Rural Roads: Hydrologic and Water Quality Impacts

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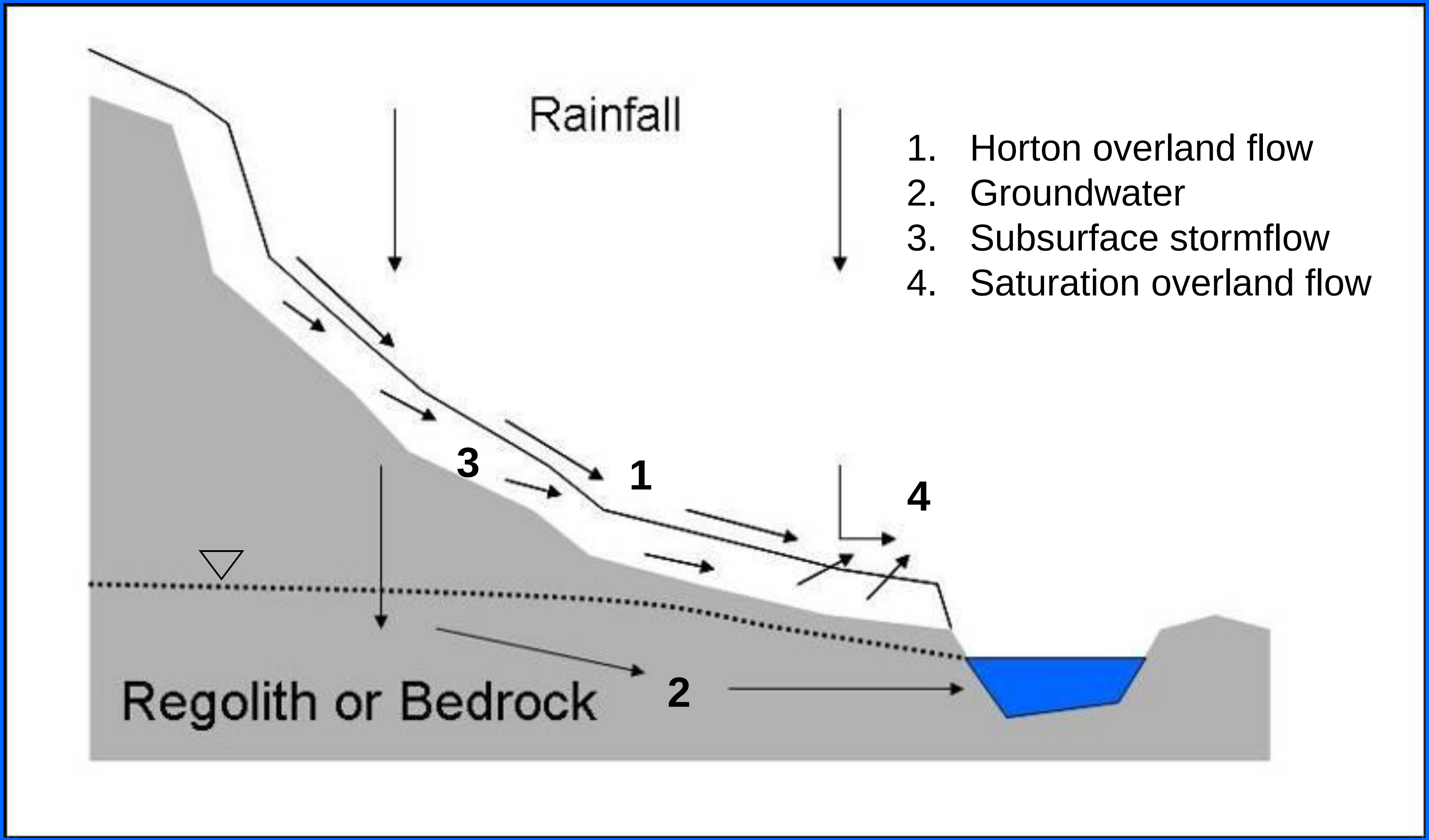
Gaining Understanding:

- What are the hydrological processes and pathways affected by rural roads?
- How are hillslope erosion processes affected by rural roads?
- How are road networks linked to channel networks and water quality?

Hillslope Runoff Processes



(Dunne and Leopold, 1978)

Horton Overland Flow (HOF)

- Infiltration rate << Rainfall rate;
- Common in arid to subhumid climates;
- Thin vegetation;
- Soil disturbance (e.g. compaction);
- **NOT COMMON IN UNDISTURBED FORESTED AREAS.**

Subsurface Stormflow (SSF)

(Hillslope trench; McDonnell, 2005)

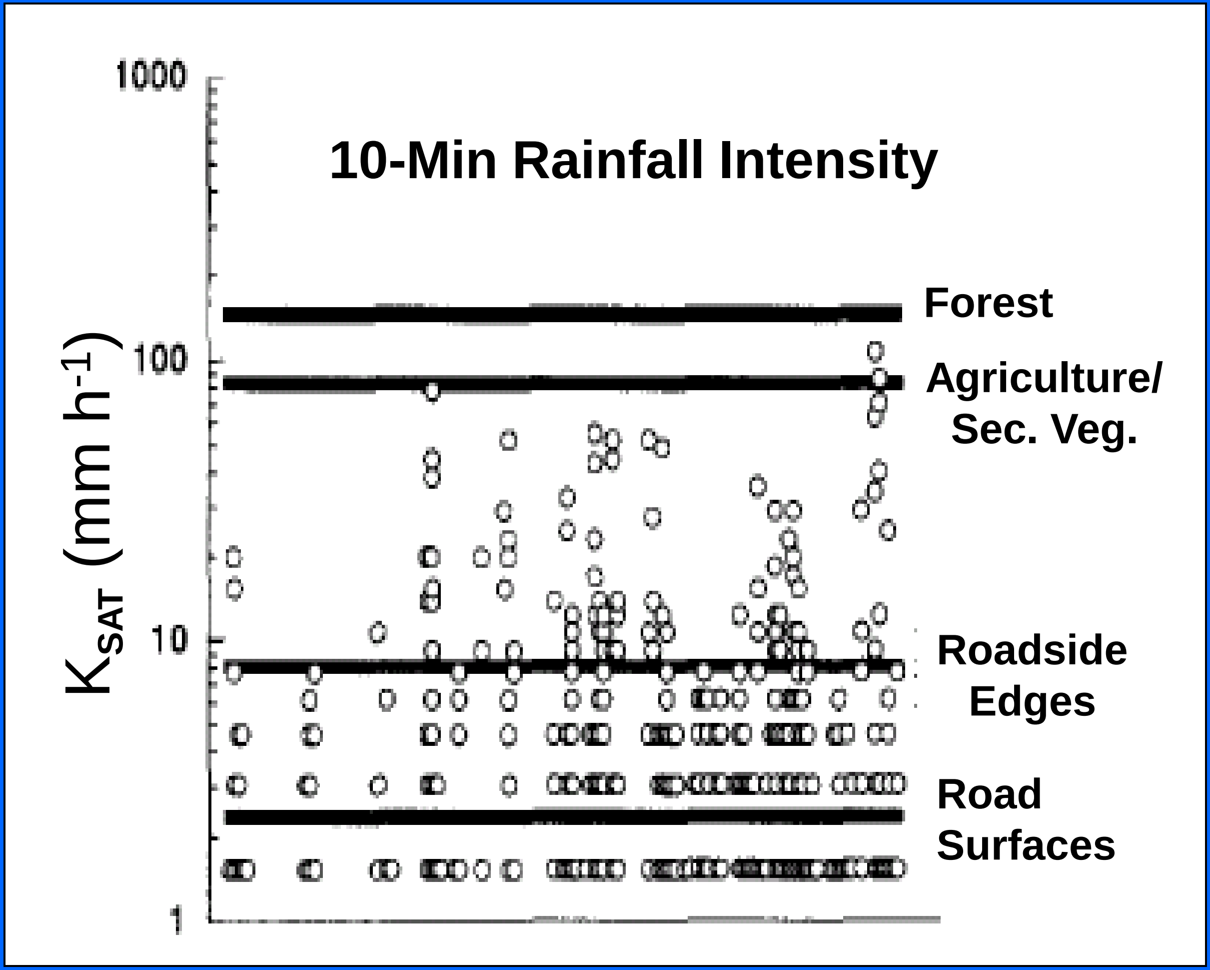
- Steep hillslopes
- Permeable soils overlying relatively impermeable bedrock or regolith
- Humid climate w/ abundant vegetation
- **COMMON IN FORESTED WATERSHEDS**

Road Surface Hydrology

- Highly compacted;
- High bulk densities;
- Little or no pore space.

