

# Where does water go when it rains?

## *Conceptualizing runoff processes in headwater catchments*



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After July 1, Global Institute for Water Security

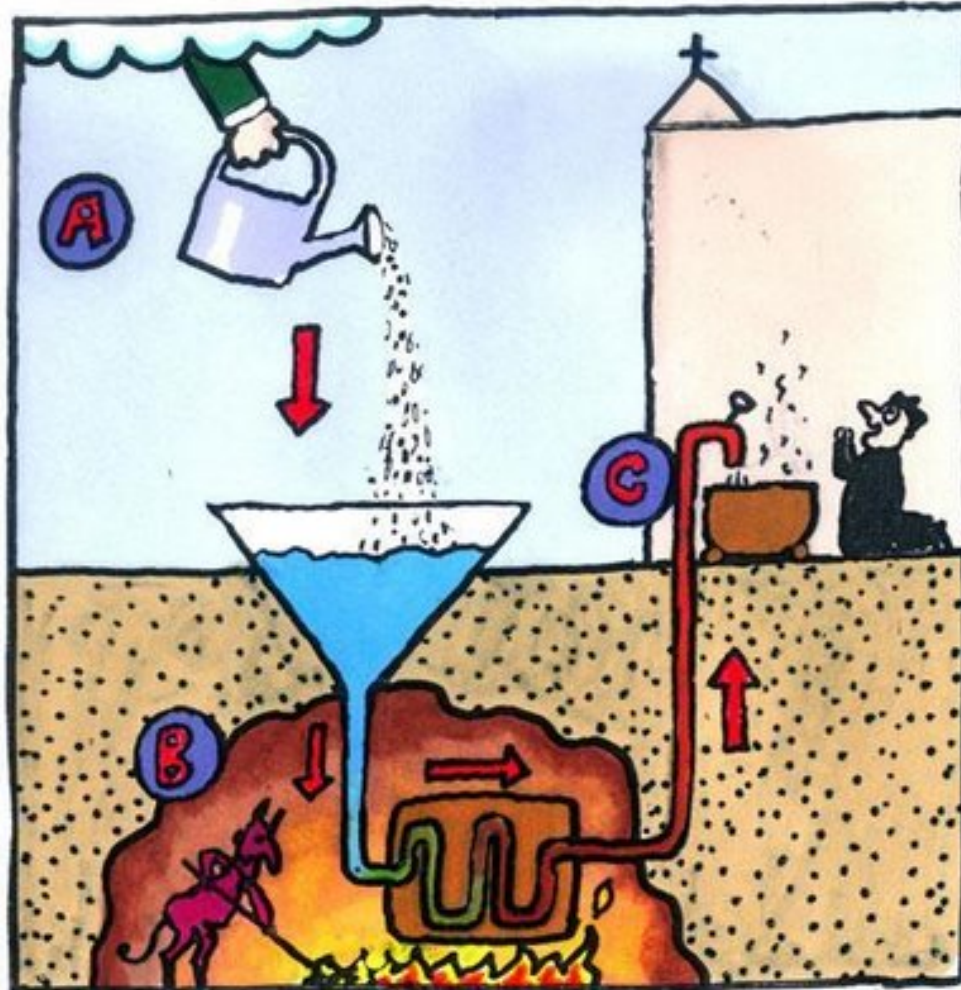
University of Saskatchewan, Canada



# Technical and environmental mgmt. for water sustainability

Where  
does water  
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rains?

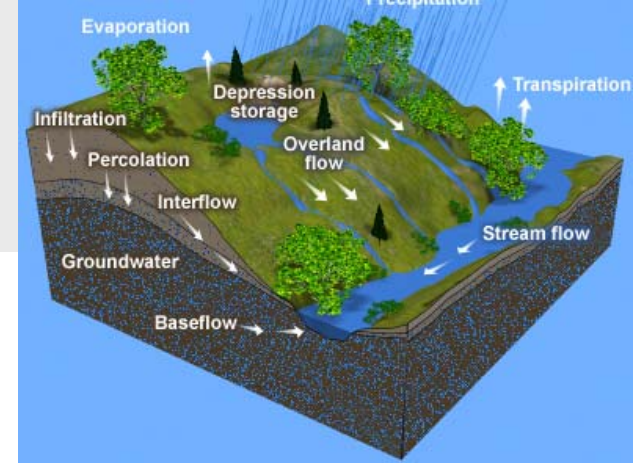
## ¿Sustainable?



- Where does water go when it rains?
- How long does water reside in the watershed?
- What flowpath does water take to the stream?



# Outline for today

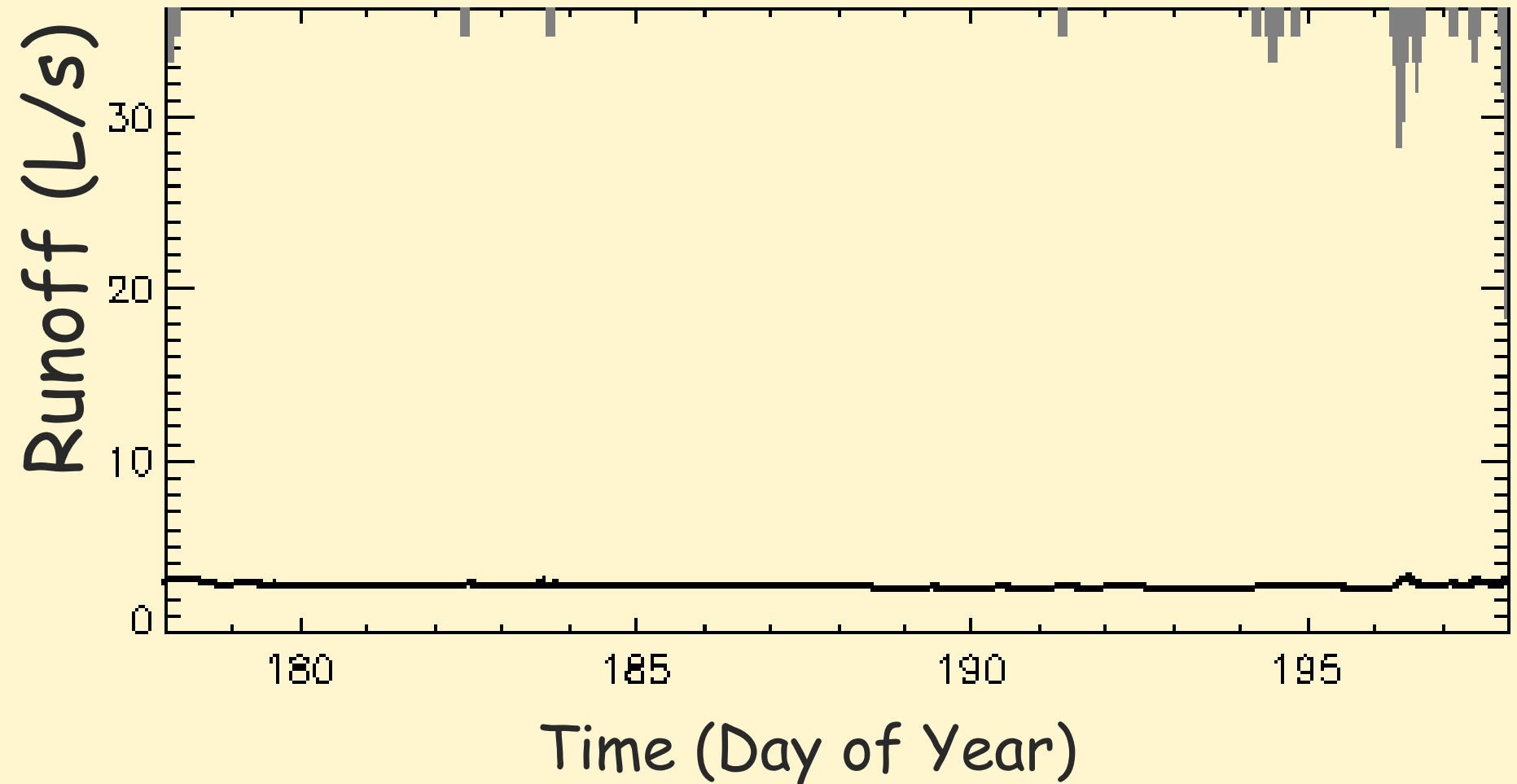


- Background on isotope hydrology (isotopo naturalmente estable)
- Conceptualizing runoff processes
  - Rapid mobilization of old water
  - Streamwater age and scaling relations
- Implications for water mgmt.

# Precipitation-Caudal

*what we usually examine.....*

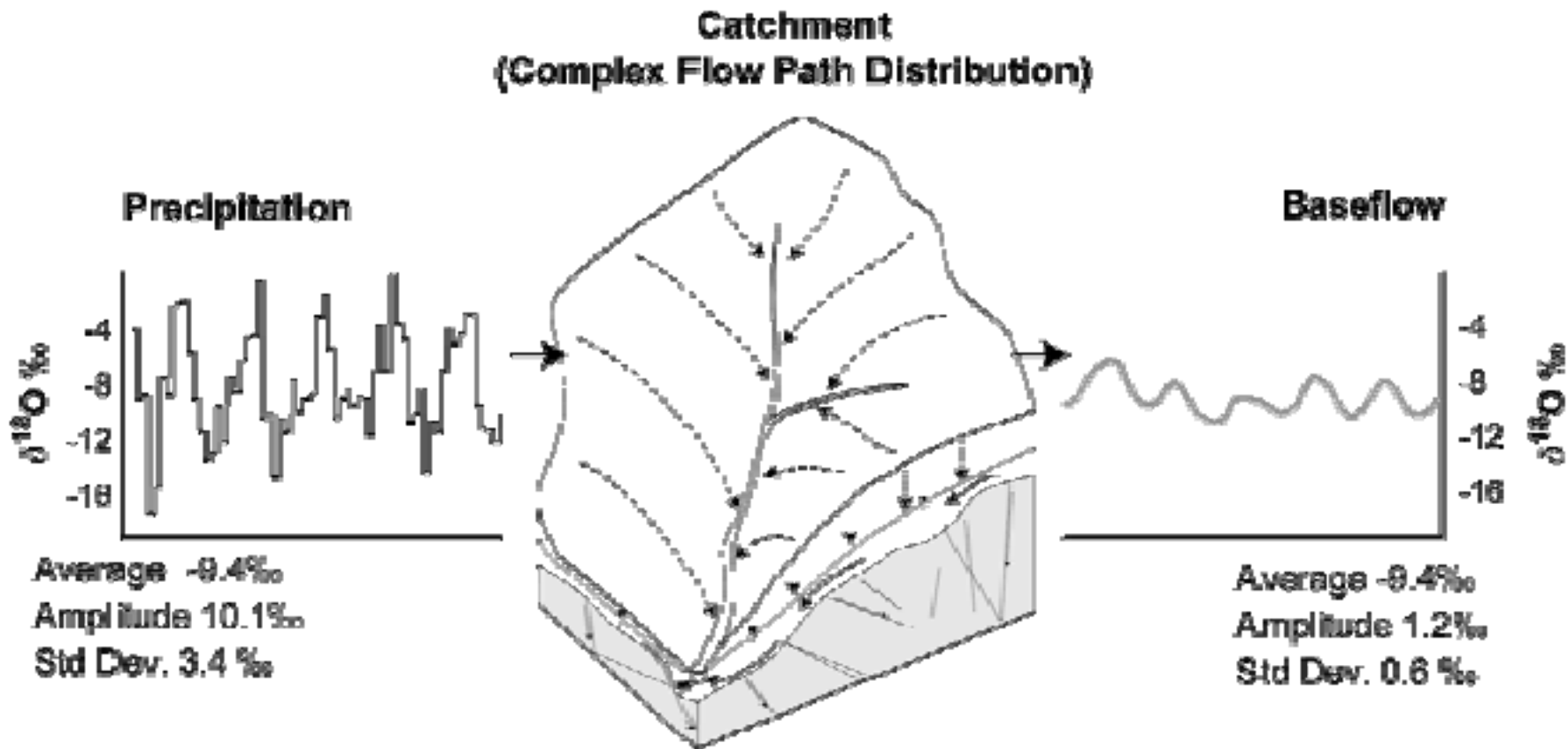
Where  
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# Stable isotopes of water

