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ESTIMATION OF RIPARIAN ZONE EVAPOTRANSPIRATION FROM DIURNAL GROUNDWATER PATTERNS

Theses of PhD dissertation

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Preliminaries

Phreatophyte plant communities are generally found in shallow goundwater environments, such as topographic depressions and riparian zones. These plant communities are often valuable ecosystems with a significant impact on water use, therefore the determination of their evapotranspiration is important from a natural protection and also from a water resources management viewpoint. The nowadays widespread numerical hydrodynamic models also require an accurate determination of the evapotranspiration rates, for a reliable regional or local water balance they estimate.

The diurnal cycle of climatic forcing, such as temperature, solar radiation, and humidity, often induces a similar daily fluctuation in the groundwater level of the riparian zone and, especially during drought periods, in the flow rate of the adjacent low-order stream through the mediation of the riparian vegetation *(Fig. 1).* This vegetational effect on the groundwater levels and baseflow rates originates from a daily rhythm in the metabolic rate of vegetation further modulated by phenological changes through the seasons.

In riparian forests the primary inducing factor of these diurnal fluctuations is the temporally changing transpiration rate of the trees, because in forests with a dense canopy cover, soil evaporation is negligible during drought periods in comparison with the transpiration rates of vegetation. Several authors have investigated the linkage between riparian transpiration and streamflow rates (Troxell 1936, Croft 1948, Tschinkel 1963, Pörtge 1996, Lundquist és Cayan 2002, Bond et al. 2002, Loheide et al. 2005, Butler et. al. 2007, Boronina et al. 2005, Shah et. al. 2007) but only a few attempted to estimate the evapotranspiration (ET) rate of the riparian zone (White 1932, Reigner 1966, Bauer et al. 2004, Nachabe et al. 2005) from the observed streamflow, groundwater or soil moisture fluctuations or to provide an analytical description of these signals (Czikowsky 2003, Czikowsky and Fitzjarrald 2004).

Aims of the PhD thesis

The aim of my PhD dissertation is to a) summarize and evaluate the relevant historical research on diurnal fluctuations of the hydrological variables, and; b) develop new techniques that upgrade or replace the existing groundwater evapotranspiration estimation methods.

Methodology

The main characteristics of the diurnal signal

A typically observable diurnal pattern in groundwater level and streamflow rate is displayed in *Fig. 1b*. The maxima occur in the morning hours, between 6 and 8 a.m., and the minima in the afternoon, between 4 and 5 p.m. (Gribovszki 2002, Gribovszki et al., 2006). Both signals are characterized by sharp minima, but express differences in the peak regions, the streamflow signal being more rounded. Notably, the two extrema do not overlap in time, the groundwater extrema lag behind those of the streamflow rate by about 1-1.5 hours. No such lag has ever been reported or explained in the literature before. In an accompanying paper by Szilagyi et al. (2008) the problem is further investigated with the help of a numerical model and an explanation is furnished.

Basic principles of the new evapotranspiration estimation method

By upgrading the original White-method a new technique was developed to calculate groundwater evapotranspiration. My new model based on the fundamental observation of Troxell (1936) that groundwater supply, Q_{net}, to the riparian zone changes over the day (Gribovszki et al. 2008, Fig. 1). I supposed that in the late night/dawn period of the day ET is negligible and the storage change (dS / dt) of the riparian zone equals the net groundwater supply, $\frac{dS}{dt} = S_y^* \frac{dWT}{dt} = Q_{net}$ where, WT is the groundwater level in the riparian zone, S_y* is the readily available specific yield.

