# Potential Roles of Groundwater in Mitigating or Exacerbating the Impacts of Floods

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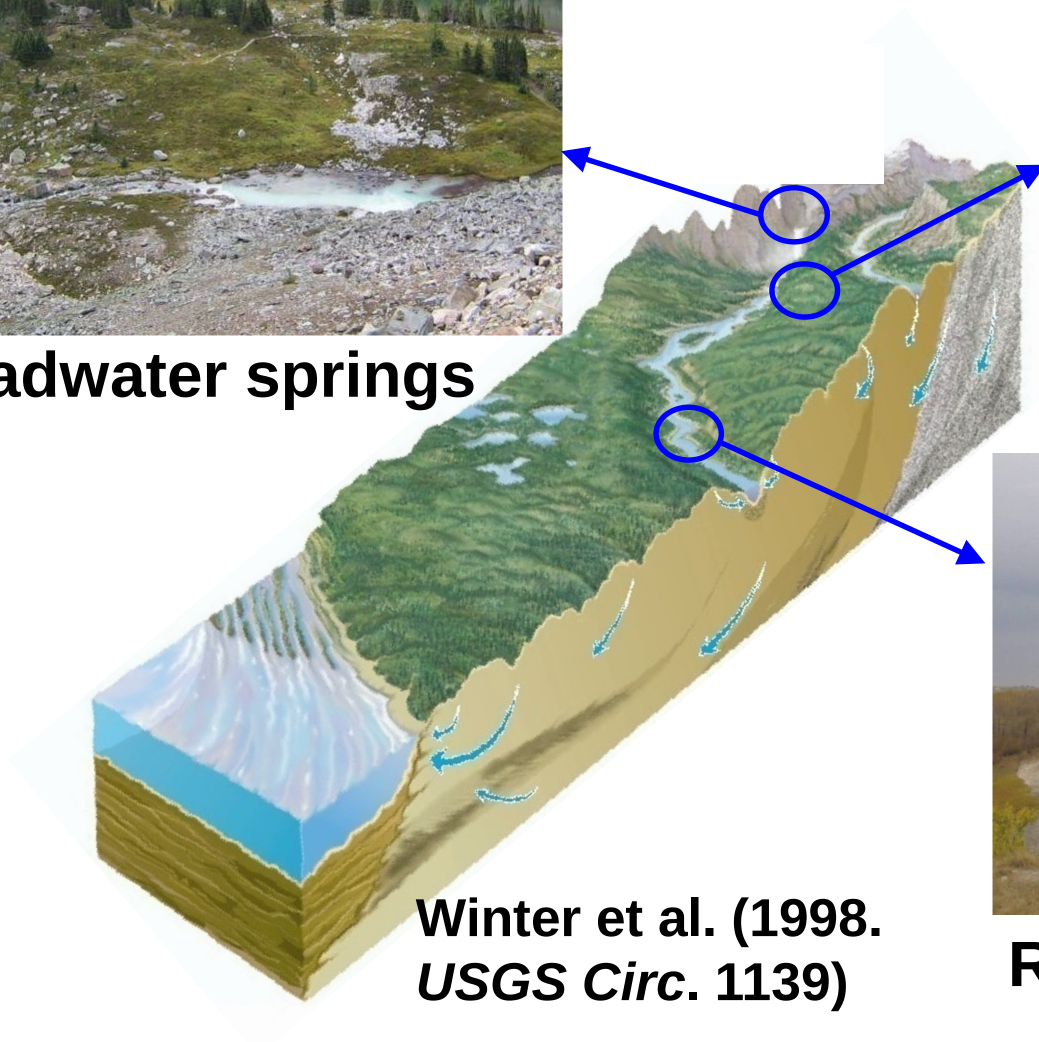
# Groundwater is Dominant Source of River Water

Headwater springs

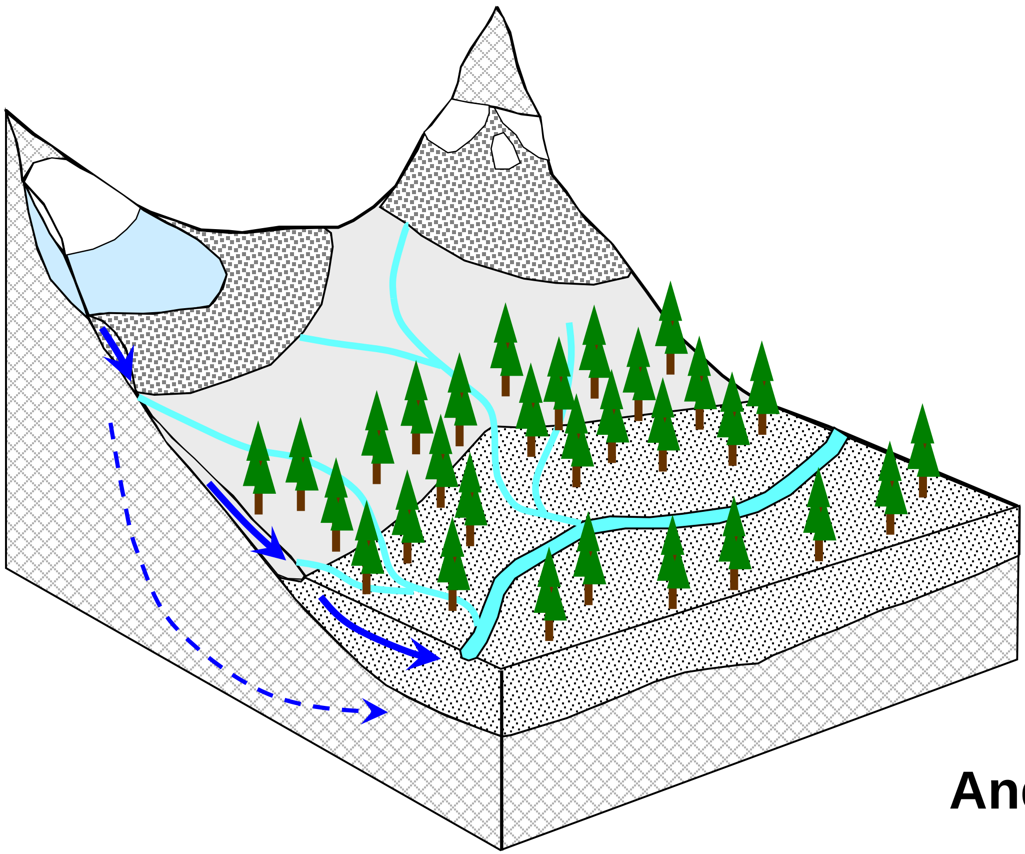


Winter et al. (1998. *USGS Circ*. 1139)

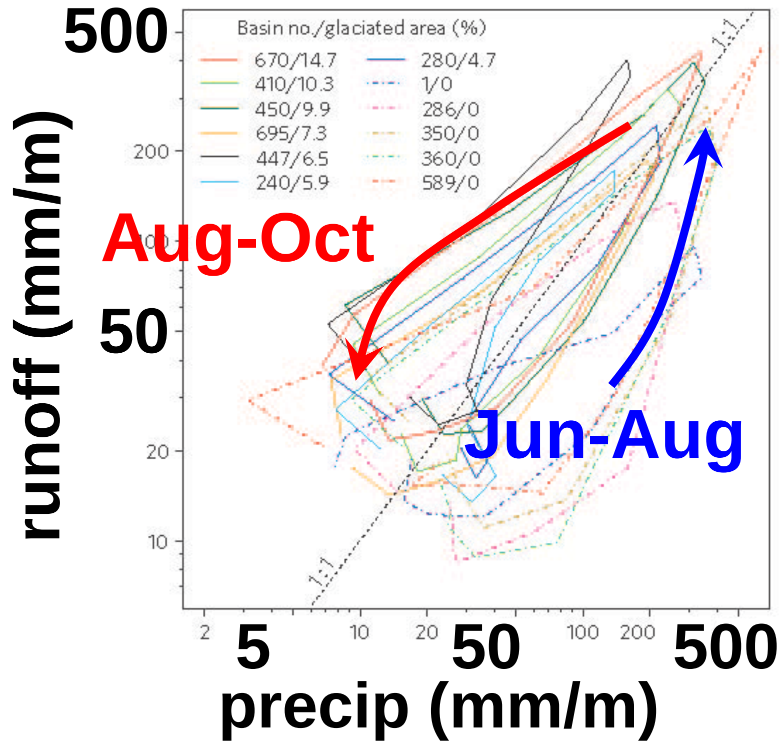
Springs on river bank

River-aquifer exchange

# Mountain Groundwater



## River basins in Himalaya




Andermann et al. (2013, *Nature GS*)

