The Water Balance Model on ClimateAnalyzer.org

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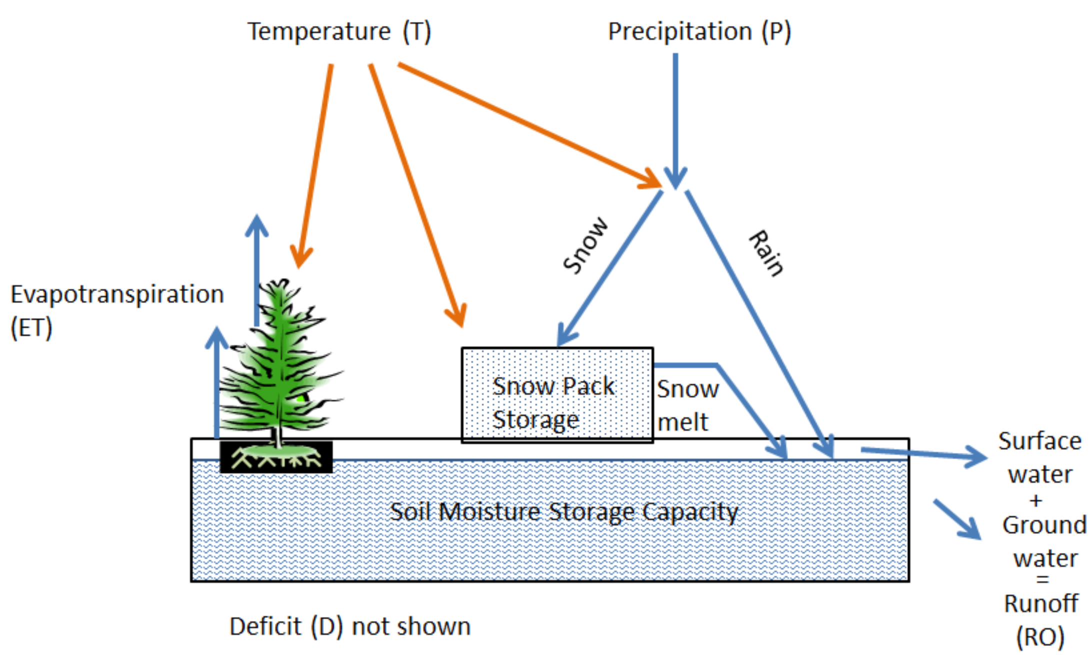
Water balance is a tool for increasing our understanding of climate influence on natural resources. Like balancing a check book, it is a way of tracking the balance of nature's most important asset. Most natural resources we manage are either water itself (springs, rivers, wetlands), or life that depends on water. Water and temperature interactions are based in physics that we can mathematically model. We find (and many others before us have too) that these modeled values are more strongly correlated with the things we manage than simple measures of temperature or precipitation.

Need to know…

- The water balance model tracks the fate of precipitation after it falls
- After precipitation (snow or rain) hits the ground it has three options
  - 1) Stay put temporarily as stored snow pack or soil moisture
  - 2) Go UP
    - Via evaporation or through plants via transpiration (which = growth)
      - 60- 90% of all precipitation globally returns to atmosphere this way
- 3) Go DOWN
    - infiltration to ground water
    - runoff to wetlands, lakes, streams, rivers
- Temperature = heat energy that determines snow or rain
    - Determines time water is stored as snow and when it melts
    - Determines rate of evapotranspiration
- Almost everything we care about is more closely linked to how water *moves through the environment* than simple measures of temperature or precipitation



The water balance model is an accounting system that keeps track of how much water is present in each compartment of the water cycle. The movement of water between compartments depends on the amount of energy (heat) in the system and the amount of water available. The model considers the following compartments:

Potential Evapotranspiration (PET): The amount of evaporation and transpiration that would occur if soil moisture were *unlimited*. Temperature, wind, solar radiation, cloudiness and a variety of other factors affect PET. Since each weather station type has different parameters available (snow and solar radiation are present in some locations but not others), calculating PET can be complex. Two methods for calculating PET are available in the menus of ClimateAnalyzer's water balance model: (1) Penman – Montieth, and (2) Hamon. The Penman – Montieth equations used in the ClimateAnalyzer code are described here. The Hamon equations appear in the Appendix to Lutz et al. (2010). Both methods consider the elevation and latitude of the weather station. The Penman – Montieth method considers more physical parameters such as solar radiation and has the ability to estimate these parameters when they are missing. When calculating Penman-Montieth PET, ClimateAnalyzer will use as much data as it can find and estimate when it needs to. Penman Montieth might be more accurate in locations where a lot of data are available. The advantage of the Hamon method might be consistency of method, which allows for comparison of a large of number of locations at the same time. Since the Hamon method relies on fewer measured parameters and always estimates the same parameters, differences seen among locations will not be due to the availability of, e.g. measured solar radiation data in one location but not in another.

> ***Need to know…***
> 60 to 90 % of annual precipitation is evapotranspired back to the atmosphere, mostly through plant leaves. Because this is water in a vapor form moving through millions of leaves in a watershed it is the most difficult part of the water balance to measure or model so there are numerous ways to go about it, some simple (Hamon) and others complex (Penman-Montieth). The “right” method depends on the question.

Actual Evapotranspiration (AET): The amount of water that actually evapotranspires. AET depends on soil water availability and PET. If sufficient water is available, AET = PET. If insufficient water is present in the soil, AET < PET. The maximum amount of water that can be removed from the soil reservoir during any time interval is described by equations in Lutz et al. (2010).

> ***Need to know…***
> AET is the water balance value that is most closely related to vegetation growth. When plants transpire vigorously they are alive and growing.

Moisture Deficit: The difference between PET and AET.

> ***Need to know…***
> Deficit is drought and is a measure of the water that plants would use if it were available. It is a positive value where larger values are bad for plants. Large values are associated with low river flow, dry wetlands and wildfire.

Soil water : The amount of water that is held in the soil. The model treats the soil like a bucket that can be filled by inputs (e.g. rain, snowmelt) and emptied by outputs (e.g. evaporation, transpiration). If the soil gets full, then runoff to streams results. Since the maximum water capacity of the soil depends on soil depth, texture, and other characteristics, ClimateAnalyzer allows you to choose soil water holding capacity as any value between 5 and 500mm. In the absence of a soil survey or other information, a good rule of thumb in western states is to choose 100mm. Even if this parameter is not set to the exactly true value, it will still be possible to compare drought status for a single site across years