K ($mm\ hr^{-1}$)	Location	Reference
0.0036	Oregon C.R.	Loague and Kyriakidis, 1997
0.11	N. Rockies	Luce and Cundy, 1994
0.3	NW. Washington	Reid and Dunne, 1984
2.3	Thailand	Ziegler and Giambelluca, 1997
3.0	Idaho	Luce, 1997
36.5	SE. Australia	Lane and Sheridan, 2002
9.3	Lake Tahoe - granitic	Foltz et al., 2011
7.5	Lake Tahoe - volcanic	Foltz et al., 2011

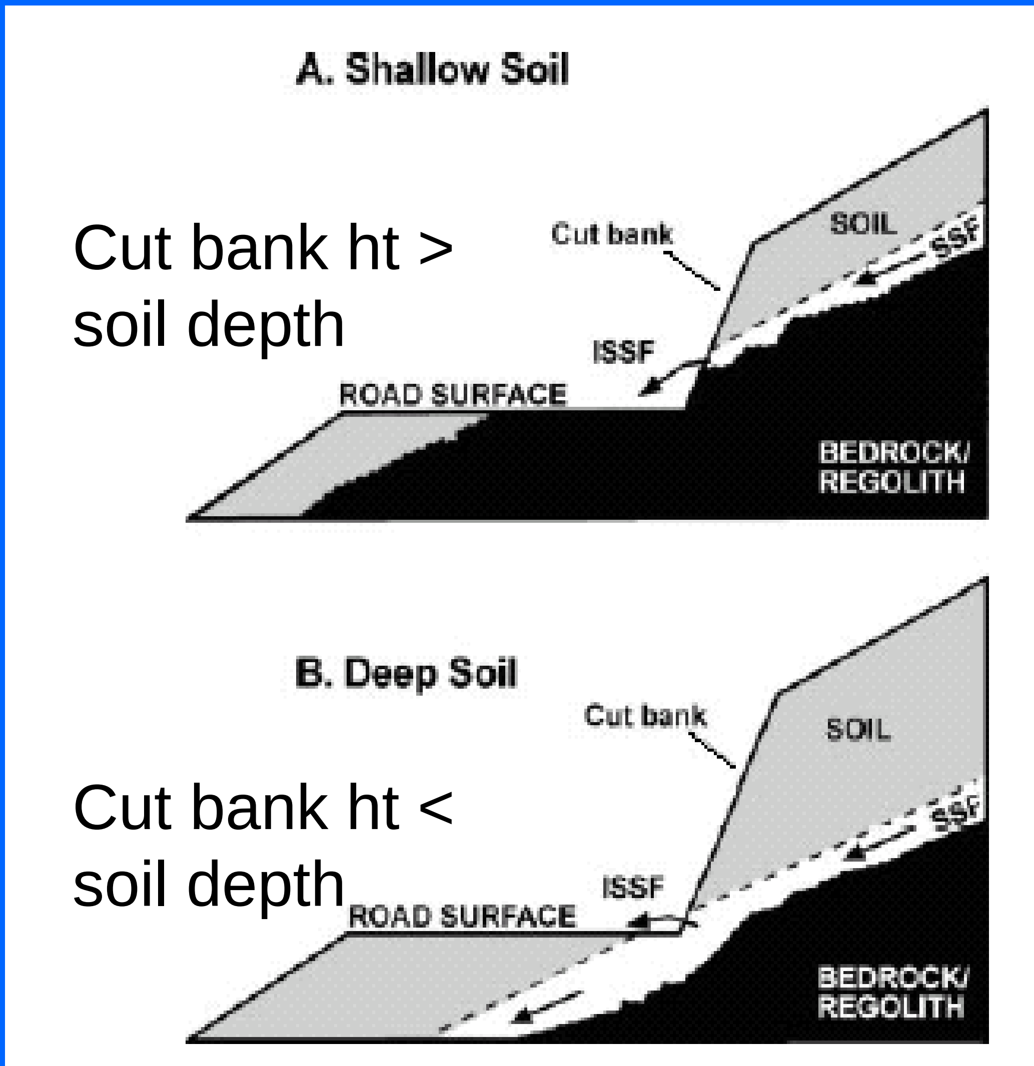
Road Surface Hydrology



- Have the potential to produce runoff during small storms;
- Abundance of HOF on road surfaces.

(Ziegler and Giambelluca, 1997)

Cutslope Hydrology



Cut bank ht > soil depth

Cut bank ht < soil depth

- Cut banks intercepts SSF (ISSF) when the cutslope height > soil depth;
- ISSF is less likely on deeper soils, lower slopes, and ridgetops.

(Ziegler et al., 2002)

