Variable Source Runoff Landscapes

Rainfall intensity < infiltration capacity

Throughflow and Saturation Overland Flow

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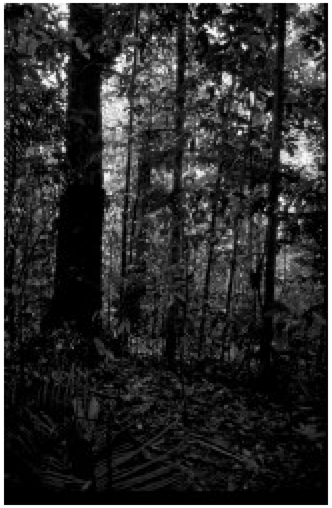
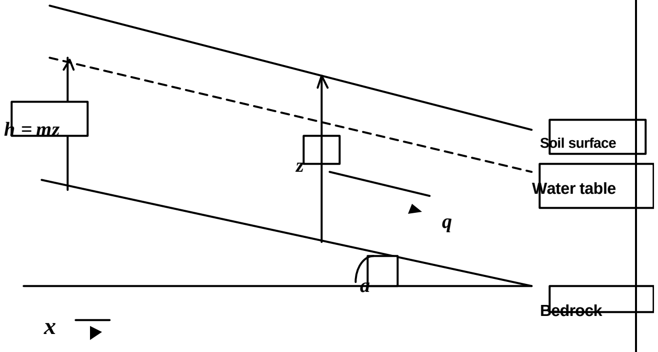
Central Amazon rainforest from canopy level

Amazon rainforest



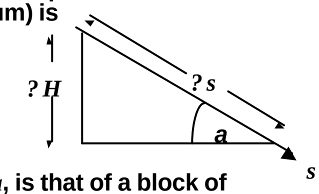
Throughflow (interflow or subsurface stormflow)

q (m^3/m-s)



- **Subsurface flow is dominantly a porous media flow, with important exceptions referred to below.**
- **Therefore, it is analyzed with Darcy's Law, which says that the flux density (flow per unit cross-sectional area of the medium) is**

$$\frac{Q}{a} = -K\frac{\partial H}{\partial s}$$



- **The cross-sectional area, *a*, is that of a block of soil or rock.**
- **Remember from ESM 203:** $H = z + \frac{p}{\rho g}$?
- **And that at the water table, where *p* = 0, the *dH/ds* is *dz/ds*, the slope of the water table along the flow path. Note that *dz/ds* = sin a**

- **In the case of flow down a slope of angle *a*, this becomes**

$$\frac{Q}{a} = K \sin a$$

K **depends on the moisture content, ?, up to a maximum of** K_{sat}

Some 'typical' numbers:

K_{sat} **= 0.1-10 m/hr for forest topsoils; 0.001-0.01 m/hr for subsoils**

0.01<sin *a* <0.10 for 'lowlands'; 0.1< sin *a* < 0.7 for 'mountains'

- **Flow speed of a *water particle* is different from this 'flux-density' bulk flow speed because the cross-sectional area that the water can travel through is only the porosity, ?, (not the whole cross section). Thus the speed of a particle of water is**

$$\frac{Q}{h a} = \frac{K \sin a}{h}$$

- **Thus, to calculate the time it would take water to flow from the top of a slope of the length, *L*, to the stream:**

$$t_{equilib} = \frac{L}{waterflowspeed} = \frac{Lh}{K \sin a}$$

At this equilibrium, the water would be flowing down slope approximately parallel to the hillslope surface, or to some impeding layer at a discharge per unit contour width of

$$q(x) = I\int_0^x dx = Ix$$

$$and$$

$$q = IL$$

at the base of the hill.

Returning to the concept developed for overland flow, the length of slope, L_{eq}, that can supply runoff at steady state during a storm of duration, t_{end}, is given by

$$L_{eq} = \frac{t_{end} K \sin a}{h}$$

On a long hillslope (say L = 300m) only one-third may come to equilibrium in a storm of, say, 12 hours duration (L_{eq} = 100m). Only one-third of the landscape can supply runoff at this maximum rate.

