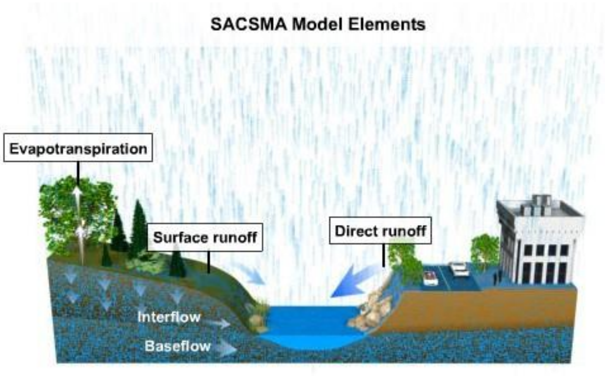
SACRAMENTO SOIL MOISTURE ACCOUNTING MODEL (SAC-SMA)

The Sacramento Soil Moisture Accounting Model (SAC-SMA) is a conceptual, continuous, area-lumped model that describes the wetting and drying process in the soil. In the following we provide a concise description of the model while a detailed SAC-SMA description and formulation is presented in Burnash et al. (1973) and Georgakakos (1986) for the discrete-time and continuous-time forms, respectively. The SAC-SMA simulates soil column response to tension and gravity forces to determine the water content of various soil layers at a given time, the evapotranspiration flux and surface and subsurface flow components (percolation to the deeper soil layers, interflow and baseflow).



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SAC-SMA Model Elements

Real time input variables for the model in the FFGS are 6-hour mean areal precipitation, soil, terrain and land cover and snow melt data are, used to a priori estimate the model's time invariable parameters.

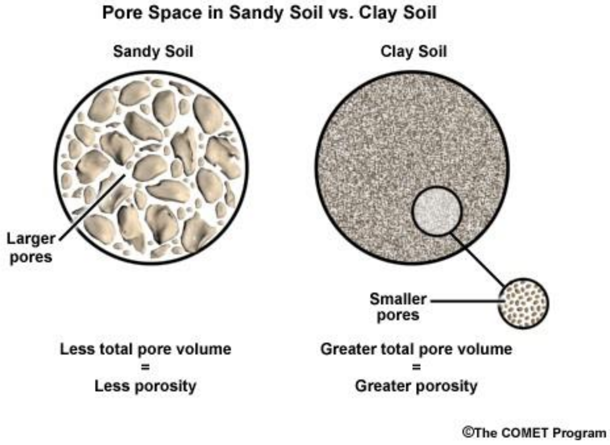
The SAC-SMA model is comprised of a two-layer structure of a relatively thin upper layer that represents the top soil regime and interception storage and a commonly thicker lower layer that supplies moisture to meet the evapotranspiration demand and channel baseflow (flow that is not direct response to a rainfall rate). Each layer tracks water content changes to estimate soil moisture states through conceptual tension and free gravitational water storage components.

Surface runoff that contributes significantly to flash flooding is the result of filled upper soil water tension and free water reservoirs and the relationship between rainfall rates and percolation rates to the deeper soil layers.

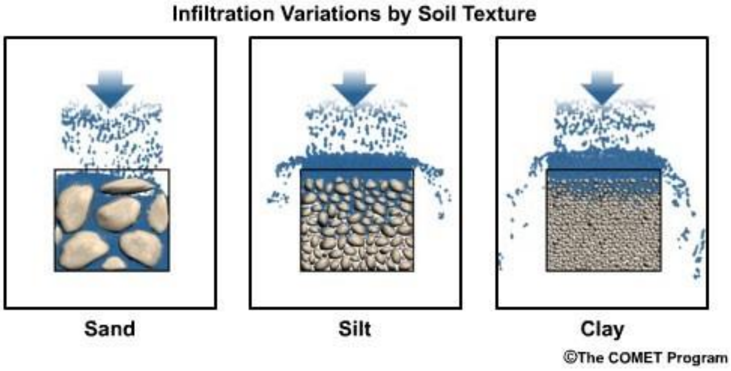
Direct runoff contributes to flooding from permanently impervious areas and variable impervious-area surface runoff allows for flooding contribution by the increase and decrease of the saturated soil area near the stream.

Tension water refers to the portion of the soil moisture system, which can be separated from the soil and returned to the atmosphere through processes of evapotranspiration. Normally, tension water is held in position against the force of gravity by the molecular attraction between soil particles and water molecules. The potential volume of tension water within the soil is generally determined by interrelationship between the area's climate, the catchment's soil types and the characteristics of those plant forms that exist in the catchment.

