

Water Storage



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Question

Investigative

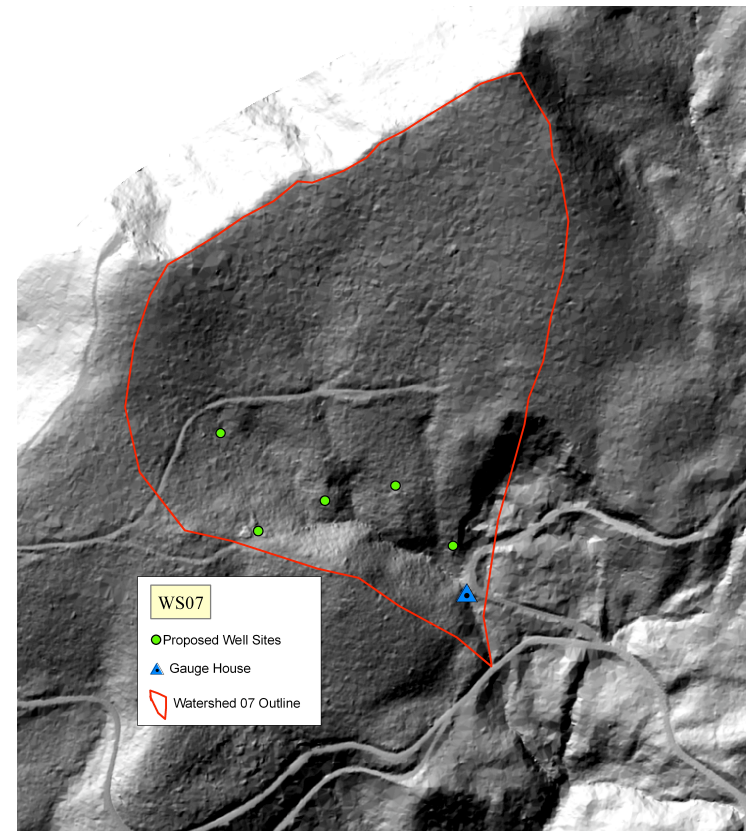
- During a large scale flood event how much water discharged can be attributed to the precipitation? What is the storage capacity for groundwater in a watershed?

Predictive

- What are the origins of water in a headwater watershed, and how could a changing water year alter the supply of water to streams in the Pacific Northwest?

Watershed 07

- Small headwater (15 ha)
- Low gradient
- Climatic transition zone (rain and snow mix)
- Partially cut
 - 1974 (50% of basal area)
 - 1984 (remaining overstory removed)
- Few roads



Methods

Top-down (long-term data)

- Water Balance
 - Meteorological Data
- GIS

Bottom-up (field based)

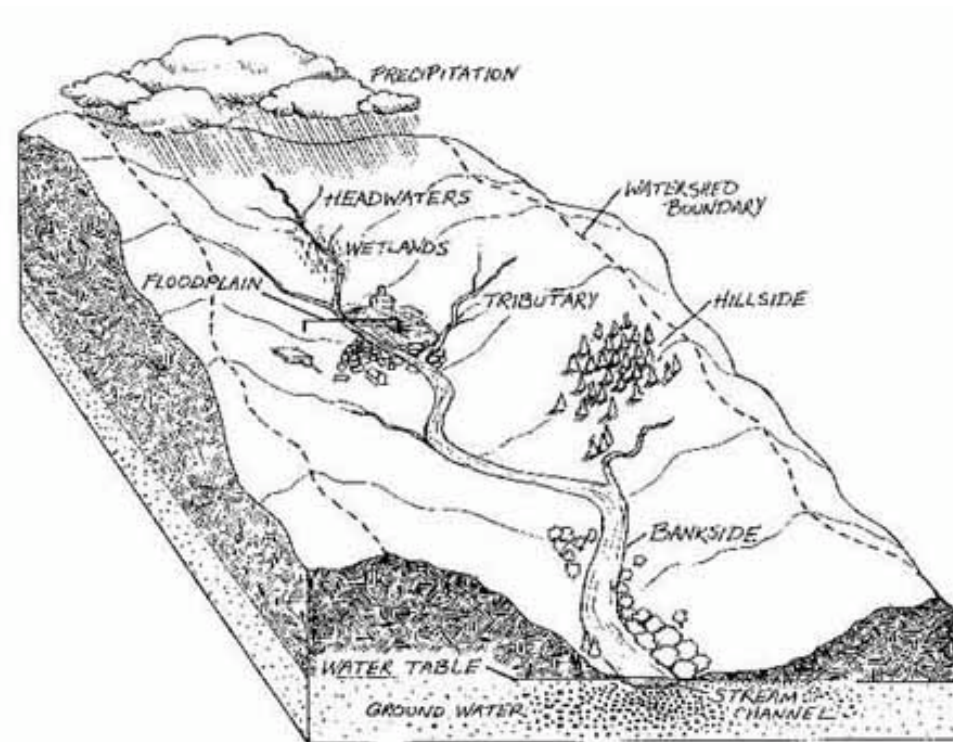
- Knocking pole
 - Water Storage
 - Soil Volume
- Isotopic Analysis