**Mountain aquifers detain rain and snowmelt.**

**Need for understanding small-scale processes.**

# Groundwater in the Headwater Region

## Lake O’Hara Watershed Study

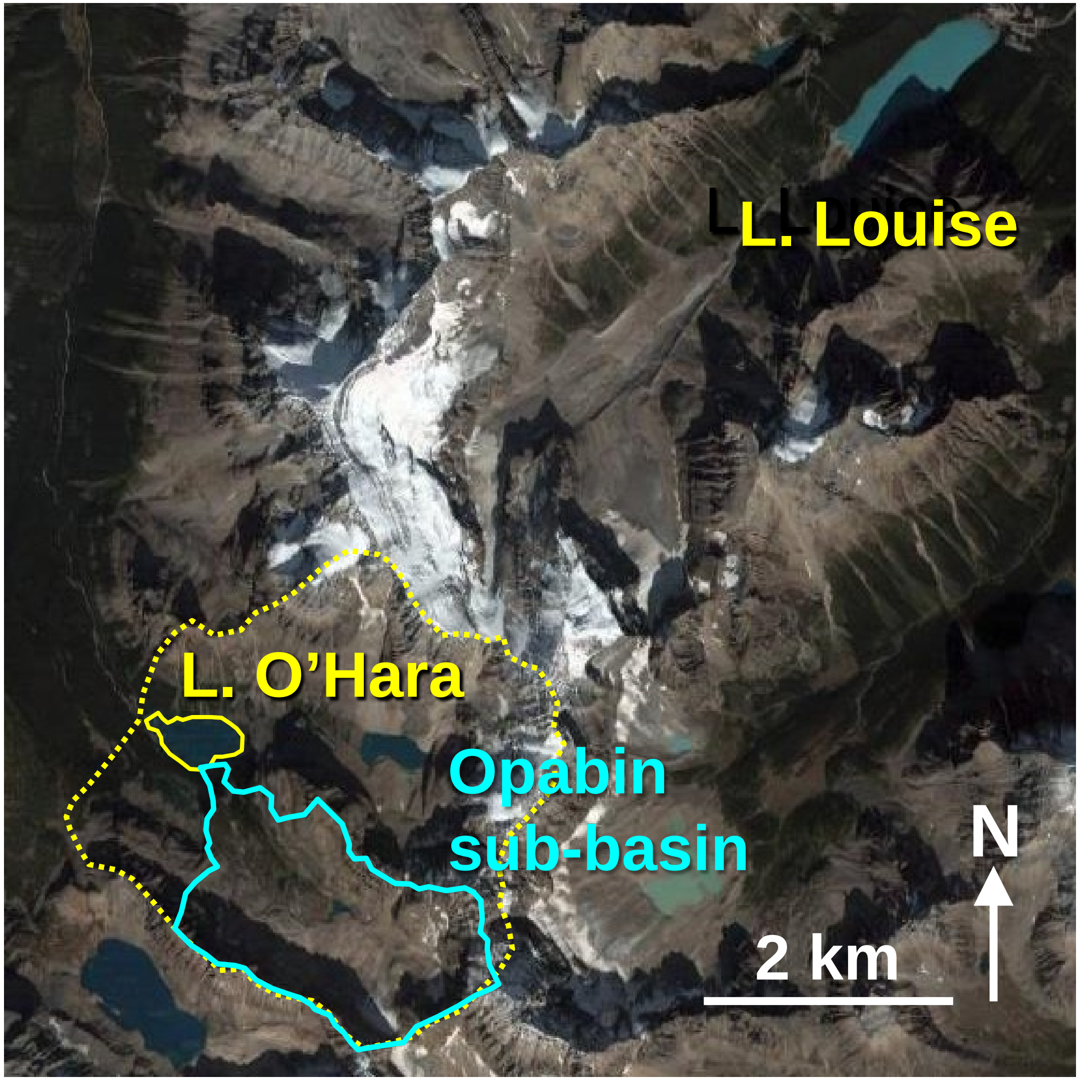
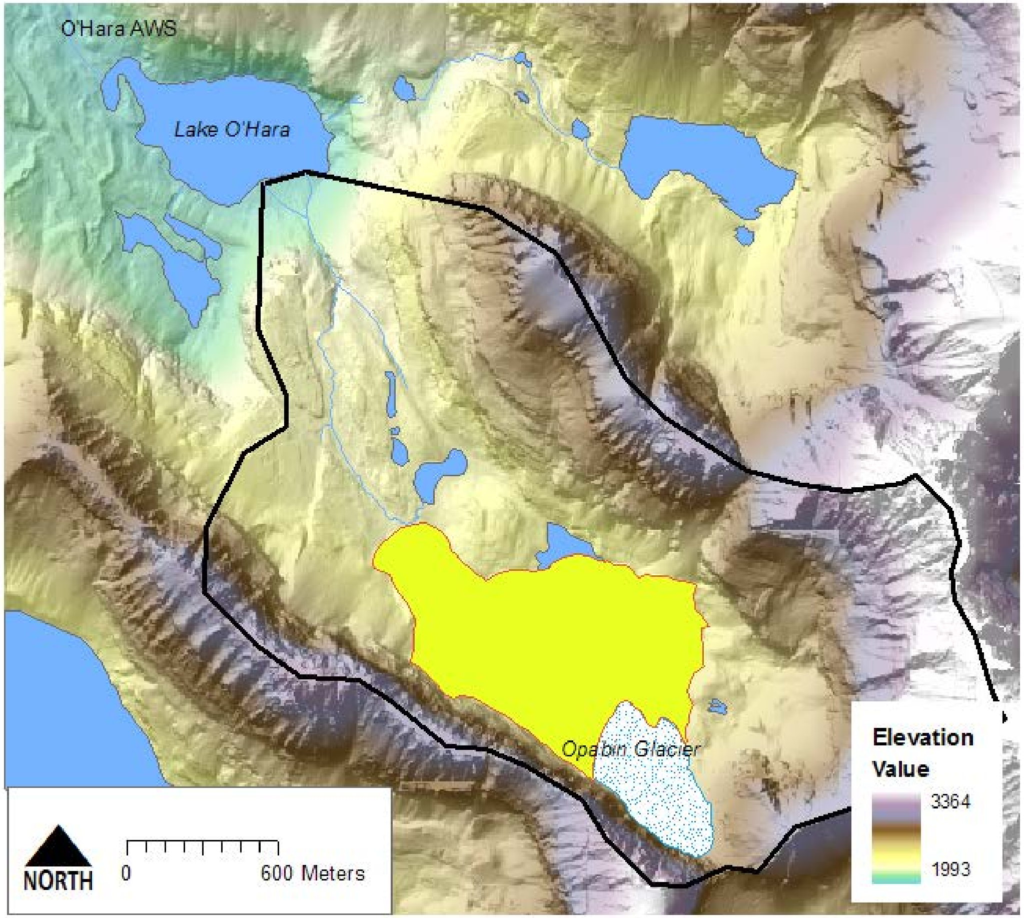