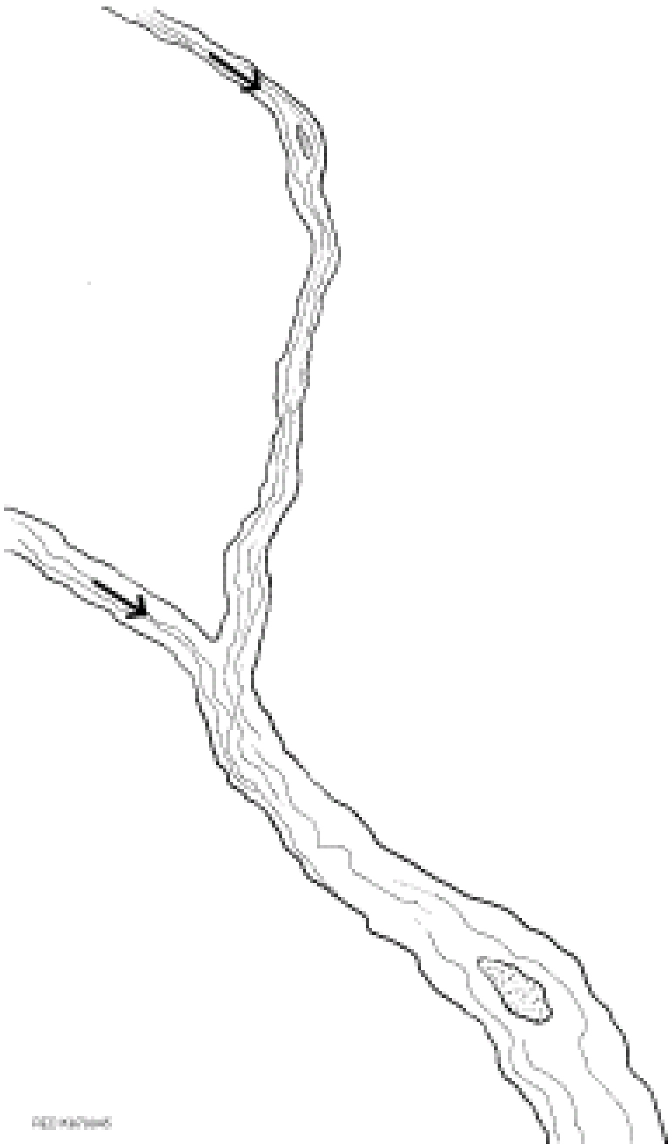
Cutslope Hydrology

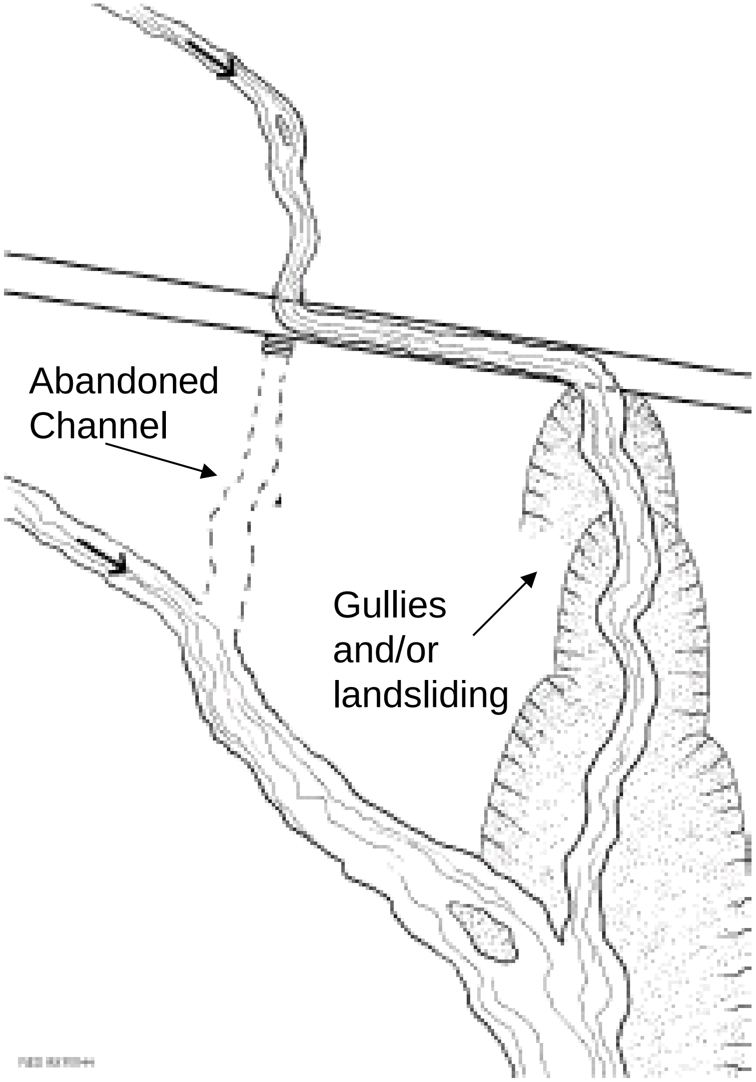
- **Subsurface stormflow interception accounted for 7.3 times more runoff than road surface in snow-dominated Idaho Batholith (Megahan, 1972)**

Impacts on Runoff Timing

- Velocity of overland flow is 10-10000 time greater than SSF (Dunne, 1978);
- Increases rising limb of hydrograph.

Road Segment Hydrology – Stream Diversion





Furniss et al., 1997)


Erosional Impacts from
Rural Roads

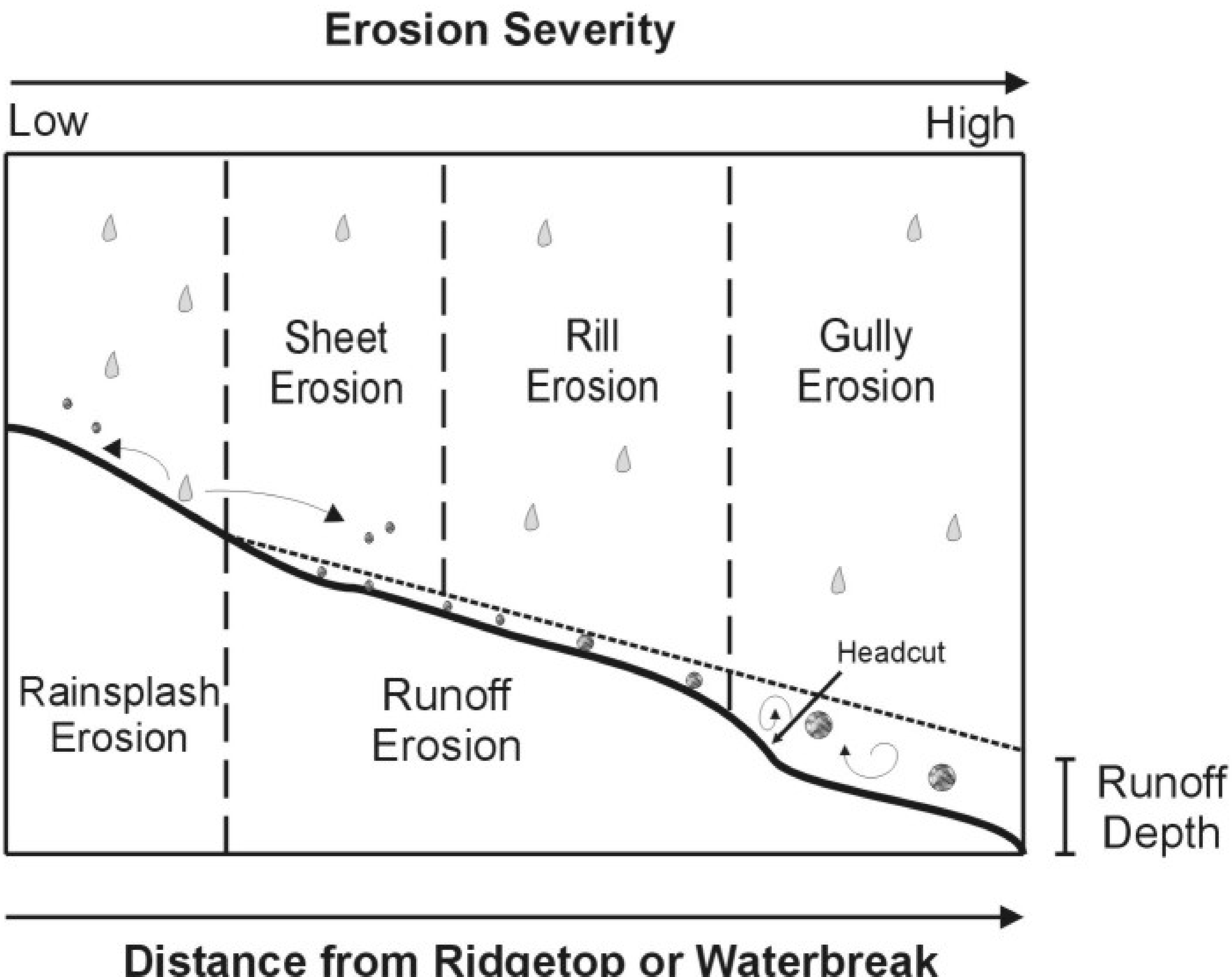
Surface Erosion:

