GSI Technical Paper 1: The Water Balance as a fundamental methodology to inform sustainable water management

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In order to manage water for economy, people, and ecosystems, the catchment water balance provides fundamental quantitative information to describe the water situation in catchments. The catchment water balance provides information on opportunities for water use improvements, supports the assessment of water risks, and facilitates site level water reporting. Furthermore, it is a key element in water stewardship implementation. Beyond that, it provides the foundation for water targets development.

This GSI Technical Paper describes how the catchment water balance can be used by stakeholders in a catchment for activities related to sustainable water management. While rooted in science, the paper has practical focus. It is assumed that the reader has some basic understanding of what a catchment is and how water behaves in a catchment.

Water balance

A water balance of a geographical location refers to a mass balance conducted for water in this location, following the principle of mass conservation. It can be described in terms of an equation that describes the water flows in and out of the system. In this case, we define the system as the catchment.

A simple catchment water balance equation is:

Precipitation (P) = Runoff (R) + Evapotranspiration (ET) + Change in Storage (ΔS)

$$P = R + ET + \Delta S$$

P: Precipitation: Total amount of rain falling in a catchment.

R: Runoff: Surface and groundwater flows out of the catchment.

ET: Evapotranspiration: Evaporation from the soil and water bodies in the catchment, as well as the transpiration from vegetation.

ΔS: Change in storage: Change in groundwater storage, soil water storage but can also describe storage in lakes and reservoirs.

Other two important definitions in the catchment water balance are:

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Green water: When precipitation on land does not runoff or recharge the groundwater but is stored in the soil as soil moisture or temporarily stays on top of the soil or vegetation.

Blue water: Fresh surface and groundwater, in other words, the water in freshwater lakes, rivers and aquifers.

Water balances can be created for various spatial and temporal scales

The temporal scale of a water balance refers to the definition of a certain time frame or period of time in which the balance will be conducted, for example one or several years, as well as the definition of a time resolution, such as a year, a month, or a day.

A water balance as presented above with the equation, can be conducted for different geographies at various spatial scales, for example, a farm or a watershed or basin, as long as the geography defined for the balance can be considered confined in the sense of accountable inflow and outflows of water.

Because water balances can be created with varying spatial and temporal resolutions, they can be nested in time and space, or both. For example, we can create a water balance for each month of a given year and aggregate results to present the components of the water balance equation (P, R, ET, ΔS) at a yearly level. Also we can create a water balance for a site and nest the site water balance in the catchment water balance where the site is located. While this seems obvious, it is an important characteristic with practical implications, as it enables the logical translation of the water balance information at the catchment level to the site level and vice versa, as well as the change in the water balance components through time, for both catchment and site.

Water balance in a catchment context

In most catchments, water availability (determined by Precipitation) and water consumption (mostly determined by Evapotranspiration, although water consumption also refers to water incorporated into a product, the later being usually of minimal proportion with respect to the former) fluctuate mainly because of the climatic situation in the catchment during the year. This means that if a water balance is conducted with a yearly time resolution, important effects of water availability in relation to water consumption, at the seasonal or monthly level, remain invisible. In order to inform sustainable water management, a water balance with monthly resolution is required. Figures 1 and 2 below display yearly and monthly water balances for the same example catchment. Figure 1 shows that the storage of water in the catchment is positive for the year, and that water consumption is less than precipitation. Figure 1 provides therefore a good impression of the water situation in that catchment. In figure 2, the water balance is calculated using the same input data; and presented with a monthly resolution. The water situation looks very different in this case. It is clear that the water consumption (ET) in the months April to September is largely dependent on water stored from November to March where the rainfall is concentrated. These dynamics are totally obscured in the yearly water balance.

