

# Calibration of Runoff Models with Remotely Sensed Small Reservoirs

## Authors

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## Scope

In most semi-arid areas, small reservoirs are located in upland watersheds. To understand the filling process of reservoirs, and to determine their impact on flow, hydrological models are needed. Most existing runoff models are, however, geared towards temperate climates and may not capture relevant hydrological processes and runoff production in semi-arid areas. This tool presents a method to develop simple hydrological models for dammed upland watersheds based on monitoring reservoir surface areas with radar remote sensing.

## Target group

Hydrologists, water resources planners

## Requirements for application

- Sequences of radar images, covering a period from the dry season into the rainy season (see Near –Real-Time Monitoring of Small Reservoirs with Remote Sensing Tool)
- Regional area-volume equation (Small Reservoir Capacity Estimation Tool)
- Digital elevation model, i.e. SRTM
- Precipitation data, i.e. daily Rainfall Estimates (RFE), provided by the Famine Early Warning Systems Network (FEWS NET)
- Evaporation data
- GIS and Remote Sensing Software

## Description and application

### *Classification of reservoir sizes, stream network, and watershed extraction*

Developing hydrological models by remote sensing reservoir surface areas requires a sequence of satellite images, ranging from the dry season to the rainy season. Image acquisition about every two weeks with, for example, ENVISAT, is advisable insofar as it is possible. Changes in reservoir sizes can be determined by comparing crop sown area near the reservoir for different time periods (see the tool on Near Real Time Monitoring of Small Reservoirs with Remote Sensing, described separately).

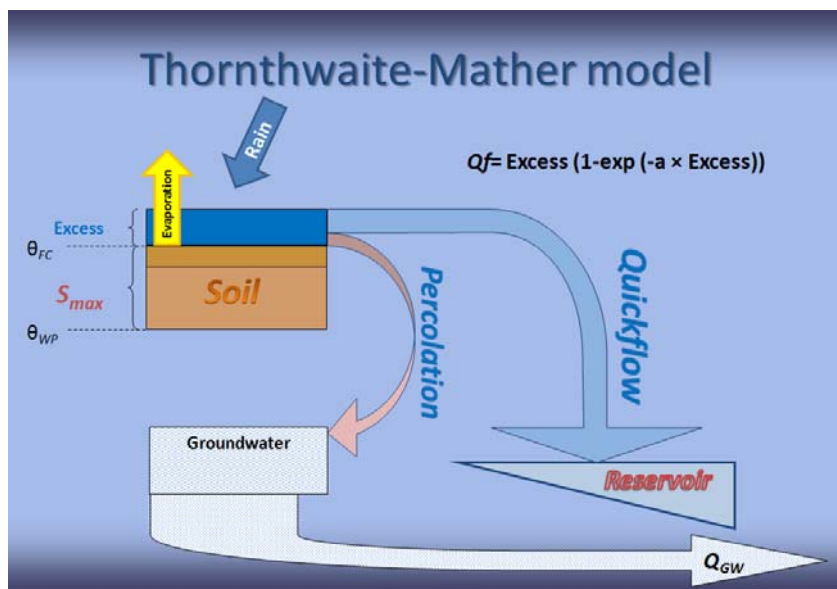
Next, the drainage network, and the reservoir's contributing watersheds, can be extracted from a digital elevation model (DEM). The publicly available Shuttle Radar Topography Mission's (SRTM) DEM's, with a pixel size of 90 m, is a suitable dataset in absence of more detailed information. After a "pit removal" procedure, to remove unwanted data artifacts, the stream network can be extracted from the DEM. A GIS is used to overlay reservoir size information with stream network information. This makes it possible to identify the position of the dam wall. To define the reservoir's watershed, a seed point needs to be digitized at the downstream side where reservoir and stream network intersect. With these seed points, the stream network, and the DEM, each reservoir's watershed can be determined.

### Hydrological modeling

Reservoir storage volumes can be determined with the classified surface areas, and regional area-volume equations (Small Reservoir Capacity Estimation Tool). When monitoring is repeated, changes in reservoir storage volume can be determined. An increase in storage is attributed to rainfall on the reservoir itself, and to water that flows in from its watershed.

Daily rainfall and evaporation data, available from the national meteorological services or, for example, from FEWSNET, are the remaining data needed to calibrate the runoff model. From the rainfall and evaporation data it is possible to infer how much of the storage change observed in the reservoir is due to rainfall directly into the reservoir, as the reservoir area is known. If reservoir storage increases are larger than what can be explained through rainfall directly into the reservoir, the additional contribution must come from the watershed.

This watershed contribution can be modeled with a simple runoff model, such as Thornthwaite and Mather's (1955) water balance model. A good, practical description of the method can be found in Dunn and Leopold (1978).

