Runoff and Erosion

Summary

- Introduction
- Runoff
- Erosion
- Application to post-fire conditions

Introduction

Scope

- Hillslope scale
- Monsoon season
- Semi-arid grassland/oak woodlands
- Runoff – Infiltration based
- Erosion – Rill/interrill based
- Walnut Gulch and Rainfall simulator data

Runoff

The Runoff Process

In semi-arid regions runoff occurs when the rainfall rate > infiltration capacity of the soil

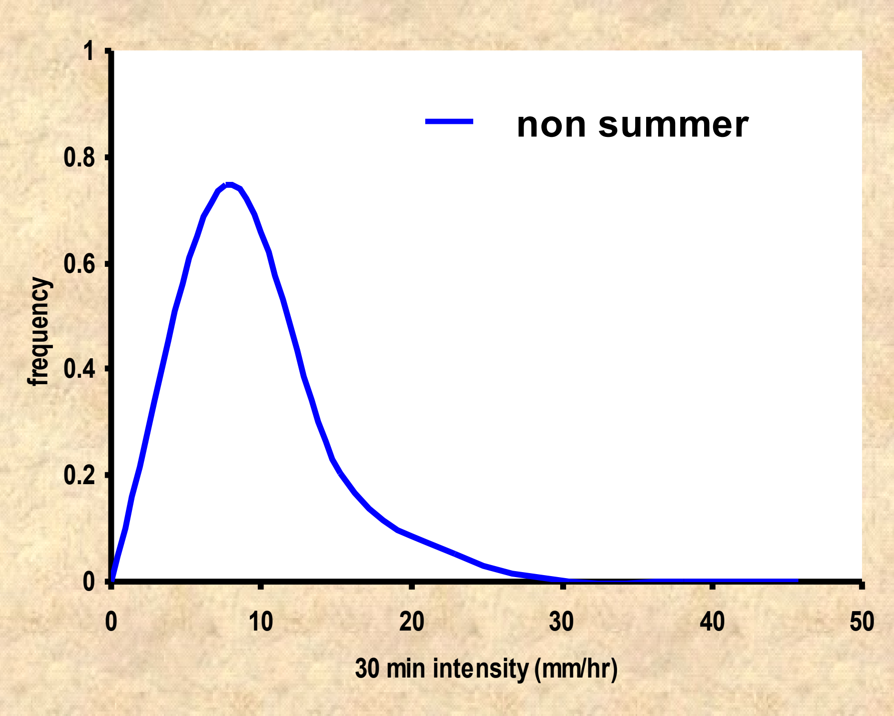
This process is termed

Hortonian runoff

Rainfall excess runoff

Runoff

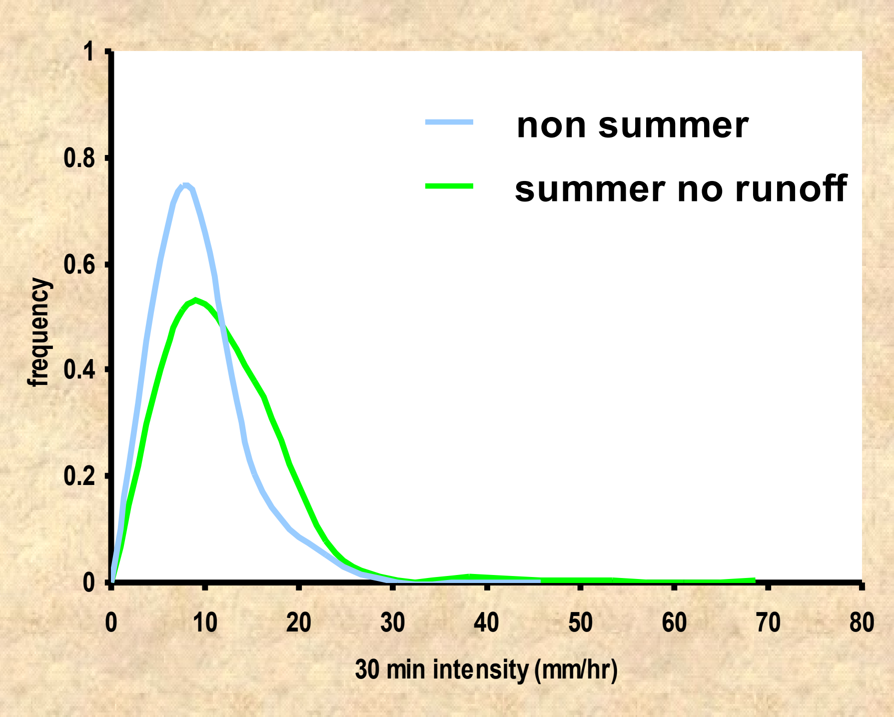
Rainfall intensity effects on runoff



Season	Ave
	Intensity
non summer	**6 mm/hr**

Runoff

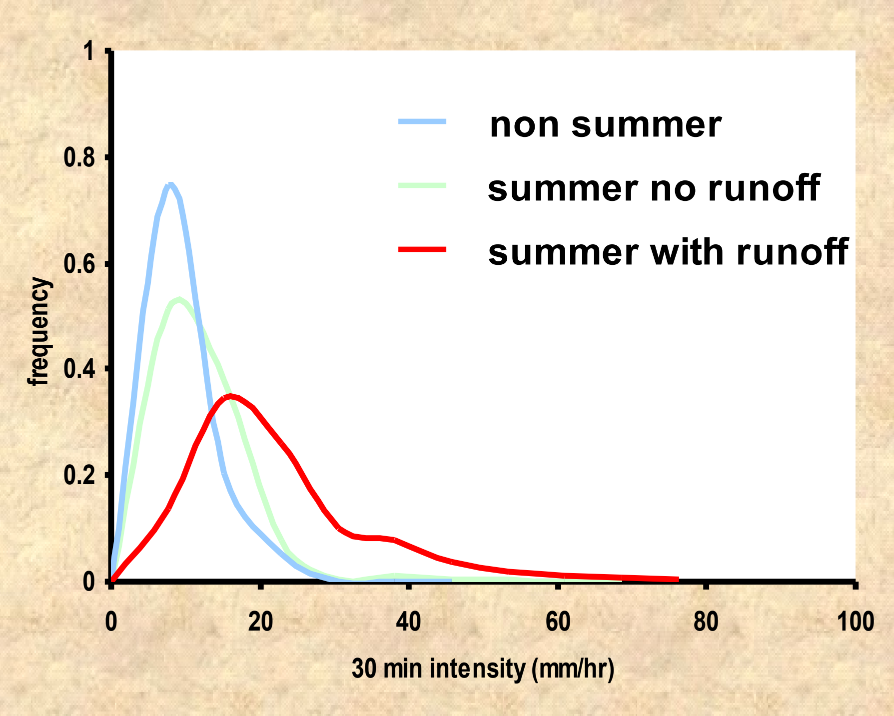
Rainfall intensity effects on runoff



Season	Ave
Intensity	
non summer	6 mm/hr
summer no runoff	9 mm/hr

Runoff

Rainfall intensity effects on runoff

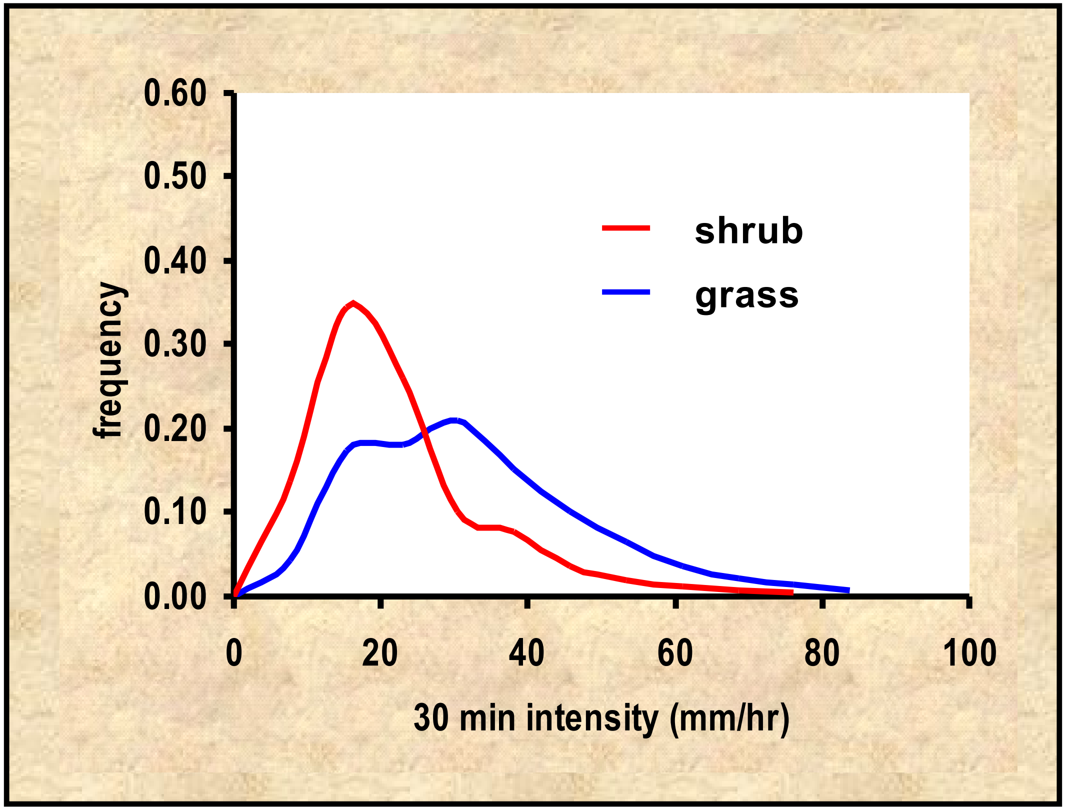


Season	Ave Intensity
non summer	6 mm/hr
summer no runoff	9 mm/hr
summer runoff	19 mm/hr