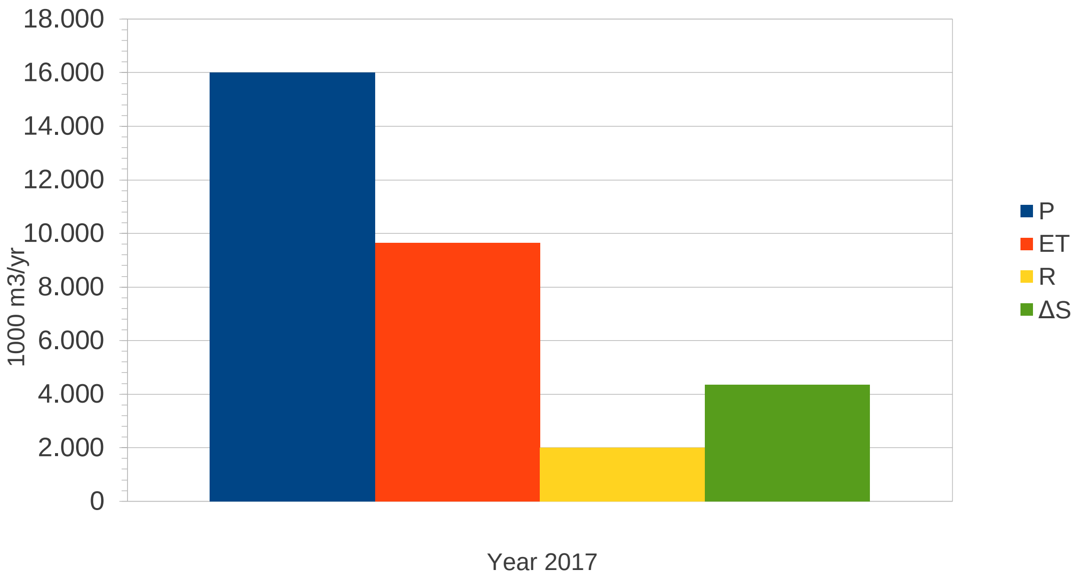

Figure 1. Example of a catchment water balance with yearly resolution

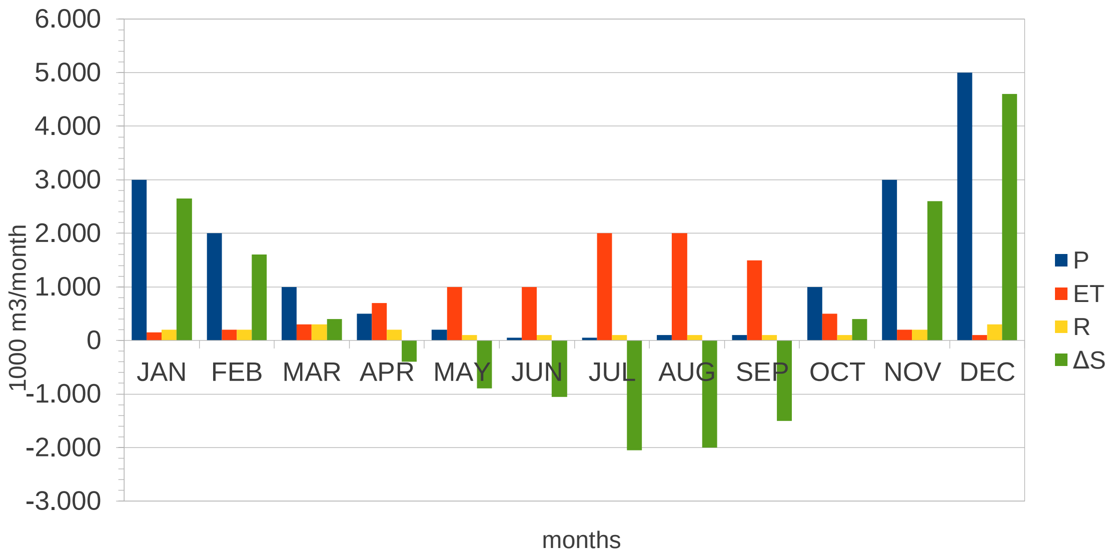

Figure 2. Example of a catchment water balance with monthly resolution (same input data used in figure 1)