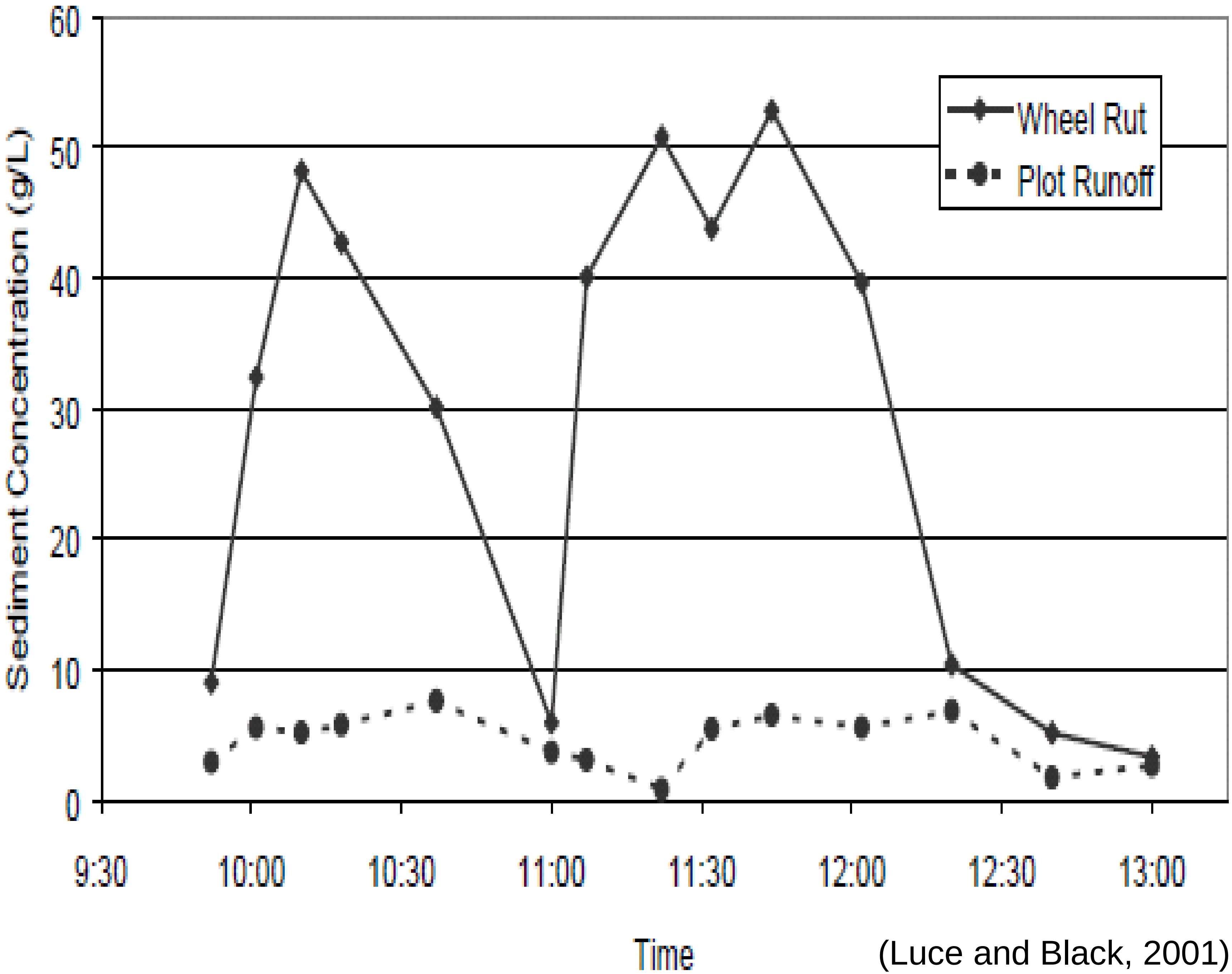
- Amount and energy of surface runoff applied to road prism

- Erodibility of road prism

Erosive Power

- Runoff depth and slope of the flowpath dictate erosive force (depth x slope).
- Runoff depth controlled by ppt. intensity, distance between waterbreaks, and degree of runoff concentration.


Erosion Severity
Low
High
Sheet
Erosion
Rill
Erosion
Gully
Erosion
Headcut
Rainsplash
Erosion
Runoff
Erosion
Runoff
Depth
Distance from Ridgetop or Waterbreak



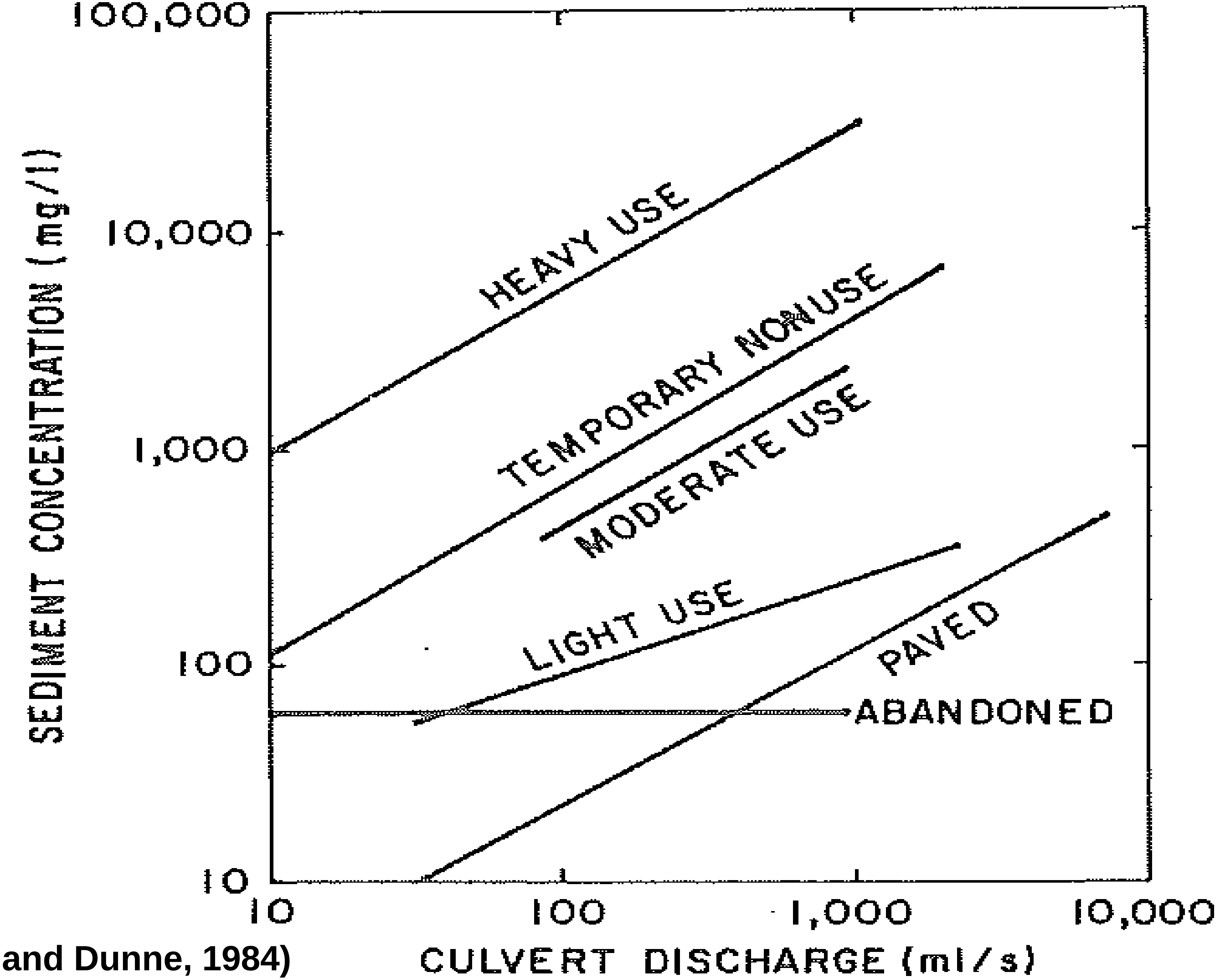
(Luce and Black, 2001)