An empirical and a hydraulic version of the upgraded White-method were developed. The hydraulic version calculates the background (i.e., outside the riparian zone) hydraulic head, H, a distance, l, from the riparian zone by the late night Q_{net} value using Darcy's law and the above simplified water balance equation. To obtain intermediate H values, a spline interpolation is employed. The subsequent Q_{net} values over the day are then obtained from Darcy's equation by making use of the interpolated H values. In the empirical approach the subdaily changing Q_{net} values were calculated by selecting control points (circles in *Fig. 1.c*), obliterating the use of Darcy's equation and the prescription of the hydraulic conductivity (k) value. Finally, for either version the ET rates, characteristic of the riparian zone, can be obtained as $ET_G = Q_{net} - S_y^* \frac{dWT}{dt}$ *(Fig. 1c).*

The method was tested with hydro-meteorological data from 2005 in the Hidegvíz Valley experimental catchment, located within the Sopron Hills region at the western border of Hungary. Evapotranspiration values of this new method were compared to the Penman-Monteith evapotranspiration values on a half hourly scale and to the White method evapotranspiration values on a daily scale. At the start and end of the growing season ET rates by the current method lag behind those of the Penman–Monteith approach but otherwise the two estimates compare favourably for the day. On a daily basis the newly-derived ET rates are typically 50% higher than the ones obtainable with the original White-method. Sensitivity analysis showed that a) the hydraulic version of the present ET estimation technique is moderately sensitive (i.e., linearly) to the laboratory- and/or slug-test derived values of the saturated hydraulic conductivity, k, and; b) both methods are sensitive to the accurate determination of the specific yield value, S_y* [associated with short time-scales of aquifer drawdown and a shallow water table (Nachabe 2002)], characteristic of the riparian zone.