*a different type of information...*

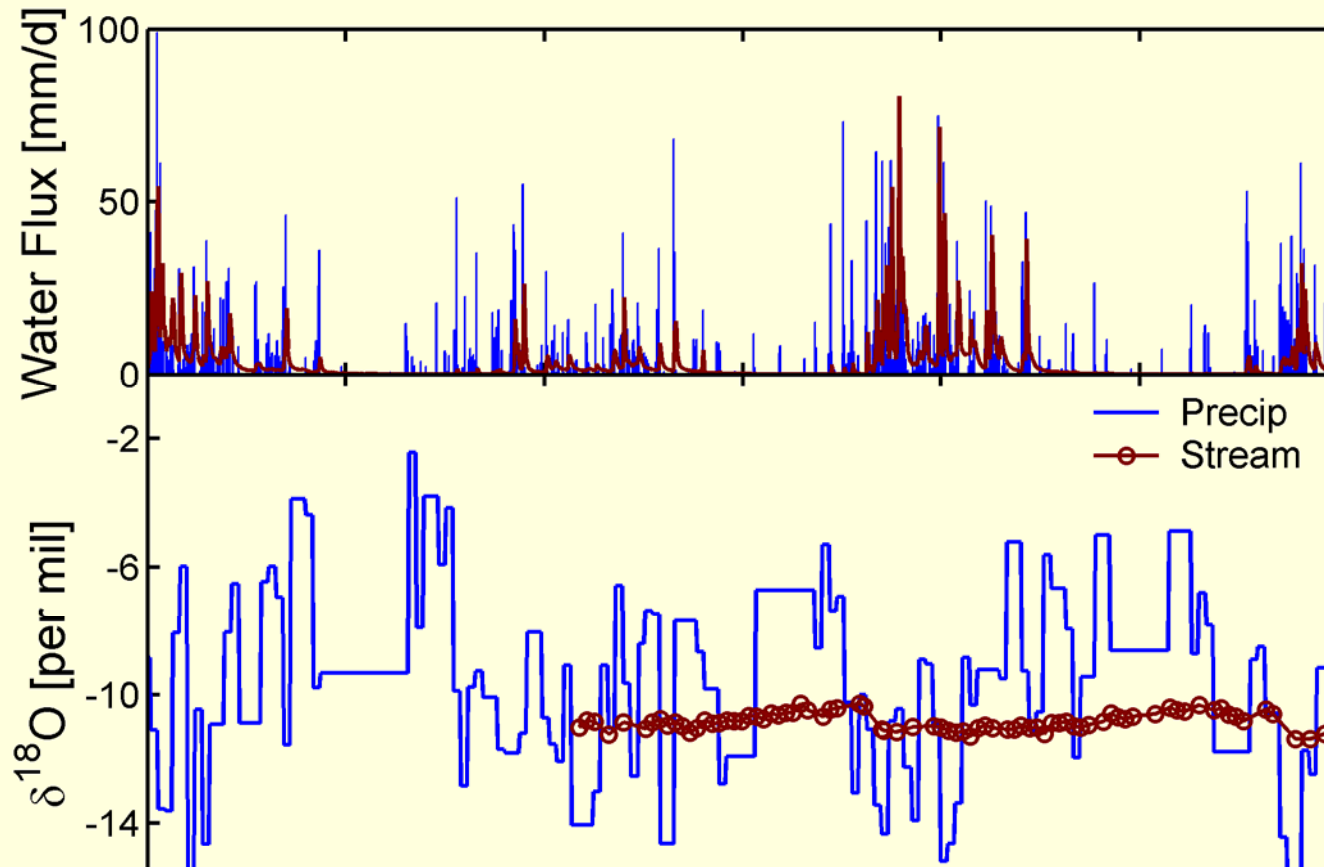
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Transporte de particulas

# One of catchment hydrology's biggest findings in the past 30 years

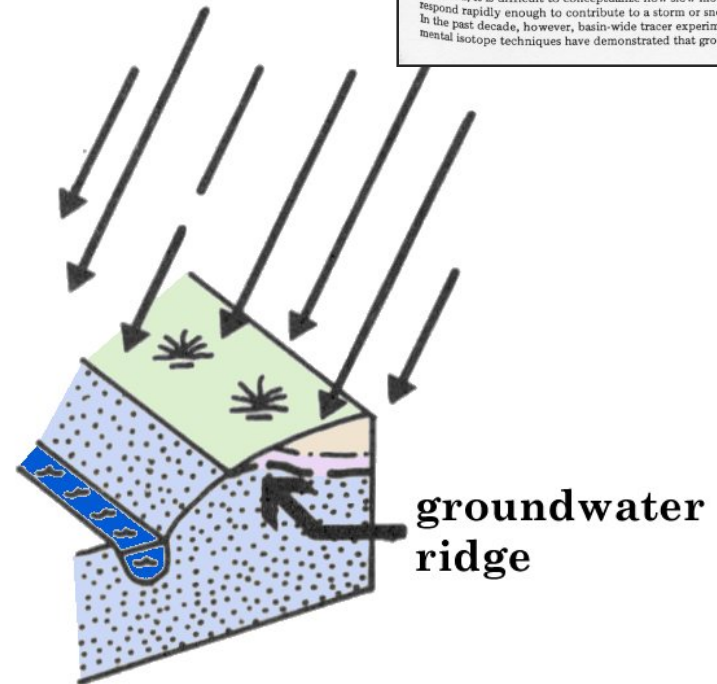
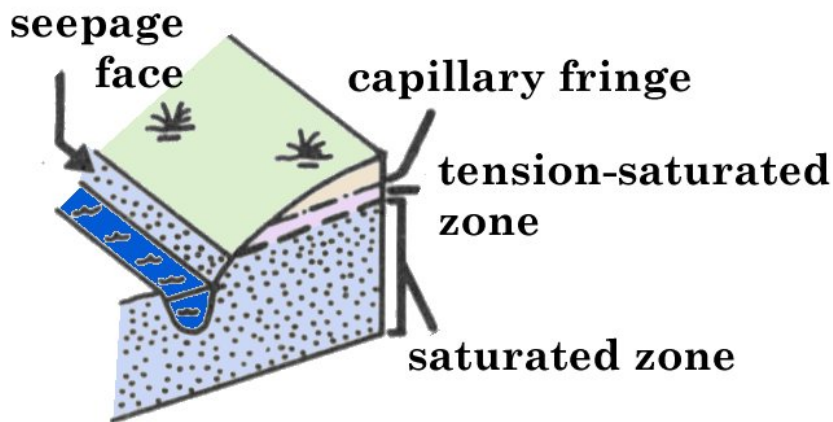
Where does water go when it rains?



Hillslopes store water for months to years and then release it in minutes or hours to streams (Kirchner, 2003 HP)

# How is old water so quickly mobilized?

## Groundwater ridging



Anderson and Burt, 1990

Journal of Hydrology, 43 (1979) 45-65  
© Elsevier Scientific Publishing Company, Amsterdam - Printed in The Netherlands  
[1]  
THE ROLE OF GROUNDWATER IN STORM RUNOFF  
MICHAEL G. SKLASH and ROBERT N. FARVOLDEN  
Department of Geology, University of Windsor, Windsor, Ont. N9B 3P4 (Canada)  
Department of Earth Sciences, University of Waterloo, Waterloo, Ont. N2L 3G1 (Canada)  
(Accepted for publication April 26, 1979)

**ABSTRACT**  
Sklash, M.G. and Farvolden, R.N., 1979. The role of groundwater in storm runoff. In: W. Beck and D.A. Stephenson (Guest-Editors), Contemporary Hydrogeology - The George Burke Maxey Memorial Volume. J. Hydrol., 43: 45-65.  
Groundwater plays a much more active, responsive and significant role in the generation of storm and snow-melt runoff in streams than the recent literature on the subject suggests. Basin-wide tracer experiments using environmental isotopes ( $^{18}\text{O}$ , deuterium, tritium) and hydrometric studies carried out in hydrogeologically diverse watersheds, indicate that for all except the most intense rain storms and the most prolific melting days, groundwater dominates the runoff hydrographs in the study basins. The increased groundwater discharge during runoff events is apparently related to a rapid rise in hydraulic head along the perimeter of transient and perennial discharge areas. This groundwater ridging phenomenon probably arises from the almost instantaneous conversion of the near-surface tension-saturated capillary fringe into phreatic water. The ridging precedes, and is apparently independent of the response of the rest of the basin. In addition to its compatibility with several of the field observations commonly associated with contemporary concepts of runoff generation, the groundwater discharge theory explains some of the temporal variations in stream water chemistry which are not adequately accounted for by other theories.

**INTRODUCTION**  
Most of the recent literature on storm runoff generation has overlooked true groundwater flow as a significant and active factor in the storm and snow-melt runoff process. Freeze (1974) summarized the hydrologic thought on the subject as:  
"True groundwater flow is seldom the cause of the major runoff during storms. Its primary role is in sustaining streams during low-flow periods between rainfall and snow-melt events..."