Rainfall which causes runoff has a higher intensity than rainfall which has no runoff

Runoff

Vegetation effects on runoff

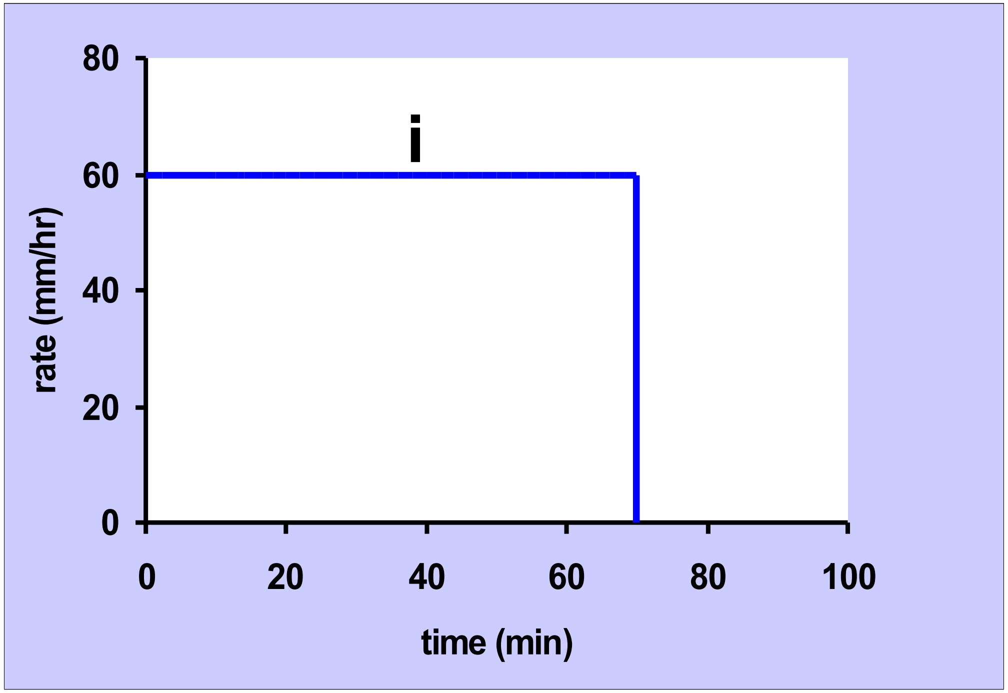


Season	Ave Intensity
shrub	19 mm/hr
grass	29 mm/hr

It takes higher intensities to generate runoff from grasslands

Runoff

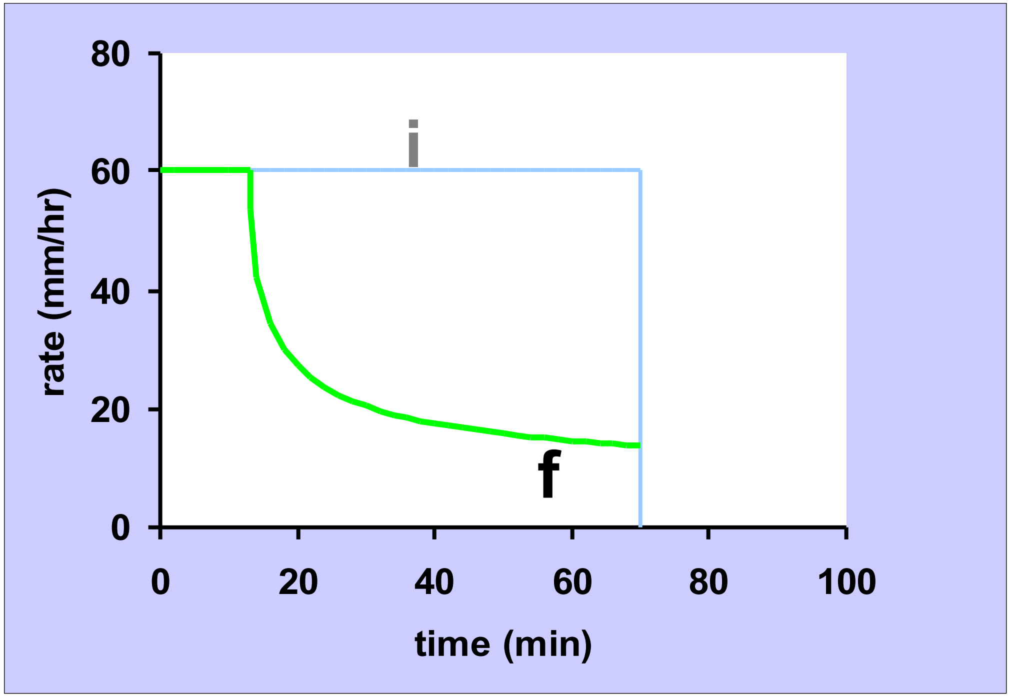
The Runoff Process



Consider a constant rainfall intensity, i

Runoff

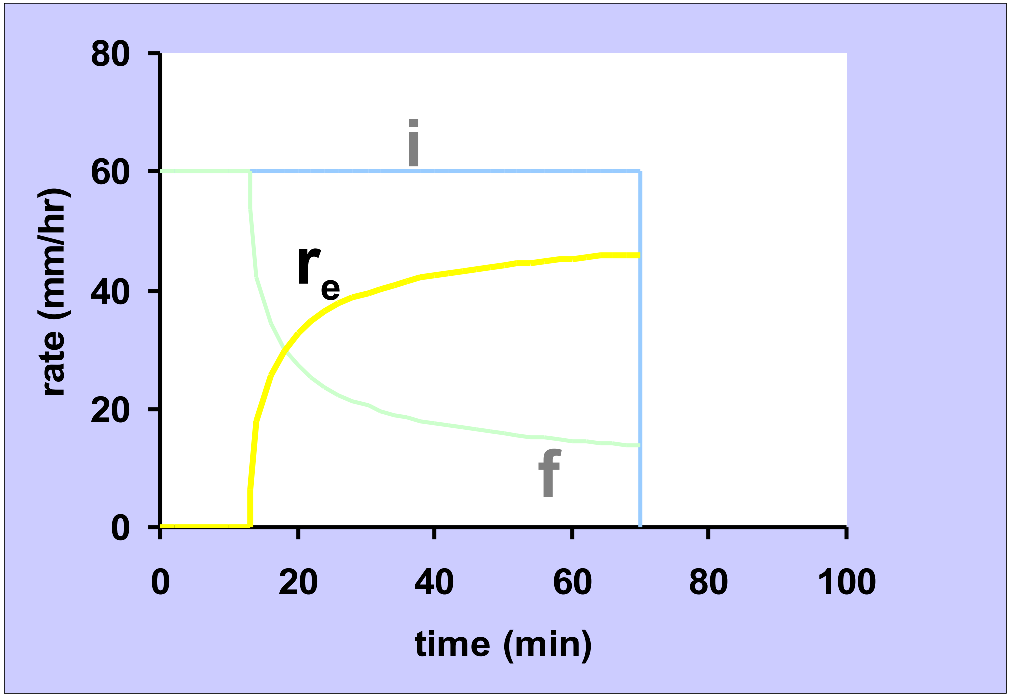
The Runoff Process



When i > than the infiltration rate, f, water begins to pond on the surface. f is a function of soil and vegetation characteristics