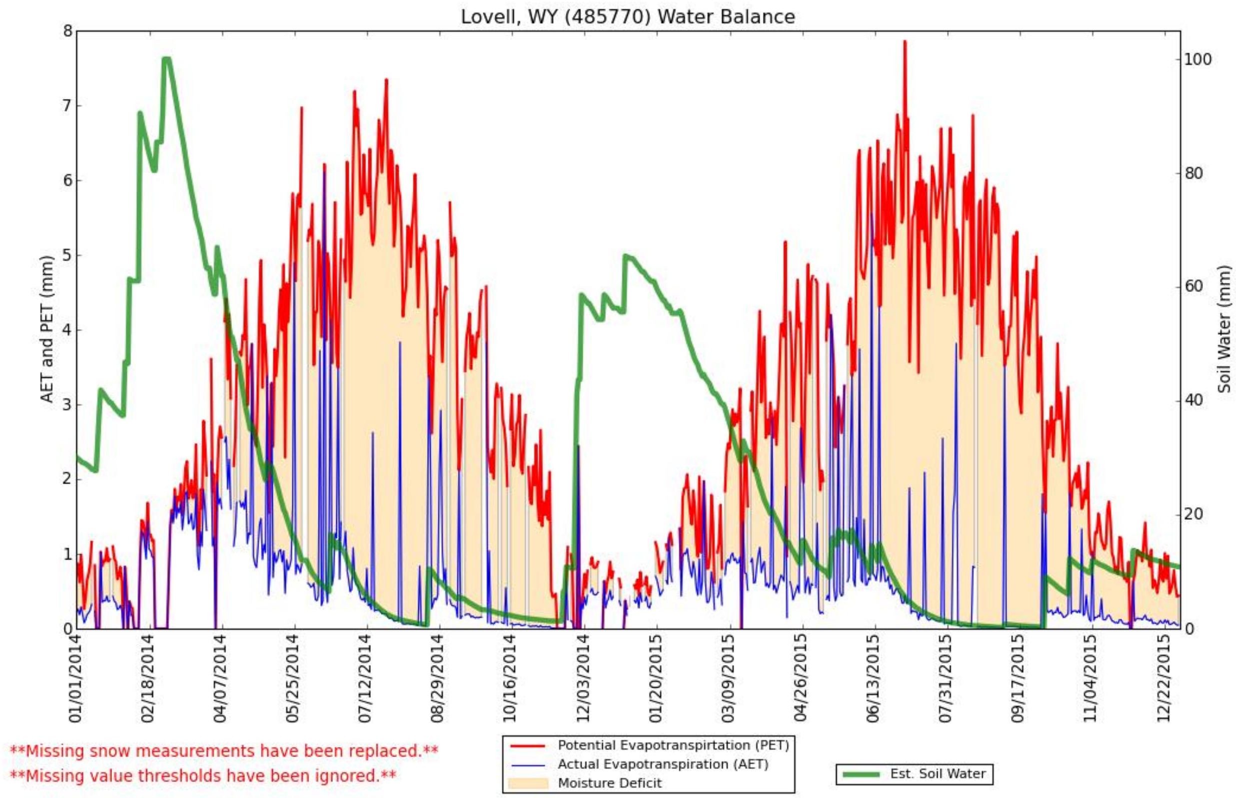
> ***Need to know…***
> Water holding capacity is the amount of water soil retains after it is saturated then drains. Think of a saturated sponge left on a counter –without squeezing. Soil typically fills with water in winter in deserts and spring with snowmelt in mountains. As plants use water from soil it can be replenished by rain. If rain doesn't fall deficit or summer drought occurs. Plants "drink" water from soil and soil stores water, but not all soils are equal. Some are shallow, some rocky, sandy, or loamy, thus different soils store different amounts of water.

Rain, Snow Melt, Runoff, Evapotranspiration: Moisture inputs and outputs to the soil reservoir.

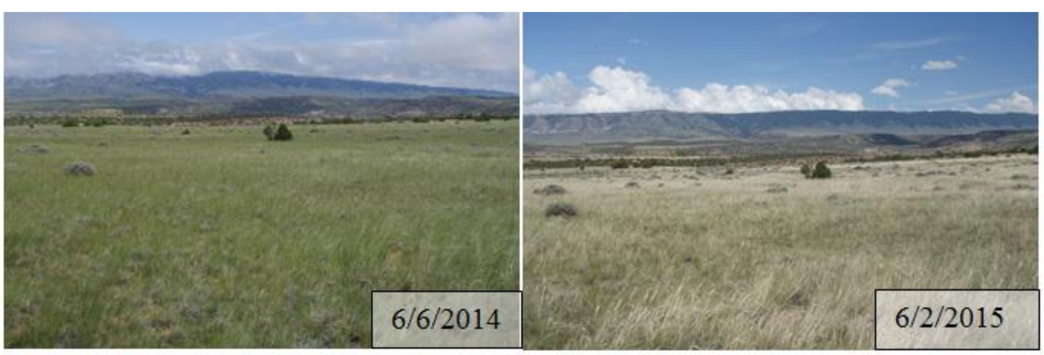
Spin-up:
The water balance model starts with an initial set of assumed parameter values that are probably inaccurate, for example that soil water = maximum_holding_capacity. The model then runs for one year, allowing these parameters to adjust to the physical data that are available. For this reason, the model will always run for one extra year prior to the dates chosen in the menus. For example, if the user chooses to view output from 2010 – 2014, the model actually runs from 2009 – 2014 but only shows the 2010 – 2014 results. For this reason, it is never possible to view the model for the first year available in the weather station record. If you choose the first year in the record, the web site will modify your choices for you.