Image from Google Earth

- Weather stations
- Water level gauges
- Stream flow gauges
- Other instruments

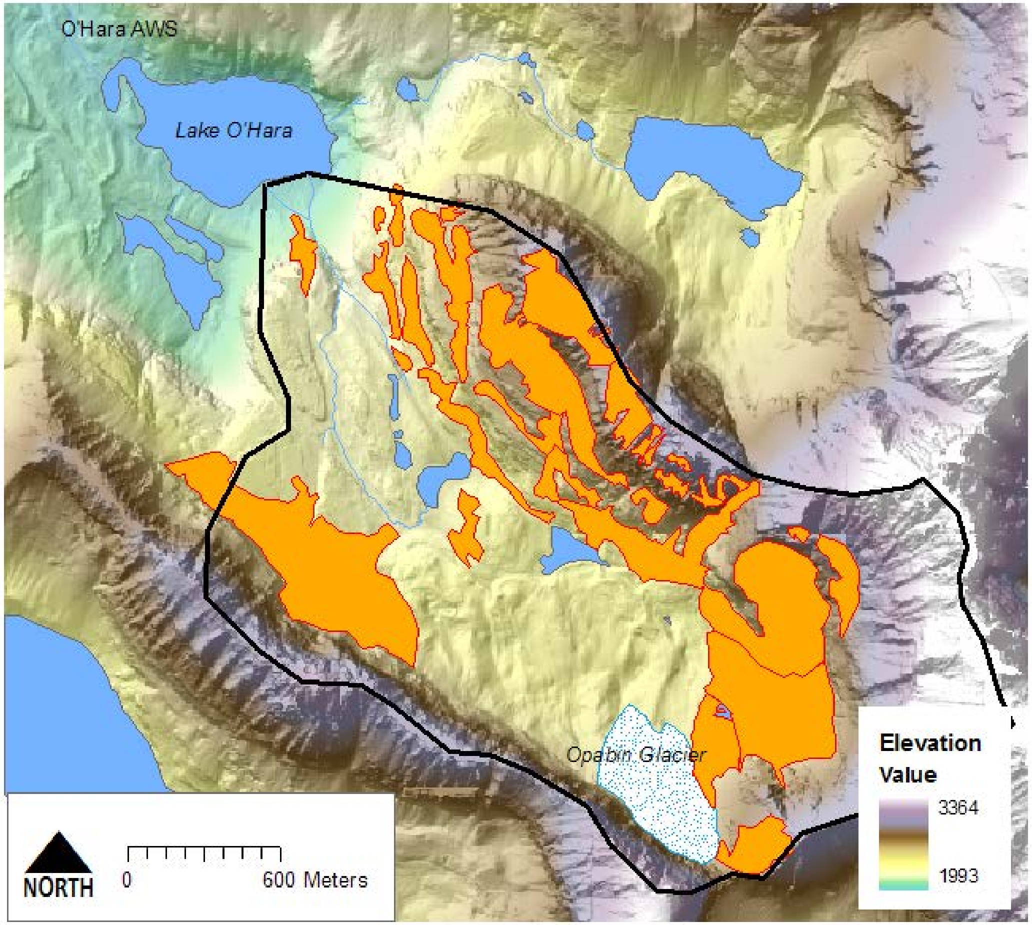
# Hydrogeological Response Units

- **Bedrock (hard quartzite)**
- **Proglacial moraine**




# Hydrogeological Response Units

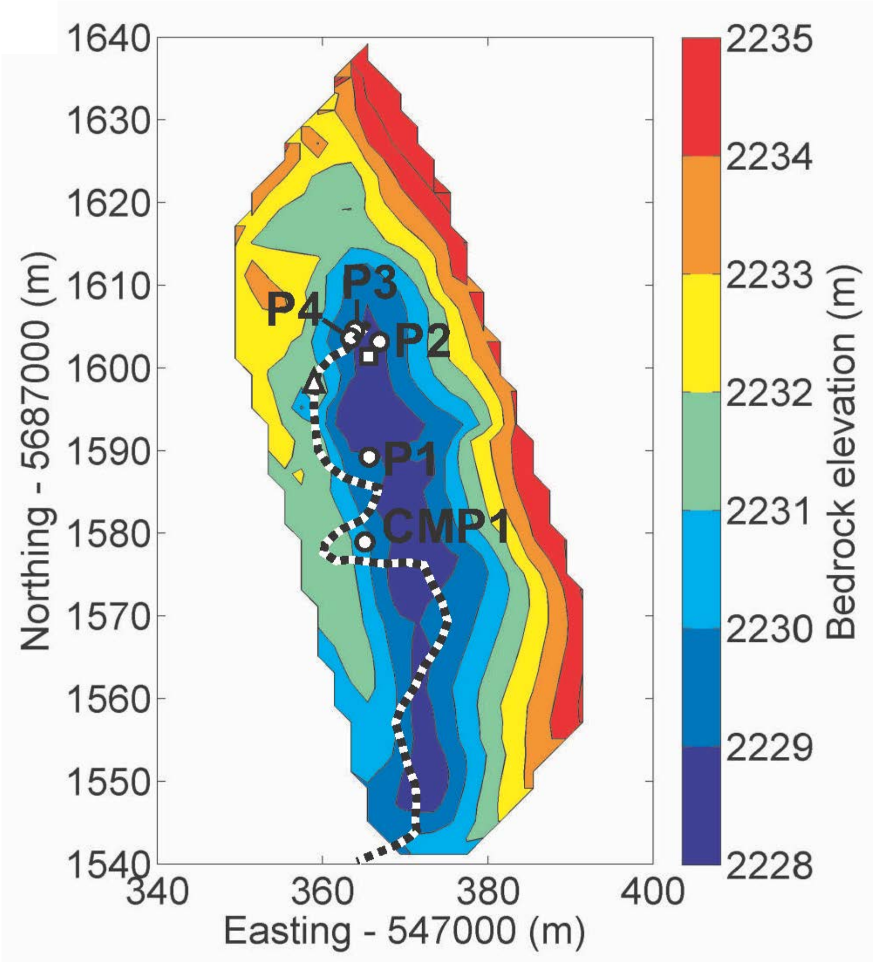
- **Talus slopes and cones**



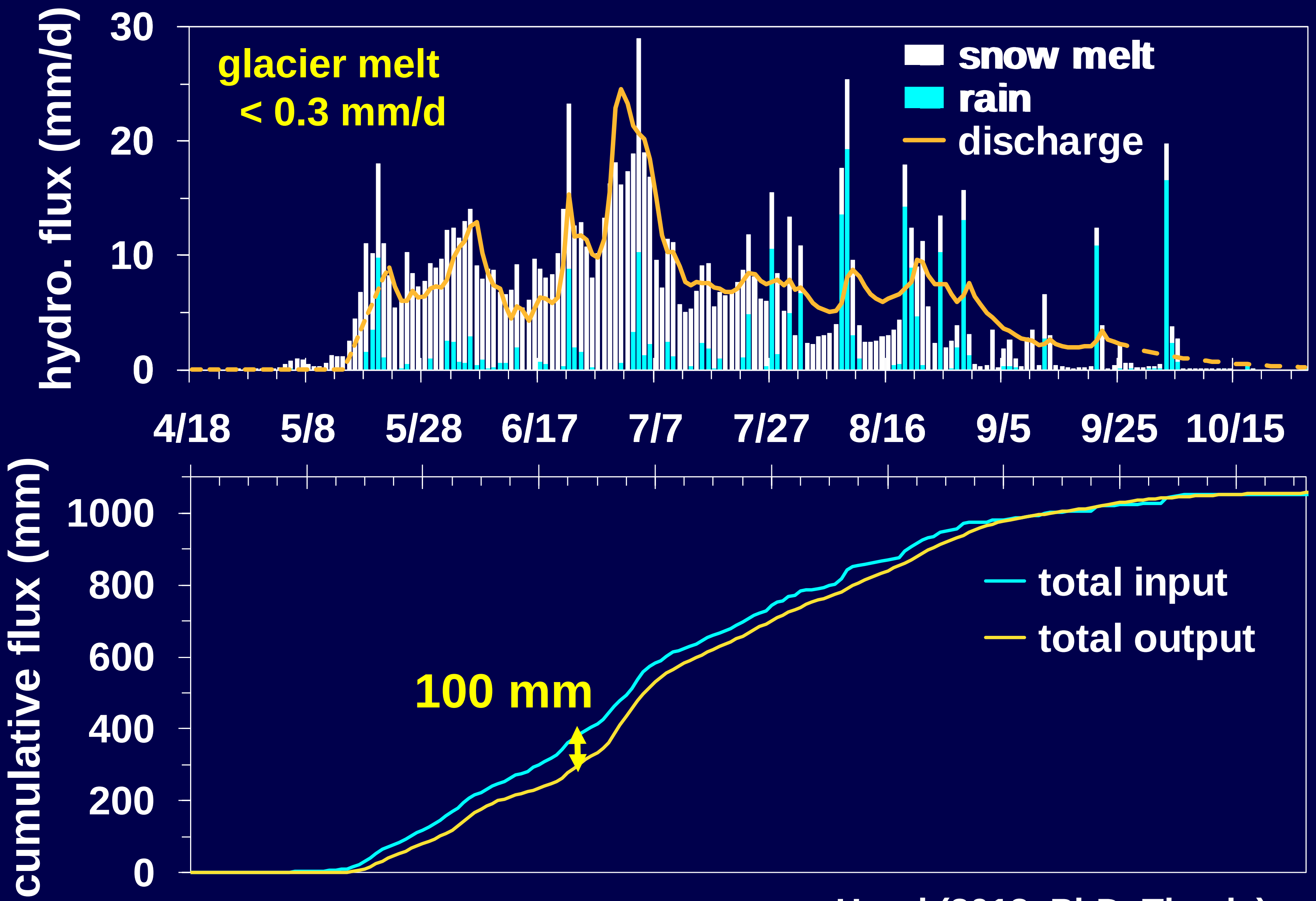

# Hydrogeological Response Units

- **Alpine meadow**

**Water table is controlled by fill-spill of bedrock basin.**




# Opabin Basin Water Balance (2008)




Hood (2013. PhD. Thesis)

# Headwater of Foot Hills Watershed
## Creek Originating from Marble Mountain

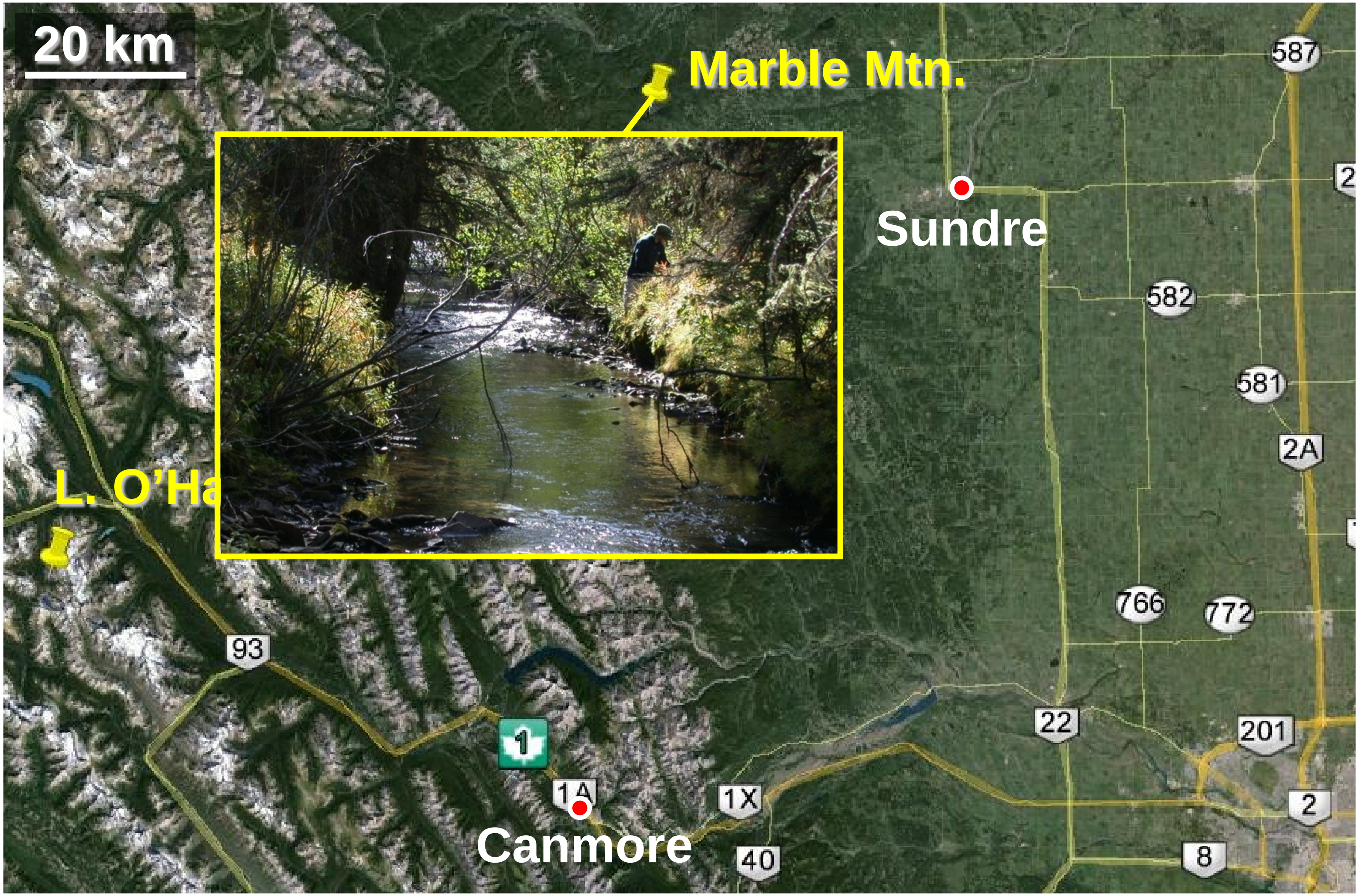
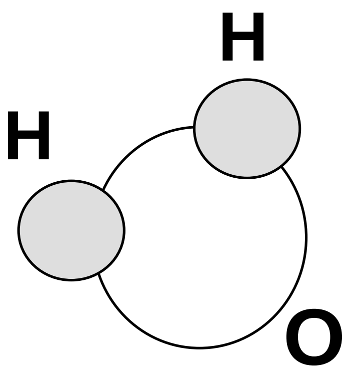



**Image from Google Earth**

# Tool for Measuring Groundwater Contribution



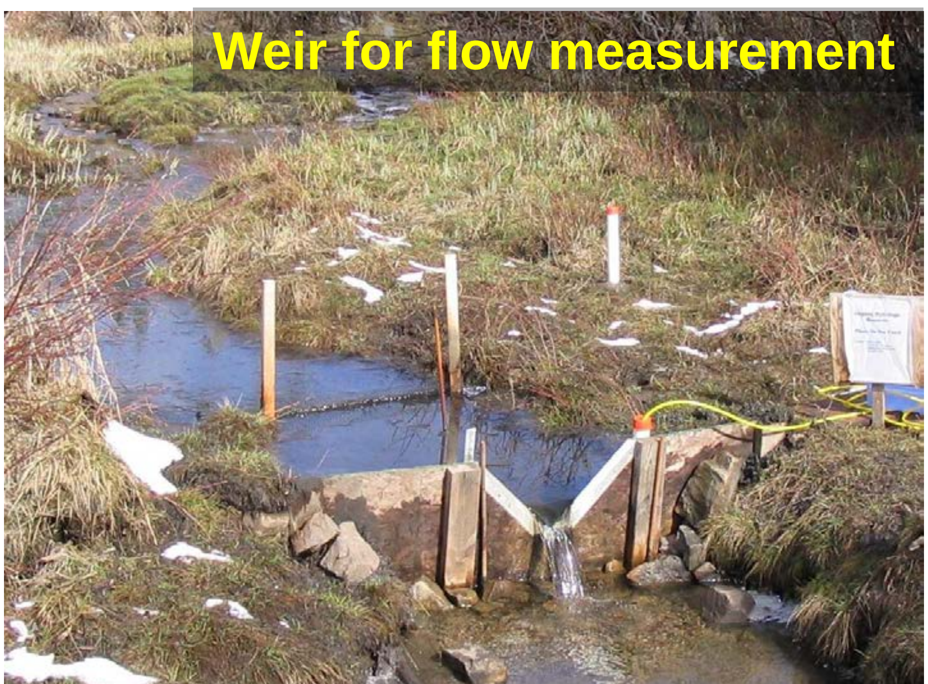

Water is $H_2O$.