Free water is water in the liquid state, which is free to travel through or across the soil. Such water will percolate through the soil, resupplying any soil moisture deficiencies it encounters. When rainfall occurs at a rate that is greater than the rate at which the surface can transfer water to its depths, the excess rain will reach the stream channel as surface runoff. The relative components of tension and free water, which can be held within the soil, vary with soil types. For a given quantity of soil, the small particle sizes associated with clay soils will generally accommodate the highest proportion of tension water. The large particle sizes associated with sandy soils provide more storage space between soil grains, and such soils will generally accommodate the highest proportion of free water.



Pore space in sandy soil vs. clay soil



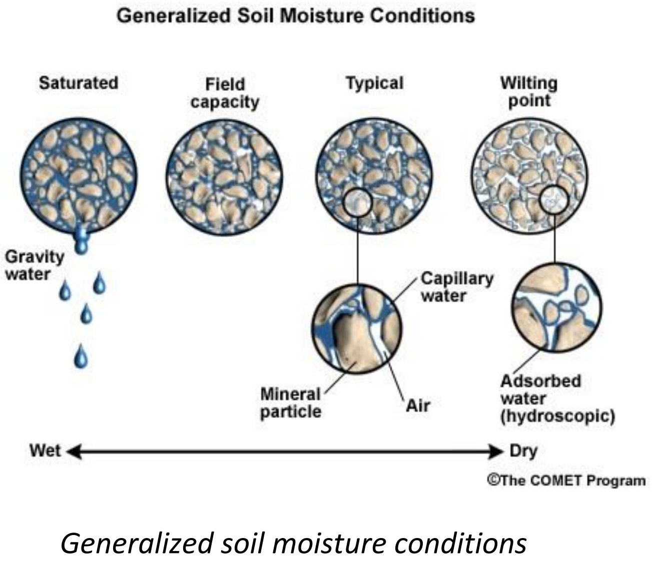
Infiltration variations by soil texture

The SAC-SMA, as a simplified representation of catchment processes, includes intercepted precipitation as a portion of upper soil’s tension water volume.

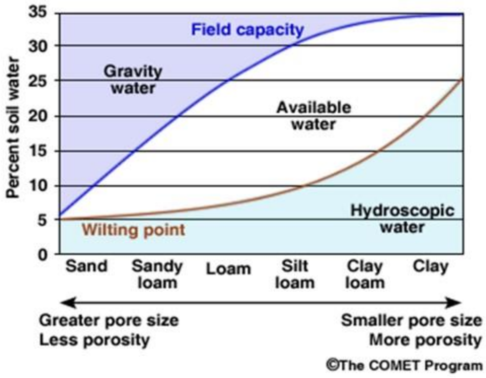
Despite the physical conceptualization embedded in the model structure, the model parameters (Table 1) cannot be directly measured from in-situ field observations. When streamflow, rainfall and soil moisture data are available for a specific basin, the parameter values are often estimated with an interactive calibration methodology that explicitly recognizes the function of the physical/conceptual components of the models (e.g. *NWS 1999; Koren et al. 2000; Shamir et al. 2005; Georgakakos et al. 2013; Shamir and Georgakakos 2014*).

The coarseness or porosity (PO) of the soil determines two other important factors – field capacity (FC) and wilting point (WP). If the pore spaces are filled with soil water and this water can drain freely from the soil as "gravity water," then the soil is called saturated. As the water drains from the soil, some pores will become filled with air and water vapour. When the pores no longer drain by gravity force, the capillary tension of the soil holds the water in place. Some of the larger pores will have drained but most still contain water. At this point the soil is said to be at field capacity. FC is also defined as the soil moisture level at or above which vegetation transpires at the maximum possible rate.

As water continues to be removed from the soil through evapotranspiration, more of the pore space will empty of water. As this process continues, only the tightly held water to the soil particles remains. There is a point where the tension of the water to the soil particle becomes so tight that the water cannot be used by plant roots. This is called the "wilting point." WP which is also defined as the soil moisture level at or below which vegetation will not be able to transpire.