Approach

- Event Scale
- 6 Storm events from 1991 to 2005
- Averaged Annual Scale

Water Transport and Storage

- Transport
 - Overlandflow
 - Soil/Bedrock
 - Groundwater Ridging
 - Macropore Interflow
- Storage
 - Snow
 - Soil
 - Bedrock



EPA.gov,, 2006

Water Residence Times

Water Origins

- Origins
 - Precipitation
 - Snow
 - Soil Moisture
 - Groundwater
- Hydrograph Separation
 - “New” vs. “Old” water

New

Old

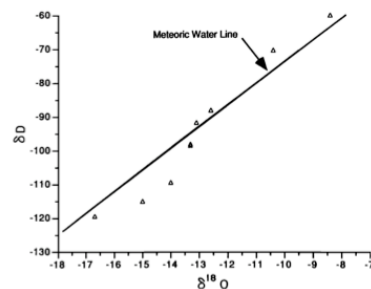
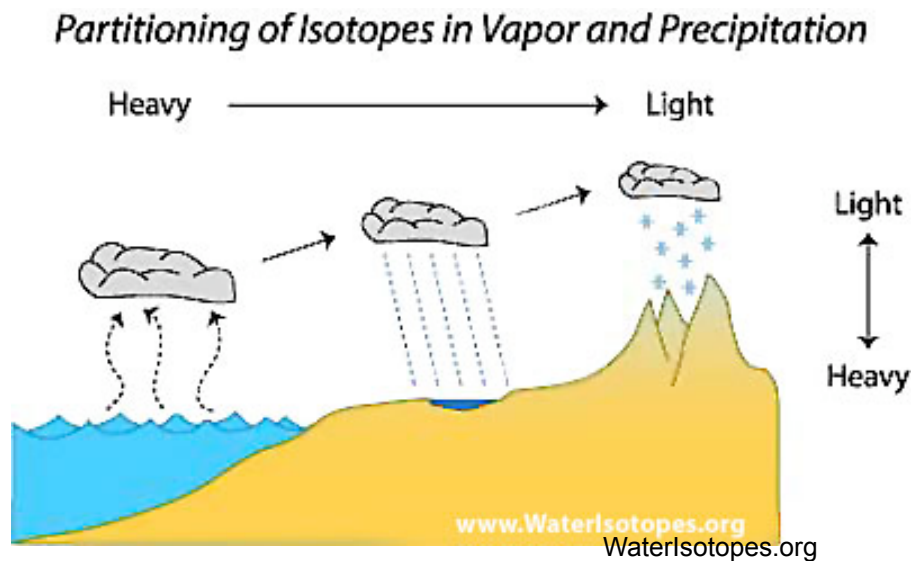
Residence Times

- Mean Residence Time:
 - WSo7: 3.3 years
 - HJA Average: 1-2 years
- Residence Time Controls
 - Slope
 - Spatial Variability
 - Flowpath Length
 - Groundwater Exchange

• (McGuire et al. 2005)

Isotopic Analysis of Stable Water Isotopes

- Endmembers
 - Snow
 - Rain
- Stable Isotopes (H₂O)
 - Hydrogen
 - ²H (or D) and ¹H
 - Oxygen
 - ¹⁸O and ¹⁶O
- Meteoric Water Line:
 - Ocean Standard