H has a weight of 1, O has 16.

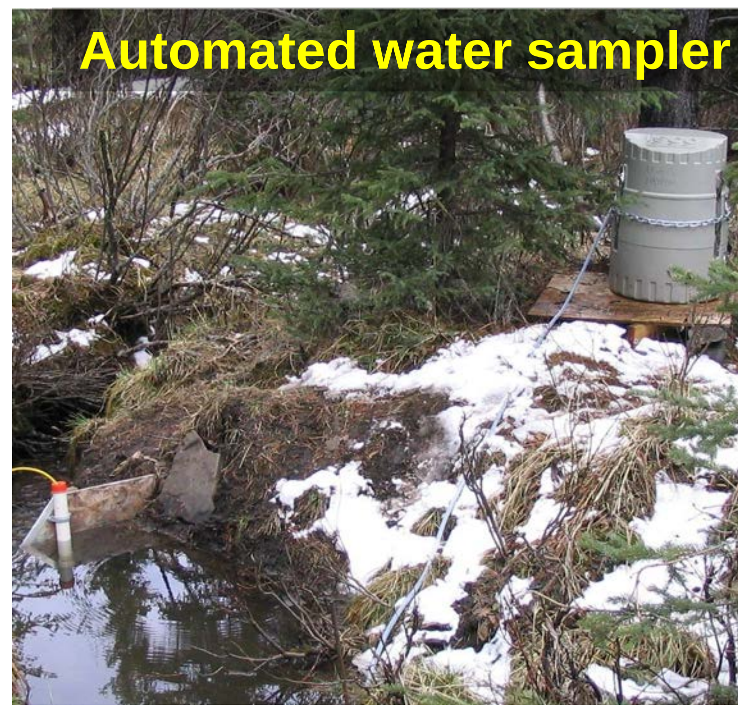
Total is 1+1+16 = 18 for “normal” water.

Some O has a weight of 18 $\rightarrow$ $^{18}O$ isotope.

Summer rain contains more $^{18}O$ than GW.



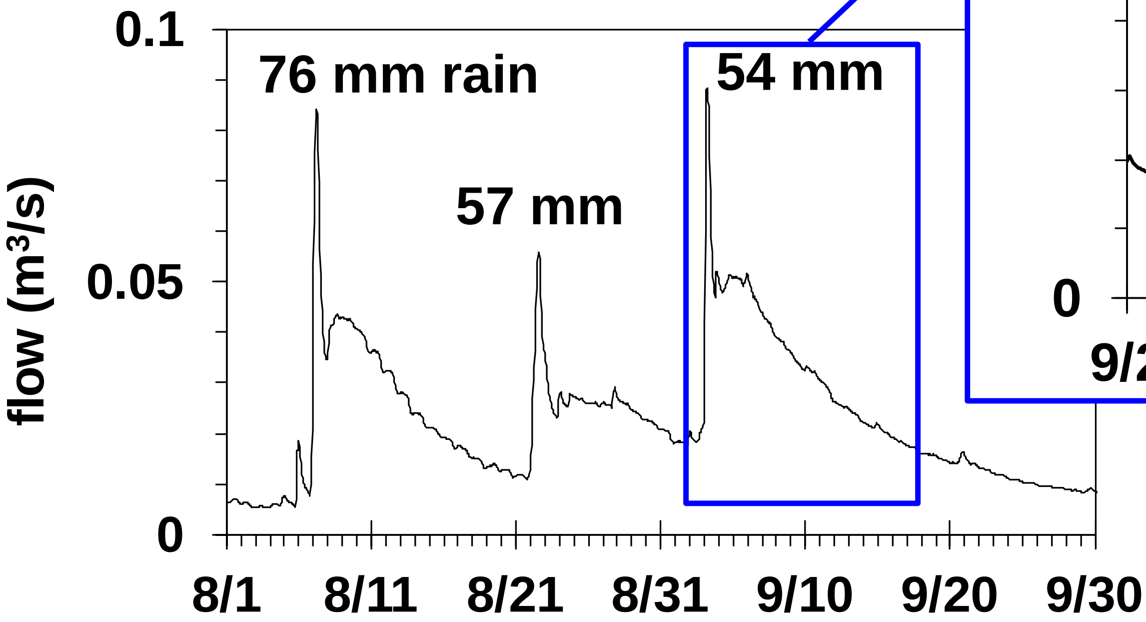
Weir for flow measurement

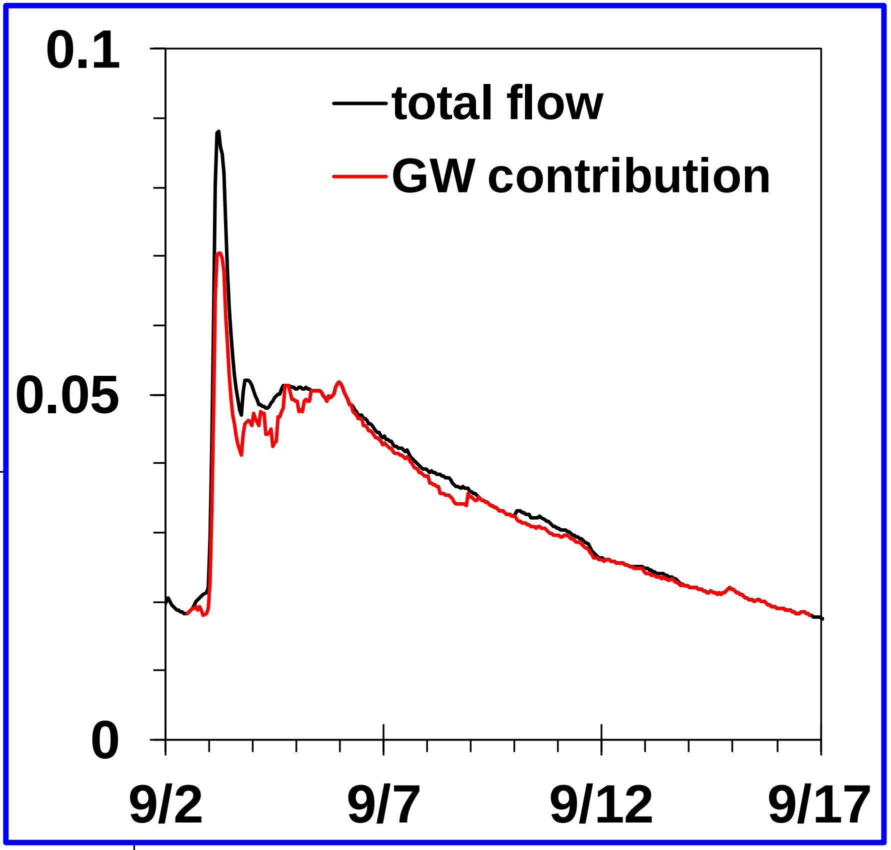


Automated water sampler

# Examples of Strom Events in 2004

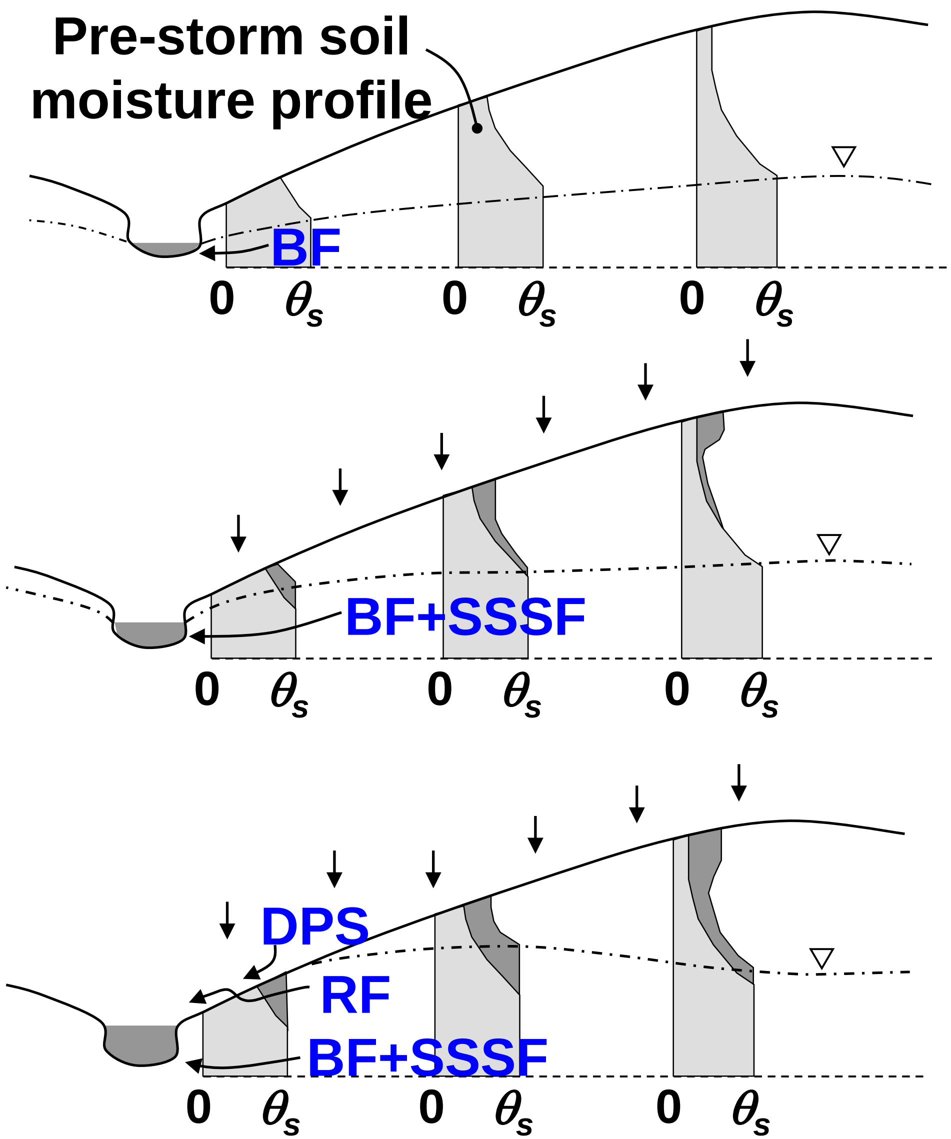
**Majority of storm flow is sourced by the groundwater coming out of “reservoir”.**




Lejbak (2007. MSc. Thesis)