Indeed, it is difficult to conceptualize how slow-moving groundwater can respond rapidly enough to contribute to a storm or snow-melt runoff peak. In the past decade, however, basin-wide tracer experiments using environmental isotope techniques have demonstrated that groundwater often



Maimai



HJ Andrews



12.30.2002

Panola



Low Pass



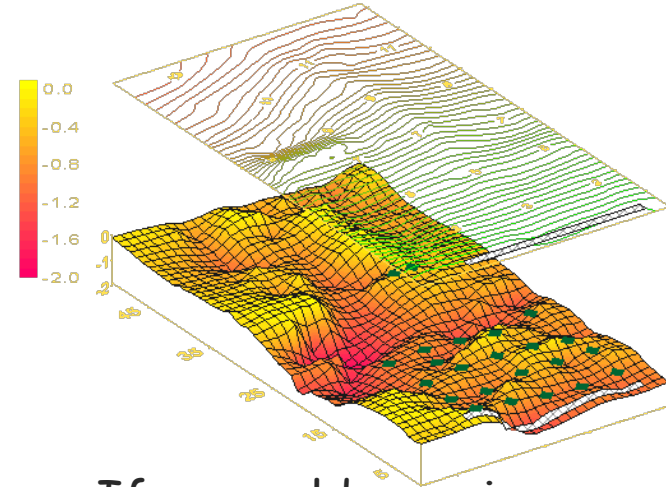
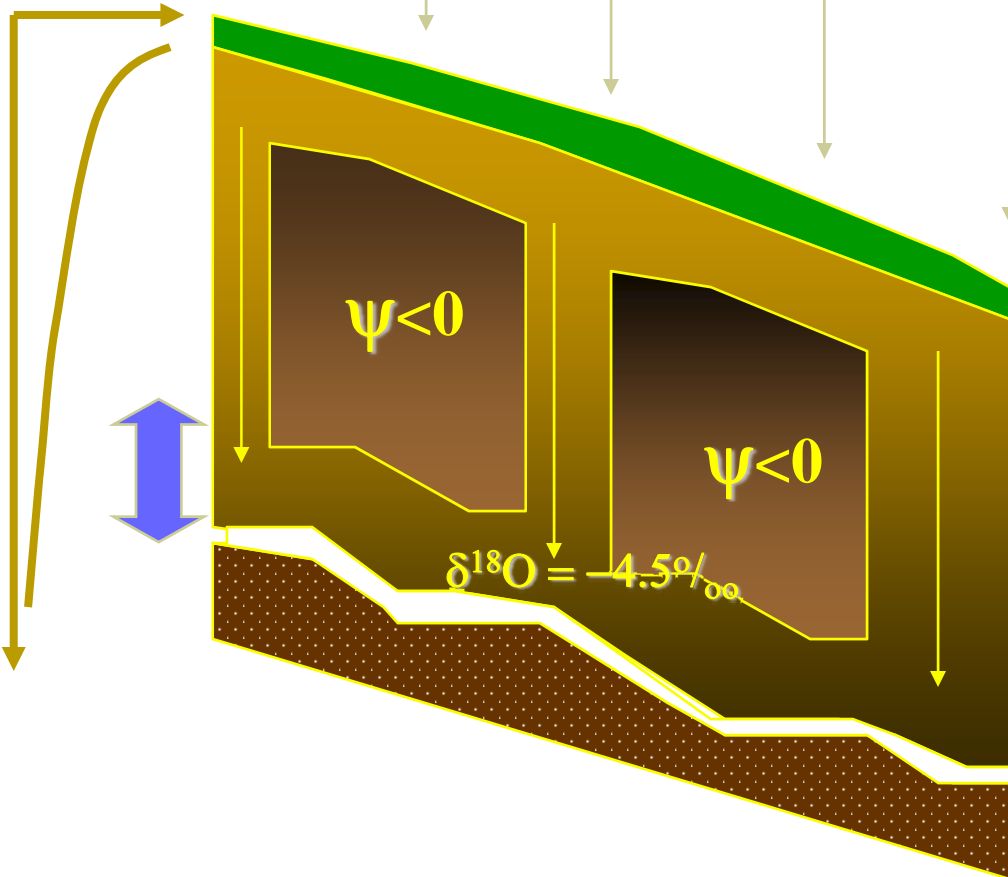


# How is pre-event water mobilized? *Plot scale*

Where  
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Storm Rainfall  $\Sigma\delta^{18}\text{O} = -10\text{‰}$

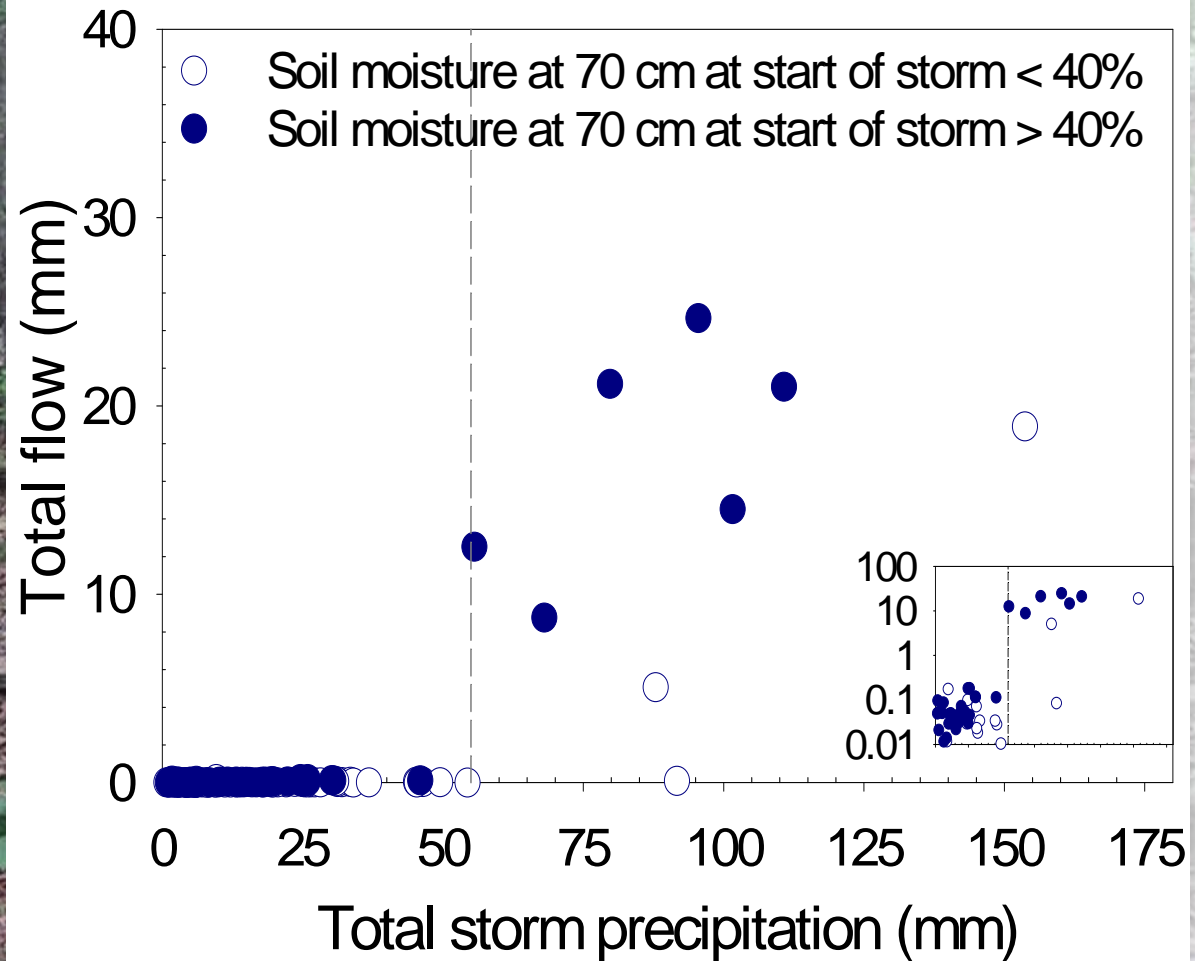
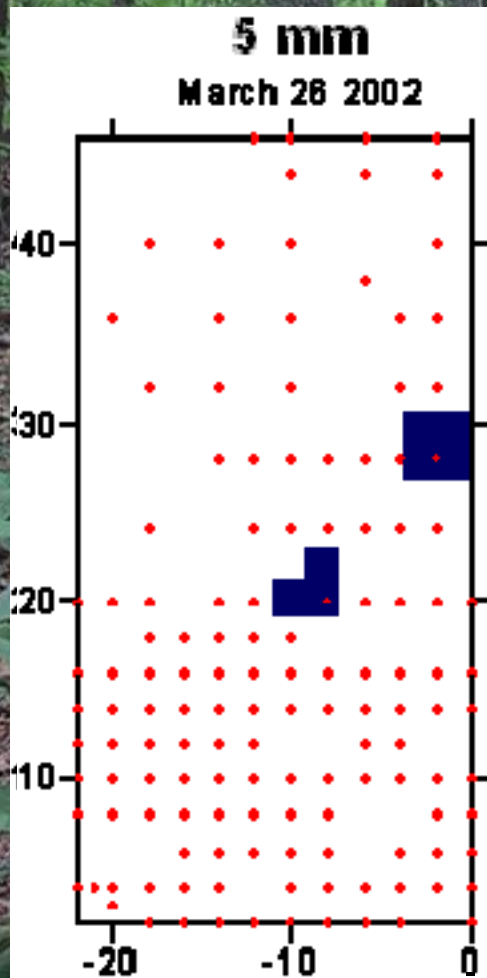
$d\theta/dZ$



If we could examine one  
pixel from this slope...

$\delta^{18}\text{O} = -5\text{‰}$

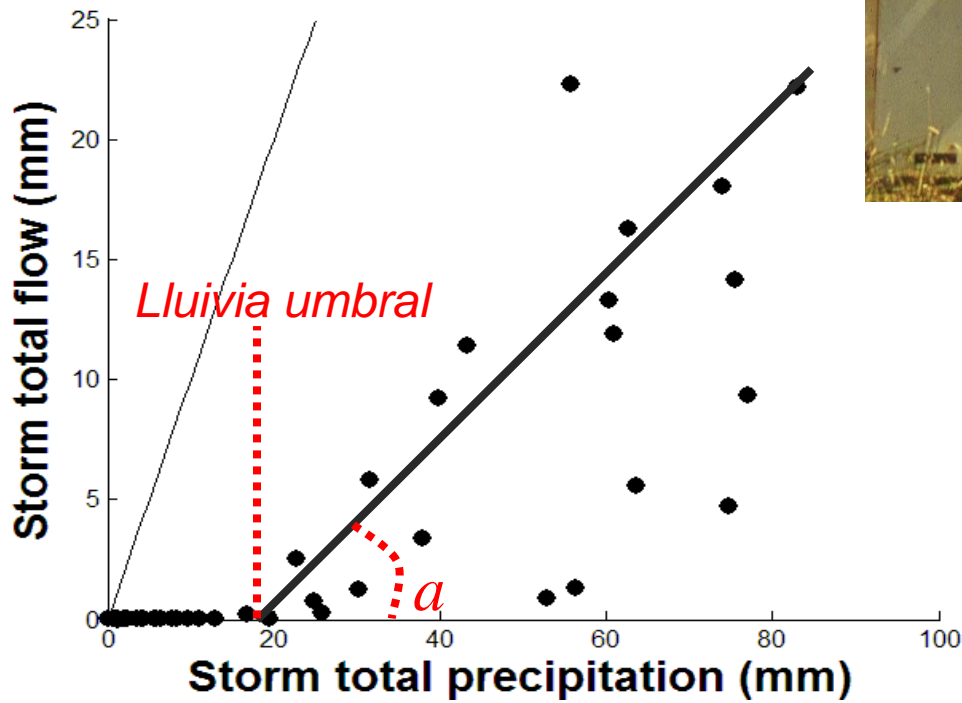
# How is pre-event water mobilized?