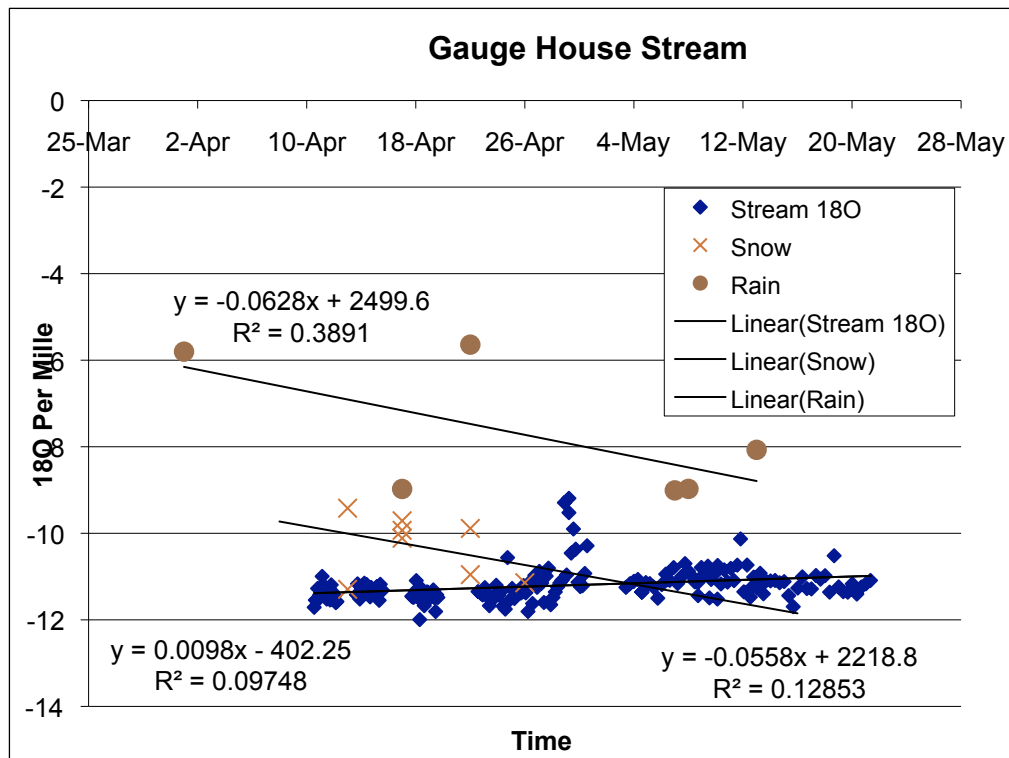
Hooper et al. 1986

“δ” Equation:

$$\delta_x = 1000 \frac{R_x - R_{std}}{R_{std}}$$

R. E. Criss, 1999

Isotopic Analysis



- Trend Line Locations
 - Below endmembers
- Trend Line Slopes
 - Endmembers: Negative
 - Stream: Positive

Water Balance

$$GW = (P - \Delta SWE > 0 + N) - (ET - \Delta SM + Q)$$

Water Balance Variables

GW = Ground Water Recharge/
Release

ET = Evapotranspiration

ΔSM = Change in Soil Moisture

P = Precipitation

Q = Discharge

N = Snowmelt

ΔSWE = Snowpack

Water Balance Formulation

- Groundwater contributions are unknown
- Inputs:
 - Precipitation
 - Snowmelt
- Storage:
 - Soil Moisture
 - Snow
- Outputs:
 - Discharge
 - Evapotranspiration

Storm Events

- 6 Events
- Event Period:
 - Event day ± 5 days
- Data Sets:
 - Discharge
 - Precipitation
 - Snowmelt
 - Temperature
 - Snow Water Equivalent (SWE)

Event (Date)