Runoff

The Runoff Process



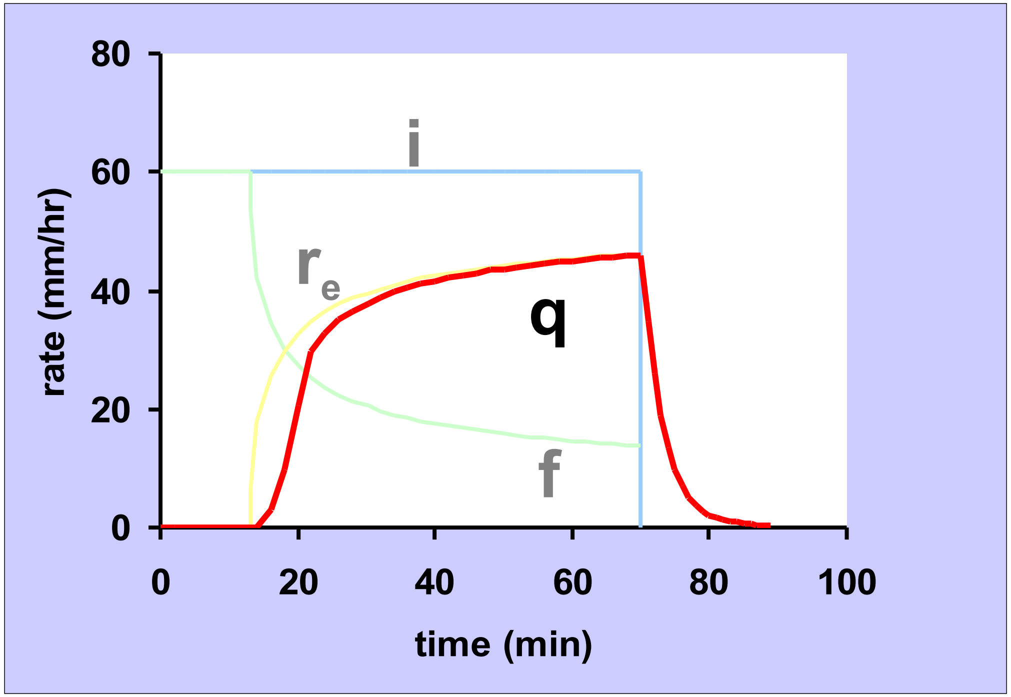
The rainfall excess, r_e, rate is defined as

$r_e = i - f$

This is the rate that water ACCUMULATES on the surface

Runoff

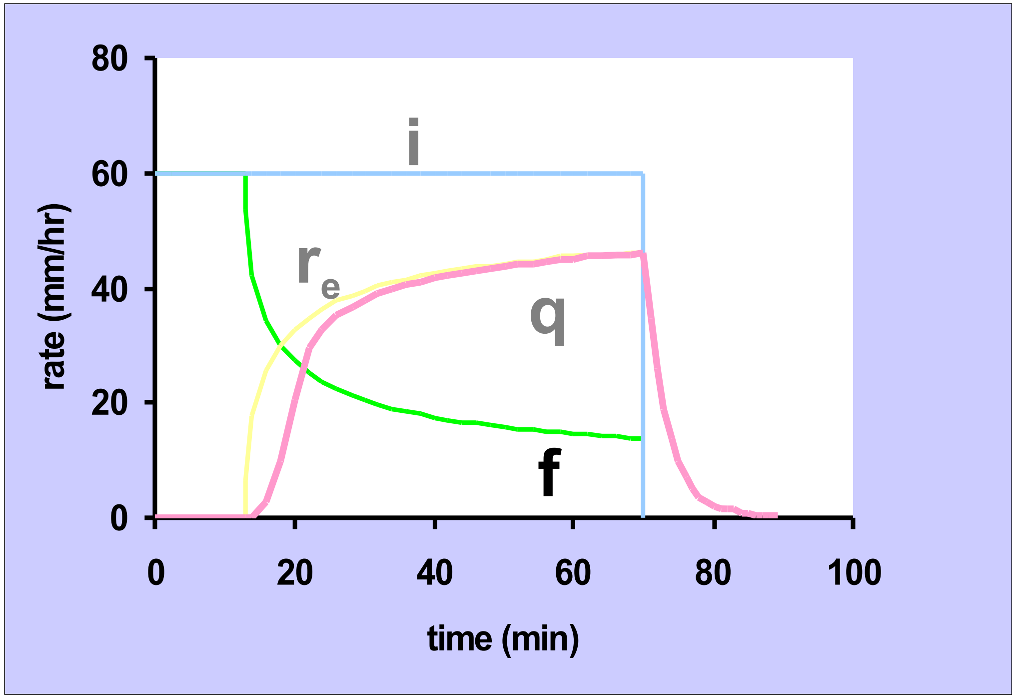
The Runoff Process



The runoff rate, q, is the rate that r_e flows OFF the surface and is a function of slope and roughness

Runoff

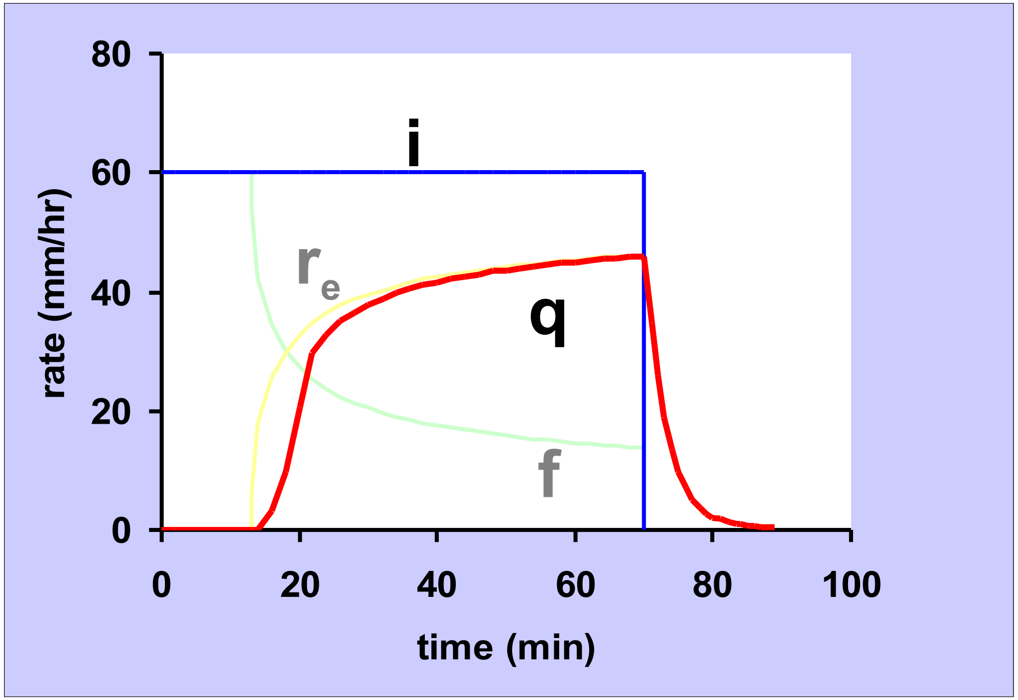
What We Measure



At the point scale f can be measured.

However, it is NOT rainfall infiltration.

What We Measure



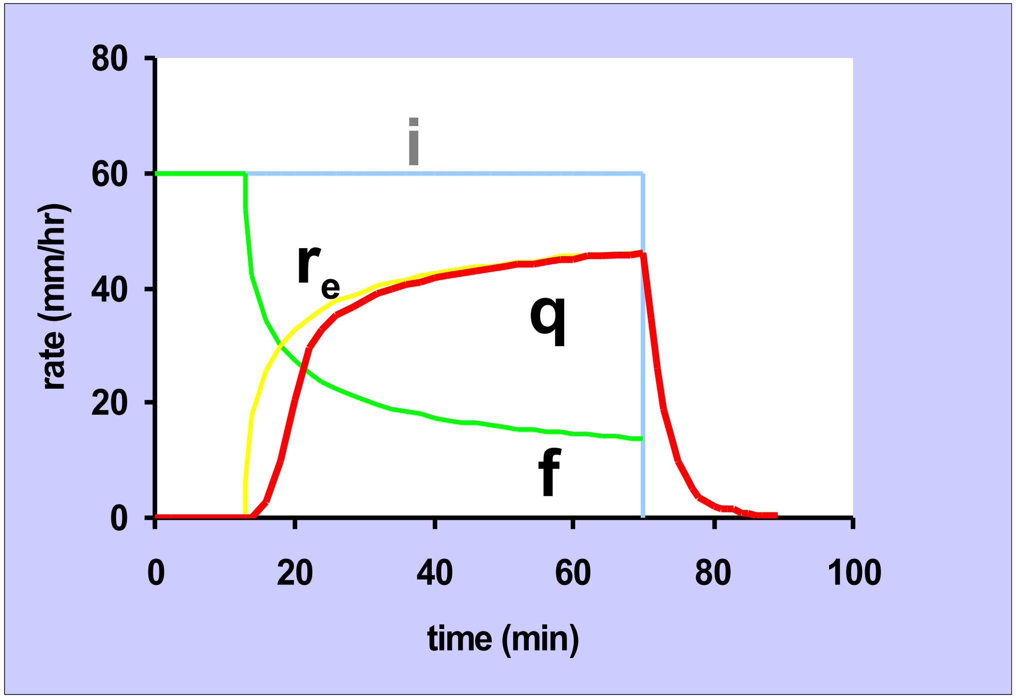
At the point scale

f can be measured.

