Runoff

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A Simple Water Balance

\[ \text{INPUT} = \text{OUTPUT} + \Delta \text{Storage} \]

\[ \text{RF + CWI + IRR} = \text{RO + ET + GWR} + \Delta \text{SM} \]

Definition

Runoff:
- The flow of water over the land surface, in rills, in stream channels, and in rivers
- In small watersheds, runoff is often equated with streamflow

Importance

- Source of water for streams and rivers
- Chief water supply source for many parts of the world
- Flooding
- Soil erosion
- Transport of sediment and other pollutants
- Geomorphological agent
Soil Hydraulic Properties

- Soil surface acts as a “filter” allowing water to enter (infiltrate), but limiting how fast infiltration can occur
- Soil acts as a porous medium, both storing and transmitting water
- Soil properties vary according to soil type, vegetative cover, and human activities

Infiltration

- Dry Bulk Density: Mass per unit volume of the soil with the water removed
- Hydraulic Conductivity: Rate of water movement under a unit gradient; increases as water content increases; saturated hydraulic conductivity is maximum

Both of these properties vary among different soils and are affected by vegetation and compaction from human activities.
Land Use Effects on Soil Properties

Soil Moisture Retention

Porosity, Field Capacity, Wilting Point

Available Water Capacity

Runoff Mechanisms

Runoff Mechanisms:
Horton Overland Flow (HOF):
When rainfall intensity exceeds infiltration capacity, water accumulates on the soil surface. If high intensity rainfall continues, pond storage capacity will be exceeded and Horton overland flow will begin.
Runoff Mechanisms:
Horton Overland Flow (HOF):

BF: base flow
SSSF: subsurface stormflow
RF: return flow
DPS: direct precipitation onto saturated area
SOF: saturation overland flow (Dunne Flow)
Runoff Mechanisms:

Storm Hydrograph

Annual Hydrograph

Streamflow measurement

Streamflow measurement

Rating Curve: relationship between stage and discharge
Runoff modeling
Runoff Model: An equation or set of equations that estimate the runoff or streamflow hydrograph (time series) as a function of the rainfall time series and parameters (variables) that describe the watershed response.

Input Required for All Models:
- Rainfall time series
- Drainage area

Watershed Characteristics That Might Be Represented:
- Soil hydrologic properties
- Vegetation cover
- Watershed topography
- Stream channel network
- Characteristics of groundwater aquifers
- Antecedent soil moisture content

Runoff model types
- Empirical—Physical
- Deterministic—Stochastic
- Single hillslope—Watershed
- Lumped—Distributed

Streamflow modeling
- Historical development
  - Rational Method: \( Q_{\text{peak}} = CIA \)
    - \( C = \) runoff coefficient; \( I = \) rainfall intensity; \( A = \) catchment area
    - Peak flow model
    - Small watersheds only

Streamflow modeling
- Historical development
  - Unit hydrograph
    - Whole hydrograph rather than just peak flow
    - Requires estimate of excess rainfall as input
    - Shape of hydrograph determined for “unit” storm (e.g. 1-inch excess RF)
    - Hydrograph re-scaled for larger/longer storms

Streamflow modeling
- Historical development
  - Conceptual linear reservoir models
    - Flow equation: \( Q = A \times S \)
      where \( Q = \) runoff or stream discharge; \( A = \) response factor; and \( S = \) water storage
    - Continuity equation: \( R = Q + dS/dt \)
      where \( R = \) recharge; \( dS = \) change in storage; and \( dt = \) time increment
    - Runoff equation: \( Q_2 = Q_1 e^{-A(t_2-t_1)} + R e^{-A(t_2-t_1)} \)
      - More complex reservoir models
        - Non-linear
        - Multiple outlets

Streamflow modeling
- Historical development
  - Stochastic time series models (Box and Jenkins 1970)
  - Physically-based models
    - Stanford watershed model (Crawford and Linsley 1966)
    - MIKE-SHE
    - DHSVM
Streamflow modeling

- Historical development
  - TOPMODEL (Beven and Kirkby 1979)
    - Based on water accumulation concept
    - Topographic Index (TI)
    - \[ TI = \ln \left( \frac{\text{contributing area}}{\tan \text{(slope)}} \right) \]

- Land-atmosphere models: BATS, SiB, VIC, etc.

Soil Conservation Service (Natural Resources Conservation Service) Curve Number Method

- Empirical, lumped, agricultural emphasis, Horton-based
- Advantage: can be used to estimate runoff in basins without streamgage
- \[ Q = \left( P - 0.25 \right) \left( P + 0.8 S \right) \]
- \( Q \) = runoff (inches)
- \( P \) = storm precipitation total (inches)
- \( S \) = retention parameter = \( \frac{1000}{CN} - 10 \)
- \( CN \) = curve number = \( \frac{1000}{S + 10} \)

Curve numbers estimated from:
- Soil type
- Land use
- Conditions
- Antecedent moisture conditions

Curve Number Method
Curve Number Method

Table 10.1 Curve numbers for estimating overland runoff following storms of various intensities and durations (from U.S. Soil Conservation Service, 1972).

<table>
<thead>
<tr>
<th>Duration (hr)</th>
<th>Curve Number</th>
</tr>
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<tbody>
<tr>
<td>10</td>
<td>100</td>
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<tr>
<td>20</td>
<td>70</td>
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<tr>
<td>30</td>
<td>50</td>
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</tbody>
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Figure 10.9 Composite runoff curve numbers for various concentrations of impervious area and curve number for the remaining unplanted area. (From U.S. Soil Conservation Service, 1972.)

Mānoa Valley Flood
October 30, 2004

Source: [http://www.prh.noaa.gov/hnl/pages/events/ManoaFlood20041030/](http://www.prh.noaa.gov/hnl/pages/events/ManoaFlood20041030/)