# Rapid Groundwater Runoff during Storms



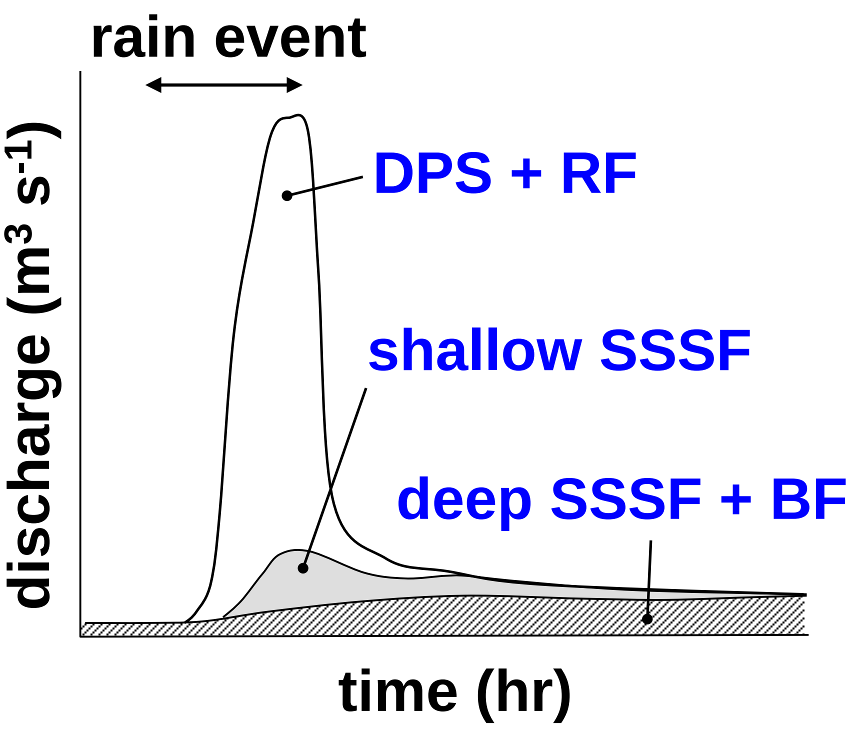

**Headwater stream flow is sustained by baseflow (BF).**

**Water table rises during storm, causing subsurface storm flow (SSSF).**

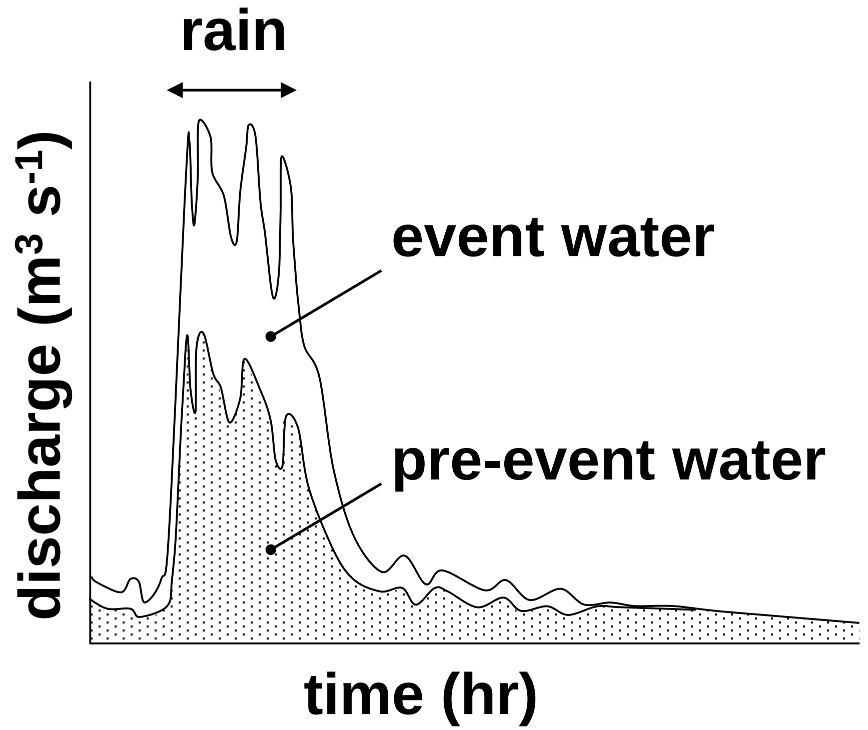
**Water table reaches the surface, allowing the return flow (RF) of groundwater combined with direct precipitation on saturated surface (DPS).**

Dunne & Leopold (1978. *Water in Environmental Planning*)

# Groundwater Contribution to Storm Flow




Dunne & Leopold (1978)

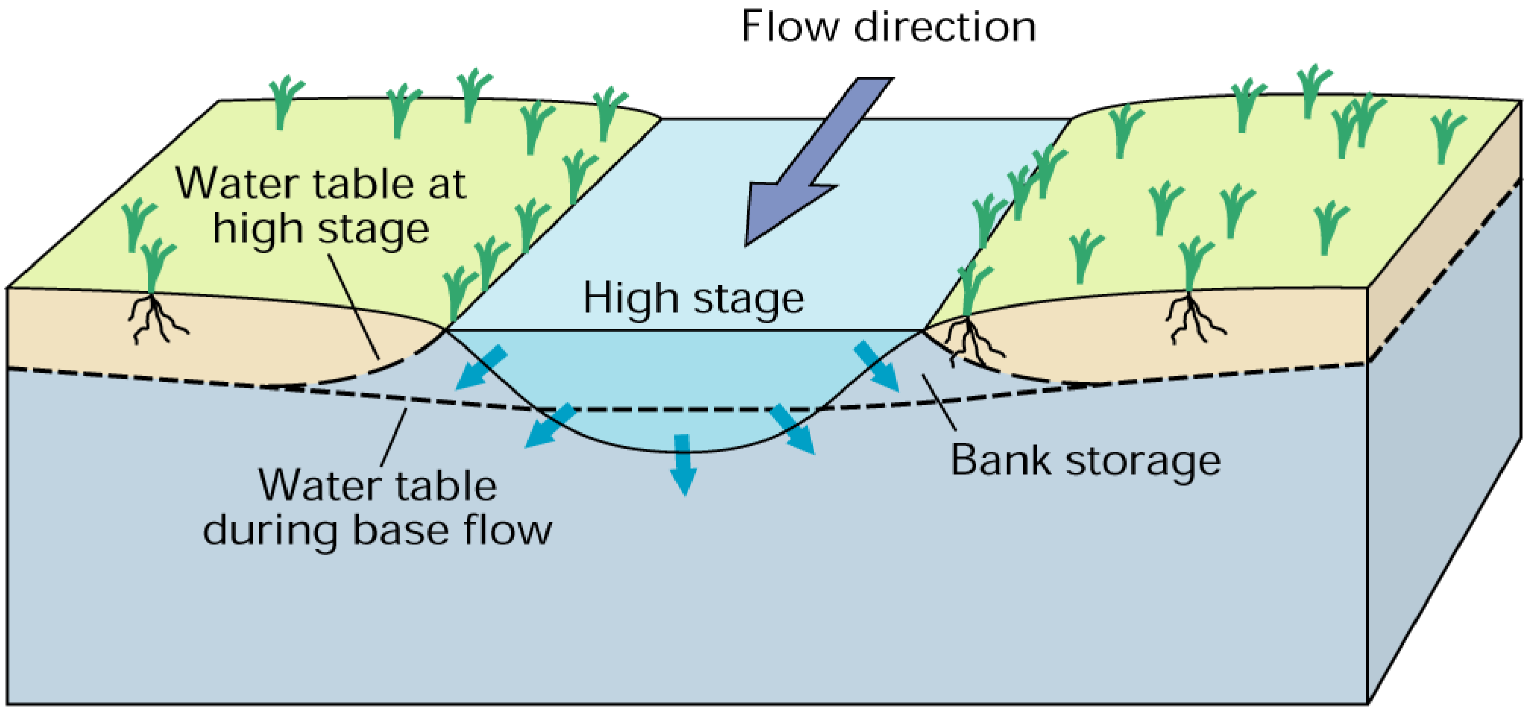



Buttle (1994. *Progress Phys. Geog*. 18:26)