Water Balance in a farm context

The farm field water balance is based on the assessment of crop water requirements, in order to determine irrigation requirements. Let's assume that we estimate monthly crop water requirements for a farm located in the example catchment above, and let's analyse the month of April. Let's assume that the crop requires an average of 25 m^3 per day per hectare to grow during this month, which corresponds to 750 m^3 per hectare for the entire month. The rainfall at the farm in April is 170 m^3 per hectare. In the majority of the cases, this rainfall is not evenly distributed during the month. Provided that the crop can effectively use all rainfall, in order to know when the farmer should provide the crop with the extra 580 m^3 per hectare it requires to grow the crop without water stress, it is necessary to know when it rains and how much. This implies that the time resolution of the farm needs to become more detailed than monthly, preferably daily, in order to be able to fulfil crop water requirements at the right time (Allen, Pereira, Raes, & Smith, 1998).

Water balance to support environmental sustainable water use in a catchment: environmental flow requirements

One of the issues in sustainable catchment management is to ensure that a river has enough flow during the year to sustain its ecosystem health and services. The amount of flow that is required for this is called environmental flow (Richter, 2010) (International_Water_Centre, 2007).

For our example catchment, the environmental flow is especially important from January to March in order to sustain the river ecosystems, for example the flooding of riparian lands and small lakes by the river in winter and early spring for productive wetlands and for creation of the habitats for fish spawning. For simplicity reasons, let's assume that the environmental flow requirement established by the local authorities during the first three months of the year is 300,000 m^3 /month (as Runoff).

The annual water balance presented in figure 1, shows a total flow (R) of 2,000,000 m^3 per year whereas the annual environmental flow is 900,000 m^3, indicating that there is enough water flow in the river to cater for the environmental needs. However, the figure does not provide any more detailed information, as to the respective flows occurring at the monthly level. On the contrary, the total water flow (R) from January to March is 700,000 m^3, as can be deduced from figure 2. In other words the environmental flow that is required to sustain the riparian ecosystem services is violated. This means that from an environmental point of view, the water management in the catchment is not sustainable. To comply with environmental flow requirements, the monthly water balance shows that additional 200,000 m^3 of water needs to be allocated to the runoff (R) during the first three months of the year.

The water balance can also inform strategies to comply with the environmental flow required: either a reduction in water consumption (ET), a reduction in storage (ΔS), or a combination of both. Both strategies imply that the water users in the example catchment will need to reduce their overall annual consumption (ET) by 200,000 m^3 or ~2% of the total ET as depicted in figure 2. Also, the strategy required may imply that the reduction on water consumption by water users is achieved during the summer months (July to September), whereas the change in storage, so that more water is released to the river, is required from January to March.

Water balance to support environmental sustainable water use for a specific water user

Picking up the example above and using the 'nesting characteristic' of the water balance, we propose a way to incorporate the environmental flow requirement of the river in question into the farm water balance.

Following the previous sections, let's assume that we require a reduction of blue water consumption of 200,000 m^3 over the whole year for the example catchment, and that we need to allocate this amount of water to the runoff of the river during the three months January-March, in order to reach an average flow of 300,000 m^3/month during these three months. In other words, the storage in these months needs to be decreased by 200,000 m^3. This needs to be lead by the relevant water management authority.

However, specific stakeholders like the farmer above can also make a contribution to this. They can do so by translating the environmental flow requirement in a reduction of their water consumption. This can be done either by becoming more efficient in water use, by changing crop, by changing cropping season, by making better use of rainfall, or by vacating their agricultural lands. To assess the feasibility of the various options, scenario soil water balances can be produced that incorporate the 2% reduction and test the various strategies.

If a farmer or other water user wants to set a target for reduction that is based on the environmental flow requirements of the catchment from which the water is taken, they could adopt the 2% reduction as a volumetric consumption reduction target. A more qualitative target could be the requirement that the farmer engages with other stakeholders in the water allocation process for the catchment to agree on allocating the environmental flow water requirement from the storage.

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References and further reading:

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