Generalized soil moisture conditions

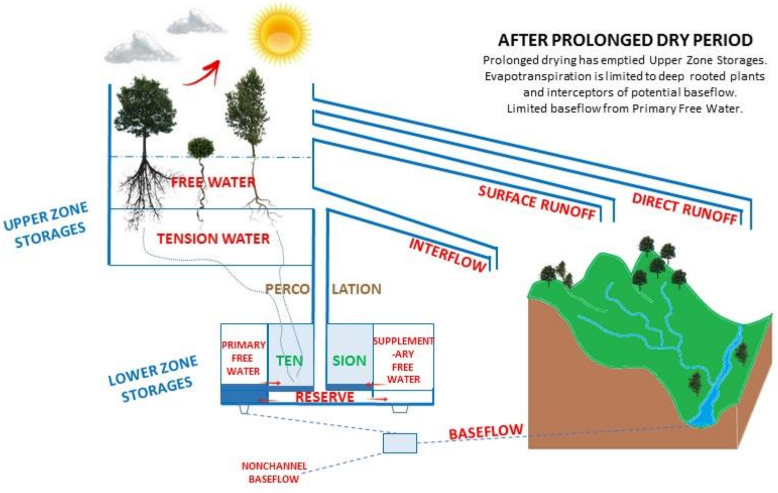


Soil moisture conditions for various soil textures

The link of the SAC-SMA parameters to soil and land cover characteristics was developed by Koren et. al (2000) – it is based on empirical association between soil-texture classes and soil hydraulic indices (such as saturated hydraulic conductivity and volumetric water content that is associated with wilting point, field capacity and saturated retention conditions). This method of parameter estimation requires spatial information that includes soil texture, soil depth and land cover. For the land cover data, Land cover USGS AVHRR (Advanced Very High Resolution Radiometer; 1 km resolution) was used.

The SAC-SMA utilizes a set of storage of determinable capacities that are linked by process which allow the system to approximate many soil moisture conditions that control the production of streamflow. The algorithm computes runoff in five basic forms: 1) Direct runoff from permanent and temporary impervious areas; 2) surface runoff due to precipitation occurring at a rate faster than percolation and interflow can take place when both upper zone storages are full; 3) interflow resulting from the lateral drainage of a temporary free water storage; 4) supplemental baseflow;, and 5) primary baseflow.

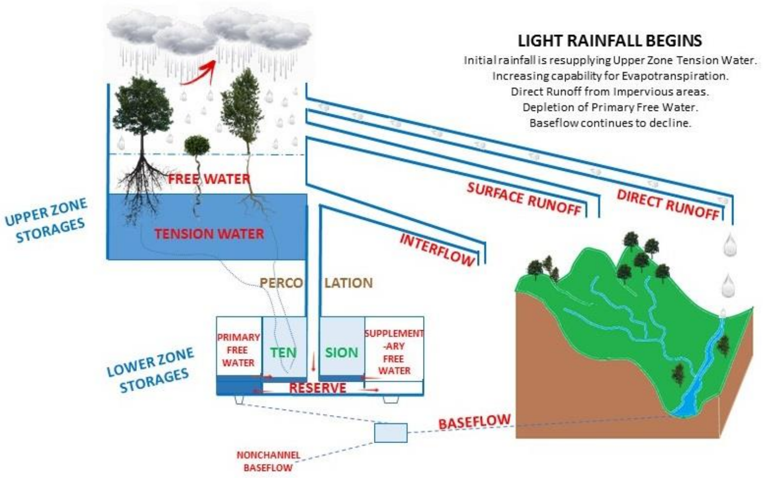
According to the Burnash (1995), the images below visualize the SAC-SMA model storages and typical seasonal response of soil moisture and discharge. The sequence shown in these figures traces the transition from a very dry condition, through a seasonal wetting cycle, and the return to dry weather.



AFTER PROLONGED DRY PERIOD

Prolonged drying has emptied Upper Zone Storages.
Evapotranspiration is limited to deep rooted plants
and interceptors of potential baseflow.
Limited baseflow from Primary Free Water.