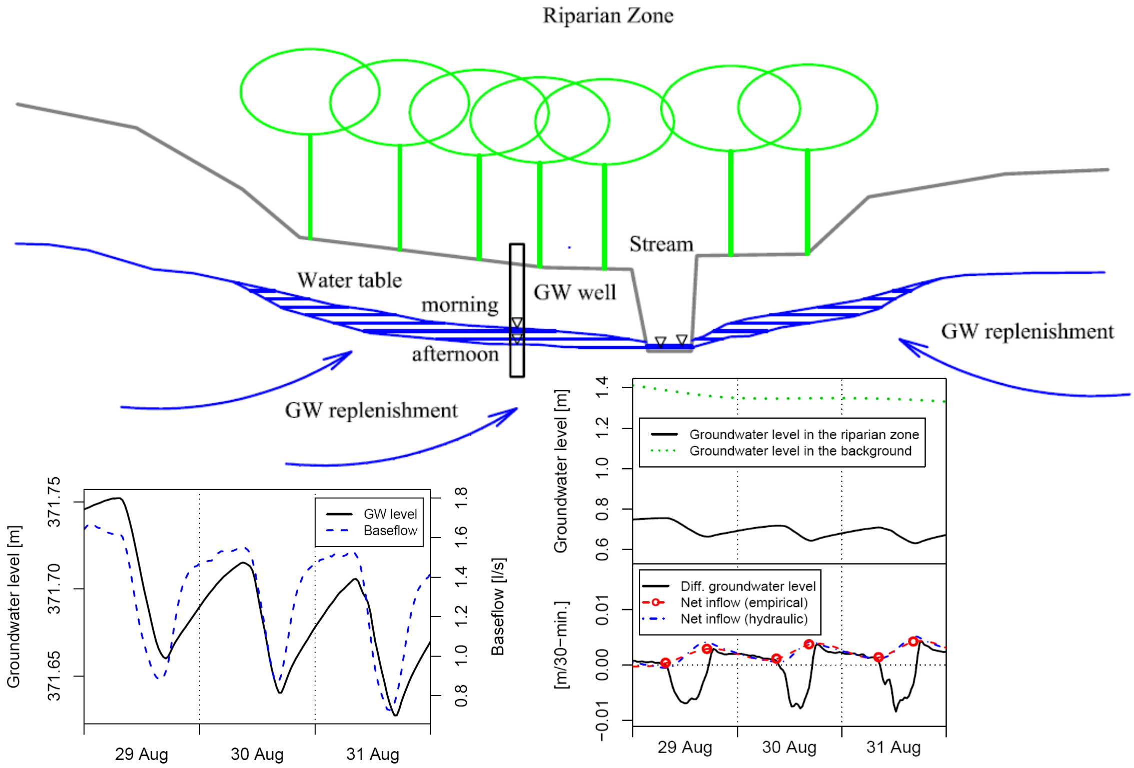

Fig. 1. (a) Schematic model of the riparian zone; (b) diurnal signal in streamflow and groundwater levels, and; (c) the main principle of the upgraded White method.

New scientific results (Theses)

I. The types and inducing factors of the diurnal groundwater and streamflow fluctuations were reviewed and characterized [4,8].

- In temperate climates, one of the most important diurnal fluctuation-inducing factors is the water uptake of vegetation, therefore a detailed overview is provided on the history of the relevant research.
- Beside a systematic categorization of the relevant historical research, models that estimate groundwater evapotranspiration from diurnal fluctuations of the groundwater level and/or the streamflow rate have been critically reviewed.
- Modifications of historical evapotranspiration estimation methods were developed to determine riparian and catchment scale groundwater evapotranspiration values employing datasets collected by self.

II. Temperature and evaporation types of the diurnal fluctuations were identified and characterized employing data collected by this candidate. The seasonal change of the evaporation type and its relationship with other environmental parameters (e.g., sap flow) were analysed in detail with the help of time series models [6,7].

III. A significant delay between the groundwater level and streamflow rate extrema was detected in the Hidegviz-valley field data (obtained either by automatic data loggers or manual measurements) [2]. No such lag has ever been reported or explained in the literature before. The problem is further investigated and explained [1] with the help of a numerical model.

IV. By modifying the well-known method of White, an empirical as well as a hydraulic version of a new estimation technique were developed to calculate evapotranspiration (ET) from groundwater-level readings within and outside the riparian zone [2, 3, 5].

- The hydraulic approach employs a simplified water balance equation and Darcy's law to calculate groundwater evapotranspiration from the diurnal signal of groundwater elevation.
- The empirical approach is based on control points, so it does not require the Darcy equation or even the hydraulic conductivity.

V. The new ET estimation method was successfully tested with hydro-meteorological data for 2005 in the Hidegvíz Valley experimental catchment [2, 3].

- The ET rates (which were very close to potential ET values in this place) of the present method were compared with those of the Penman-Monteith approach on a half-hourly time-scale and on a daily basis, with the original White method.
- Sensitivity analysis showed that the hydraulic version of the present ET-estimation technique is most sensitive to the laboratory- and/or slug-test-derived values of the saturated hydraulic conductivity and specific yield (its sub-daily estimation developed by this candidate), taken from the riparian zone.

The present methods will probably be improved in the future and possibly even be simplified. It is hoped that in the coming years they will be applied and tested widely by the scientific community. With the help of these new estimation techniques it is further expected that more accurate and temporally more detailed information on groundwater evapotranspiration, especially by phreatophyte vegetation, will gradually be gathered.

The utilisation of the results

Few direct methods exist for an accurate determination of the groundwater consumption of the vegetation even though these methods have a number of benefits when compared to other more traditional methods. Firstly, these methods calculate groundwater evapotranspiration, which may differ in many cases from the potential evapotranspiration rate. Furthermore, when compared to traditional evapotranspiration estimation methods these approaches may excel in that they a) generally employ a small number of parameters and/or variables to be measured; b) are typically simple to use, and yet can yield results even on a short time-scale (i.e., hours). While, e.g., temperature-based methods of evapotranspiration estimation are simple also, they cannot be applied or become inaccurate over shorter time periods. Similarly, traditional approaches (such as eddy-correlation or Bowen-ratio based) are accurate for shorter time steps but they require a number of measurable input variables.

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