At all other scales, only i and q are measured.

Runoff

What We Calculate



i and q are used with a infiltration-runoff model to optimize the model's parameters.

Runoff

Infiltration-Runoff Model

Green-Ampt

$$f = K_e\left(1 + \frac{N_s}{F}\right)$$

f = infiltration rate

K_e = effective hydraulic conductivity

N_s = effective matric potential

F = cumulative infiltration depth

Runoff

Infiltration-Runoff Model

Kinematic Wave

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r_e$$

Continuity Equation

h = flow depth

α = C $S^{1/2}$ (Chezy)

α = $S^{1/2}$/n (Manning)

t = time

x = distance

$$q = \alpha h^m$$

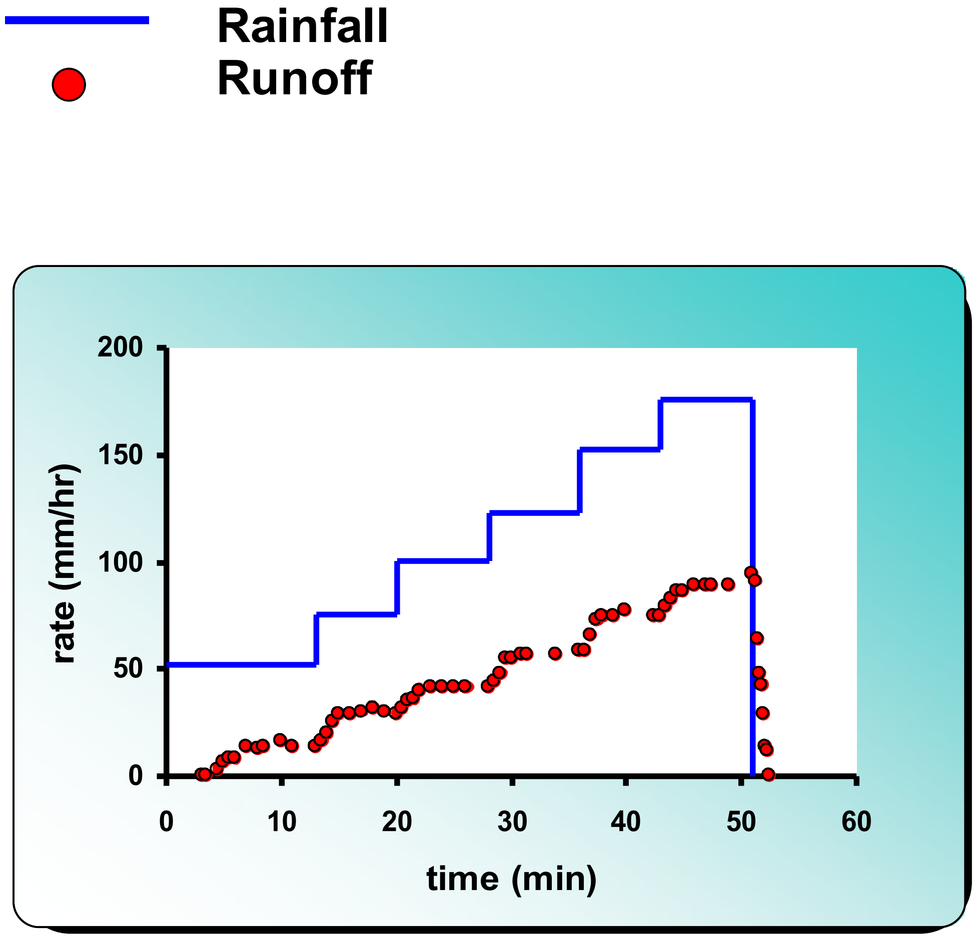
Depth-discharge relationship

Runoff – Observation vs Theory

Walnut Gulch Rainfall Simulator

Variable intensity - 25-180 mm/hr

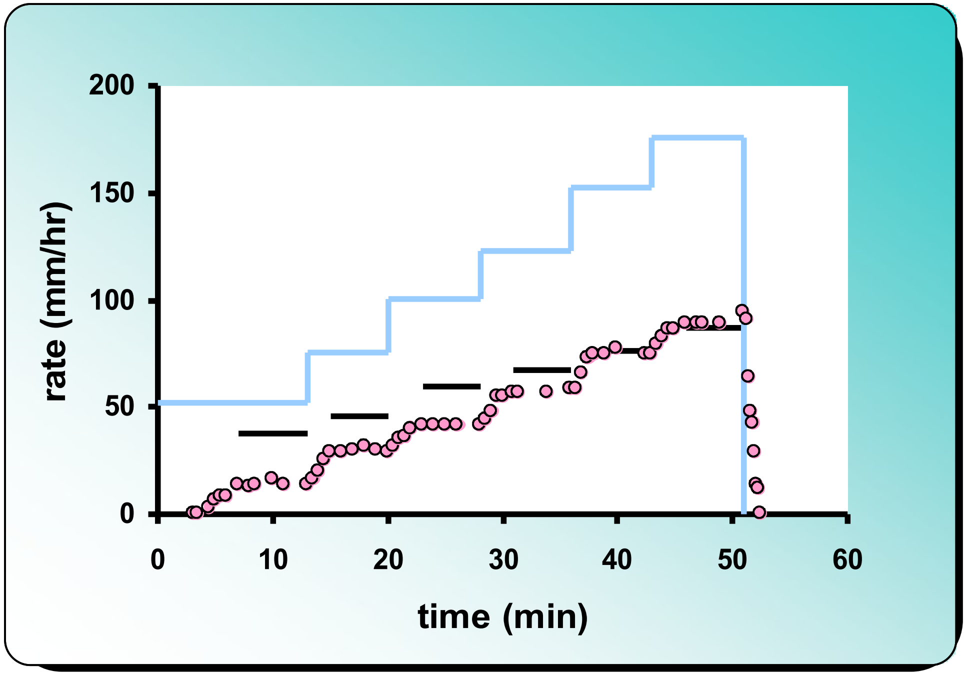
Runoff – Observation vs Theory



In rainfall simulator experiments where multiple rainfall rates are used,

Runoff – Observation vs Theory

— **Rainfall**
● **Runoff**
— **Infiltration = rainfall - runoff**



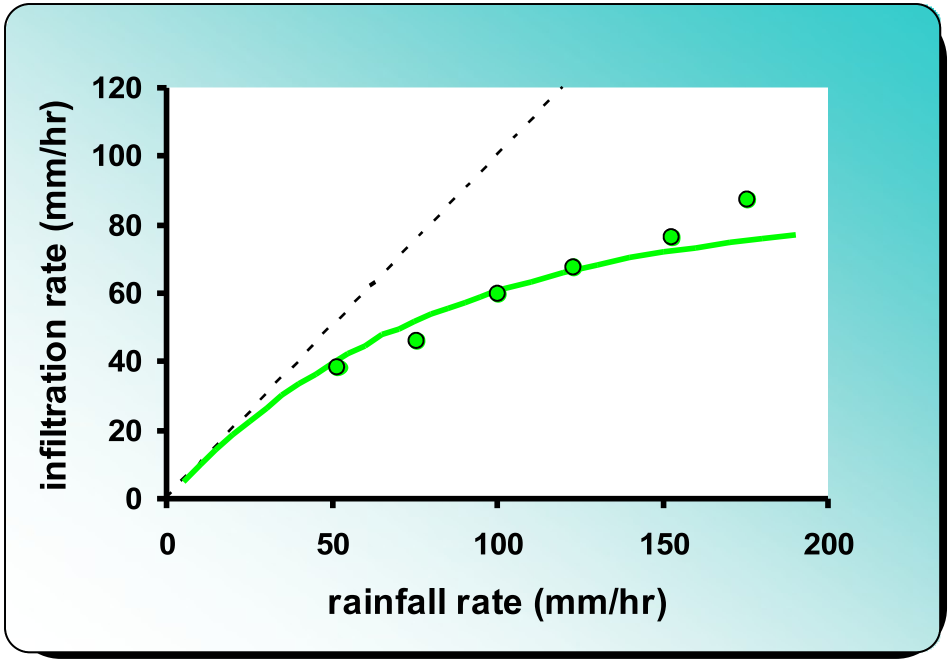
In rainfall simulator experiments where multiple rainfall rates are used,

the steady state infiltration rate frequently increases with increasing rainfall rate