11-26-1991

2-24-1994

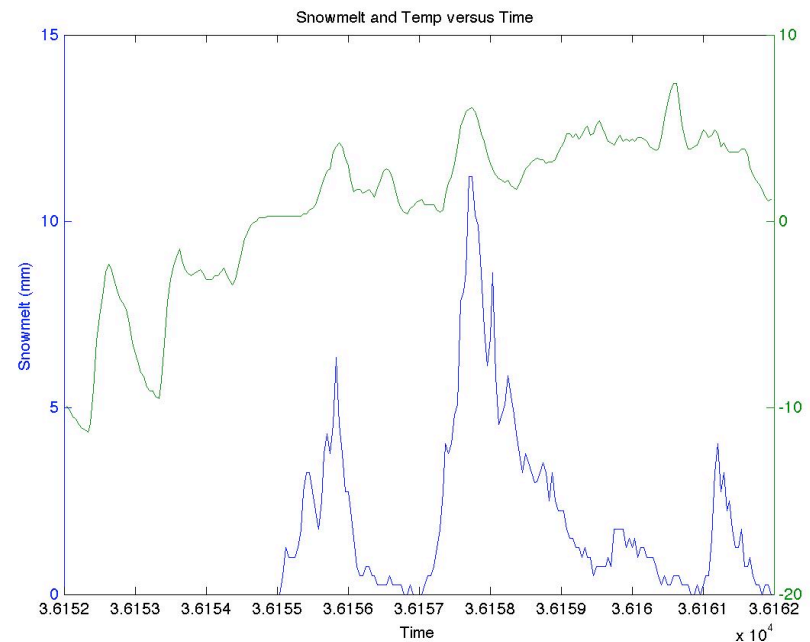
2-6-1996

12-27-1998

12-13-2001

12-30-2005

1998 Event:



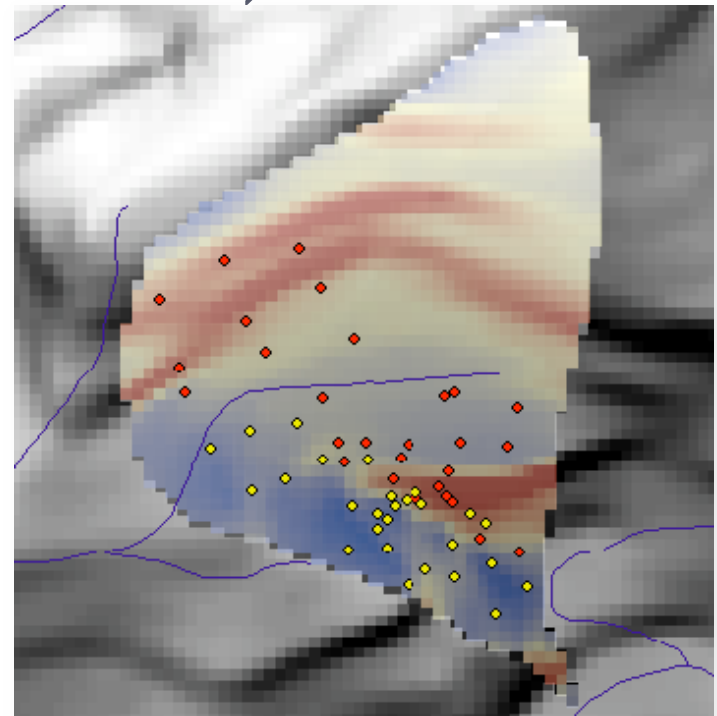
Field Work (Knocking Pole)

- The knocking pole:
 - 0.5 m flights of 15 mm diameter stainless steel rod
 - etched graduations every 5 cm.
- Repeated droppings of a 5 kg sliding weight from a 50 cm height.
- Data are recorded as the number of “knocks” required to drive the pole each 5 cm increment.
- Bedrock was operationally defined as the point where more than 25 knocks.



Field Work (Knocking Pole)

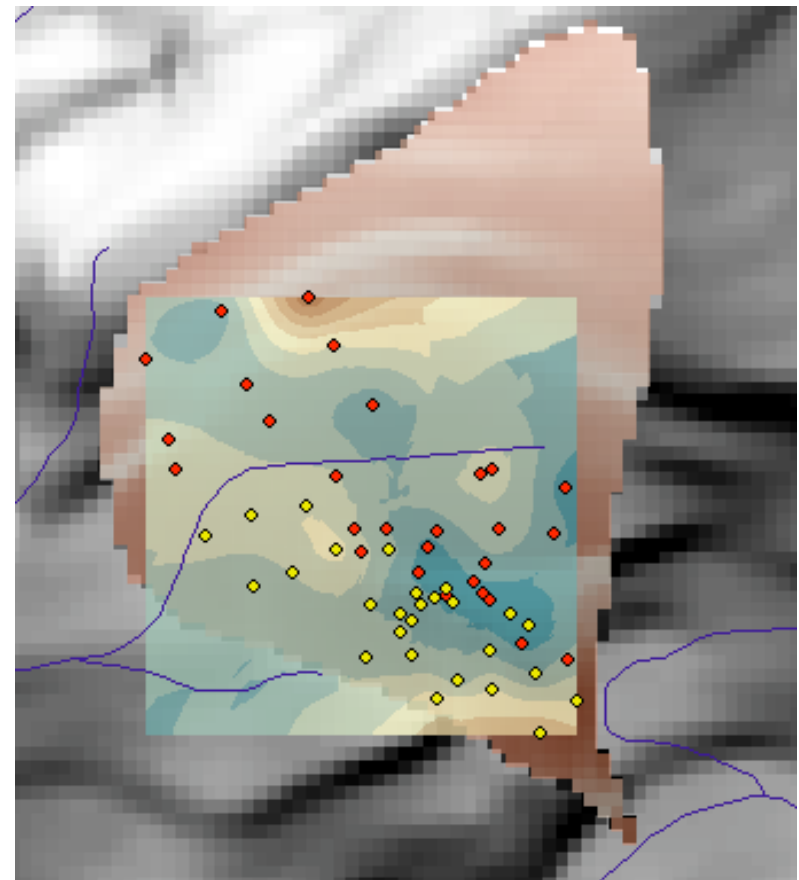
- * 29 knocking sites were completed this season
- * With this data we should be able to predict the density of soil and depth to the bedrock throughout the watershed.
- * Nobody has mapped bedrock depths.