Erodibility

Loose material on road

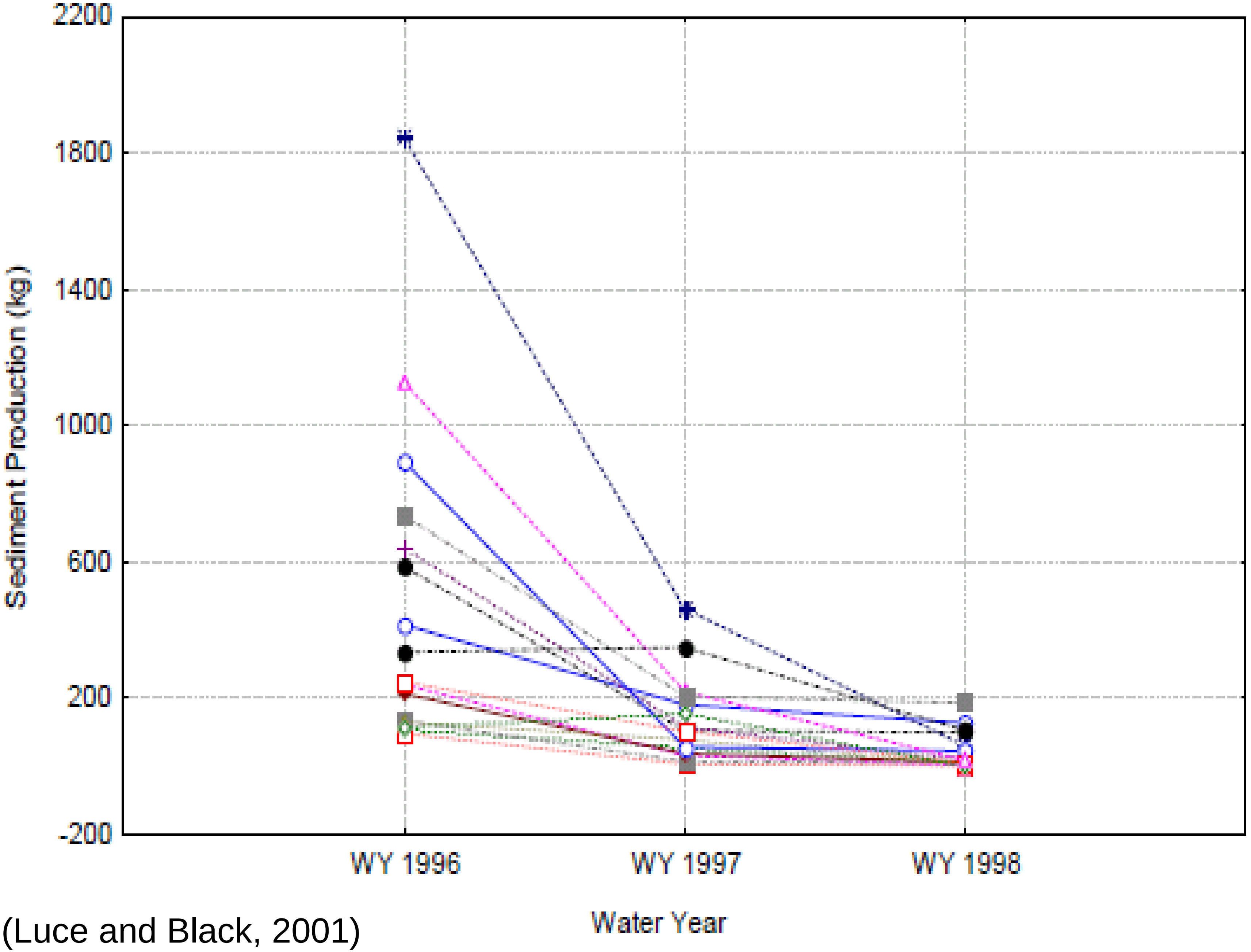
- Erodibility a function of:
  - **Geology**
    - **Soil properties**
  - **Traffic**
  - **Maintenance**
  - **Age of road**


5. 19. 2006

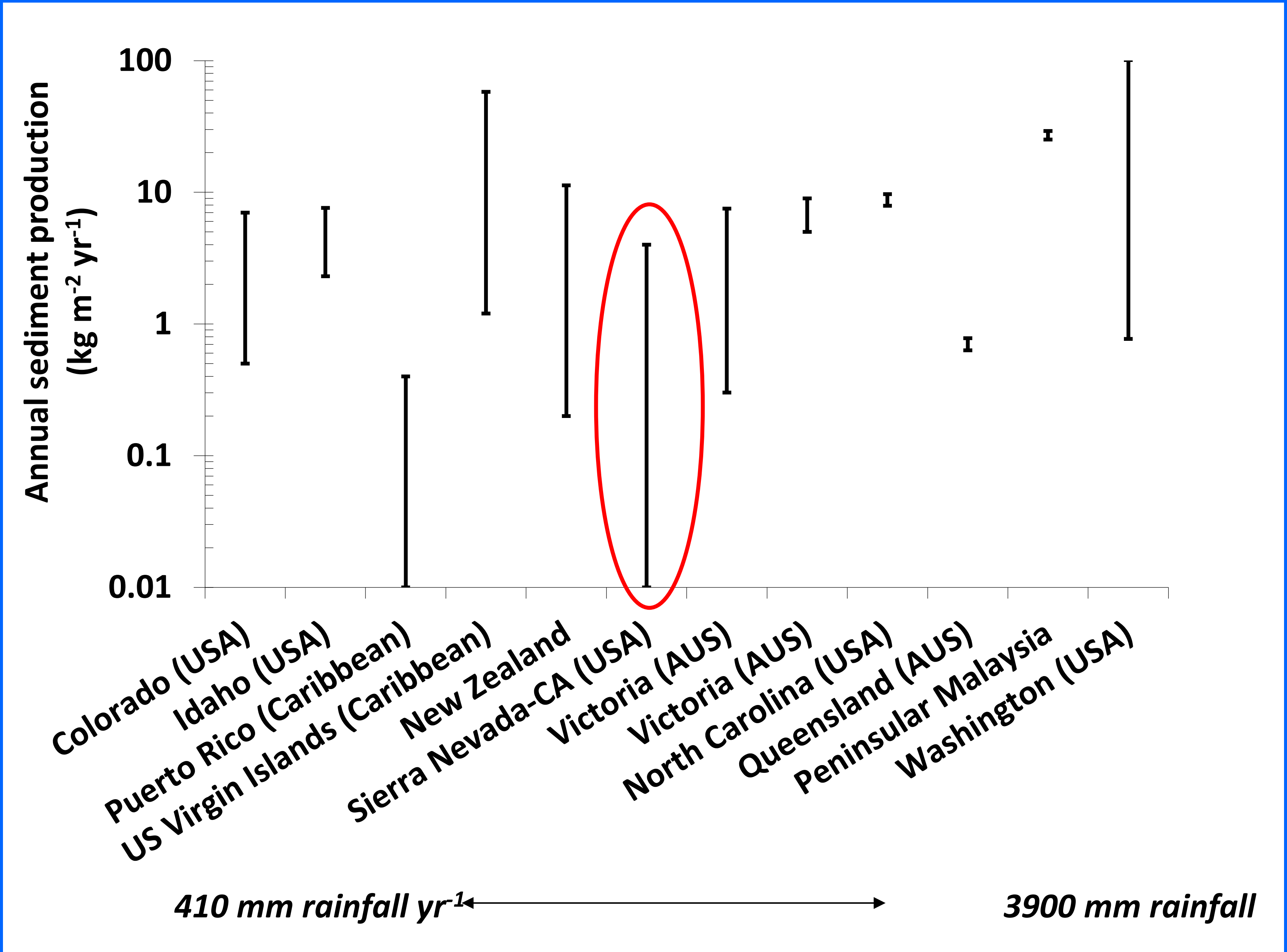


(Reid and Dunne, 1984)

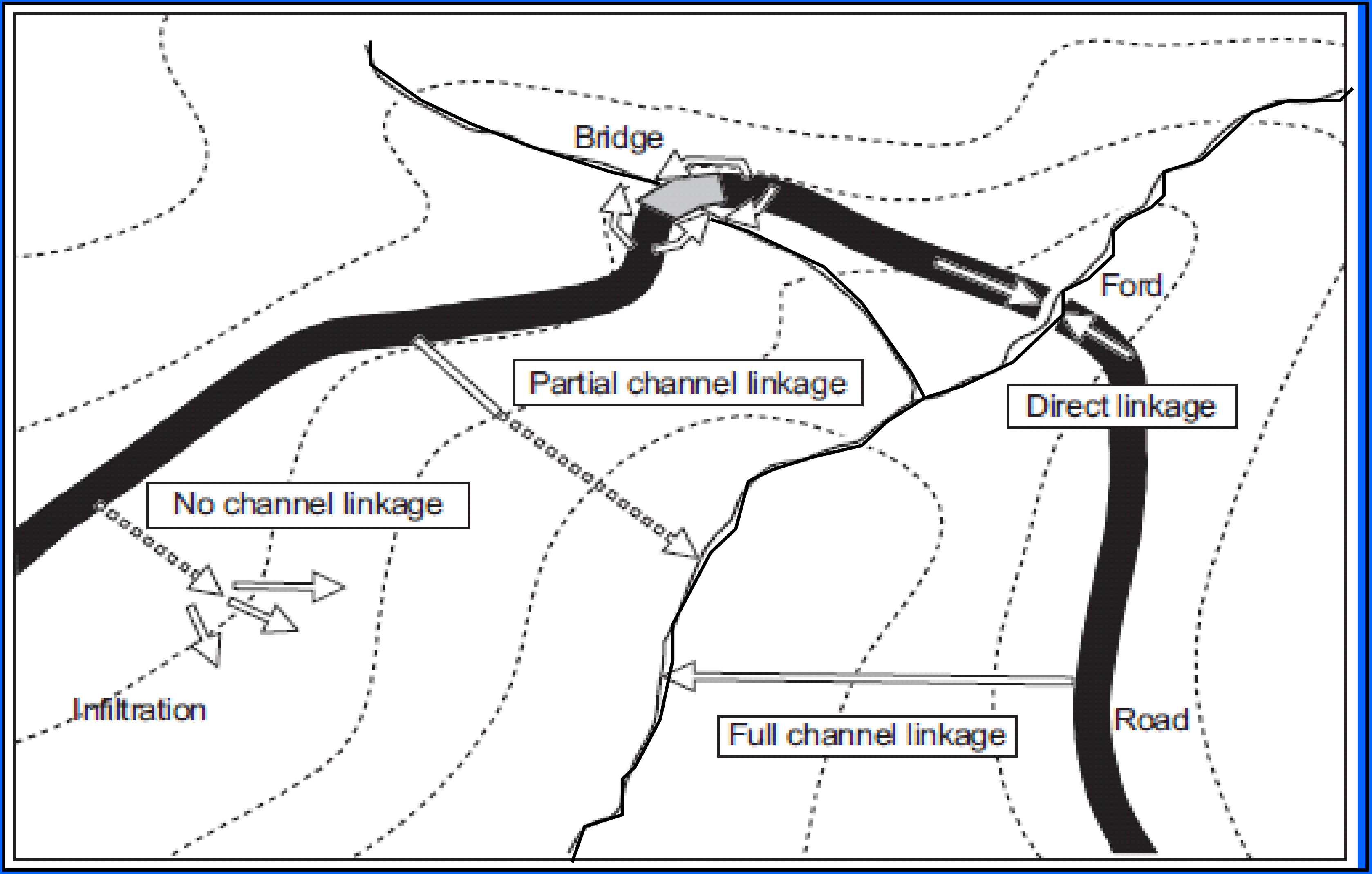
http://www.fhueng.com/environmental/Sustainability/traction_sand.html



