Extreme stages of the basin wetness conditions. 
Variability of the soil moisture in a lowland basin

URSZULA SOMOROWSKA
Faculty of Geography and Regional Studies, Warsaw University, Krakowskie Przedmiescie 30, 00-927 Warsaw, Poland
e-mail: somorows@mercury.el.uw.edu.pl

Abstract The extreme stages of the wetness conditions in a basin derived from direct soil moisture measurements are investigated. Current variability of soil moisture and soil water storage is estimated in the Lasica basin, situated in central Poland on the Mazovian Lowland, within the boundaries of the Kampinos National Park. Temporal decrease of soil water storage is presented as a function of groundwater level change and storage coefficient. The range of the water storage variability is presented in a spatially distributed way. Results can be used as a basis for restoration of wetness conditions facilitating the re-development of natural vegetation.

Key words soil moisture; time domain reflectometry (TDR); water storage decrease function; Kampinos National Park; central Poland; spatial variability

INTRODUCTION

Prediction of water availability under both normal (average) and anomalous (wet or dry) wetness conditions is important for sustaining ecosystems, especially those that are water-related. Soil moisture in the upper soil layers is essential for natural vegetation or agricultural crops. Although the volume of these soil water resources is relatively small it is of great importance to many hydrological, biological and biochemical processes. Changes in soil moisture regimes have a large impact on ecosystems.

Nowadays, soil moisture estimates can potentially be retrieved from space-based systems. However, there is still a challenge in developing this technology on an operational basis. Therefore field studies are still of great importance to provide reliable and direct estimates of the soil moisture content (Robock et al., 2000; Vinnikov et al., 1997).

Conventional laboratory procedures measuring water content are often slow and time consuming. An alternative solution for soil moisture measurements is use of a moisture meter based on the method of time domain reflectometry (TDR). This technique realizes quasi-simultaneous measurements being taken directly in the field. This technique was used in this research.

The aim of this study was to provide an estimate of the variability of current wetness conditions for the Lasica basin, Poland. In this basin valuable marshland, swamps and woodland ecosystems are present but they have been influenced by agricultural drainage in the past. The control of the dynamic soil water resources was started in 1995 (Somorowska, 1998). Results serve as a basis for restoration of wetness conditions facilitating re-development of vegetation. This approach is similar to the
concept of development of abiotic conditions to support ecological sustainability (Van Rijen, 1998).

STUDY AREA

The area chosen for this study is the Lasica basin (approximately 500 km²), situated in the central region of Poland on the Mazovian Lowland, within the boundaries of the Kampinos National Park. Two distinct types of hydrological zones with different regimes occur, i.e. wet zones that appear within lowlying and flat areas with relatively shallow groundwater tables and, in contrast, dry zones where the groundwater table is found at greater depths (Fig. 1). This research focuses on soil water resources stored in wet zones, although measurements have been conducted in both areas.

SOIL MOISTURE DATA

Field measurements of soil moisture have been conducted along three transects over the period 1995–2000 (Fig. 1). The measurements have usually been taken at depths of 5 and 10 cm, and then with increments of 20 cm. Readings have been taken down to the first saturated layer. A Field Operating Meter produced by Easy Test (1995) was used for determination of soil moisture in the field. Measurements were conducted in the spring, summer and autumn tracking the characteristic stages of soil water storage. In the spring measurements were taken to monitor relatively high soil water storage values. In the summer measurements were carried out in July or August, after a distinct dry period, to monitor relatively depleted soil water storage values. However, in the summer of 1997 measurements were conducted during an extremely wet period. In the autumn soil moisture was monitored in October or the beginning of November, when the soil water storage is affected by recharge. At each location where soil moisture was measured,
soil drilling were made. These drillings are to different depths, from 50 cm in case of sites located in wet zones, to 200 cm in dry zones where saturated layers are deeper. Measurement sites represent characteristic types of soils in which peat soils dominate in the wet zones, while podsol and brown sandy soils are characteristic for the dry zones.

WATER STORAGE DERIVED FROM SOIL MOISTURE MEASUREMENTS

Volumetric soil moisture profiles have been derived from direct soil moisture data for each season for the hydrological years 1995–2000. Some selected soil moisture profiles are presented in Fig. 2. Due to the extreme flood and drought events that have occurred during the observation period, the soil moisture data collected represent a broad range of possible wetness conditions. The envelopes of the soil moisture curves give the range of soil water contents recorded in the years 1995–2000. The depth of water storage has been calculated from volumetric soil moisture data from the 0–100 cm layer. The temporal variation of the water storage in wet zones is shown in Fig. 3. Water storage at a particular time was calculated as an average from water storage values, separately for wet sites with very shallow groundwater levels and for wet sites...
with shallow groundwater levels. Then observed differences in temporal water storage between extreme values in each year were derived separately for both types of wet sites. On this basis the average difference in temporal water storage was calculated as a six-year average. The difference was 45 mm at sites with very shallow groundwater levels and around 100 mm at the remaining wet sites.

