume VE (Beven 2006), defined by the following formulae:

$$RE = 1 - \frac{F}{F_o} \quad (3)$$

$$PE = \frac{\sqrt{(F/N)}}{Q_P} \quad (4)$$

$$F = \sum_{i=1}^{N} (Q_i - Q_{Ci})^2 \quad (5)$$

$$F_o = \sum_{i=1}^{N} (Q_i - Q_P)^2 \quad (6)$$

Table 5. Decadal water balance April–October 2003 (dry year) in mm per decade

Decade	Rainfall SP	Actual evapotranspiration SAE	Change of storage			Total runoff		Imbalance SP-SAE-STF-DW
			unsaturated ASM	saturated GWS	total storage DW	calculated STF	observed SQM	
1	14.10	7.21	–7.50	–1.95	–9.45	4.88	4.68	11.46
2	7.20	18.13	–16.49	–4.46	–20.95	6.68	6.65	3.34
3	12.40	22.47	–11.31	–4.67	–15.98	5.91	5.68	0.00
4	29.21	33.52	–31.75	7.78	–23.97	4.66	3.61	15.00
5	36.51	20.88	0.18	11.95	12.13	28.12	30.53	–24.62
6	3.40	29.98	–17.59	–2.40	–19.99	13.80	13.89	–20.39
7	11.50	33.45	–34.37	–0.62	–34.99	3.04	2.56	10.00
8	11.40	27.79	–15.88	–0.60	–16.48	0.10	0.08	–0.01
9	1.60	27.14	–23.72	–1.92	–25.64	0.10	0.01	0.00
10	12.61	18.42	–5.95	0.04	–5.91	0.10	0.10	0.00
11	22.41	18.89	2.34	1.04	3.38	0.15	0.21	–0.01
12	48.40	20.89	21.41	5.47	26.88	0.36	0.32	0.27
13	0.40	18.37	–16.93	–0.87	–17.80	0.10	0.02	–0.27
14	2.26	17.91	–15.05	–0.69	–15.74	0.08	0.02	0.01
15	2.20	12.92	–10.27	–0.54	–10.81	0.10	0.02	–0.01
16	14.20	9.24	4.61	0.10	4.71	0.25	0.03	0.00
17	7.79	7.26	0.17	–0.06	0.11	0.42	0.01	0.00
18	12.70	8.35	3.71	0.22	3.93	0.43	0.01	–0.01
19	58.37	5.43	44.41	5.13	49.54	2.20	0.06	1.20
20	7.70	4.20	2.96	1.25	4.21	0.49	0.59	–1.20
21	6.70	2.66	2.78	0.93	3.71	0.33	0.04	0.00
22	2.70	0.88	–3.44	0.22	–3.22	0.08	0.02	4.96
Period totals	325.80	366.0	–127.68	15.35	–112.33	72.38	69.14	–0.28