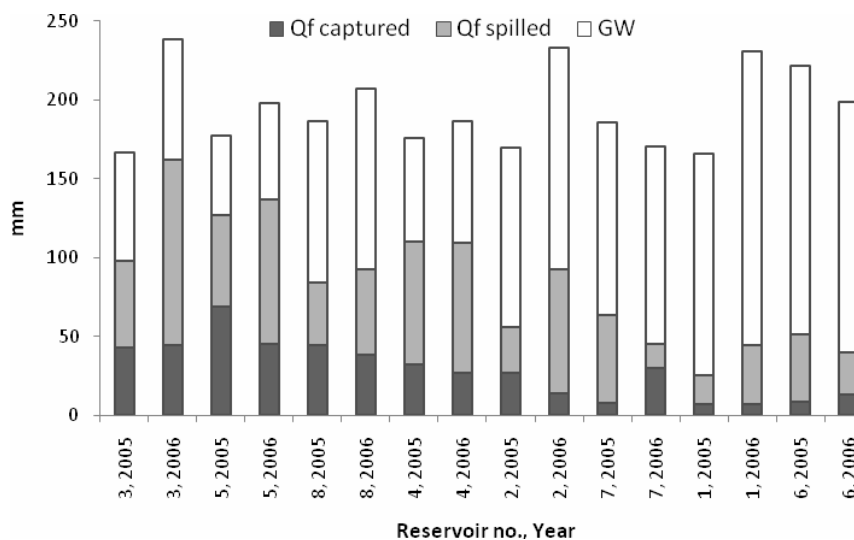


**Figure 1:** Concept of the Thornthwaite-Mather model. The water balance is kept for the soil reservoir. Rainfall exceeding the soils water holding capacity becomes excess, which is discharged as runoff. The reservoirs are filled by surface runoff and interflow, here referred to as quickflow. The groundwater is not connected to the reservoirs at the end of the dry and the beginning of the rainy season.

The Thornthwaite-Mather model (Figure 1) keeps track of the amount of water stored in the soil, which is driven by rainfall and evaporation. A soil's maximum water holding capacity is defined by the field capacity of the soil ( $\theta_{FC}$ ), whereas the lowest water content is defined by the wilting point ( $\theta_{WP}$ ). If a soil's maximum water holding capacity is exceeded, the excess rainfall becomes runoff. By analyzing the timing of the watershed response to rainfall, the soil hydrological parameter  $S_{max}$  (the maximum soil water content of catchment) can be determined such that the timing of the modeled runoff coincides with the timeframe of the observed runoff. The magnitude of runoff is calibrated by matching modeled to observed runoff volumes with the calibration parameter 'a', which defines the fraction of excess rainfall contributing to reservoir storage.

### Reservoir Impact

With a rainfall-runoff model, and information on the storage capacities of reservoirs, the impact of small reservoirs on the runoff from their watersheds can be estimated. Eight reservoirs in the Upper East Region of Ghana, and Togo, were analyzed in this study. The small reservoirs, on average, captured 34% of the surface and interflow runoff produced in their watersheds (Qf captured), with the rest being spilled (Qf spilled). Taking into account groundwater (GW), the overall effect of small reservoirs (Qf captured) is on average a 15% reduction in runoff from their watersheds. An example is given in figure 2, which shows the results for 8 reservoirs for the years 2005 and 2006.



**Figure 2:** Reservoir impact on runoff production. On average, small reservoirs captured 34% of the produced surface and and interflow runoff (Qf captured), while the remainder was spilled (Qf spilled). The overall average impact, taking into account groundwater runoff (GW), was on average 15%. These results were produced in a study in the Upper East Region of Ghana, and Northern Togo (Liebe et al., forthcoming).

### Lessons learned

With this method, simple runoff models can be calibrated, thereby giving important insights into the hydrology of otherwise ungauged basins. It helps us to understand watershed response to rainfall, and runoff production that helps fill reservoirs.

The runoff models allow us to estimate the impact of small reservoirs on the overall runoff production from these sub-watersheds. Estimates such as these can be used as building blocks in studies designed to understand the impact of collections of small reservoirs on the availability of water at larger, sub-basin or basin scales. If policy changes intended to encourage small reservoir construction, or large scale investments in small reservoirs are contemplated, studies using these techniques to assess the downstream impacts of small reservoirs could easily be justified.

## Recommendations

It is advisable to repeat the study for at least a second year. The model should produce adequate results in a different year with the same calibration parameters ' $S_{max}$ ' and ' $a$ '.

When clouds don't hinder image acquisition, optical satellite images, such as Landsat, Spot, and Aster, etc., are a suitable alternative to radar images, as their processing is simpler and more intuitive.

## Limitations

The data requirement, especially the repeated coverage with satellite images, can be challenging and expensive if these data cannot be obtained through a cost-free arrangement. Tool use requires trained personnel who are familiar with remote sensing, GIS, and hydrology. Furthermore, the method can only be used where regional area-volume relations have been established. The accuracy of storage volume estimates determined with remote sensing is higher where reservoirs have gentle side slopes, but may be less accurate where topography is steep.

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