# Umbral: One extreme

Where  
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Maimai, NZ

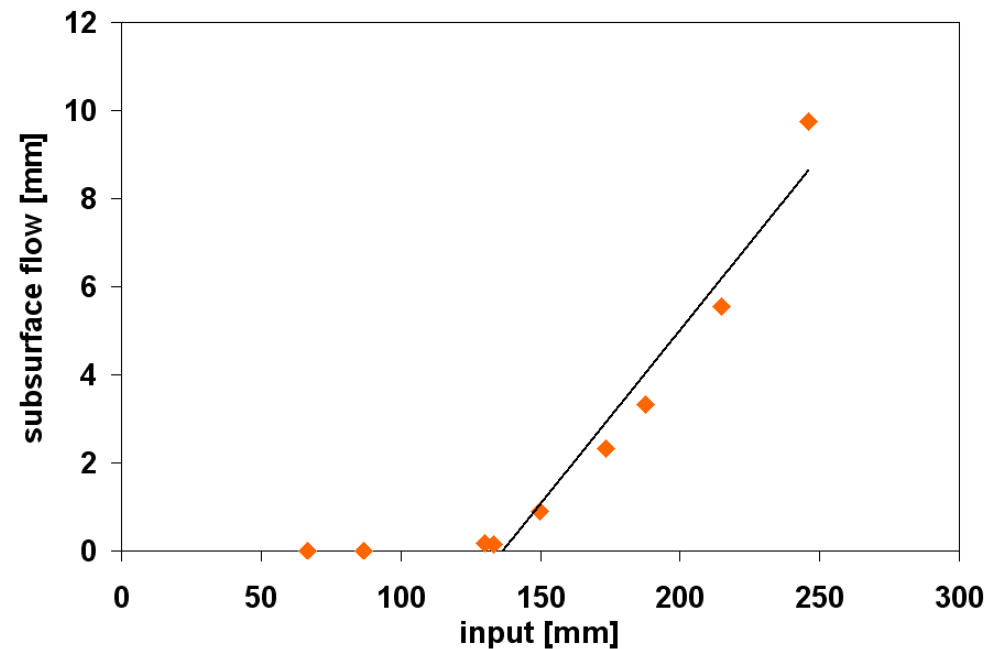




# Unbral: Another extreme

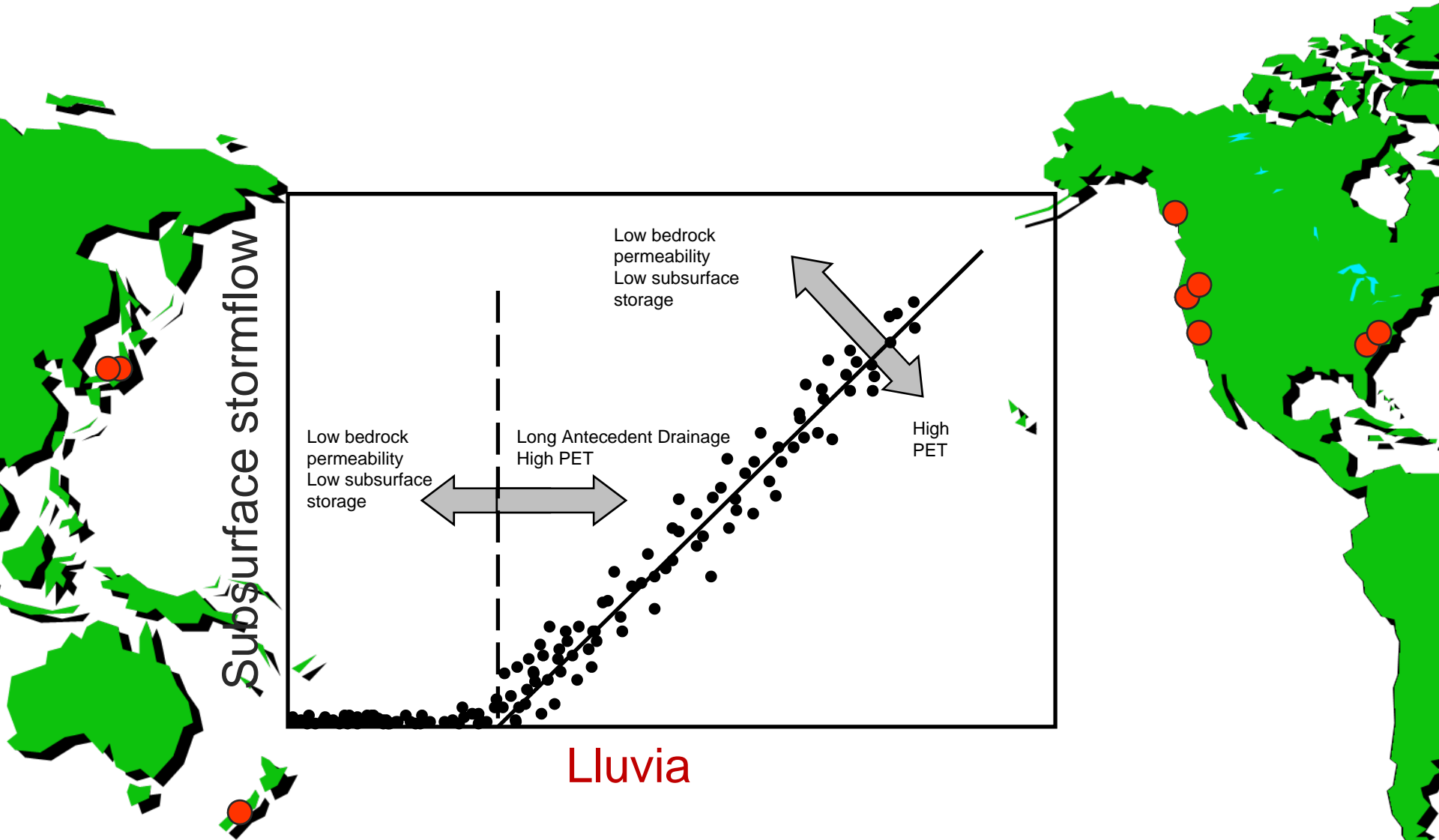


- Slope 2.5 - 5°
- Depth to argillic layer  
○ (mean: 0.97 m, cv: 21%)



# Many internal mechanisms: same emergent behavior

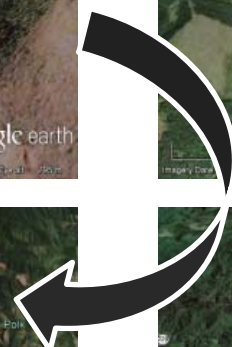
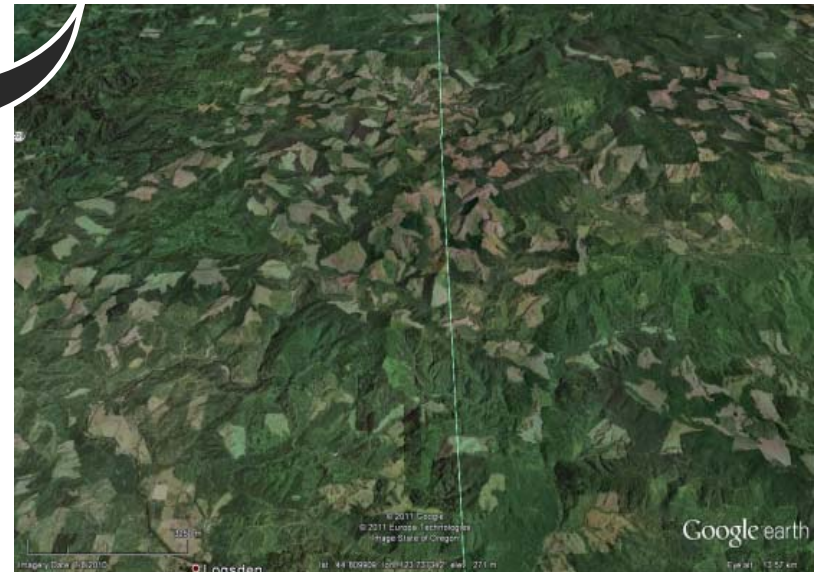
Where does water go when it rains?





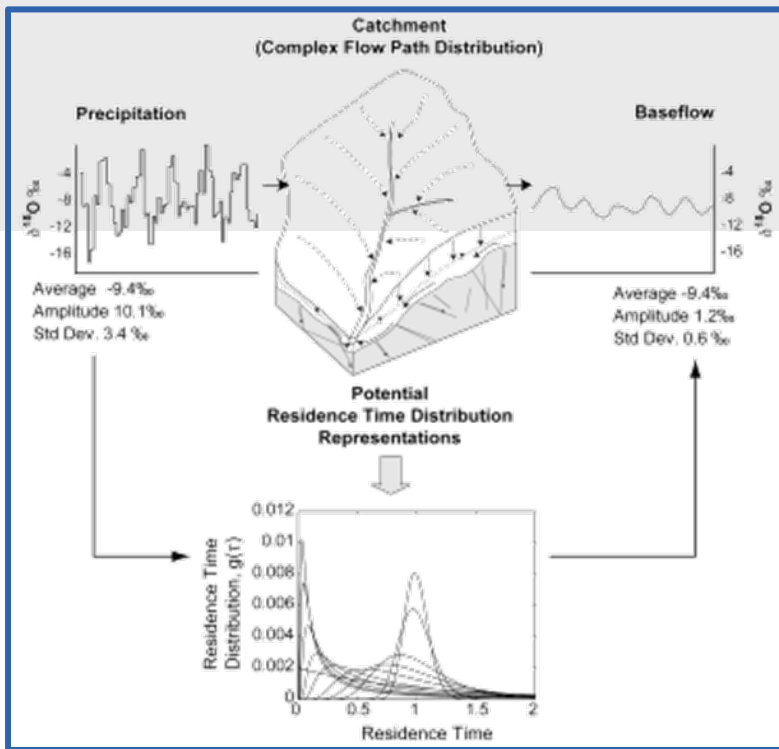
# ¿Manejo sustentable agua?

Where does water go when it rains?

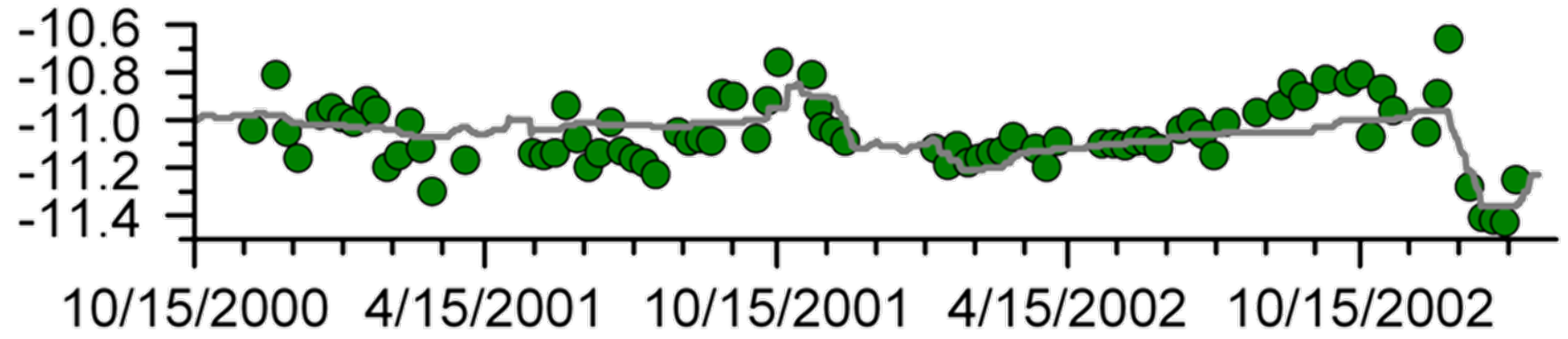


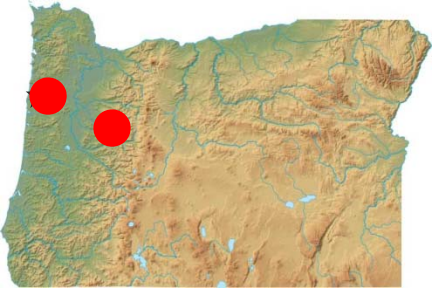


Where does water go when it rains?