**Groundwater provides detention mechanisms in numerous first-order basins.**

**But, probably to a limited extent.**

# Groundwater-Surface Water Exchange by Bank Storage

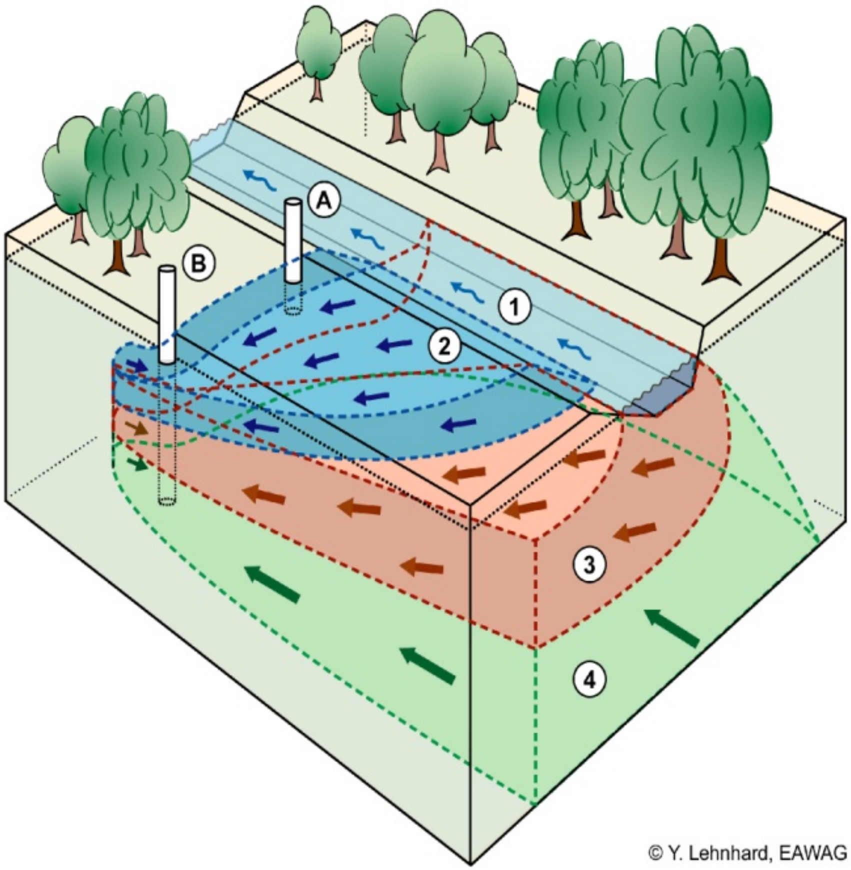


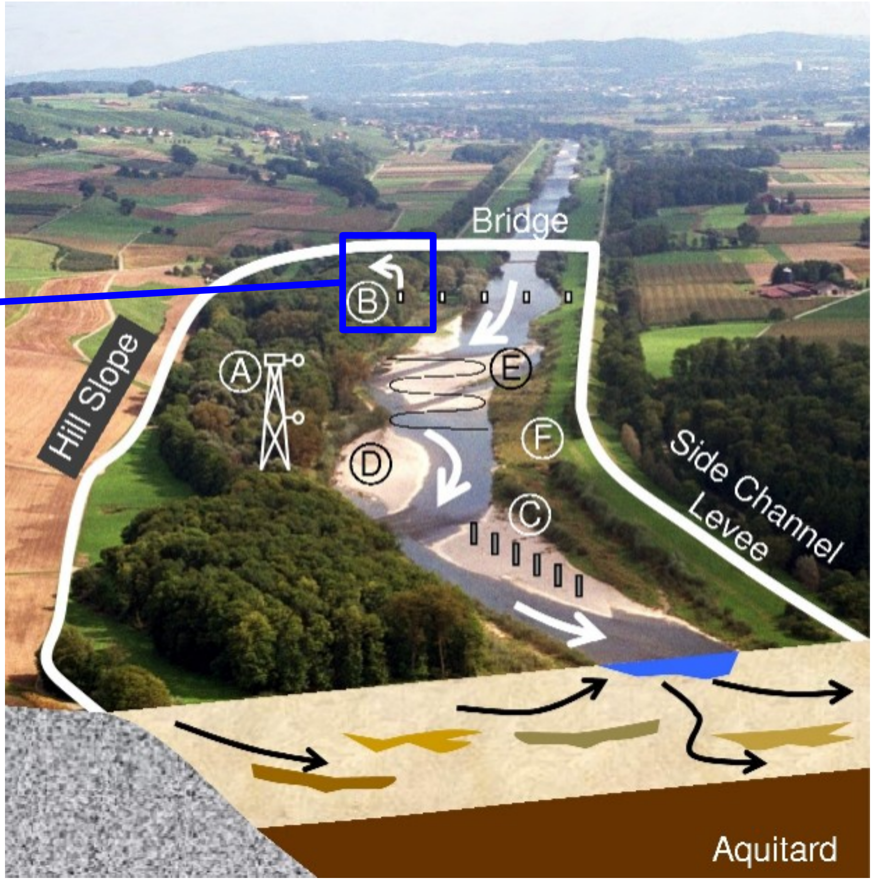

**Winter et al. (1998. http://pubs.usgs.gov/circ/circ1139/)**

# Restoration of River Corridors

**Municipal water supplies use bank-filtrated groundwater.**

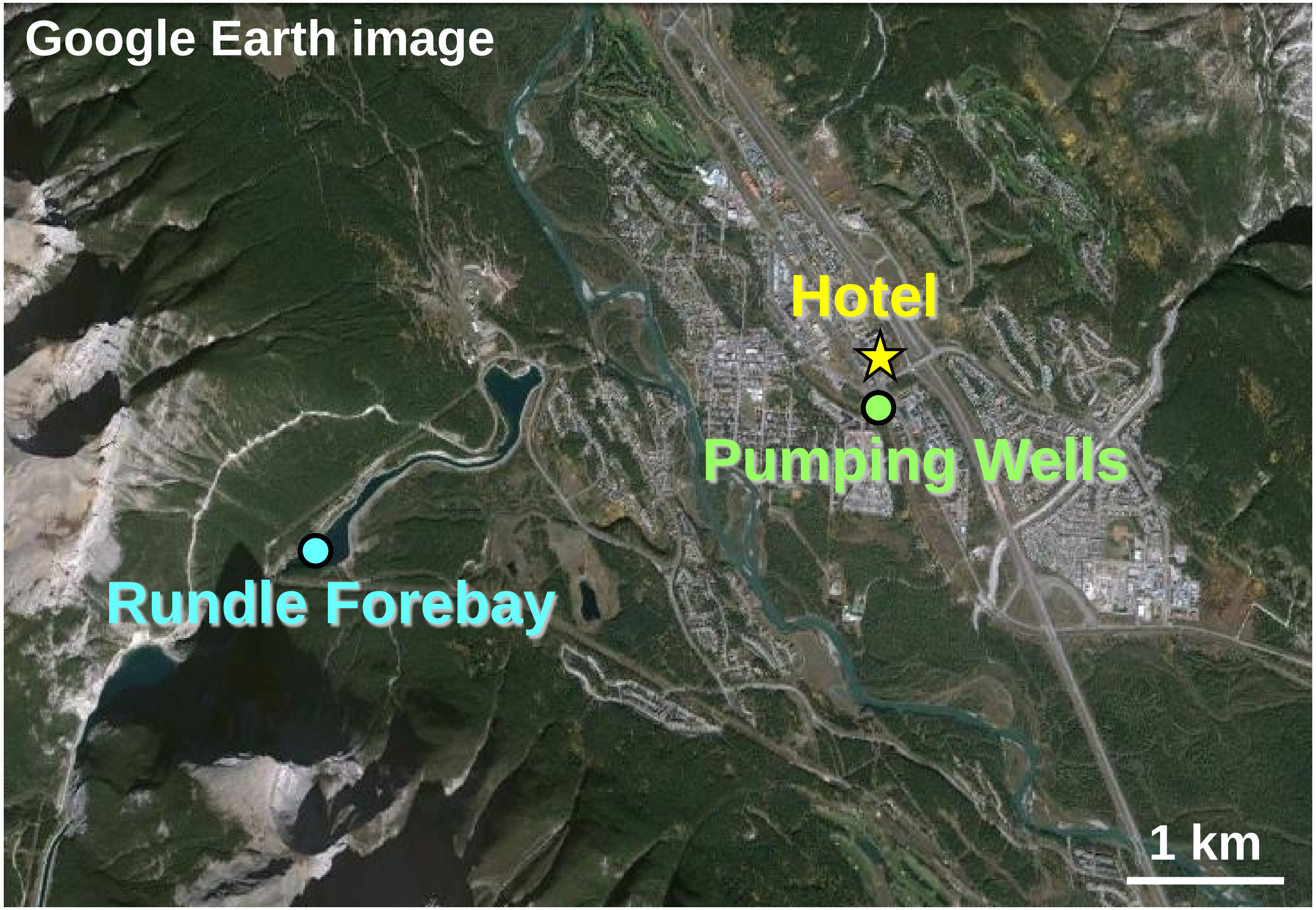
**Thur River, Switzerland**




**http://www.cces.ethz.ch/projects/nature/Record/sites**

# Water Supply for the Town of Canmore



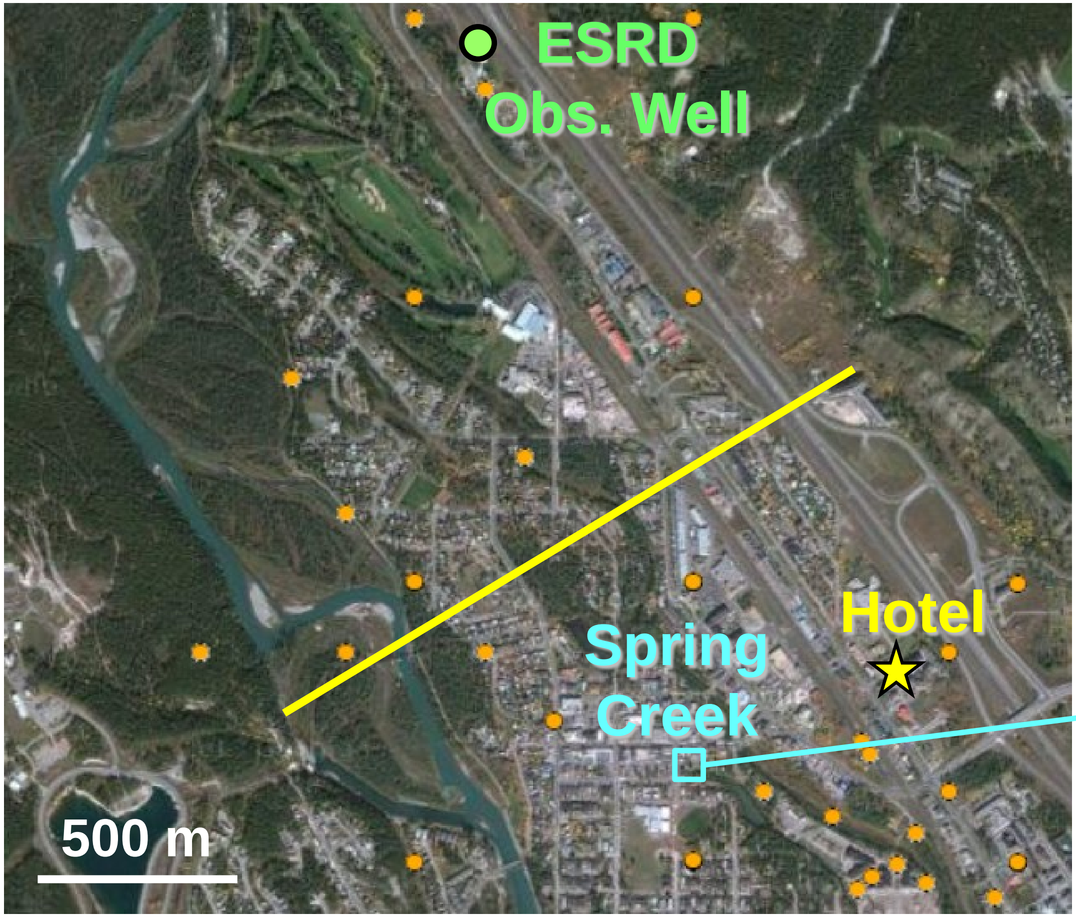

**Water production (2010)**

**530 L/day/resident**

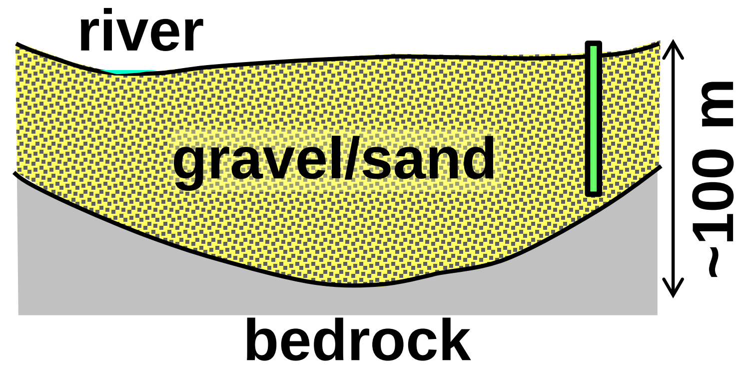
| Surface water | Groundwater |
|---|---|
| 1,390,000 $m^3$ | 970,000 $m^3$ |