GIS map displaying 2008 and 2009 knocking pole sites in WS-07. 2008 sites are represented by yellow markers and 2009 sites are in red.

GIS

- GPS points were collected for every knocking pole and well site along the stream.
- The soil volume data can be translated into a soil moisture estimation to be used in the Mass Balance equation.

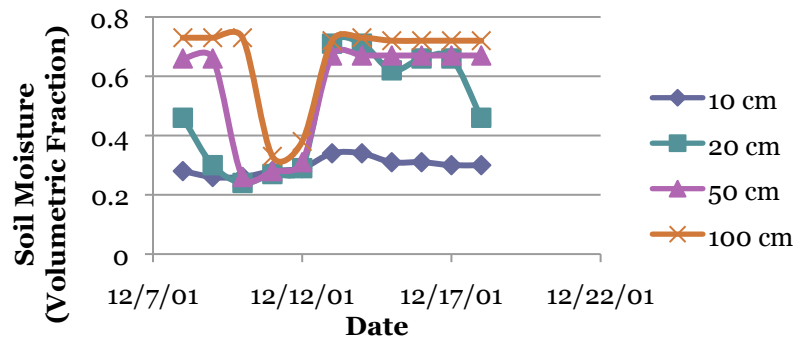


GIS kriging was used to create a layer depicting the approximated bedrock depth across a portion of the water shed.

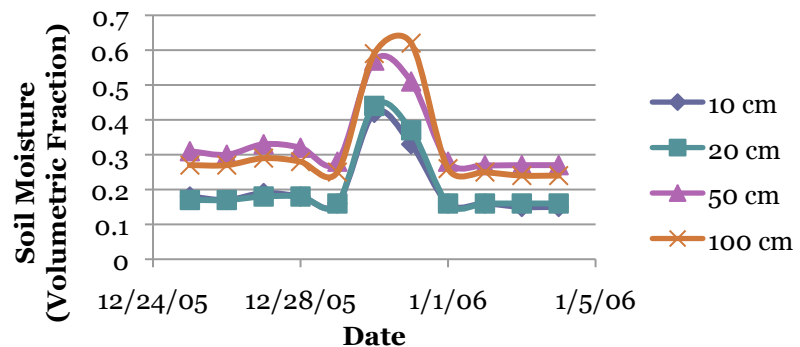
Soil Moisture

- WSo7 Soils
 - Infiltration rate $\sim 500\text{cm/h}$
 - 40%-50% Porosity
- 2001 Event
 - Early in the Season
 - Soils unsaturated
 - Previous Storm
 - One Week Prior
 - Soils Draining
- 2005 Event
 - Soils unsaturated

Soil Moisture Fluctuations (2001)



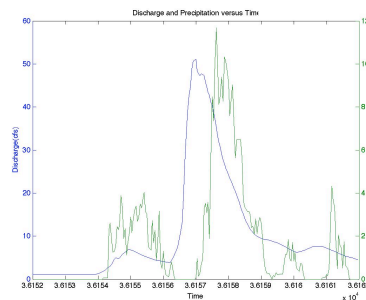
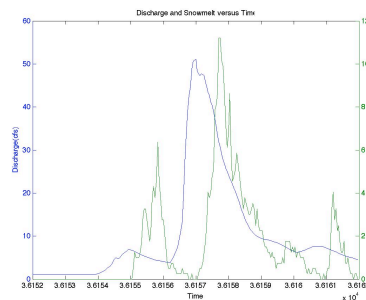
Soil Moisture Fluctuations (2005)