(Luce and Black, 2001)


Annual sediment production (kg m-2 yr-1)
100
10
1
0.1
0.01
Colorado (USA)
Idaho (USA)
Puerto Rico (Caribbean)
US Virgin Islands (Caribbean)
New Zealand
Sierra Nevada-CA (USA)
Victoria (AUS)
Victoria (AUS)
North Carolina (USA)
Queensland (AUS)
Peninsular Malaysia
Washington (USA)
410 mm rainfall yr-1
3900 mm rainfall

Watershed Scale Impacts Depend on Degree of Linkage



(Croke and Mockler, 2006)

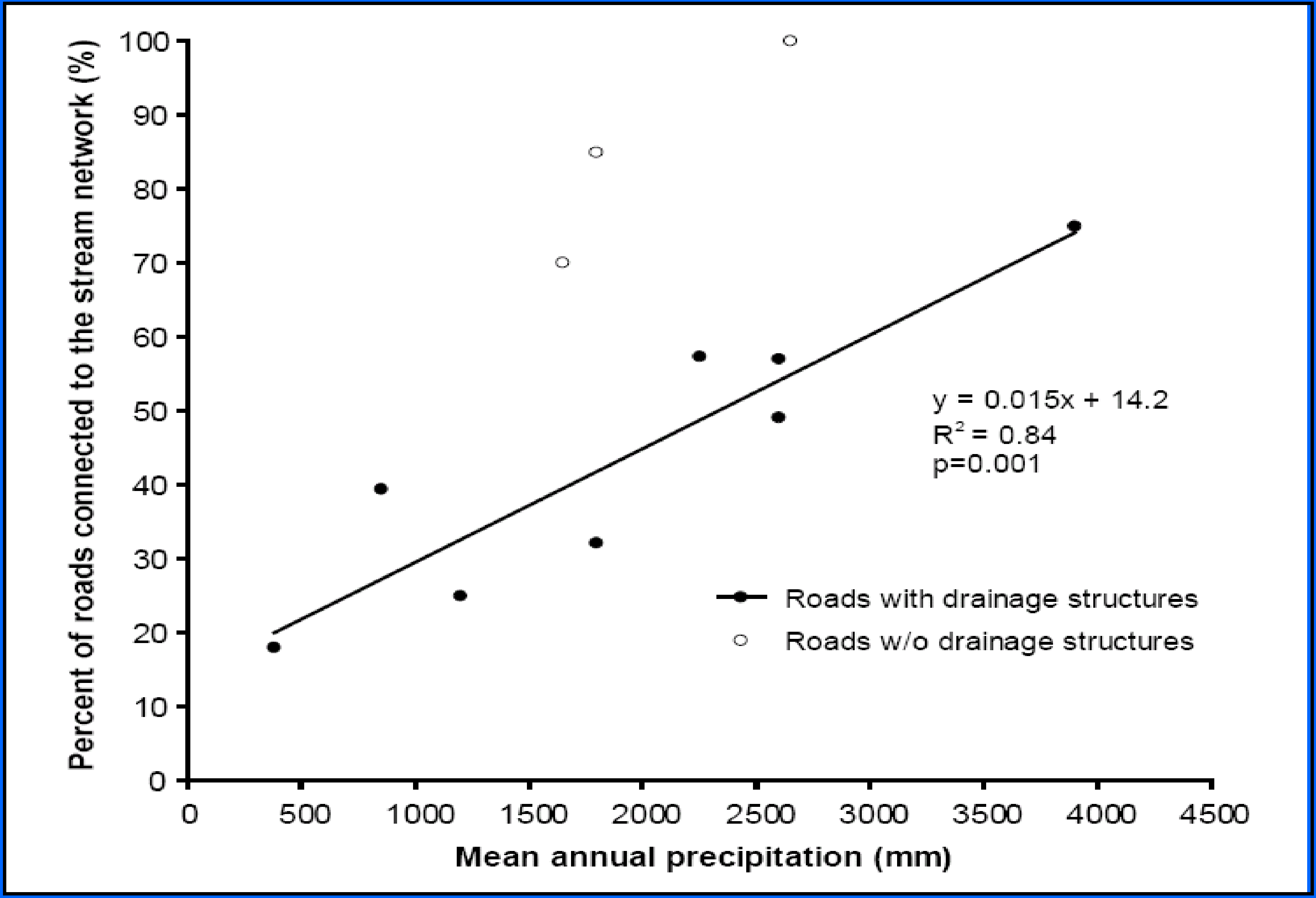
Road Linkage

- Combination of HOF, ISSF, and/or pirated water increase the likelihood of gully and landslide initiation,