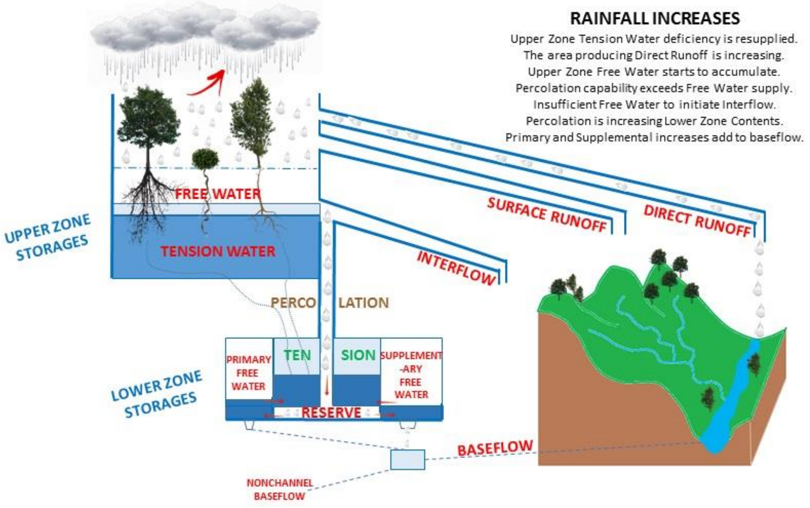
The SAC-SMA after prolonged dry period



LIGHT RAINFALL BEGINS

Initial rainfall is resupplying Upper Zone Tension Water.
Increasing capability for Evapotranspiration.
Direct Runoff from Impervious areas.
Depletion of Primary Free Water.
Baseflow continues to decline.

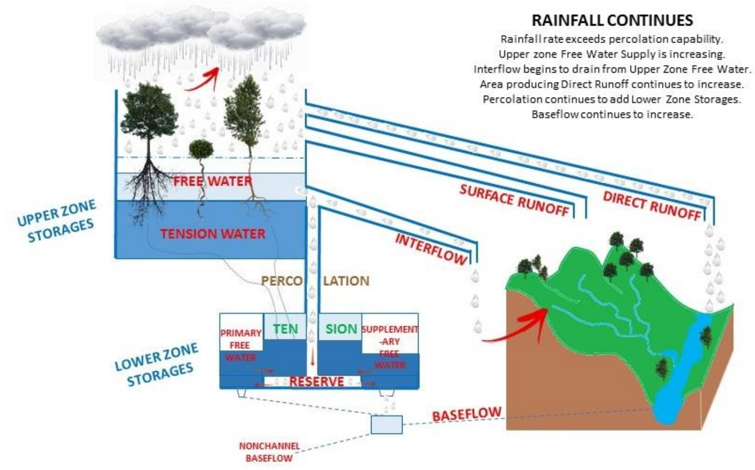
The SAC-SMA after light rainfall begins



RAINFALL INCREASES

Upper Zone Tension Water deficiency is resupplied.
The area producing Direct Runoff is increasing.
Upper Zone Free Water starts to accumulate.
Percolation capability exceeds Free Water supply.
Insufficient Free Water to initiate Interflow.
Percolation is increasing Lower Zone Contents.
Primary and Supplemental increases add to baseflow.

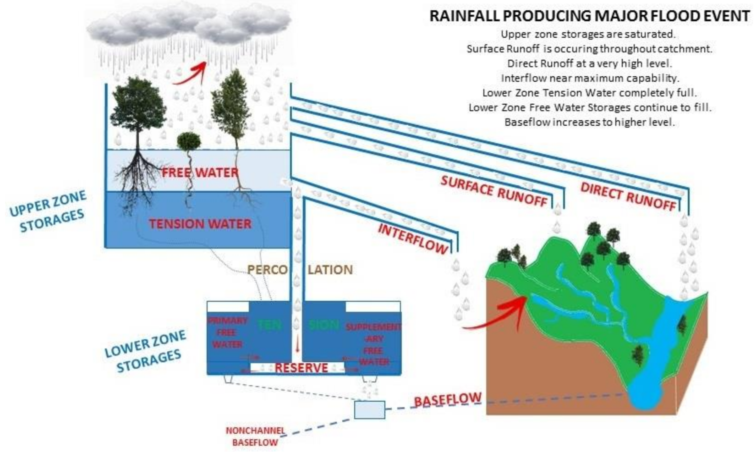
The SAC-SMA after rainfall increases



RAINFALL CONTINUES

Rainfall rate exceeds percolation capability.
Upper zone Free Water Supply is increasing.
Interflow begins to drain from Upper Zone Free Water.
Area producing Direct Runoff continues to increase.
Percolation continues to add Lower Zone Storages.
Baseflow continues to increase.