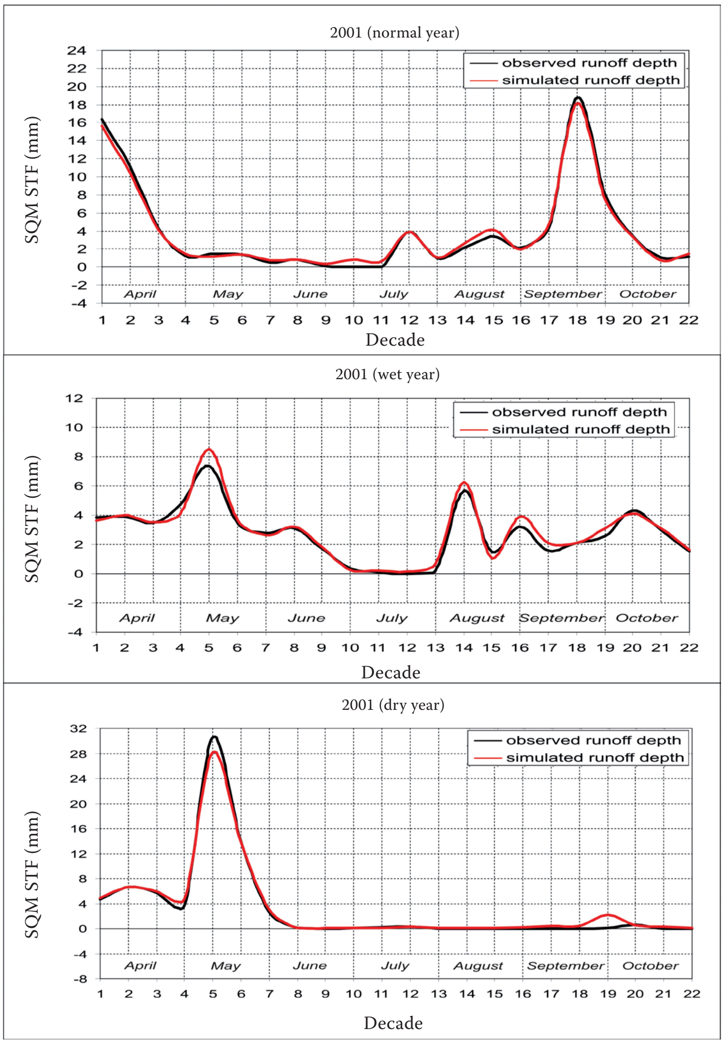

Figure 2. Observed and simulated decadal runoff depths in the Němčický Stream catchment for vegetation periods of 2001, 2002 and 2003

$$VE = 100\,\frac{\sum_{i=1}^{N} Q_i - \sum_{i=1}^{N} Q_{Ci}}{\sum_{i=1}^{N} Q_i} \qquad (7)$$

where:

Q_i – observed runoff depth for the decade i (mm)

Q_{Ci} – simulated runoff depth for the decade i (mm)

Q_P – mean observed decadal runoff depth (mm) for a particular vegetation period and

N – number of decades over the vegetation period

Ideal congruity of the observed and the simulated runoff is signalled by *RE* = 1 and *PE* = 0. The results of *RE*, *PE* and *VE* are presented in Table 7. They are acceptable.

The decadal water balance for all three vegetation periods (years 2001, 2002 and 2003) is most instructively presented in the so-called subtraction graphs in Figure 3, which show the decadal loss terms (actual evapotranspiration and total runoff) as subtracted from the decadal precipitation. Table 6 shows simulated seasonal water balance for all three years.

The second step after the parameter calibration and balance reconstruction for the actual state of the catchment was the scenario simulation. The simulated land use change scenario assumes that 10% of the existing arable land has been changed into permanent grassland. This new grassland is located on the soils of hydrologic groups C and D (Table 2), which occur in the experimental catchment on steep slopes, where soils are shallow and, thereby, highly vulnerable to water erosion. In the actual land use, the permanent grassland covers 0.86% of the catchment area only. Comparing this figure with the existing 52.9% of arable land, we must state that this is not an adequate proportion of grassland as far as the runoff generation is concerned (EU Water Framework Directive 2000). The scenario proposed above leads to the reduction of the overall