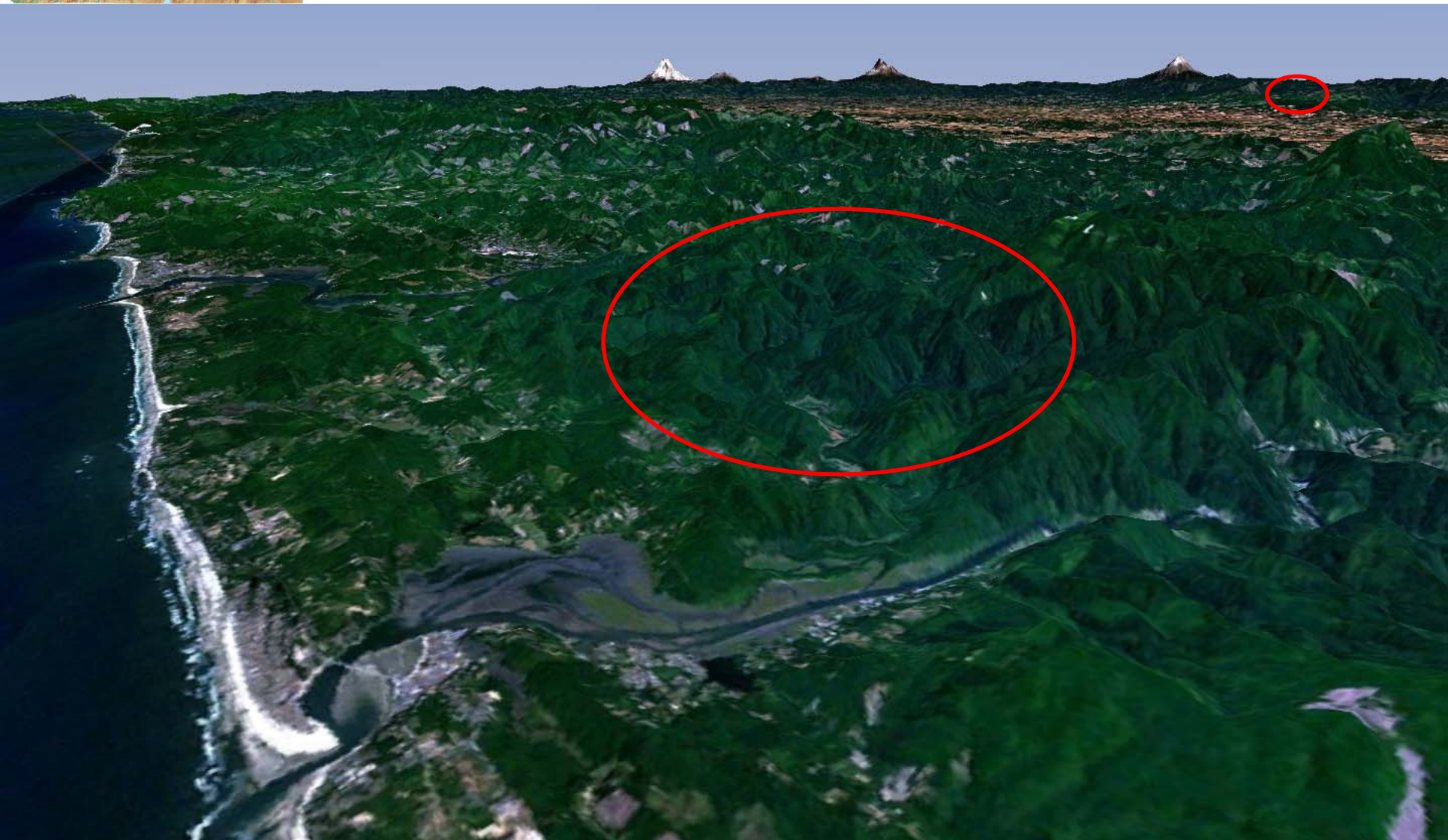
MRT = 2.2 years





# Two watersheds in Chile Oregon

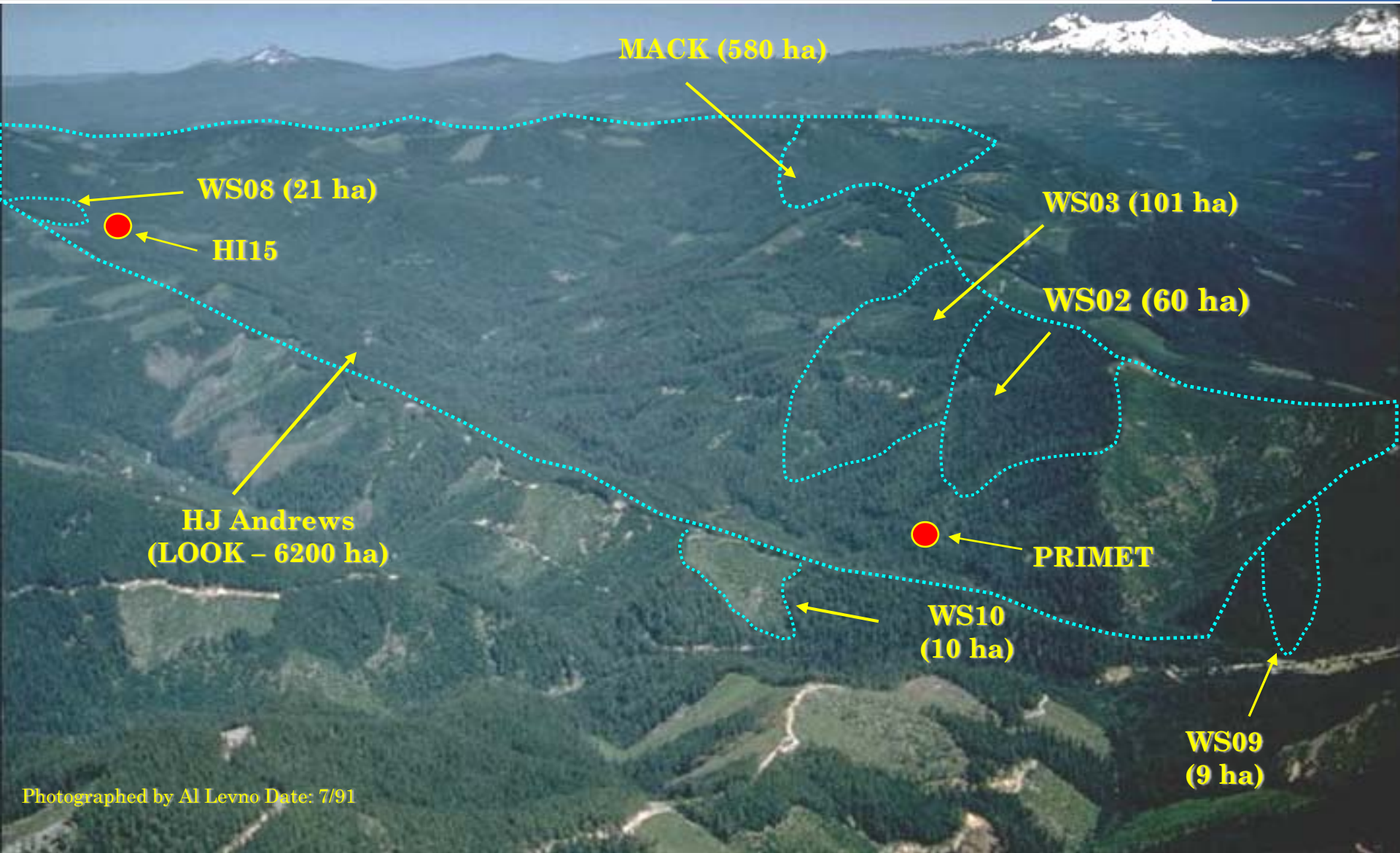
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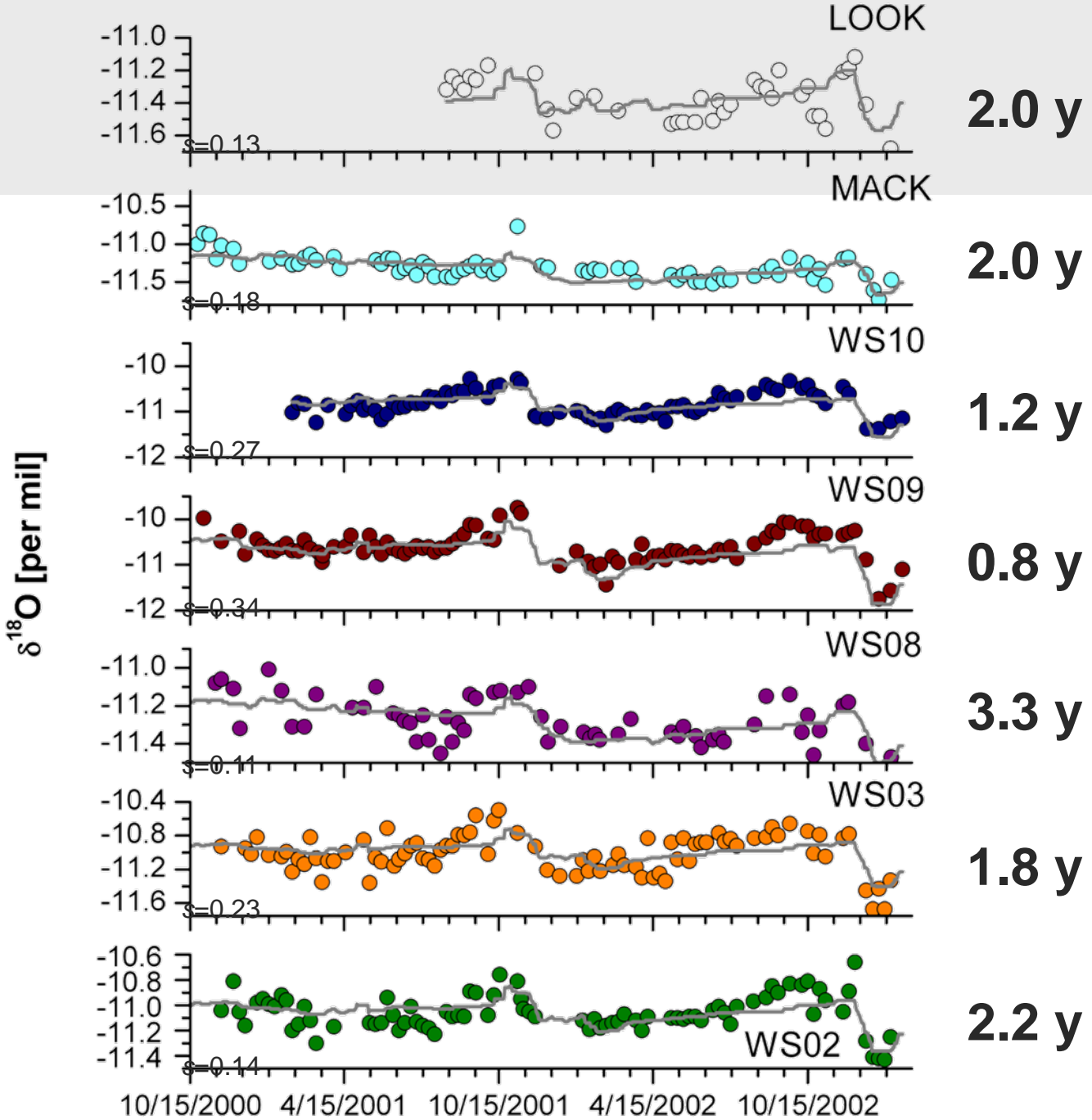
# Calculating streamwater mean residence time

Where does water go when it rains?