Runoff – Observation vs Theory

— **Hypothetical relationship**

● **Infiltration**

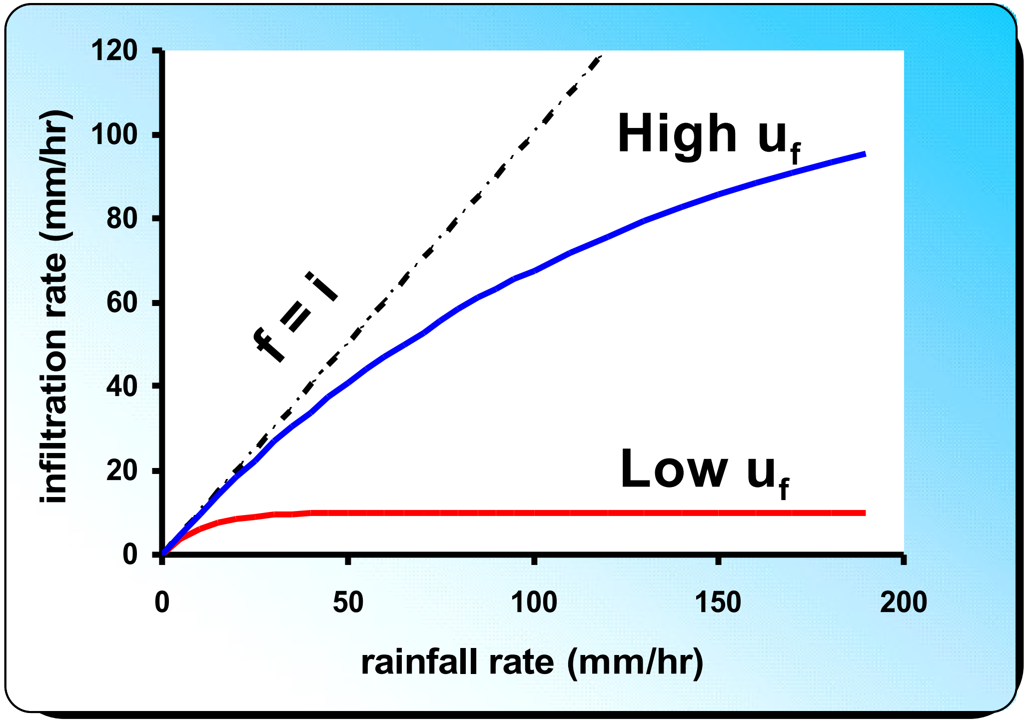


The increase in infiltration rate with rainfall rate is hypothesized to be an indication of Partial Area Response

Runoff – Observation vs Theory

$$f = u_f\left(1 - e^{-i/u_f}\right)$$

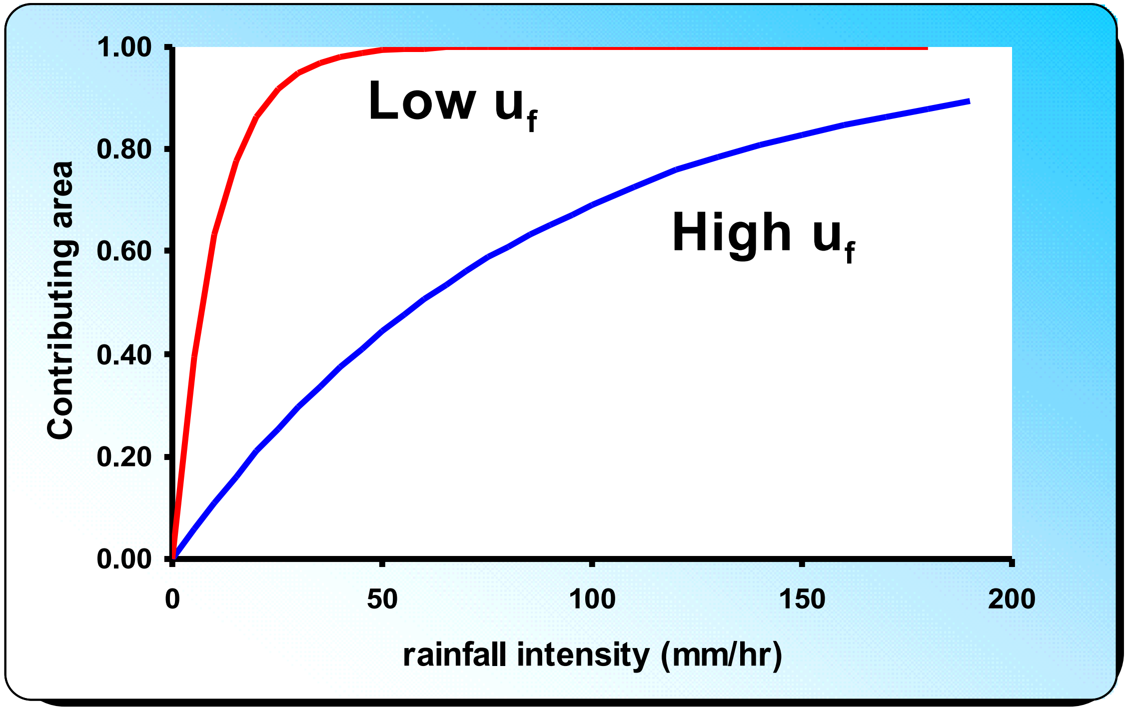
where u_f = average areal infiltration rate when entire area is ponded



Hawkins (1982) derived a relationship between infiltration and rainfall rates based on an Exponential Distribution of infiltration capacity over an area

Runoff – Observation vs Theory

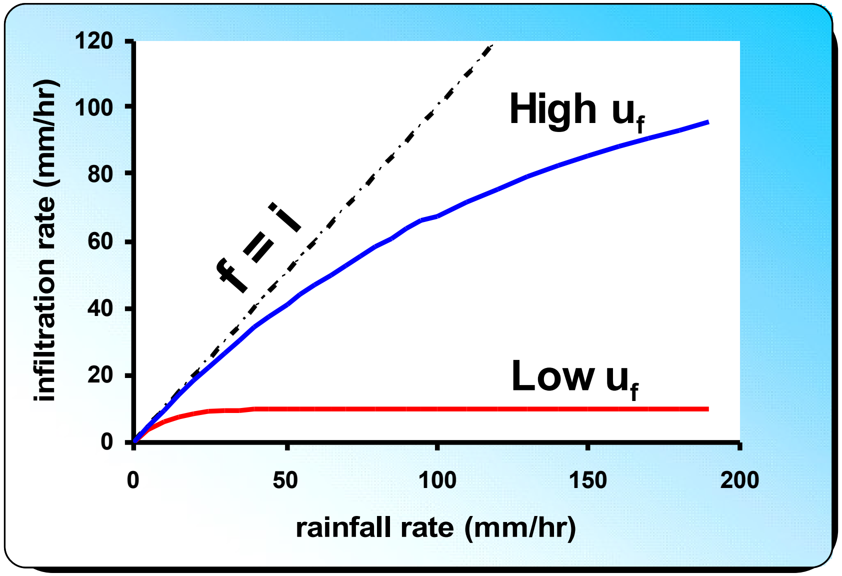
$$A = G(f) = \left(1 - e^{-i/u_f}\right)$$



If u_f can be parameterized, then the fractional contributing area can be computed using the CDF of the infiltration capacity

Runoff – Observation vs Theory

What is the impact of partial area response?



- **Significant**
  - **sandy soils**
  - **no-moderate grazing**
- **Very little**
  - **clay soils**
  - **heavy grazing**
  - **immediate post fire**
  - **High Rainfall**

Erosion

- Modeling the erosion process on rangelands is very, very, very complicated.
- Process based models, such as WEPP, are derived from cropland data.
- To date, there is no generally accepted model for rangeland erosion prediction.

Erosion

Steady State
Sediment Continuity Equation

$$\frac{dG}{dx} = D_i + D_r$$

G = sediment load

D_i = interrill detachment

D_r = rill detachment

x = distance downslope

Erosion

T_c - Transport Capacity

Runoff has a certain capacity to transport sediment based on the flow shear and sediment load, G.

Detachment or deposition will occur depending on if the load is <, >, or = to the transport capacity.