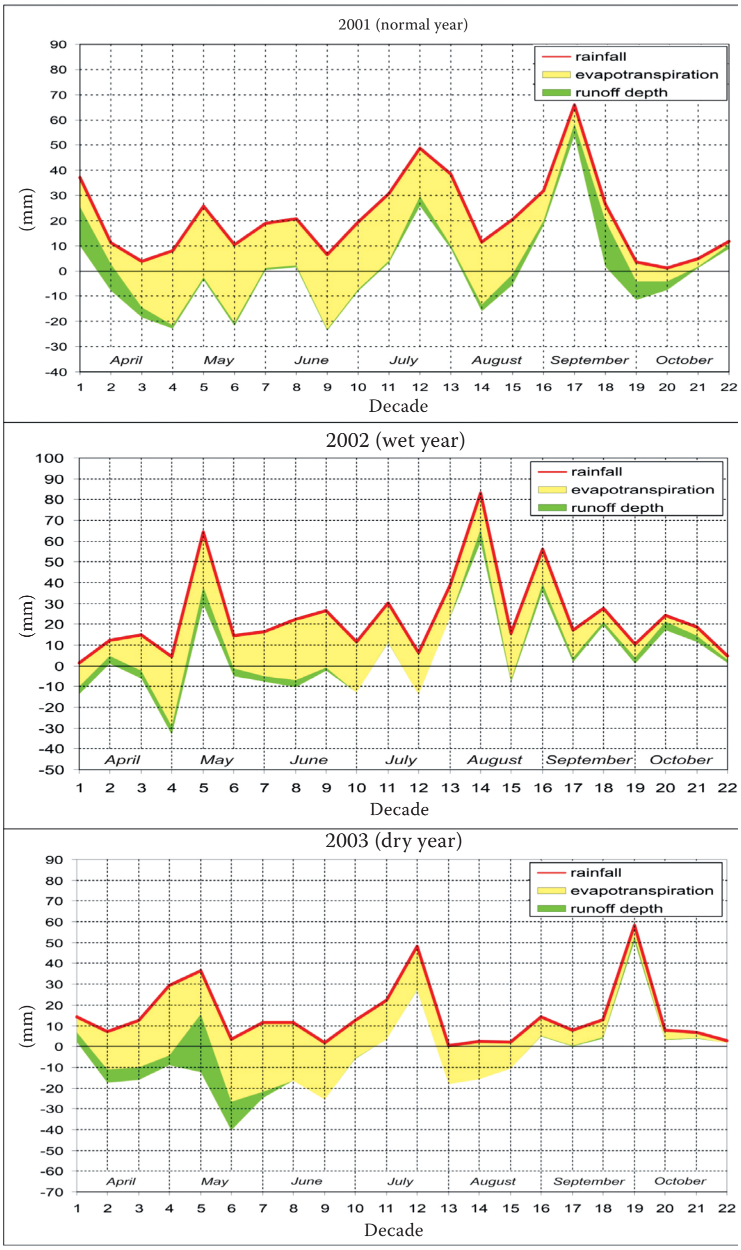

Figure 3. Decadal water balance in the Němčický Stream catchment in April–October of 2001, 2002 and 2003 (subtraction graph)

Table 6. Vegetation period (1/4–31/10) water balance in 2001, 2002, 2003 (in mm)

Water balance component	2001	2002	2003
Precipitation (SP)	457.80	521.60	325.80
Total runoff (STF)	87.28	63.89	72.38
Surface runoff (from STF) (SOF)	38.20	58.30	28.50
Potential evapotranspiration (SPE)	439.20	464.40	559.40
Actual evapotranspiration (SAE)	382.71	358.70	366.00
Interception (SAIR)	135.10	121.00	94.00
Change in unsaturated zone storage (ASM)	–116.55	–52.26	–127.68
Change in groundwater storage (GWS)	104.71	152.50	15.35
Change in subsurface storage (DW)	–11.84	100.26	–112.33
Balance error (ER) (mm)	–0.35	–1.18	–0.28
Balance error (ER) (%)	0.08	0.22	0.07

Table 7. Goodness of fit of simulated runoff to observed runoff for vegetation periods of 2001–2003

Year	Coefficient of determination RE (–)	Coefficient of variation PE (–)	Error in volume VE (%)
2001	0.99	0.11	–0.66
2002	0.95	0.15	–5.34
2003	0.99	0.24	–4.69

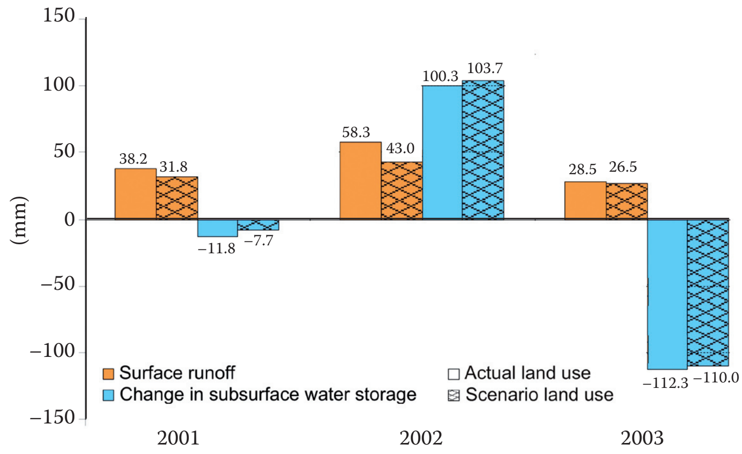

Figure 4. Scenario of water balance changes due to land use change in the Němčický Stream catchment