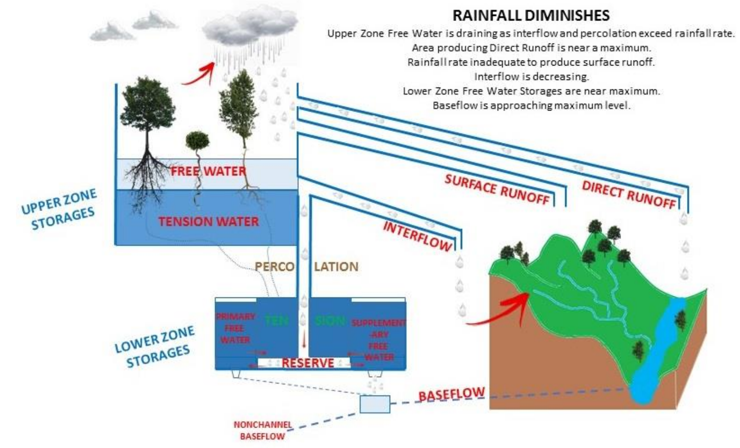
The SAC-SMA after rainfall continues



RAINFALL PRODUCING MAJOR FLOOD EVENT

Upper zone storages are saturated.
Surface Runoff is occuring throughout catchment.
Direct Runoff at a very high level.
Interflow near maximum capability.
Lower Zone Tension Water completely full.
Lower Zone Free Water Storages continue to fill.
Baseflow increases to higher level.

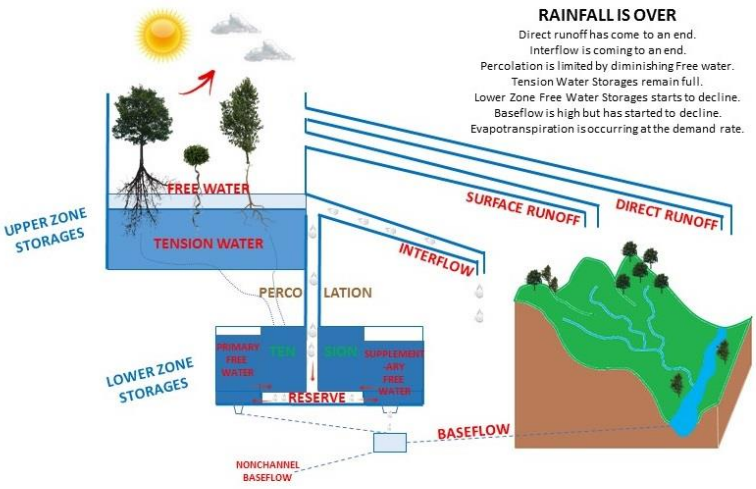
The SAC-SMA rainfall producing major flood event



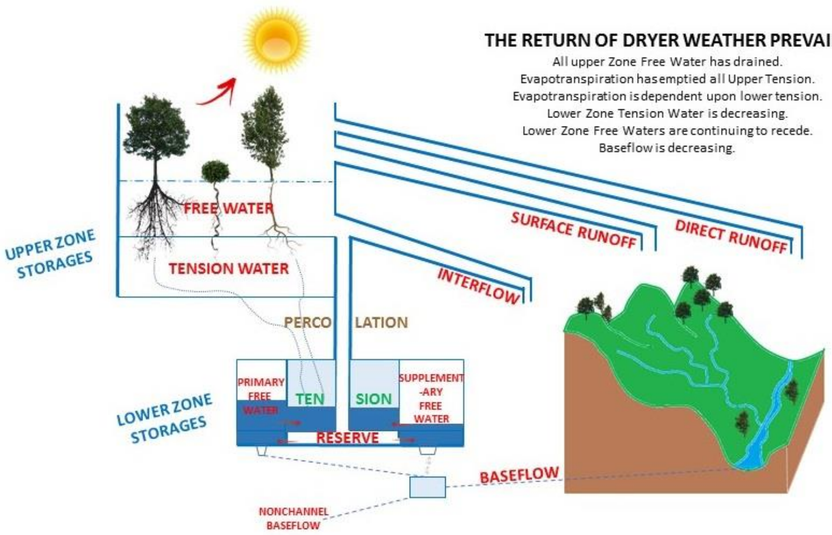
RAINFALL DIMINISHES

Upper Zone Free Water is draining as interflow and percolation exceed rainfall rate.
Area producing Direct Runoff is near a maximum.
Rainfall rate inadequate to produce surface runoff.
Interflow is decreasing.
Lower Zone Free Water Storages are near maximum.
Baseflow is approaching maximum level.

The SAC-SMA rainfall diminishes



The SAC-SMA rainfall is over



The SAC-SMA - the return of dry weather prevail

This document was prepared by WMO-FFGS team using South East Europe Flash Flood Guidance System Forecaster Guide[1]; FFGS Operational Output Product Descriptions available in the FFGS Real-Time Product Console developed by the Hydrologic Research Center and National Oceanic; The Comet Program and Atmospheric Administration (NOAA) materials and documents.

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[1] https://www.wmo.int/pages/prog/hwrp/flood/ffgs/documents/SEEFFGS_Forecaster_Guide-Final_ES_TM-AS-PM.pdf