Linkage at Road-Stream Intersections

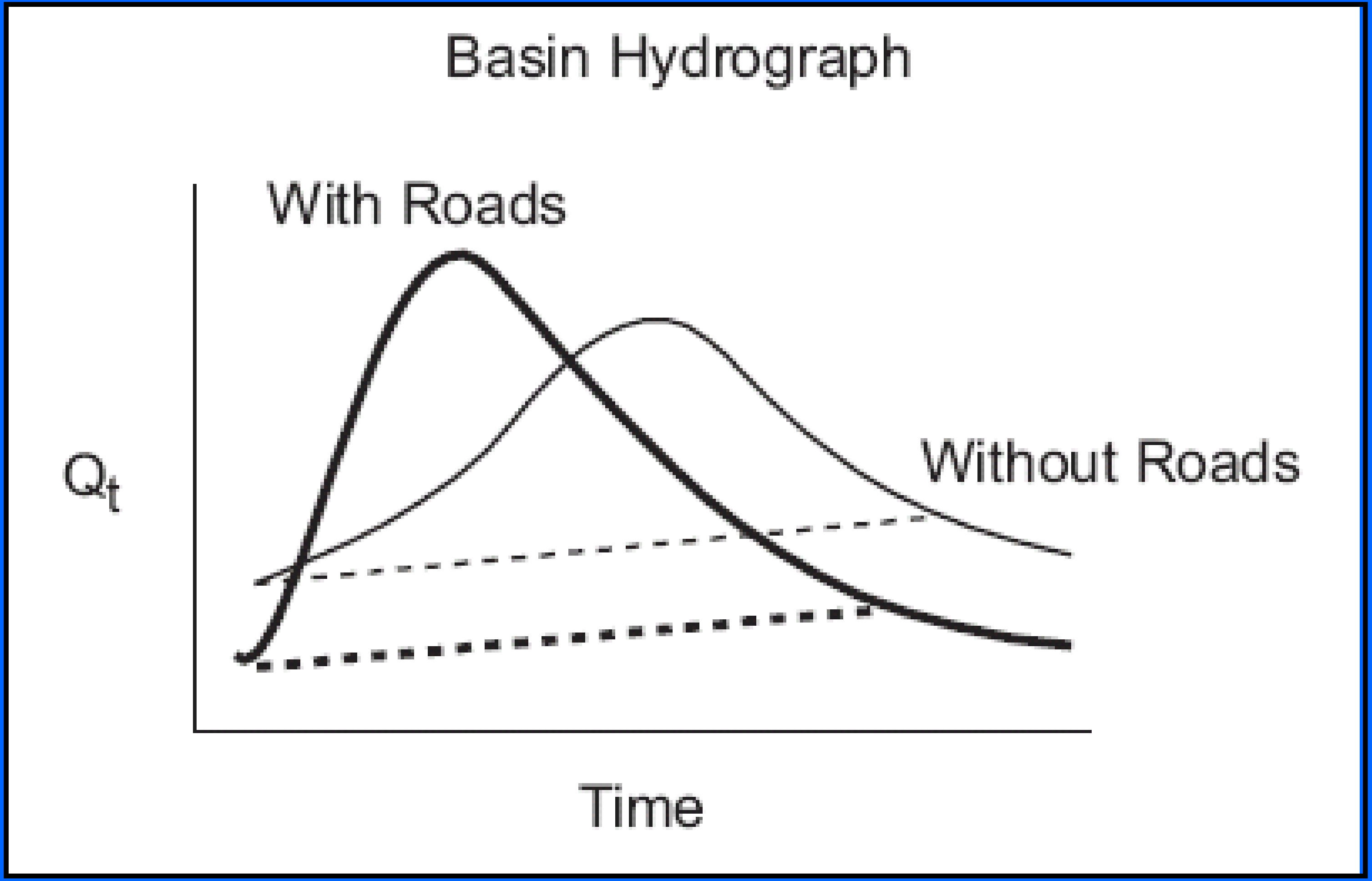
- Road segments can potentially deliver excess runoff to channel network at stream crossings

Road-Stream Connectivity



(MacDonald and Coe, 2007)

Watershed Impacts – Do the Hydrologic Impact of Roads Translate or Disperse Downstream?



(Wemple et al., 1996)

Hydrologic Effects of Roads at the Small Watershed Scale for Paired Watershed Studies in CA & PNW

- Watershed areas ranged from 61-759 acres

- Data from the HJ Andrews and Caspar Creek showed no increases in mean annual peak flow due to roads (Rothacher, 1973; Ziemer, 1981)

Small Watershed Scale:

- No detectable effects of roads except when roads occupied more than 12% of watershed area (Harr et al., 1975).
- Typical area occupied by roads in industrial forestland is 2-4%

Watershed Scale: Modeling Studies (DHVSM)

- Effects of forest roads on peak flows equivalent to harvest
- 11-12% increase per 2% of area disturbed by roads
- When roads are combined with harvest, effects are additive rather than synergistic
- Models may not accurately represent true processes (Surfleet et al., 2010)

Water-Quality Impacts

=

Erosion

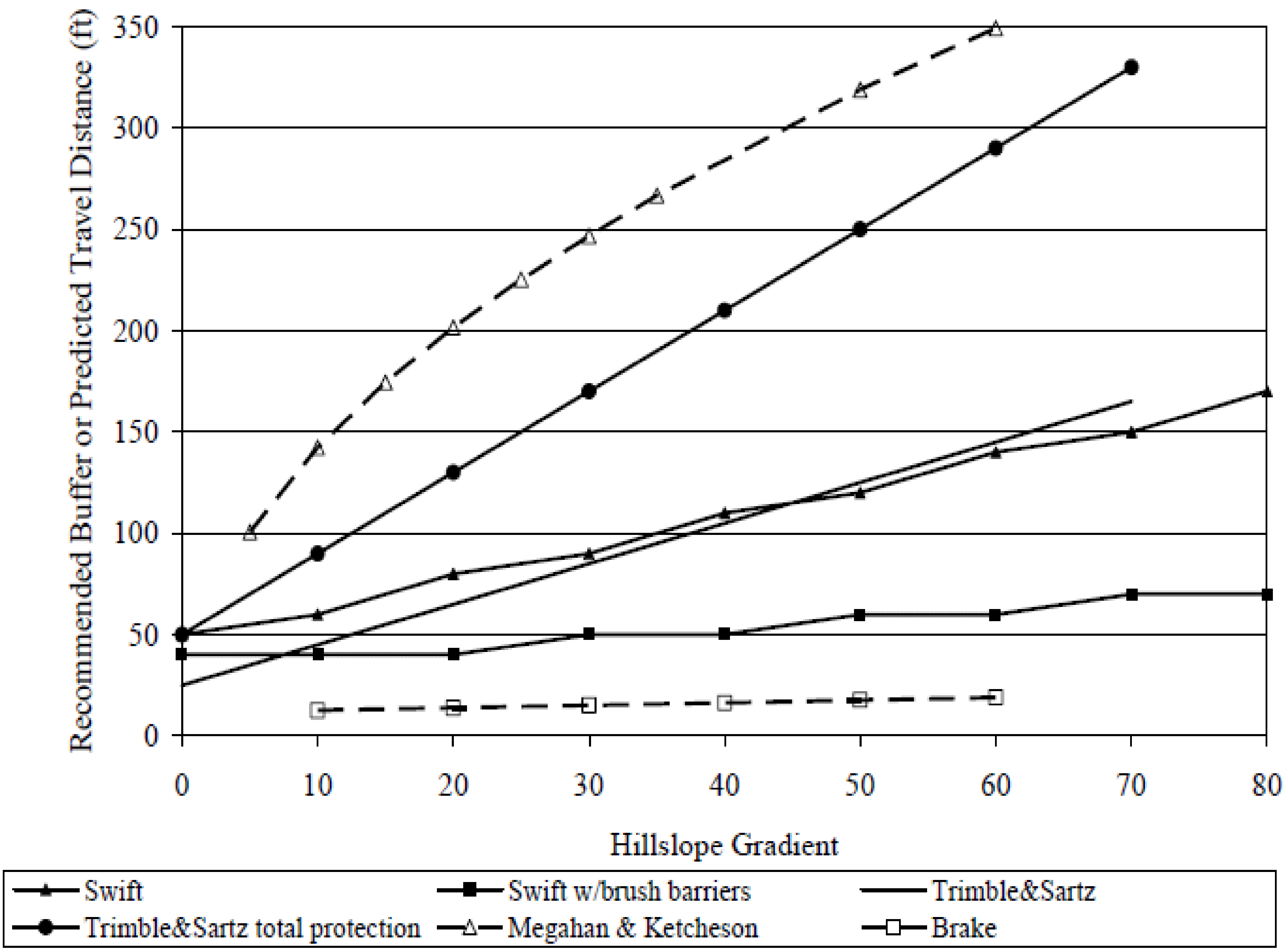
+

Delivery to a Waterbody

- Linkage most common at road-stream crossings
- Water quality impacts are typically chronic
- Sediment is fine grained

- Sediment breakthroughs can happen when:
  - Roads are close to streams
  - When roads discharge large volumes of runoff and sediment
  - Gully initiation at discharge points