WATER STORAGE DECREASE FUNCTION

Estimates of the temporal water storage in the 0–100 cm surface layer have been linked with the depth to the groundwater table using the linear regression function $\Delta R = \mu \Delta h$, where $\Delta R$ is the change in water storage in mm, $\Delta h$ is the change in depth of the groundwater table in mm and $\mu$ is the storage coefficient. The least squares method has been used to establish the values of the storage coefficient $\mu$ for the two soil conditions that were distinguished within the wet zones in the basin. Groundwater levels and soil characteristics are the main factors that vary for both types of wet zone. Therefore locations with a very shallow groundwater level (50–70 cm below the surface) and transformed peat soils have been considered separately from those with somewhat deeper groundwater depths and topsoils with lower retention capabilities. Thus two values of the storage coefficient $\mu$ representing possible rates of water storage decrease for these two soil conditions have been estimated (Fig. 4). The storage coefficient for the wet zone with the very shallow water tables is 0.0826 and for the zone with shallow water tables it is nearly twice as high (0.1731). Using these values the change in the water storage $\Delta R$ can be derived if the change in groundwater level $\Delta h$ is measured.

LONG-TERM WATER STORAGE VARIABILITY

Long-term observations of groundwater levels in the period 1951–2000 have been used for determination of extreme stages of groundwater heads, which are spatially
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Groundwater level change

Ah (mm) Groundwater level change Ah (mm)

Fig. 4 Soil water storage decrease function: (a) for wet sites with very shallow groundwater levels, and (b) for wet sites with shallow groundwater levels.

distributed within the basin (Kazimierski et al., 1996). Lines of maximum and minimum groundwater heads derived from 89 observation wells for two extreme years (wet and dry years) have been stored in separate vector files in CartaLinx Spatial Data Builder software, which were subsequently exported to the IDRISI32 GIS software. Following the rasterization process of the two vector files carried out with a resolution of 100 m x 100 m, each grid cell has been assigned a local maximum and minimum groundwater head. Overlaying the two images representing extreme stages of groundwater heads over a long period has allowed an estimation of the maximum differences in the local groundwater level lower retention capabilities of the $\Delta h_{\text{max}}$ (Fig. 5(a)). The east part of the basin is excluded from these considerations as groundwater levels are affected by the Warsaw agglomeration. Using the $\Delta h_{\text{max}}$ values, the spatial distribution of the variability of the water storage in the 0–100 cm soil layer has been established from the equation $\Delta R_{\text{max},i} = \mu_i \Delta h_{\text{max},i}$, where $\Delta R_{\text{max},i}$ is the variability of the water storage over a long period estimated in each cell $i$, $\Delta h_{\text{max},i}$ is the difference in groundwater level in each cell $i$ and $\mu_i$ is the storage coefficient in each cell $i$. The value of $\mu_i$ was set to 0.0826 at sites with very shallow groundwater levels and 0.1731 at sites with shallow groundwater levels. A map of $\Delta R_{\text{max},i}$ for the western part of the basin’s wet zones is shown in Fig. 5(b).

DISCUSSION AND CONCLUSIONS

The research provides ground truth information on the soil moisture content and water storage in the topsoil layers in the Lasica basin, Poland. The variability of the range of current wetness conditions has been detected based on field measurements that were conducted at 14 representative sites along three transects during six years of observation (1995–2000). Measurement sites represent characteristic types of soils. Average differences in water storage that have appeared between dry and wet periods were approximately 45 mm for sites with very shallow groundwater levels, and around 100 mm in locations with somewhat deeper groundwater levels (70–120 cm), both within the wet zones of the basin. These average differences characterize the dynamics of soil water storage that are the result of groundwater-level fluctuations and soil water retention capabilities. In extreme situations groundwater levels dropped by 70–90 cm causing the water storage to decrease by 120–150 mm.

The analysis of long time series of groundwater levels in the period 1951–2000 showed that differences in groundwater levels were 100 cm or more in the wetlands.
Thus differences in soil water storage for the 0–100 cm soil layer are greater than 100 mm in most of the area considered. The spatial distribution of $\Delta R_{\text{max}}$ in the basin has been derived from the maximum groundwater level recorded in 1956 and the minimum level that occurred in 1989. It should be noted that in the period 1951–2000 the average groundwater levels dropped in the basin. In the 1920s average groundwater levels in the wet zones of the basin were at a depth of 20–30 cm. Current groundwater levels occur at 50–100 cm depth. This drawdown was caused by intensive drainage in the wet zones to intensify agricultural production before the area became protected. As a consequence considerable habitat changes of the natural vegetation, including the disappearance of swamps, have taken place. Current protection policies formulated for the Kampinos National Park, in which Lasica basin is situated, indicate the necessity to
restore old natural habitats that require the re-introduction of proper soil wetness conditions and shallow groundwater levels. However, the question arises of whether it is possible to restore the natural vegetation as in some cases changes of soil substrate seem to be irreversible.

This research has provided an assessment of the general magnitude of the soil moisture resources presently stored in the upper soil layers. The estimated temporal and spatial variability of the range of wetness conditions highlights the possibility of extreme wetness situations to which present vegetation is exposed. Restoration of old soil wetness conditions, including a rise of groundwater levels, requires special attention and complex water management practices based on the detailed soil wetness parameters investigated in this research and potential habitat requirements.

Acknowledgement The author wishes to thank the Department of Environmental Sciences and Policy of the Central European University that has supported this research by grant no. 92–14.

REFERENCES


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