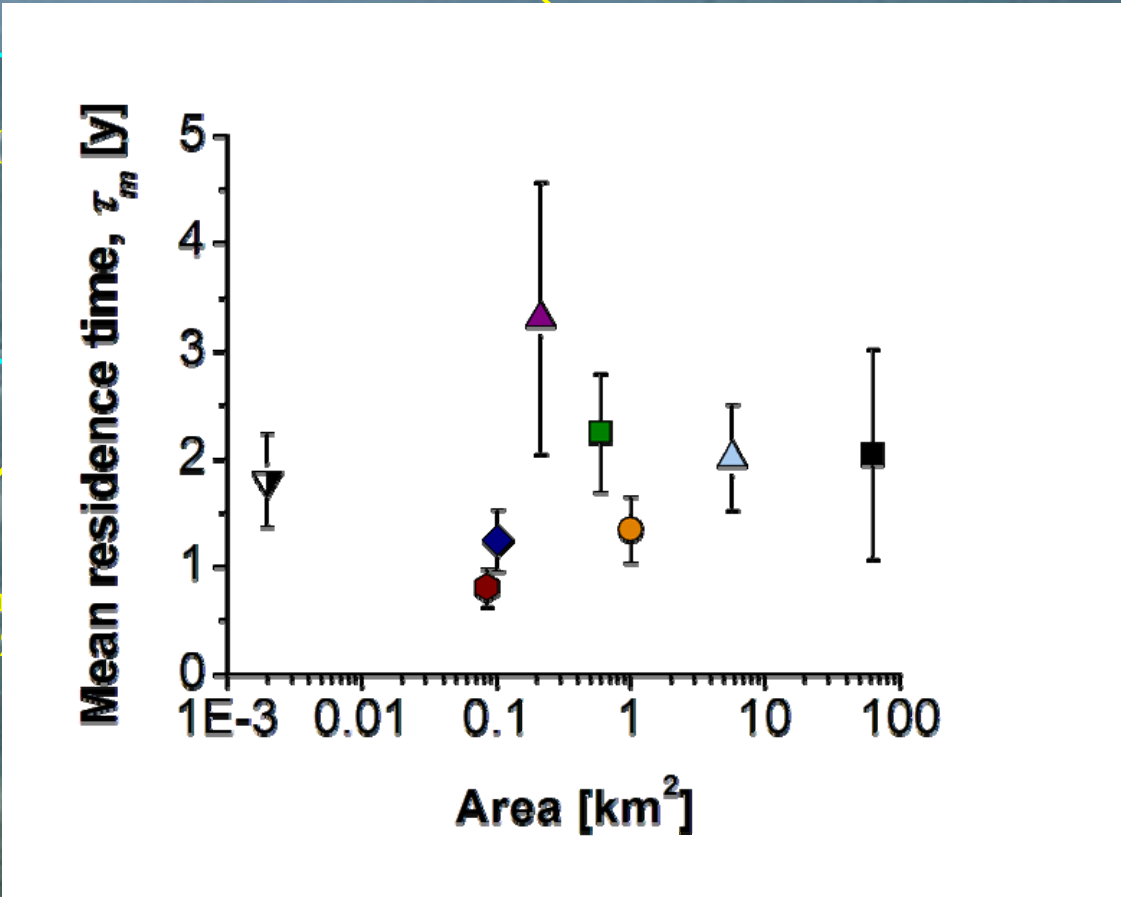
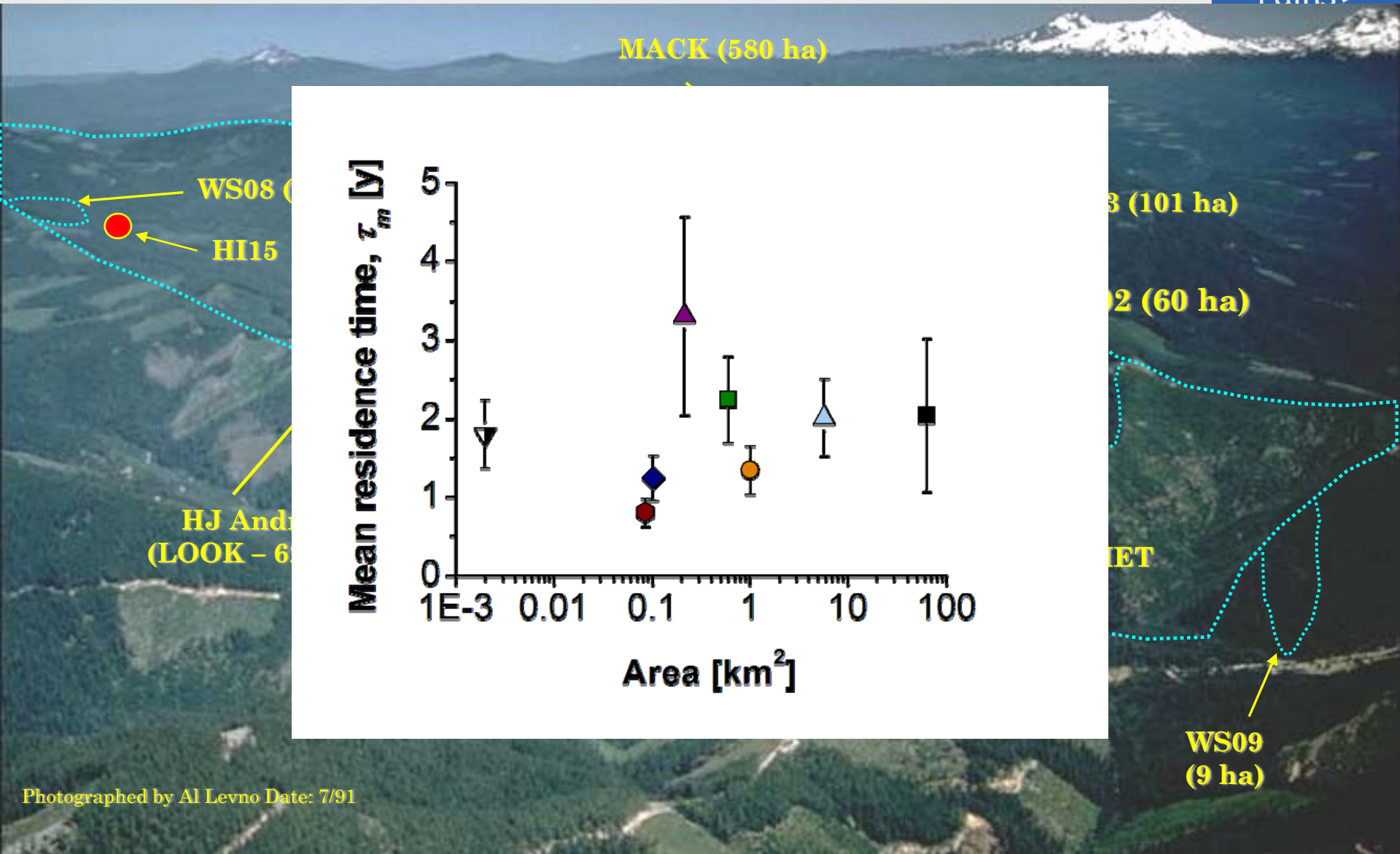


Where does water go when it rains?



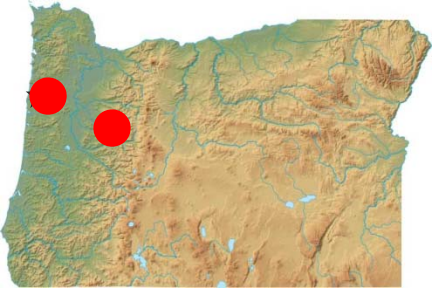
Where does water go when it rains?

...no relation to basin area, but...