Erosion

Interrill Detachment

$$D_i = a\,K_i\,i\,q$$

D_i - interrill detachment

a = coefficient

K_i = interrill erodibility

i = rainfall intensity

q = steady state runoff rate

Erosion

Rill Detachment

$$D_r = K_r (\tau - \tau_c)(1 - G/T_c) \quad \text{when } \tau > \tau_c$$

$$T_c > G$$

D_r = rill detachment (positive)

K_r = rill erodibility

τ = flow shear stress

τ_c = critical shear stress

Erosion

Rill Deposition

$$D_r = (b\ V_f)/q\ (Tc - G) \text{ when } G > T_c$$

D_r = Rill deposition (negative)

b = turbulence coefficient

V_f = fall velocity

Erosion

Sediment Transport

- Raindrop detachment ALWAYS occurs

- Rill detachment occurs when

  $G < T_c$ and $\tau > \tau_c$

- Deposition occurs when $G > T_c$

Erosion – Observation vs Theory

Attribute	Cropland	Rangeland
Soils	Disturbed, tilled	Undisturbed
Vegetation	Monoculture, regular spacing	Community, irregular spacing
Topography	Ridge-Furrow	Complex
Conservation	Terraces, contours, waterways	Grazing, fire, brush management

Erosion – Observation vs Theory

Walnut Gulch Rainfall Simulator

Variable intensity - 25-180 mm/hr

Erosion – Observation vs Theory

SMALL PLOT (0.75 m^{2})

rain drop detachment

LARGE PLOT (2 x 6 m)

infiltration/runoff

integrated erosion response

rain and flow detachment,

transport, deposition

Erosion – Observation vs Theory

Assumptions

- Rain drop detatchment is the same on small and large plots
- Any difference between small and large plot sediment discharge is assumed to be due to dominant erosion process on the large plot
  - deposition
  - flow detachment

Erosion – Observation vs Theory

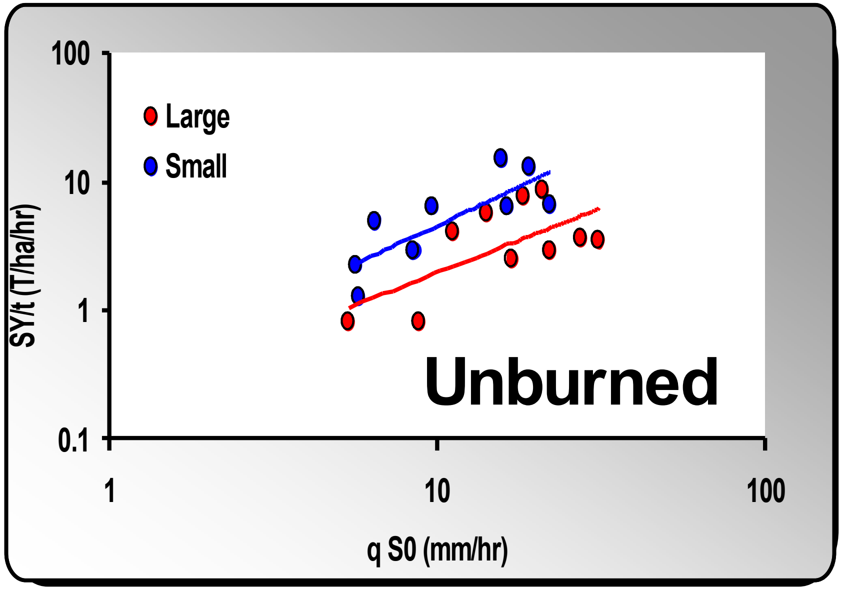
Sediment Discharge Comparisons

- small plot > large plot
  - deposition on large plot
- small plot = large plot
  - threshold of raindrop and flow detachment on large plot
- small plot < large plot
  - flow detachment on large plot

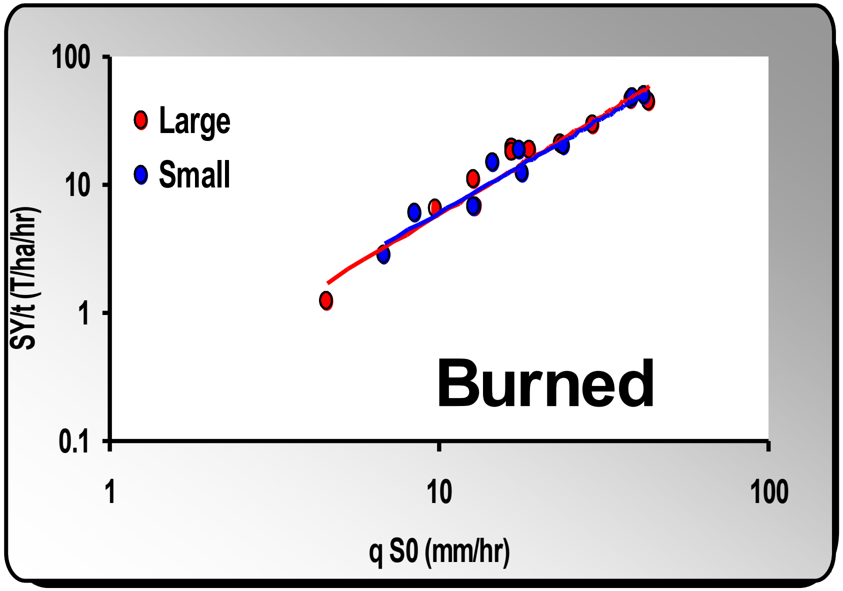
Erosion – Observation vs Theory

Grassland sites

Deposition



Threshold



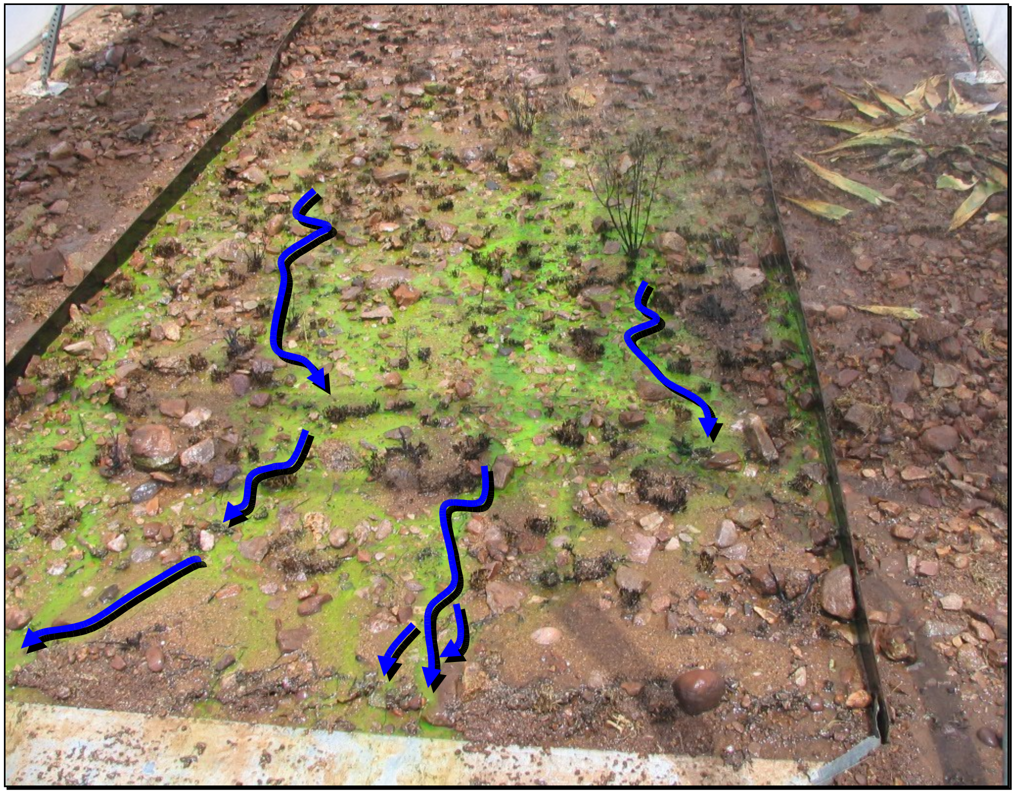
Erosion – Observation vs Theory

Grassland Sites

Erosion – Observation vs Theory

Grassland Sites

- Flow is sinuous
- Many obstructions to flow
- Depositional areas behind rocks, plants, litter



Erosion – Observation vs Theory

Grazing Prevents Blazing

(sign on Hwy 83 just north of Sonoita)