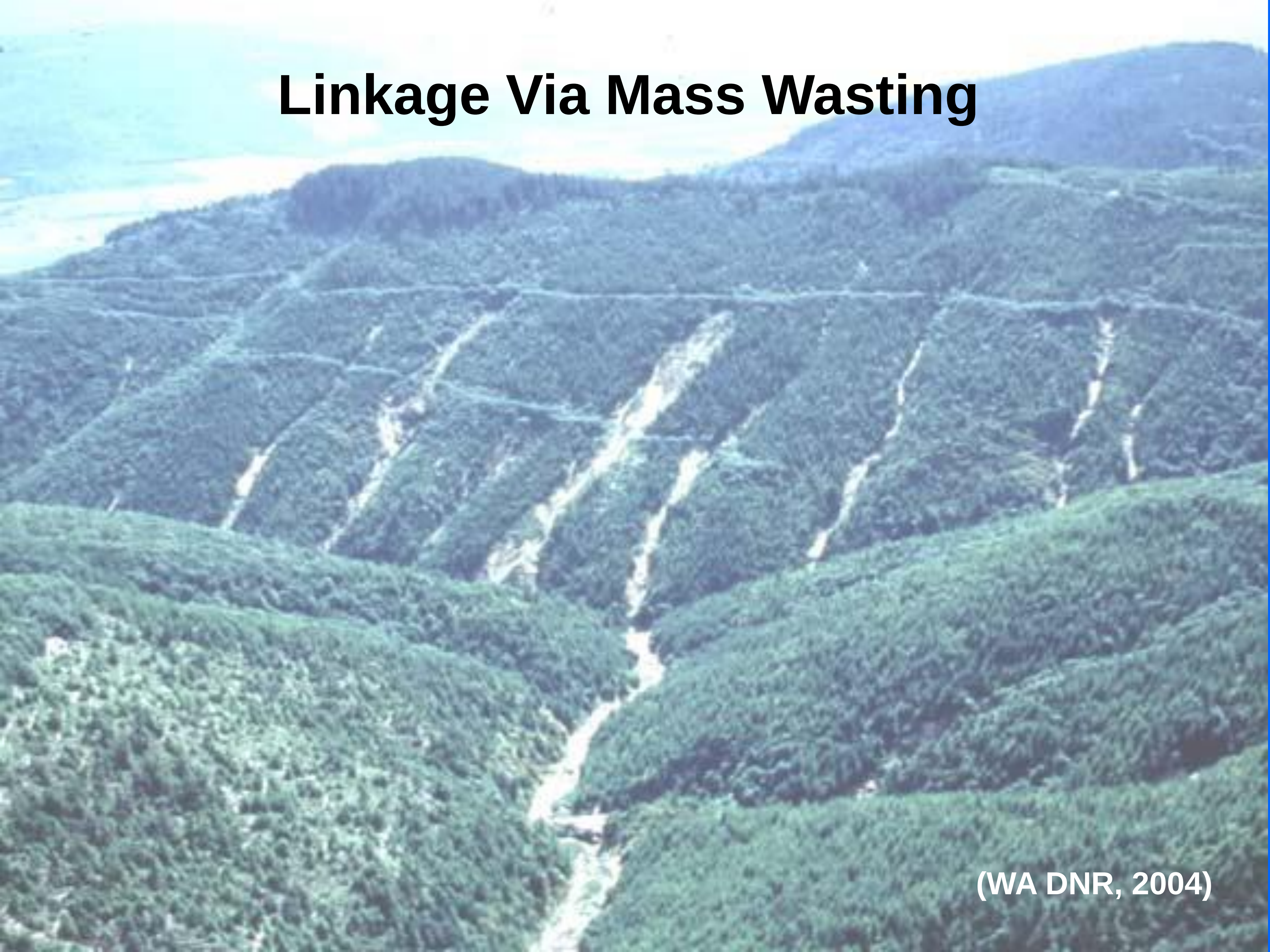
Gully Initiation Via Road Drainage



Recommended Buffer or Predicted Travel Distance (ft)
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
Hillslope Gradient
Swift
Swift w/brush barriers
Trimble&Sartz
Trimble&Sartz total protection
Megahan & Ketcheson
Brake


Fluvial Erosion From A
Diverted Stream Crossing

Linkage Via Mass Wasting



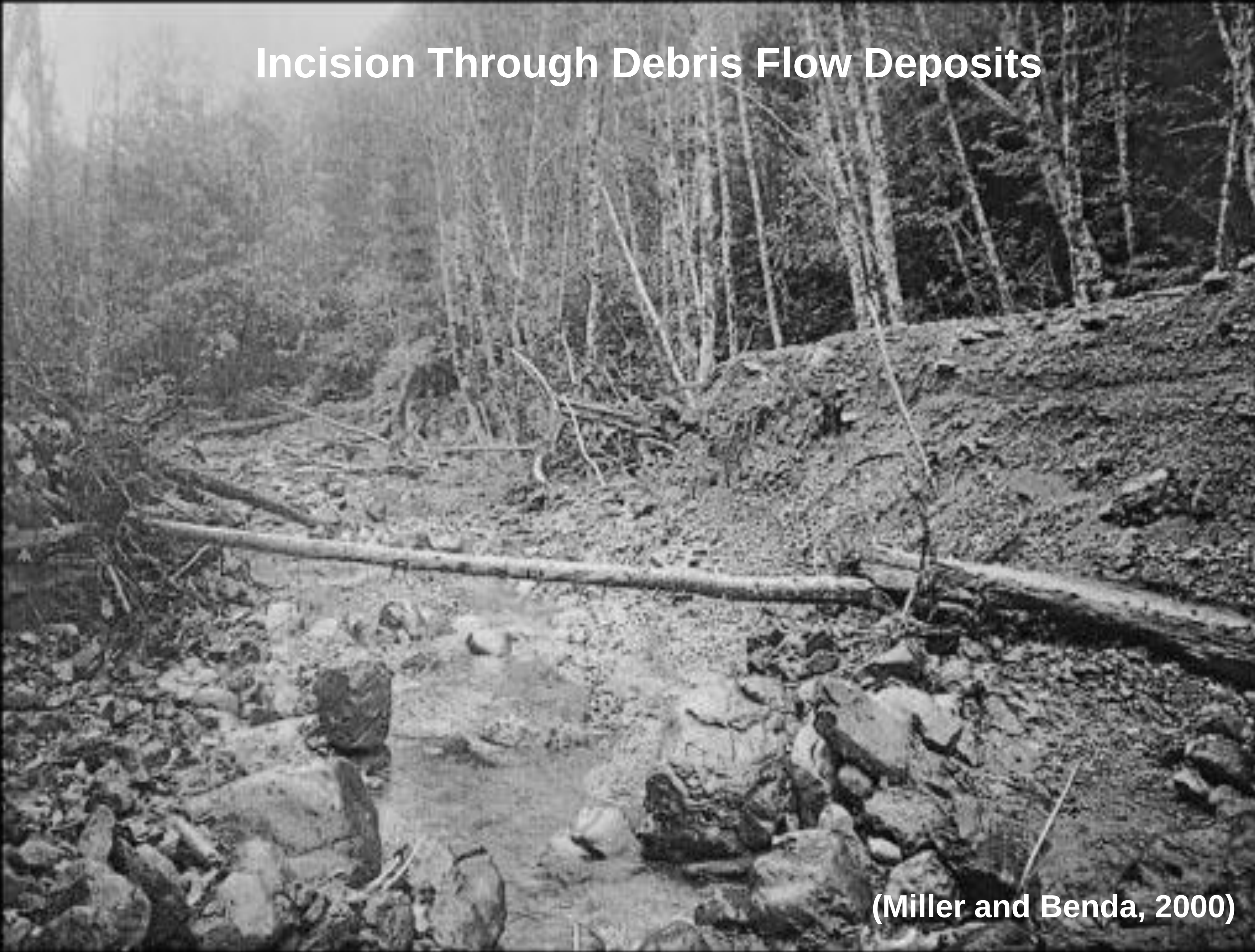
Water Quality Impacts

- Fine sediment increases suspended sediment concentrations and turbidity.

Increased Settleable Materials

(Sari Sommarstrom)

Incision Through Debris Flow Deposits



(Miller and Benda, 2000)

How Do We Mitigate the Hydrogeomorphic Impacts of Roads?

(Wemple, 2005)

Mitigation

Road ditch with intercepted groundwater

- **Drain roads frequently**
- **Disperse, rather than concentrate, runoff**
- **Avoid excess stream crossings**
- **Disconnect road runoff from stream crossings**
- **Minimize cutslope/flowpath interaction**

Mitigation

- Harden running surfaces with linkage to surface waters
- Prevent rutting of road surface (i.e., weather restrictions
- Prevent gullying or mass-wasting below roads by:
  - Decreasing runoff at discharge point
  - Draining to planar or convex slopes
  - Providing energy dissipation at the outlet