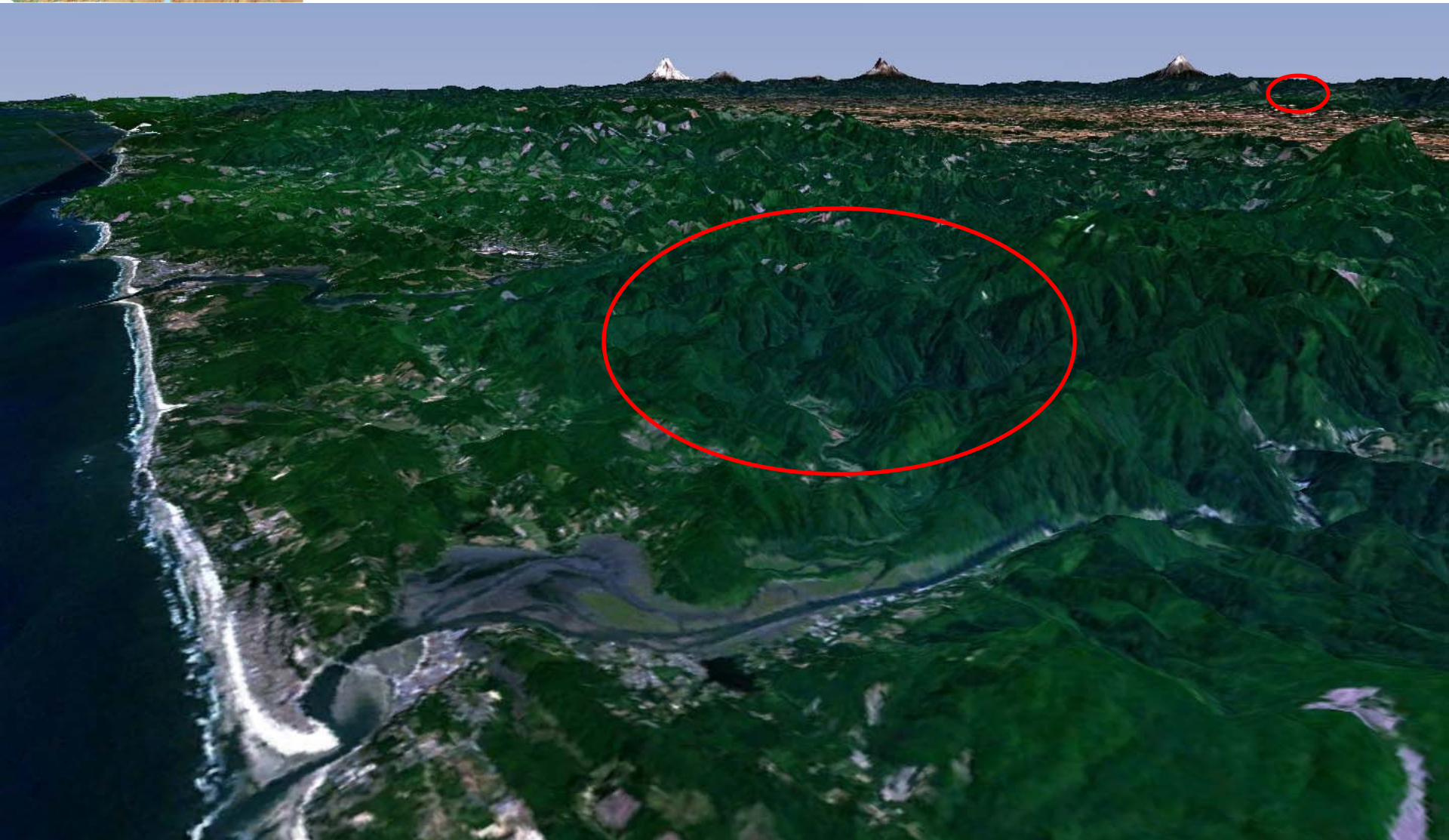
Photographed by Al Levno Date: 7/91





# The coast range site: Seemingly identical catchment

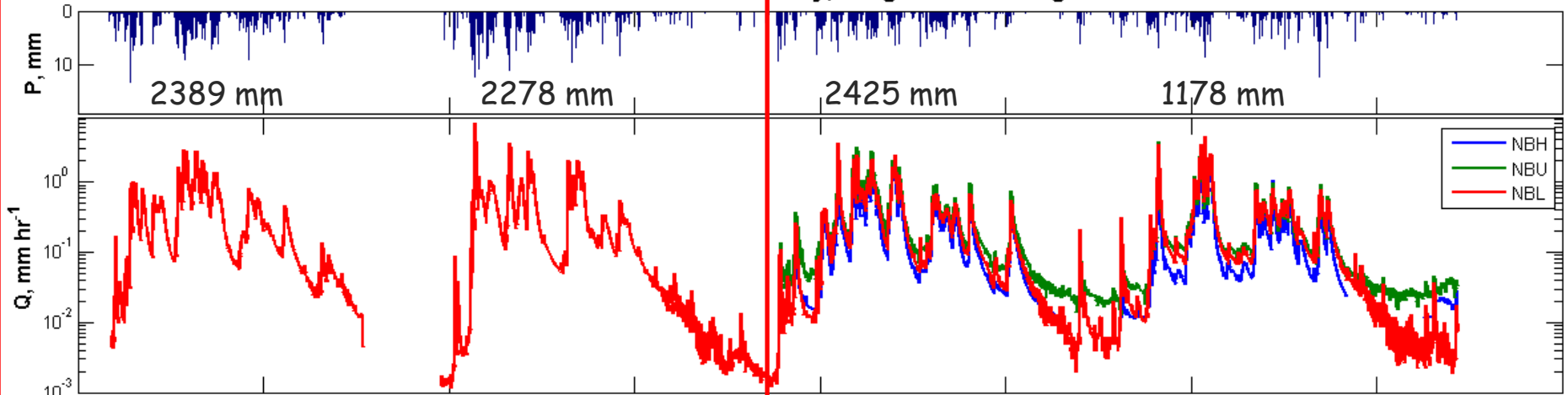
Where  
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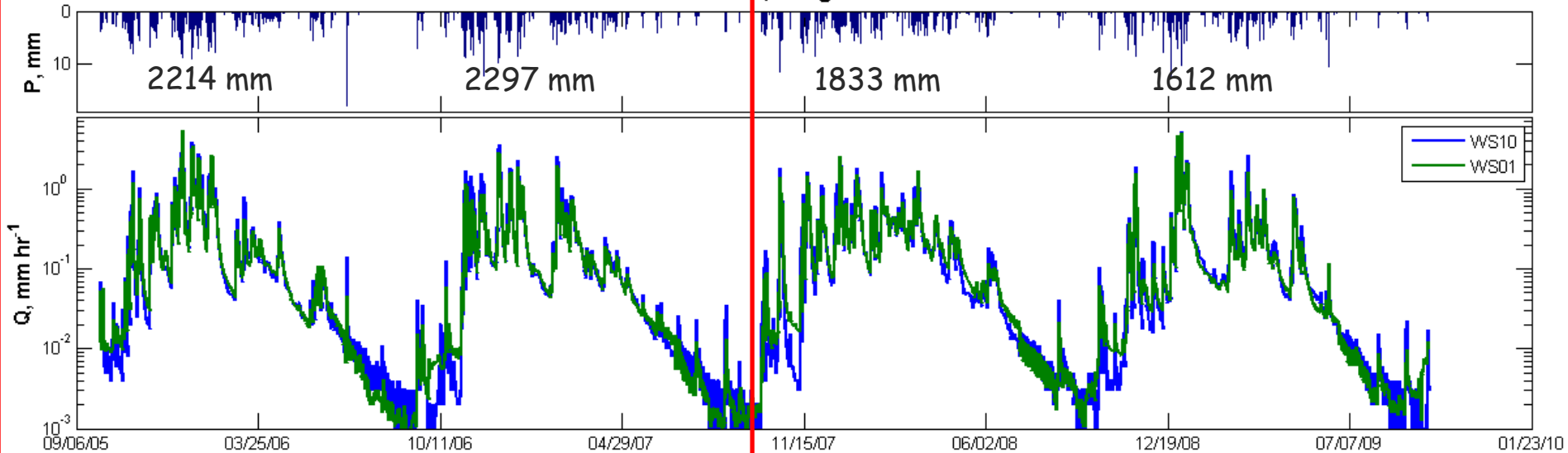
# Seemingly identical rainfall-runoff

Where  
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**Alesea Watershed Study, Oregon Coast Range**



**HJ Andrews, Oregon Cascades**



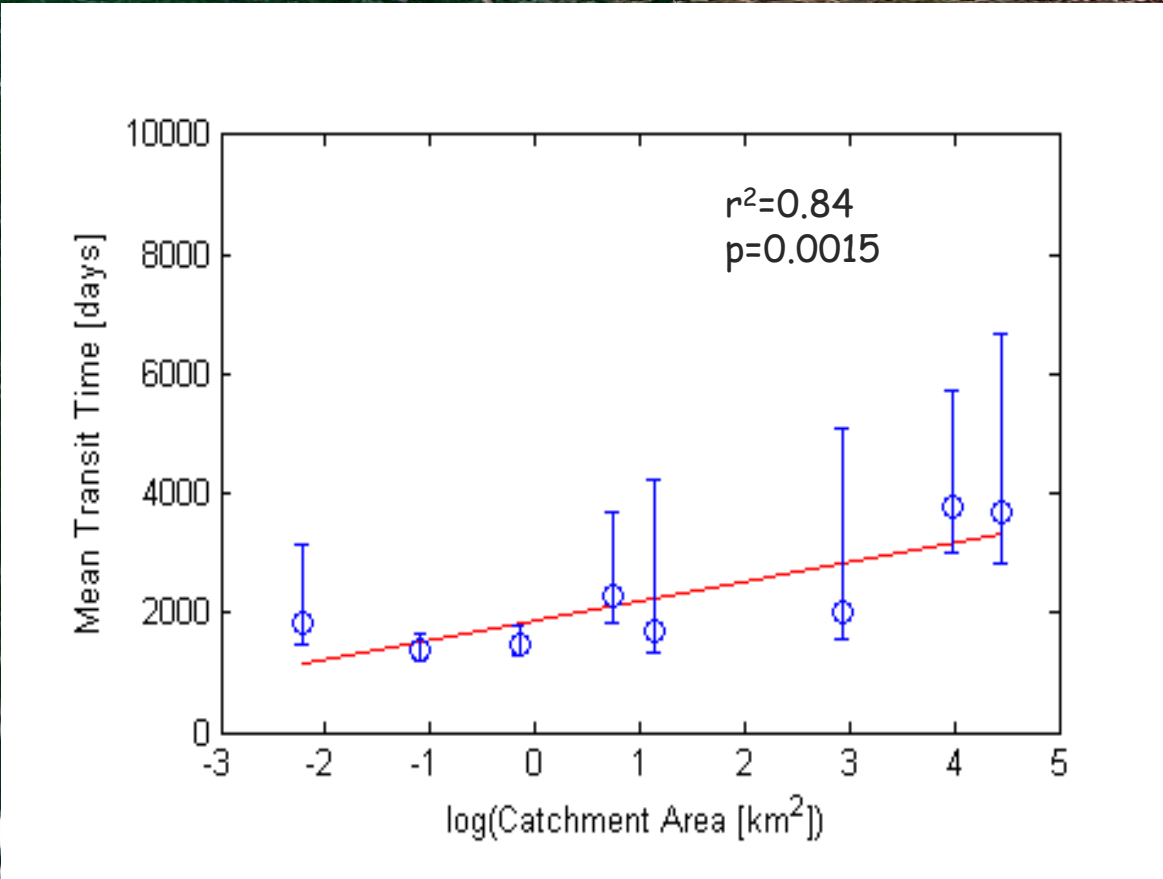
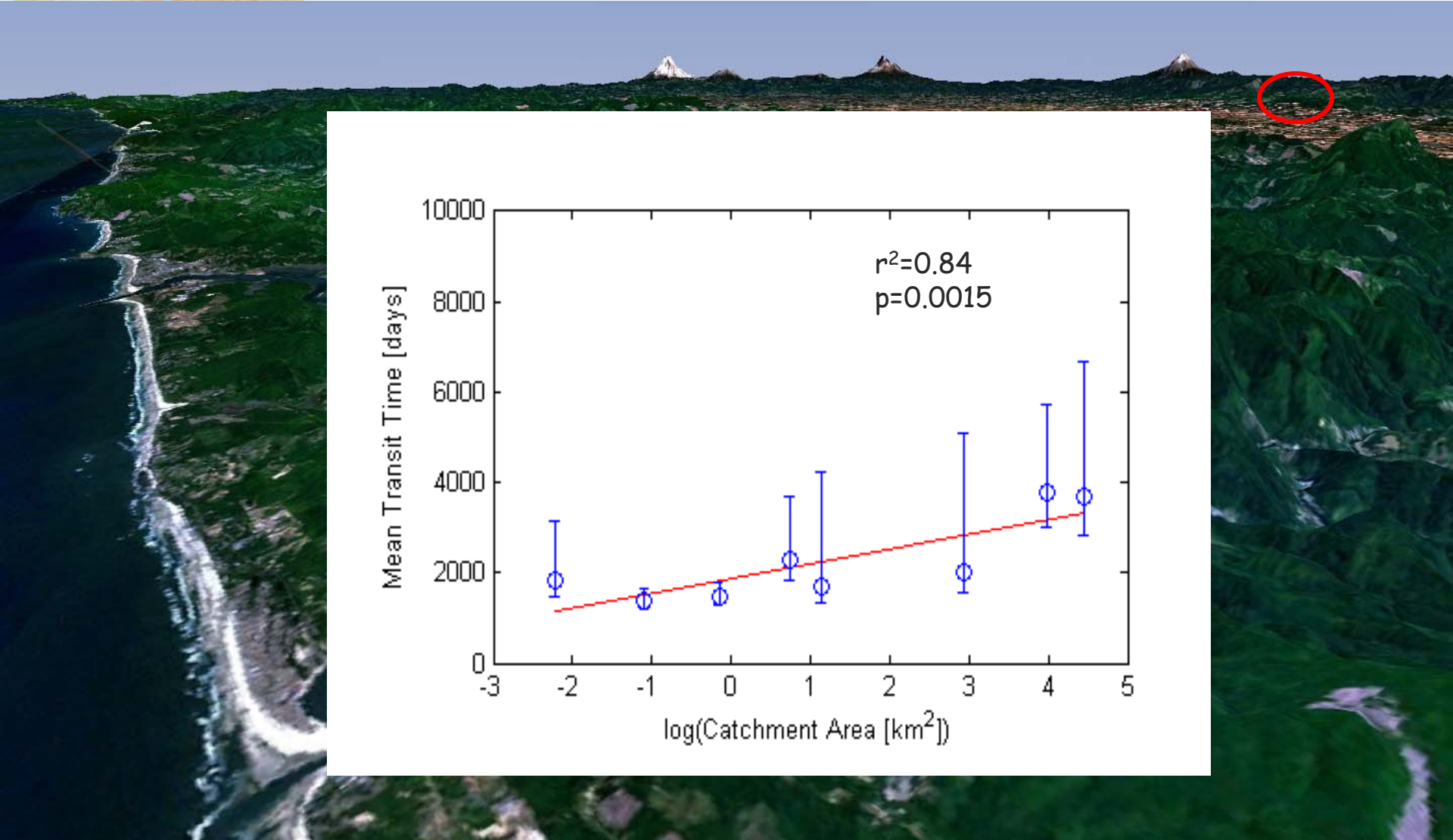
09/06/05 03/25/06 10/11/06 04/29/07 11/15/07 06/02/08 12/19/08 07/07/09 01/23/10