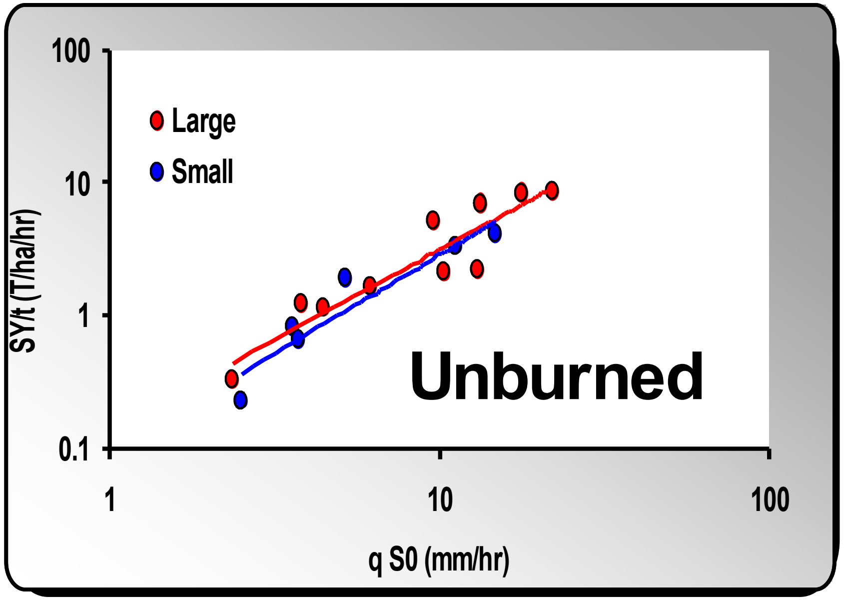
More vegetation = more fuel BUT burned litter forms litter dams retarding flow and sediment

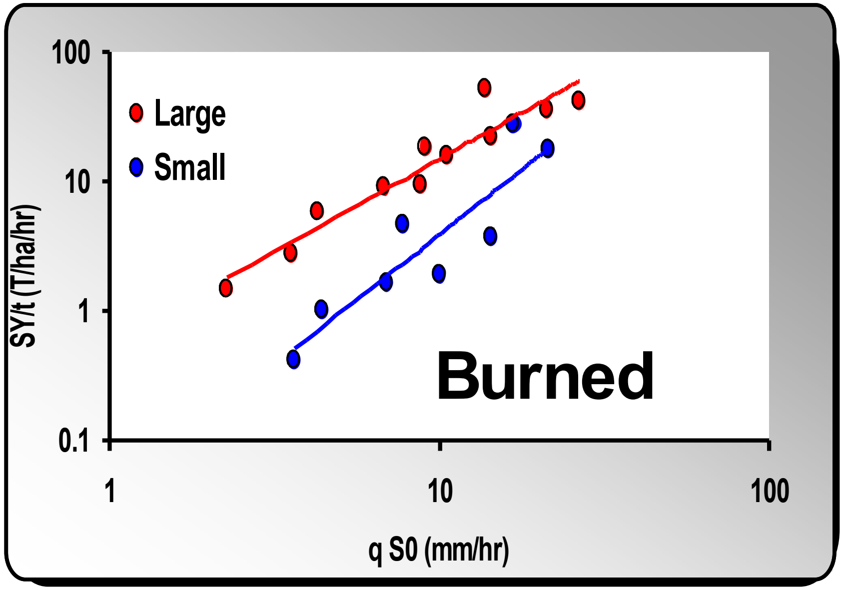
Erosion – Observation vs Theory

Oak Woodland sites

Threshold

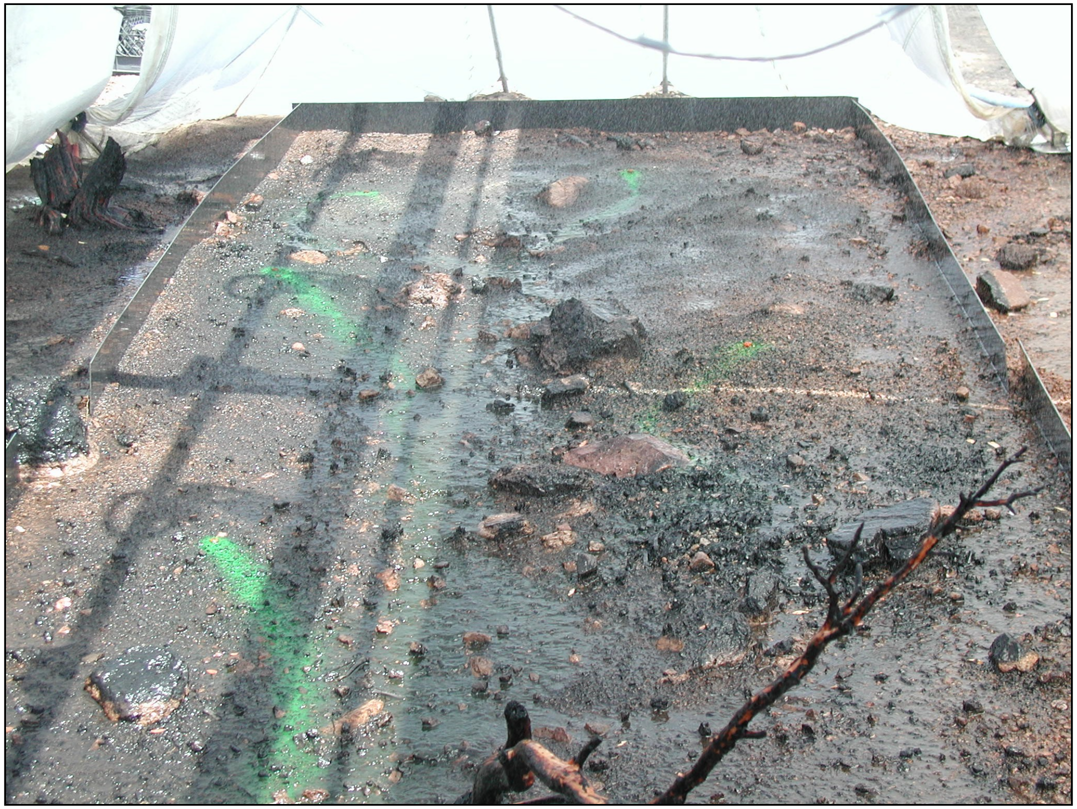
Flow detachment





Erosion – Observation vs Theory

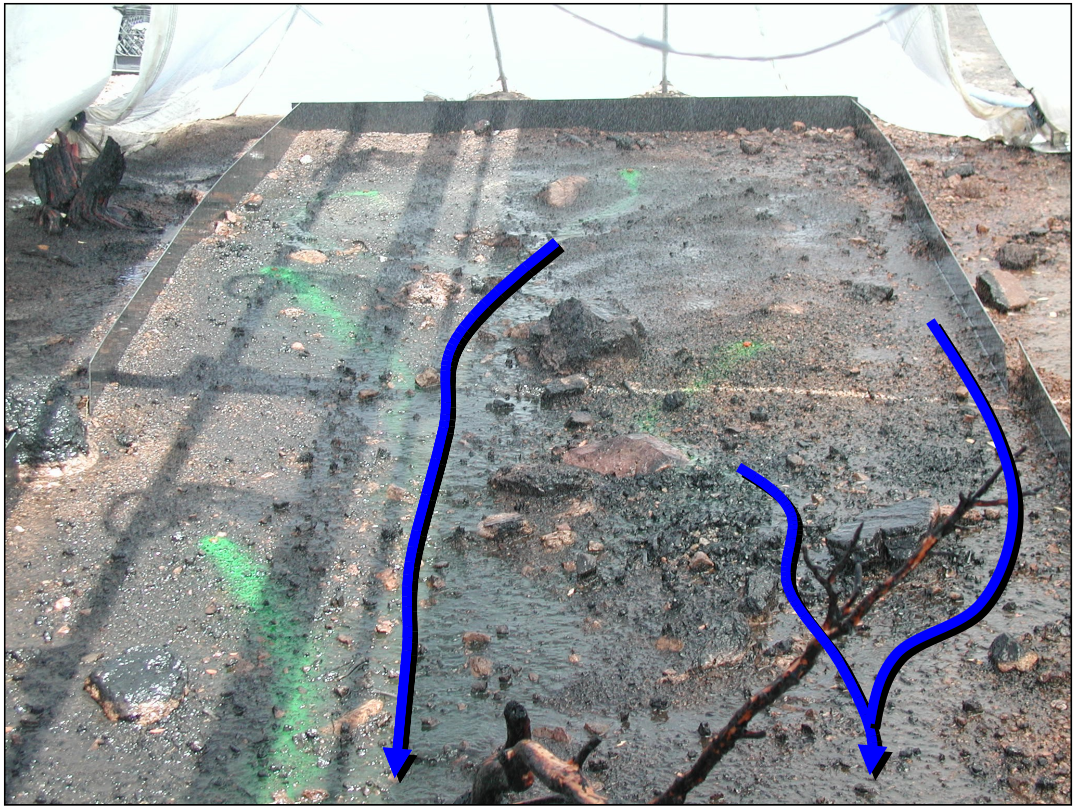
Oak Woodland Sites



Erosion – Observation vs Theory

Oak Woodland Sites

- Flow paths are continuous
- Few obstructions to flow
- Few depositional areas



Erosion – Observation vs Theory

Grassland vs Oak Woodland

- Working hypothesis - differences are due primarily to MICROTOPOGRAPHY

- No existing erosion model accounts for topographic differences among vegetation types