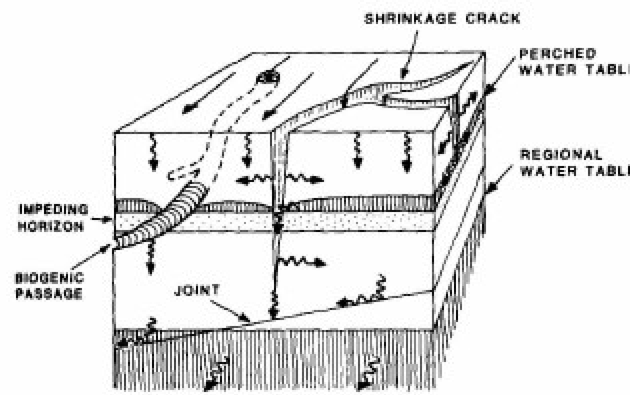
- But, if we intersect the hillslope with a logging road, cutting it into two lengths of 150 m each, then 100 m of each 150 m (two-thirds of the landscape) can be brought to steady-state runoff.

- This has enormous significance for the current debate in timber harvest regions about whether logging roads shortens hillslopes, increasing the proportion of the landscape that can be brought to steady-state runoff (or close to it) and permanently increase the flood potential of forested regions.

Macropores

Flow in these conduits does not behave according to Darcy's law, but circumvents the porous medium

Macropores



Macropores

- **Folk lore: Pores >0.3 mm diameter constitute <10% of most soils but convey >75% of the saturated flow.**

  [Source unknown, so beware. I read it in a National Research Council report!]
- **Origin?**
  - **Biogenic passages (roots, soil fauna, inter-ped spaces)**
  - **Shrink-swell cracks**
- **Macropores allow non-Darcian flow at speeds much larger than predicted by Darcy's Law.**
- **Problem is to know the proportion of the flow following such paths. Generally unknown. Anecdotal observations and measurements suggest that macropore flow occurs, but the amount is unknown. We try to represent their effects with an "equivalent K_{sat}".**

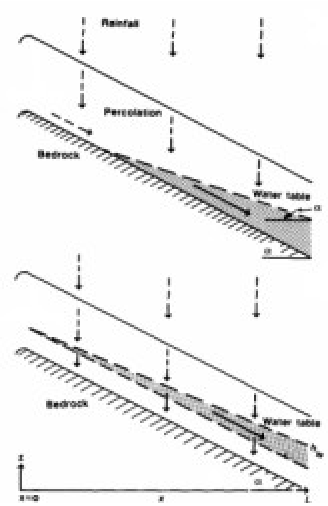
Amount of water (and contaminants) passing through macropores in soils is thought to increase with:

1. **Rainfall intensity**
2. **Density of macropores, and therefore the amount of root holes, animal holes, and cracks**
3. **Inversely with K_{sat} of the bulk porous medium**
4. **Hillslope gradient (macropore flow speed increases faster than linearly with head gradient)**

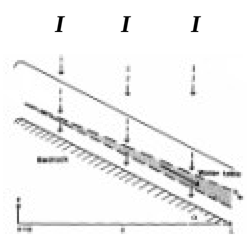
Returning to the simpler view of Darcian flow that can be used to develop a conceptual model (modified by macropore flow)

$$q(x) = I\int_0^x dx = Ix$$

Layer of saturated soil thickens downslope



Throughflow (interflow), q (m^3/m-s), h (m)



Planar hillslope

$$q(x) = I\int_0^x dx = Ix = -Kh(x)\sin a$$

$$h(x) = \left[\frac{Ix}{K \sin a}\right]$$

Nonplanar hillslope

$$q(x) = q(A) = \frac{IA}{w}$$

$$h(A) = \frac{IA}{wK \sin a}$$

Saturated thickness, *h*

$$h(A) = \frac{IA}{wK \sin a}$$

Saturated thickness is high:

- when I is high
- where A/w is high
- where conductivity is low
- where gradient is low