Water Balance

$$GW^{**} = (P - \Delta SWE > 0 + N) - (ET - \Delta SM^* + Q)$$

1991	881.9	177.3	-4	153.945	22		1191.2
1994	887.8	201.0	-114	172.3	22		1239.0
1996	3227.7	340.7	210	438.685	22		3775.2
1998	1781.0	397.5	-65	368.46	11		2535.9
2001*	1419.8	246.4	-137	192.99	11	-2.75	1850.9
2005*	1848.6	197.9	-35	379.74	11	-30	2445.3



Units: millimeters (mm)

* Includes ΔSM in water balance
in 2001 and 2005

** No data for figure

Water Balance Results

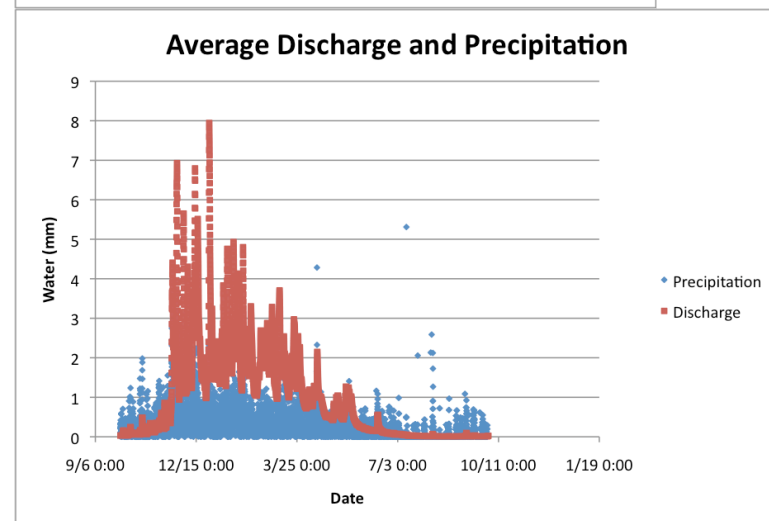
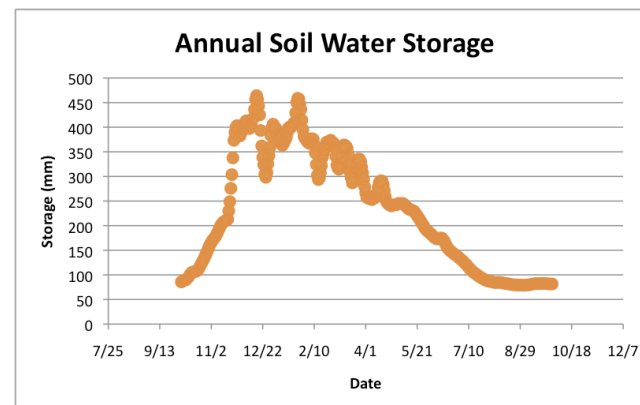
Year	Discharge (mm)	Inputs/ Outputs* (mm)	Missing Water (mm)	Missing (%)
1991	809.6	353.3	456.3	56.4
1994	842.1	395.3	446.8	53.1
1996	2565.6	801.4	1764.2	68.8
1998	1723.4	776.9	946.5	54.9
2001	1257.9	447.6	810.3	64.4
2005	1661.8	558.7	1103.1	66.4
Average				60.6

• “Right Side”
without discharge

- Groundwater contributes ~60% of discharge during peak event
- Implications:
 - Water is not stored during peak discharge events and must be stored through other slow release processes
 - Groundwater is a major contributor to water storage and transport in WSo7

Long Term Water Storage

- Soil storage follows discharge and precipitation
- Changing Water Year in the PNW
 - Increased daily minimums $\sim 1^{\circ}\text{C}$ (Mote 2003)
 - Precipitation variability increasing (Hamlet and Lettenmajer 2007) but volume the same (Mote 2003)
 - Reduced SWE values of 40% in early spring (Mote et al. 2003)
 - Peak Runoff Timing ~ 20 days earlier (Stewart et al. 2005)
- Implications:
 - Increased water release over shorter time periods
 - More rain on snow storm events



Conclusion

Investigative

- During a large scale flood event how much water discharged can be attributed to the precipitation?
- What is the storage capacity for groundwater in a watershed?
- **Water Balance**
 - 40% of the water is accounted for
- **Storage**
 - Water is stored during non-peak events

Predictive

- What are the origins of water in a headwater watershed, and how could a changing water year alter the supply of water to streams in the Pacific Northwest?
- **Origins:**
 - Precipitation (Rain and Snow)
 - Groundwater and Soil Moisture
- **Water Year Changes**
 - Shortened Period of Recharge

Thank You!

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