catchment CN (weighted mean) from 74.8 to 73.0. Such land use change expectedly increases the model parameter BK, but this is difficult to prove without observation. It is, however, known that decreasing the CN-value causes, in general, the slope of the falling limb of the hydrograph to decrease, which means a milder storage depletion (Maidment 1993). Based on the data collected by the present authors in other catchments where land use changes have been implemented (Kovář & Veselý 1998; Černohous *et al.* 2010), the BK value was increased for the scenario simulation from 17.4 days (an optimised value corresponding to the actual land use) to 20.0 days (the scenario value), reflecting a better saturated storage buildup and a slower groundwater runoff. All other parameters in the scenario computation remained unchanged.

A comparison of the existing land use with the scenario land use in terms of the catchment water balance components is shown for the three vegetation periods in Table 8 and Figure 4. The water balance components most sensitive to the land use change are the surface runoff (*SOF*), the seasonal change in subsurface storage (*ASM* + *GWS*) and, in particular,

Table 8. Scenario simulation of water balance of the Němčický Stream catchment (in mm)

Water balance component (mm)	Actual land use			Scenario land use		
	2001	2002	2003	2001	2002	2003
Precipitation (SP)	457.8	521.6	325.8	457.8	521.6	325.8
Total runoff (STF)	87.3	63.9	72.4	82.6	58.5	69.8
Surface runoff (from STF) (SOF)	38.2	58.3	28.5	31.8	43.0	26.5
Base flow (BF)	49.1	5.6	43.9	50.8	15.5	43.3
Actual evapotranspiration (SAE)	382.7	358.7	366.0	382.9	359.4	366.0
Change in unsaturated zone storage (ASM)	–116.6	–52.3	–127.7	–119.1	–53.8	125.4
Change in groundwater storage (GWS)	104.7	152.6	15.4	111.4	169.0	17.7
Change in subsurface storage (DW)	–11.8	100.3	–112.3	–7.7	103.7	–110.0

the groundwater storage *GWS*. An increase in the grassland area causes a decrease in surface runoff, with a moderate increase of the subsurface storage. The lower CN value of permanent grassland, compared to that of arable land, obviously reduces surface runoff and increases infiltration and, consequently, the subsurface storage, due to higher groundwater recharge. The proposed land use change is thus not only a positive non-structural flood control measure, but also a measure to support the "rain harvesting", i.e., it can mitigate negative impacts of droughts.

CONCLUSIONS

The WBCM-5 model has proved itself to be capable of successfully reconstructing the decadal water balance terms over particular vegetation periods in small agricultural catchments such as the Němčický Stream. Its use for land use scenario predictions is therefore justified and the results of scenario simulations are relevant.

The simulation indicates that, when 10% or more of the catchment arable land is converted into permanent grassland, surface runoff can be reduced, whilst subsurface storage is enhanced. In wet years this may lead to a perceivable increase in subsurface runoff, while the total vegetation period runoff may be reduced in all years (mainly because of the pronounced reduction of surface runoff). Of course, this simulation did not comprise dormant periods. Admittedly, the overall hydrological picture of the land use change might be a little different if the simulation were conducted over the whole year.

Acknowledgements. Field studies, assessments and evaluation have been supported by the Ministry of Agriculture of the Czech Republic, Project No. QH 92091. The generous support of the Research Institute for Soil and Water Conservation (VÚMOP, Brno branch) is acknowledged.

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Received for publication February 11, 2010
Accepted after corrections September 2, 2010

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