Application to Post-Fire Conditions

Main Issues

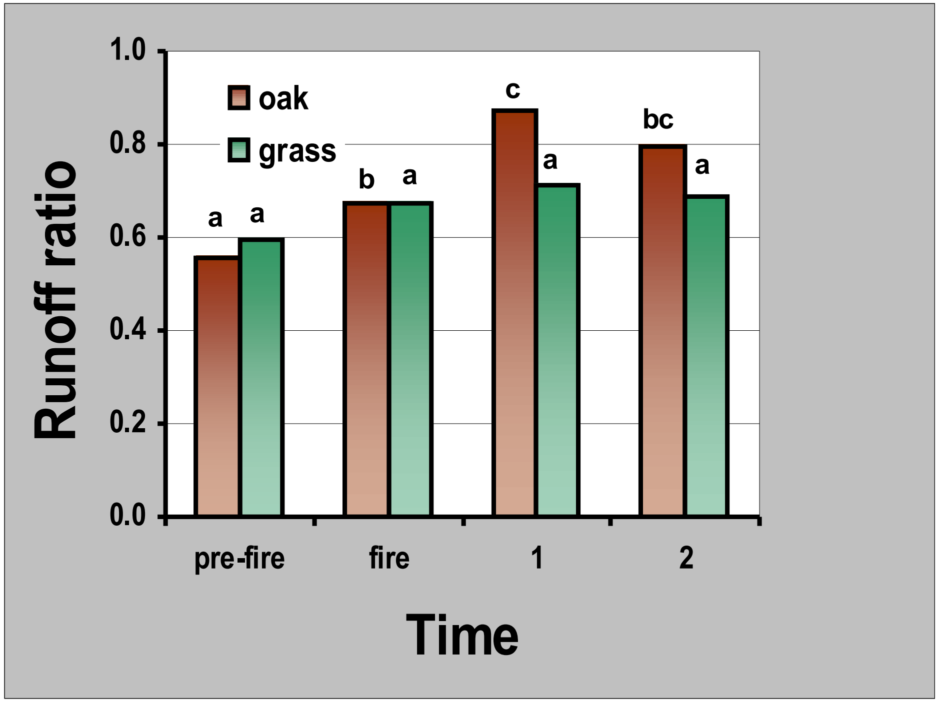
- Response to large events
- Cumulative effects over time
- Recovery time

Application to Post-Fire Conditions

Runoff ratio = Runoff volume/Rainfall volume

Grassland – no significant difference

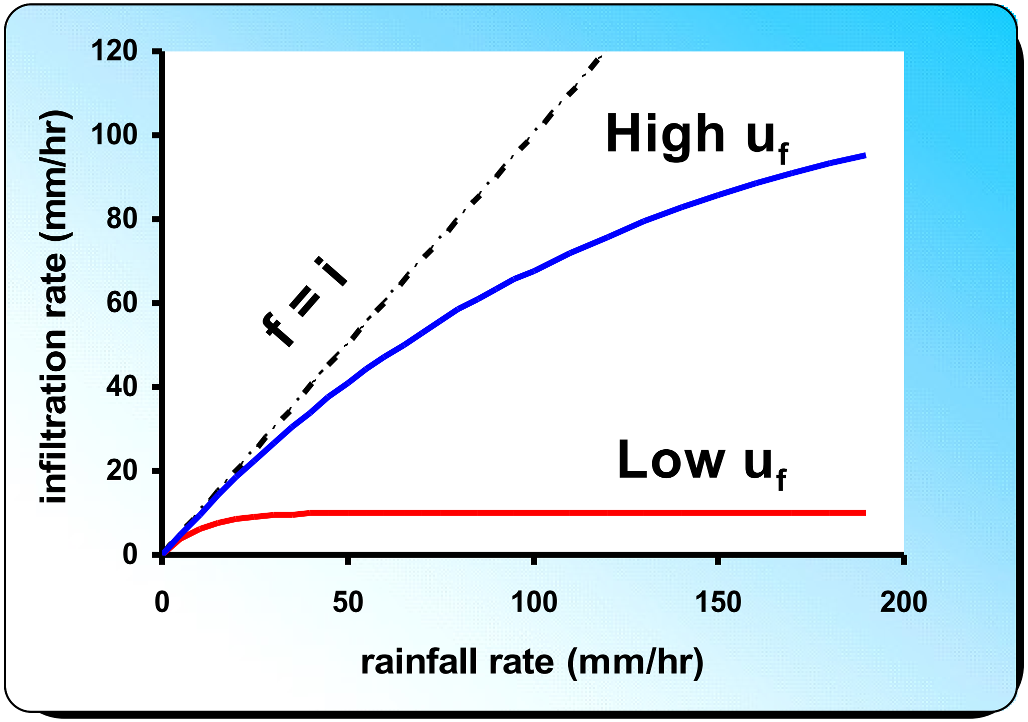
Oak Woodland – significant difference (20% increase post fire)



Application to Post-Fire Conditions

High u_f = unburned, no to moderate grazing, sandy soils

Low u_f = burned, heavy grazing, clay soils



For large events, partial area response doesn’t matter.

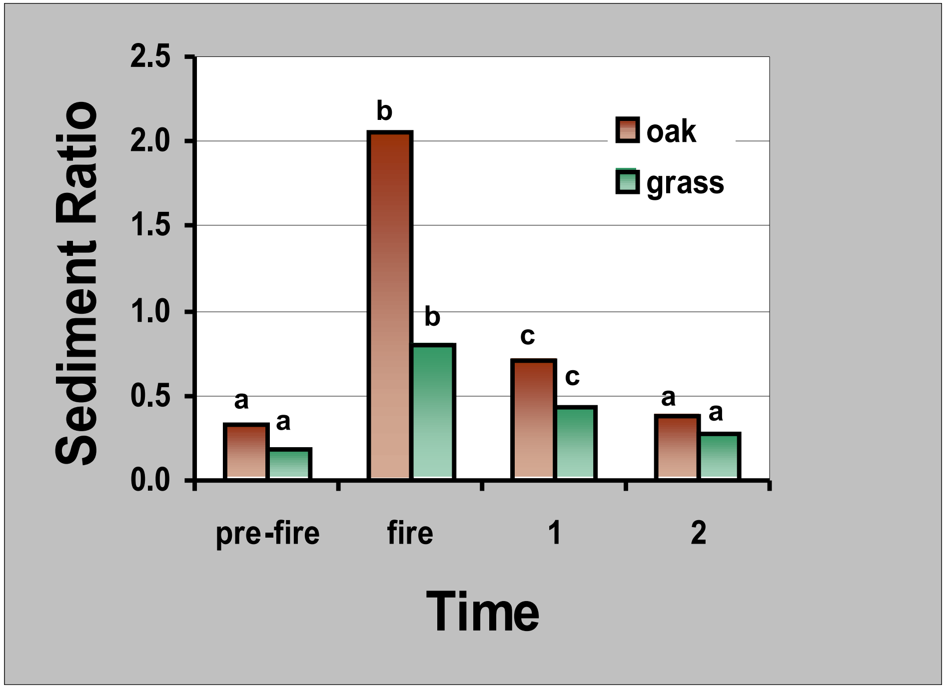
For cumulative effects, it probably does.

Application to Post-Fire Conditions

Sediment Ratio = Sediment yield/Runoff * Slope

Grassland and Oak Woodland – significant difference

Oak Woodland erosion >> Grassland erosion



Application to Post-Fire Conditions

Take Home Message

- For Large Events
  - Runoff – Most models work provided the parameters are ball park
  - Erosion – Conceptually, WEPP style model should work better for oak woodlands than grasslands

Application to Post-Fire Conditions

Take Home Message

- Cumulative Effects
  - No runoff or erosion model does well at simulating changes with time
  - No rangeland model for feedback between erosion and vegetation community (state and transition, productivity, etc)

Application to Post-Fire Conditions

Take Home Message

- Recovery Time
  - See previous slide
  - However, runoff changes slightly and erosion peaks immediately after the fire
  - 2 – 3 year recovery for erosion