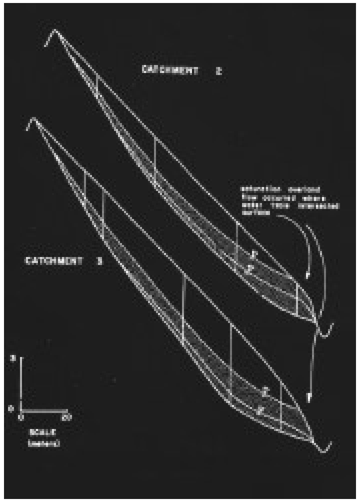
During heavy rains (especially those long enough to approach equilibrium runoff)

On long hillslopes, especially in convergent topography

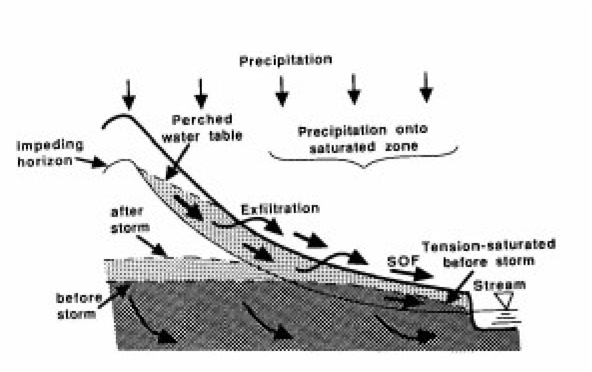
Silty-clay-rich soils (low K)

Footslopes

Water table changes during a rainstorm in bedrock hollows, Oregon Coast Range (T.C. Pierson)
h*= *f(A)



Thickness of saturated layer thickens downslope until it equals the capacity of the soil to transmit water



For a soil of thickness H_s, the maximum saturated thickness is

$$h(x) = H_s = \frac{IA_s}{wK \sin a}$$

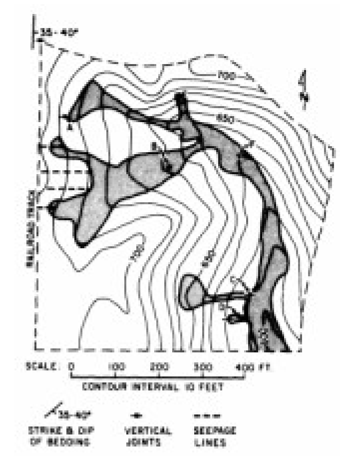
- **Landscapes in which $A_s > A$ or $x_s > L$, the average hillslope length, convey all flow underground, and remain in the SSF-dominated regime**
- **Where $x_s < L$ [for the planar, one-dimensional case] or $A_s < A_{total}$, SOF results**
- **The smaller x_s is, the larger will be the area that can generate SOF and associated pollutants.**

Area per unit width of contour required for soil saturation, A_s

$$\frac{A_s}{w} = \frac{H_s K \sin a}{I}$$

- A summary of the SOF and pollutant potentials of a watershed, especially in lowlands.
- Basins with relatively **small** A_s/A_{total} or x_s/L ratios have a **high** pollution potential, if those areas of SOF production are contaminated with fertilizer, bacteria, etc.
- Even in undisturbed forests, they tend to be areas of high dissolved organic acids, and when flushed in the Olympic Peninsula of Washington, they have been responsible for fish kills.

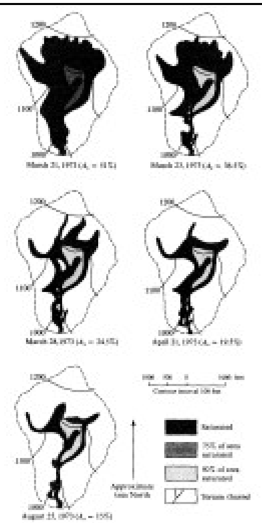
Extension of saturated zones into convergent areas (with high A/w) and low gradient in a watershed with steep slopes and sandy soils



Seasonal variation of saturated area in low-gradient, low conductivity terrain (basal till), Vermont

[***Note*** that the A_s on ***this*** slide is 100(1- A_s)% when the A_s is derived from other slides. I am not using the quantity labeled as A_s in this slide in any equations.]

The two uses are from different eras in my development of this material!



Schematic summary of controls on runoff pathways