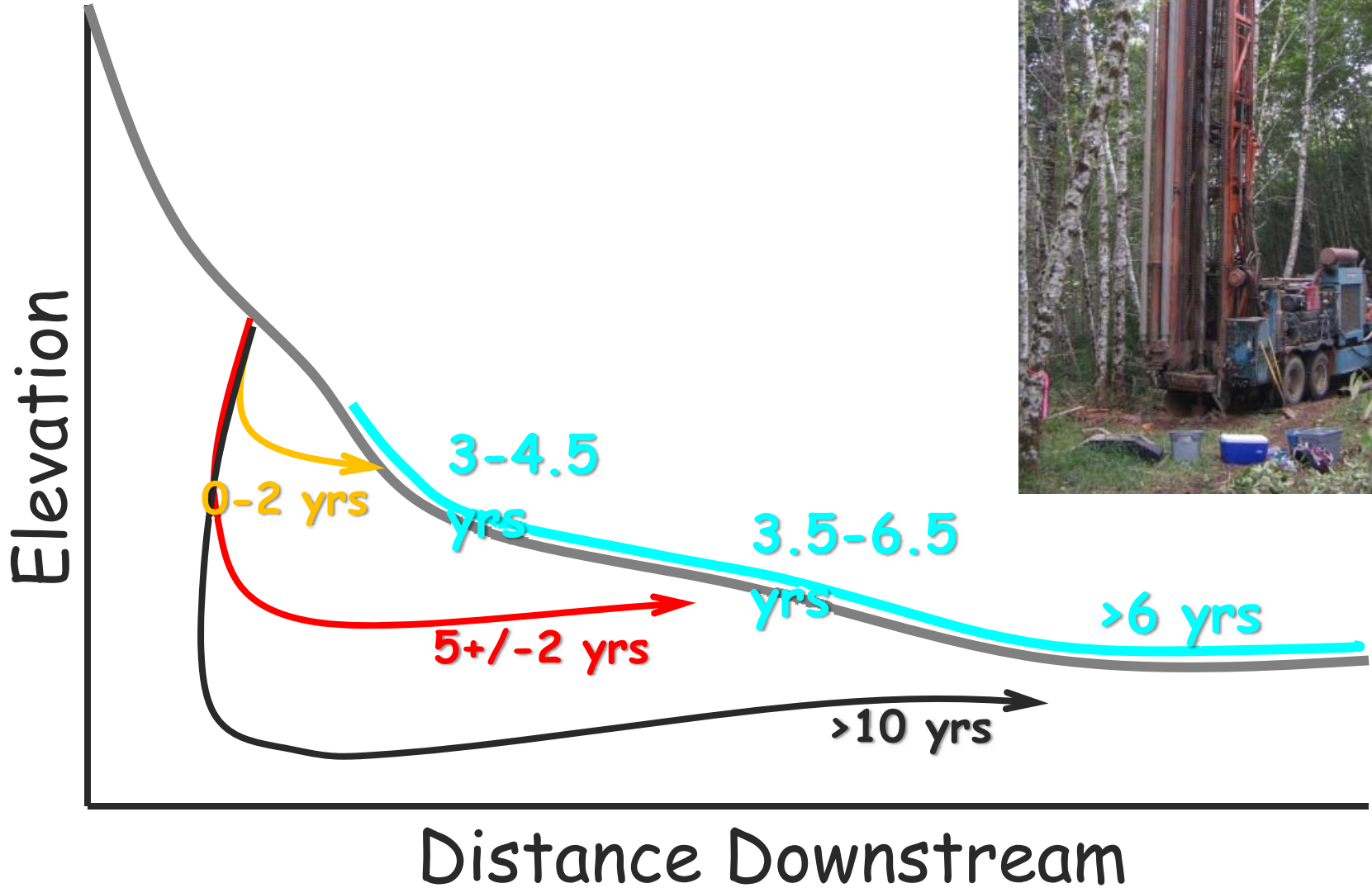
# Much older water Opposite scaling relations!

Where does water go when it rains?



# Bedrock groundwater

*Agua subterranea*



# Summary I

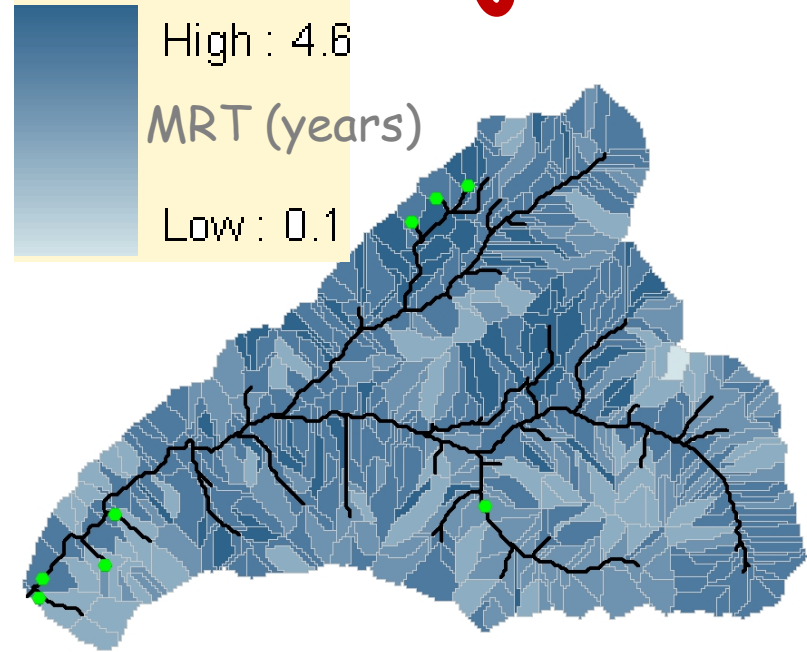
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## Manejo

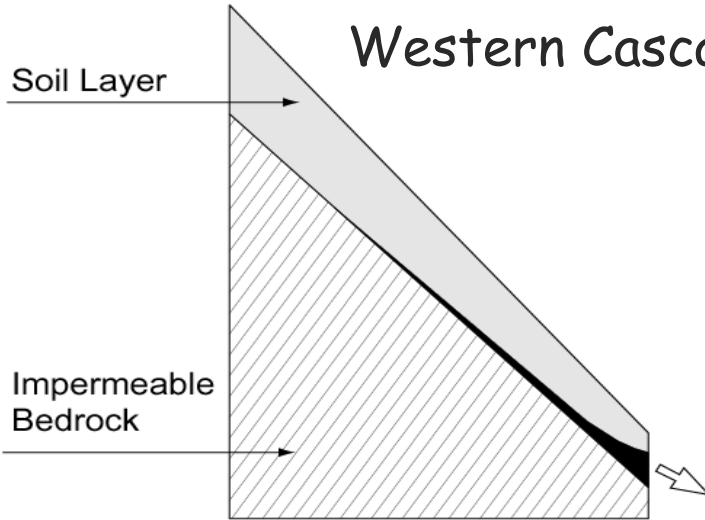
High : 4.6

MRT (years)

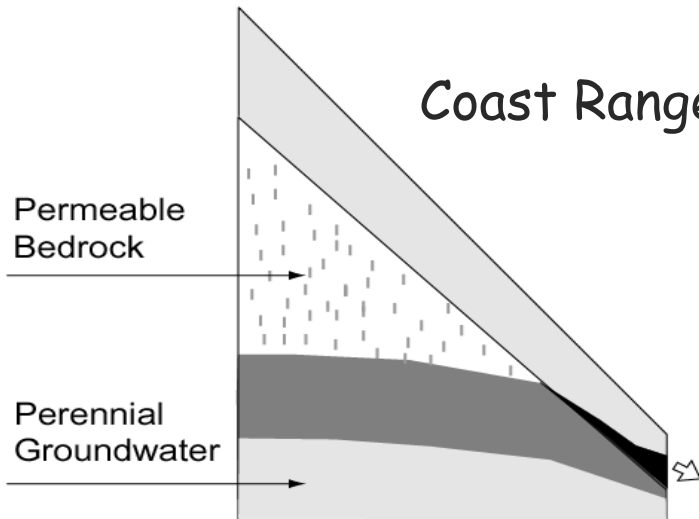
Low : 0.1



### Western Cascades

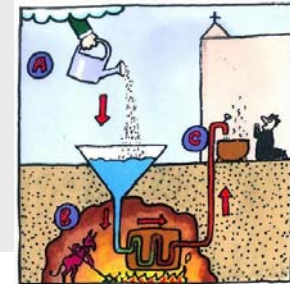


### Coast Range





# Summary II



- Runoff process conceptualization and the advent of stable isotopes
  - What we know: Pressure vs particle; old water paradox.
- Explaining the rapid effusion of old water
  - What we think we know: Fill and spill, thresholds, connectivity.
- A future storage based view of the system
  - What we need to know: How the subsurface boundary influences total/dynamic storage, MRT and MRT scaling