www.canmore.ca/Municipal-Services/

# Water Wells in Canmore Town Centre

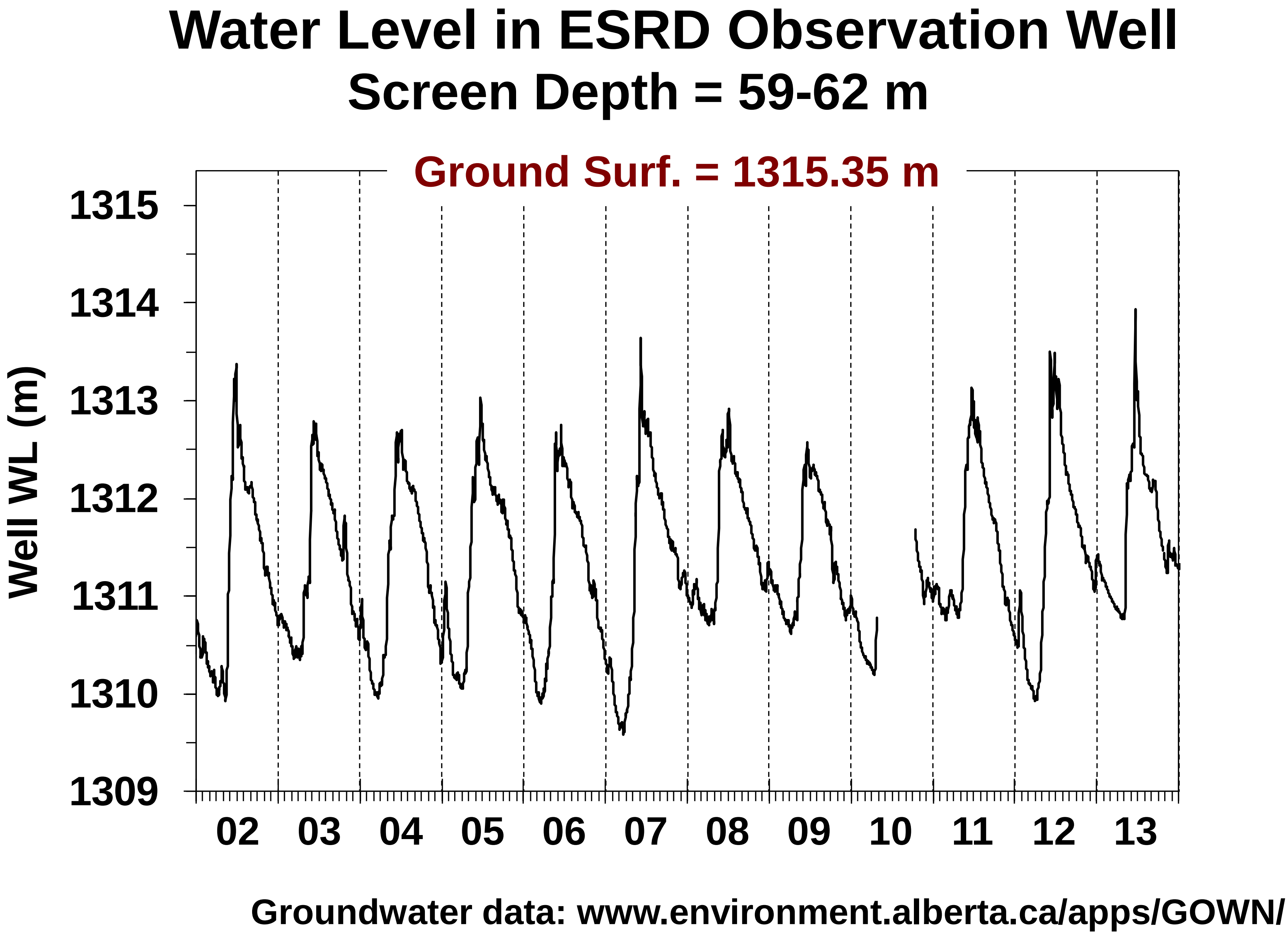



www.envinfo.gov.ab.ca/GroundWater/




Toop and de la Cruz (2002. Alberta Environment.)

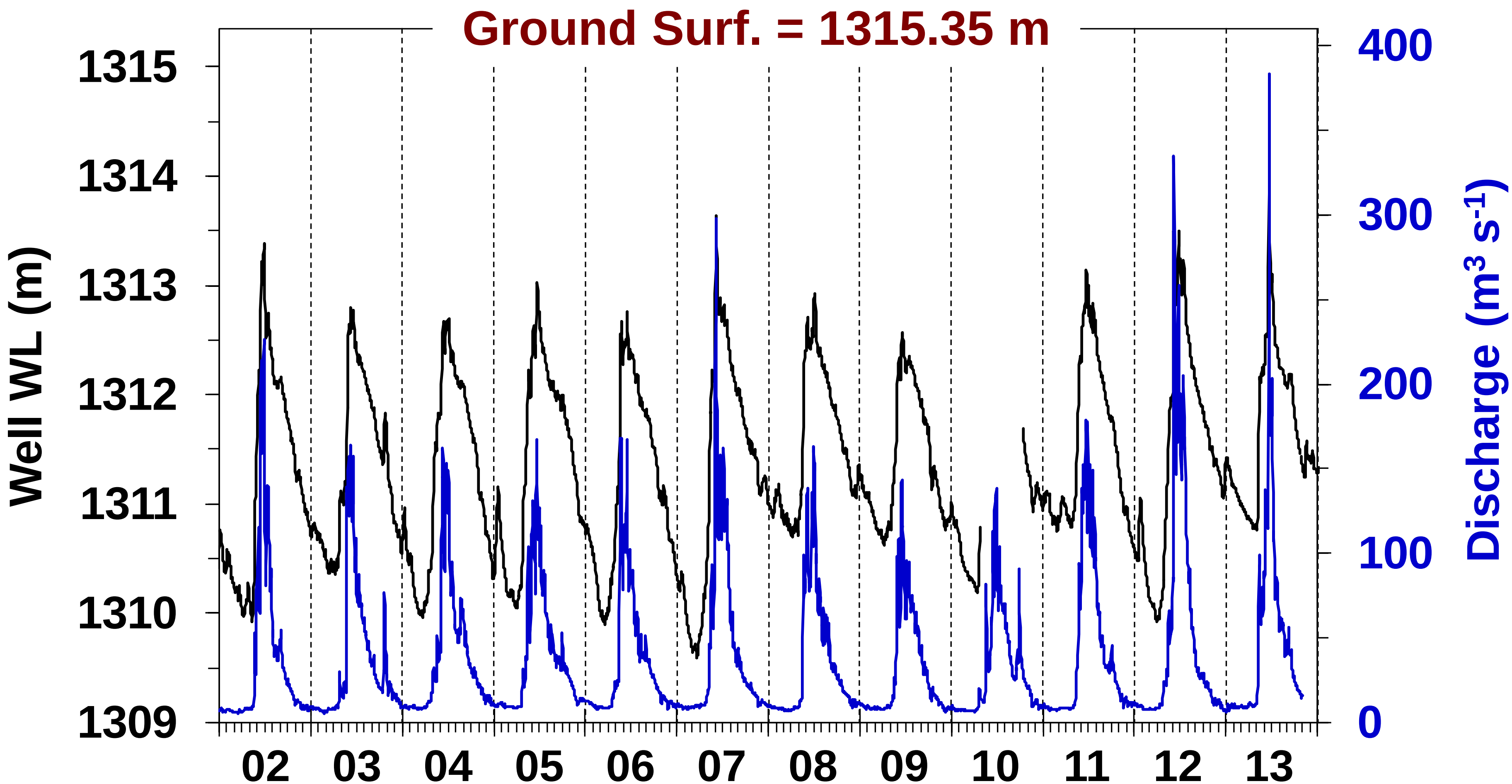
- Thick, alluvial aquifer
- Active exchange of the Bow River water with groundwater



Water Level in ESRD Observation Well
Screen Depth = 59-62 m
Ground Surf. = 1315.35 m
Well WL (m)
1315
1314
1313
1312
1311
1310
1309
02
03
04
05
06
07
08
09
10
11
12
13
Groundwater data: www.environment.alberta.ca/apps/GOWN/