Example Output

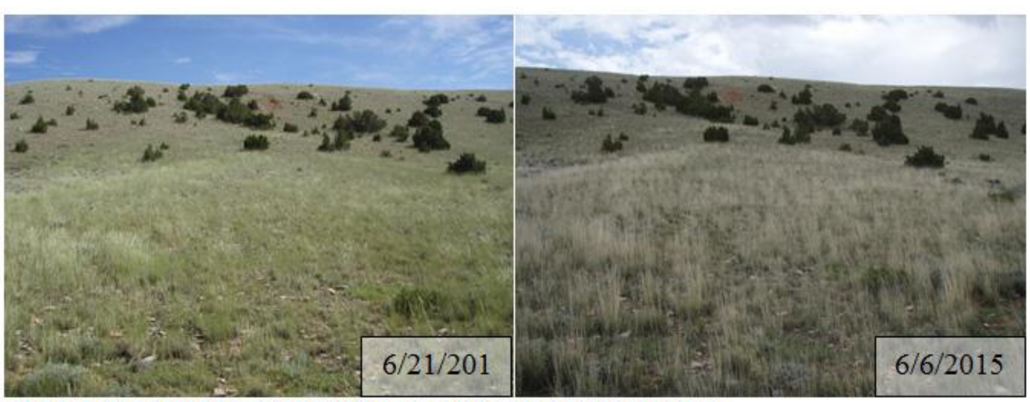
The graph below contrasts two growing seasons at Lovell, Wyoming, near Bighorn Canyon National Recreation Area. A tabular version of this output can be seen here. It is interesting to note that more soil water was available in the spring of 2014 than spring of 2015. The 2014 season also reached moisture deficit (orange shading) much later, in April rather than February.



This difference in moisture can be seen in photographs taken in the park's vegetation plots (below). Vegetation in June of 2014 is much greener and more productive than in 2015.



BICA_LTM_Veg070 photopoint number 1, east direction.



BICA_LTM_Veg080 photopoint number 2, south direction.

Evaluating Missing Values

The model has three missing value "Forgiveness Levels." If you choose to be "Not at all forgiving" of missing values, then the model will refuse to produce output if any of the months under consideration have more than 3 days missing Tmax,Tmin, Precipitation, or Snow. If you choose to be "Mildly forgiving" then the model will replace missing snow data with the previous day's snow measurement – again and again – until new data shows up. This option is useful in places where the weather station operators do not record snow in the summer, but it is reasonable to assume that there is no snow. If you choose to be 'Very Forgiving' then the model will produce output no matter how many missing values are in the data. In this last case, missing data appears as "nan" in the table and blanks in the graphs. Importantly, the tabular output of the model (available in the Tables menus of the web site) provides a missing value summary report that shows how many values were missing in each month. You can see an example missing value summary here (scroll to the bottom of the page).

If you choose to be forgiving of missing values, then it is important to evaluate the quality of your output and decide whether it is useful. Some missing values matter more than others. For example, missing temperature data in January probably does not matter as much as missing precipitation data in July because there is rarely evapotranspiration in the winter when snow is on the ground. Everyone using the water balance model should evaluate the missing value reports and carefully consider whether the model is producing realistic output. ClimateAnalyzer.org assumes no responsibility for real world decisions based on the output of the model. Users of the model should understand the ecosystem in which they are working, use their own judgement, and carefully consider the choices that they make in the menus.

Management Applications:

The NPS Inventory and Monitoring Program staff are working to *quantify* relationships between water balance and conditions like those shown in the photos above. So far we have found relationships between water balance variables and whitebark pine mortality (Shanahan et al. 2016 submitted); wetland periodicity and amphibian colonization rates (Ray et al. 2016 submitted); grazing allotment productivity in desert ecosystems (Thoma et al. 2016 in press); different responses in C3 and C4 desert grasses (Witwicki et al. 2016 submitted); and desert spring flows (Weissinger et al. 2016 submitted). In each case we found evidence that water balance can improve our understanding of vital signs response by considering *how water moves through the environment*.

There are many other studies that show how water balance is linked to hydrology of rivers (Gray and McCabe 2010;) and a USGS web site (http://www.usgs.gov/climate_landuse/clu_rd/nccv.asp) showing historic and projected water balance for the U.S. using methods like those reported by Climateanalyzer.org.

Literature Cited

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