# Water Level in ESRD Observation Well

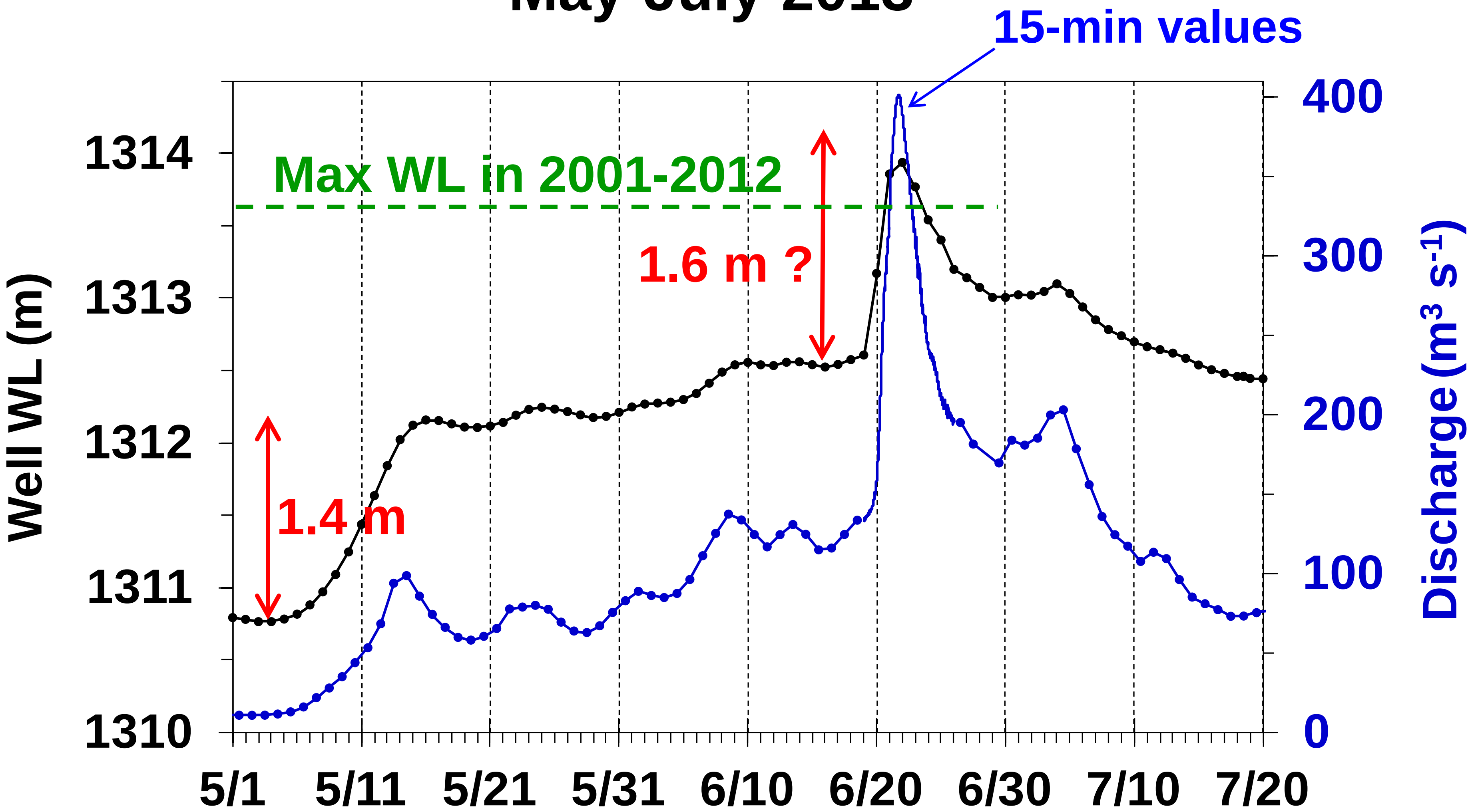
## Bow River Discharge at Banff



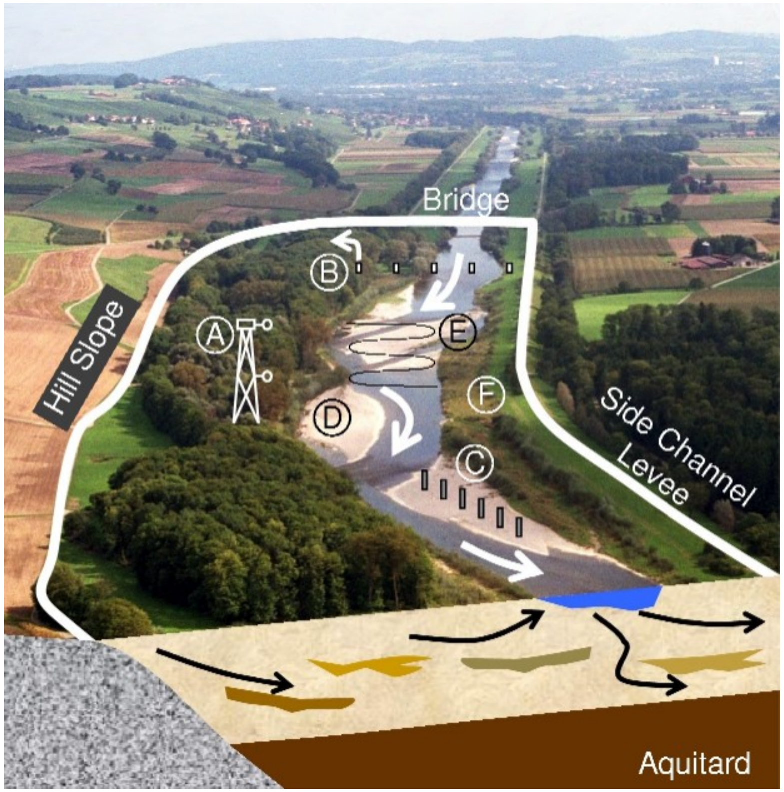

**Groundwater data: www.environment.alberta.ca/apps/GOWN/**

**River flow data: Water Survey of Canada (2012-2013 preliminary)**

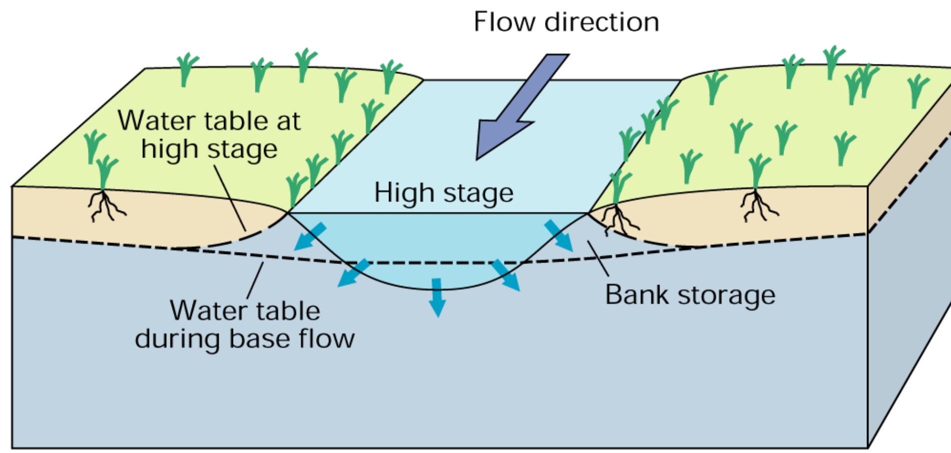
# Daily Average GW Level and Bow Discharge May-July 2013



# Flood Water Detention by Bank Storage?




**http://www.cces.ethz.ch/projects/nature/Record/sites**




**Winter et al. (1998)**

# Potential Magnitude of Bank Storage


**Alluvial Aquifer ~ 10 km$^2$**

**Water table rise ~ 2 m?**

**Storage coefficient ~ 0.3 (typical for sand/gravel)**

**Max. detention = 6 × 10$^6$ m$^3$**

**Jun. 21-22 total discharge = 60 × 10$^6$ m$^3$**

**GW storage likely detained ~ 10 % of flood flow.**

**But, this also caused the basement flooding.**

# Marmot Creek Watershed, Kananaskis

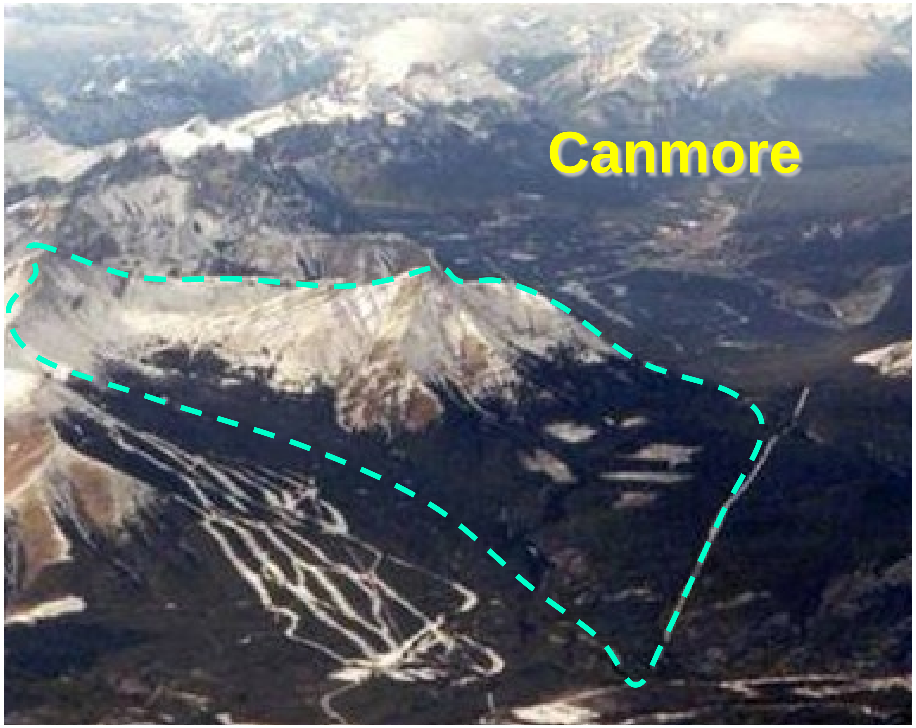
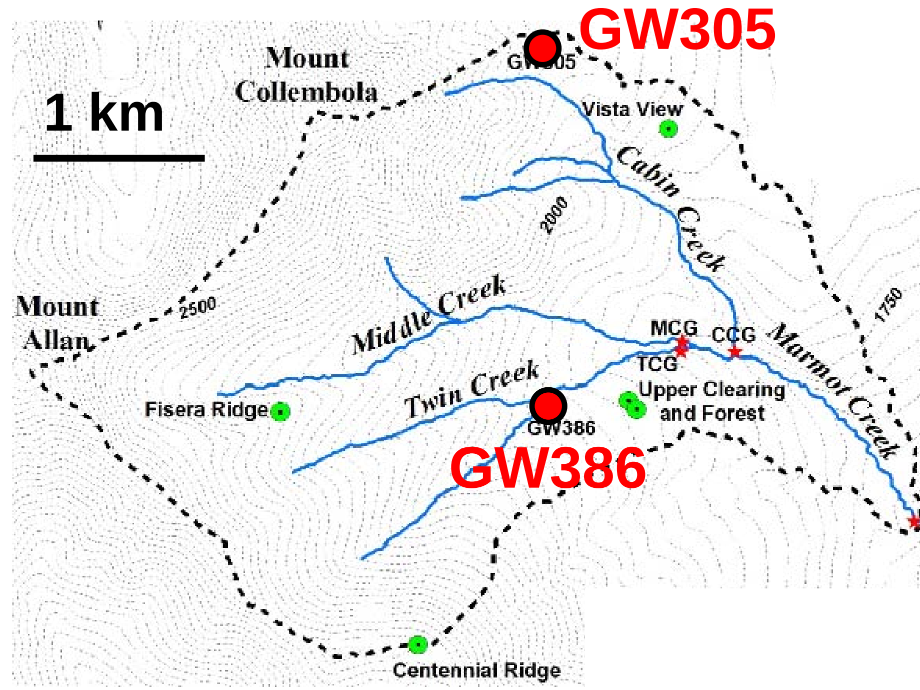
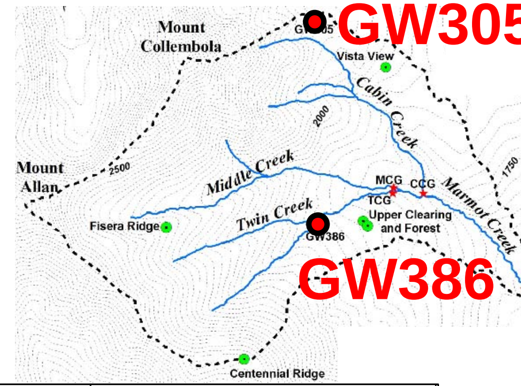


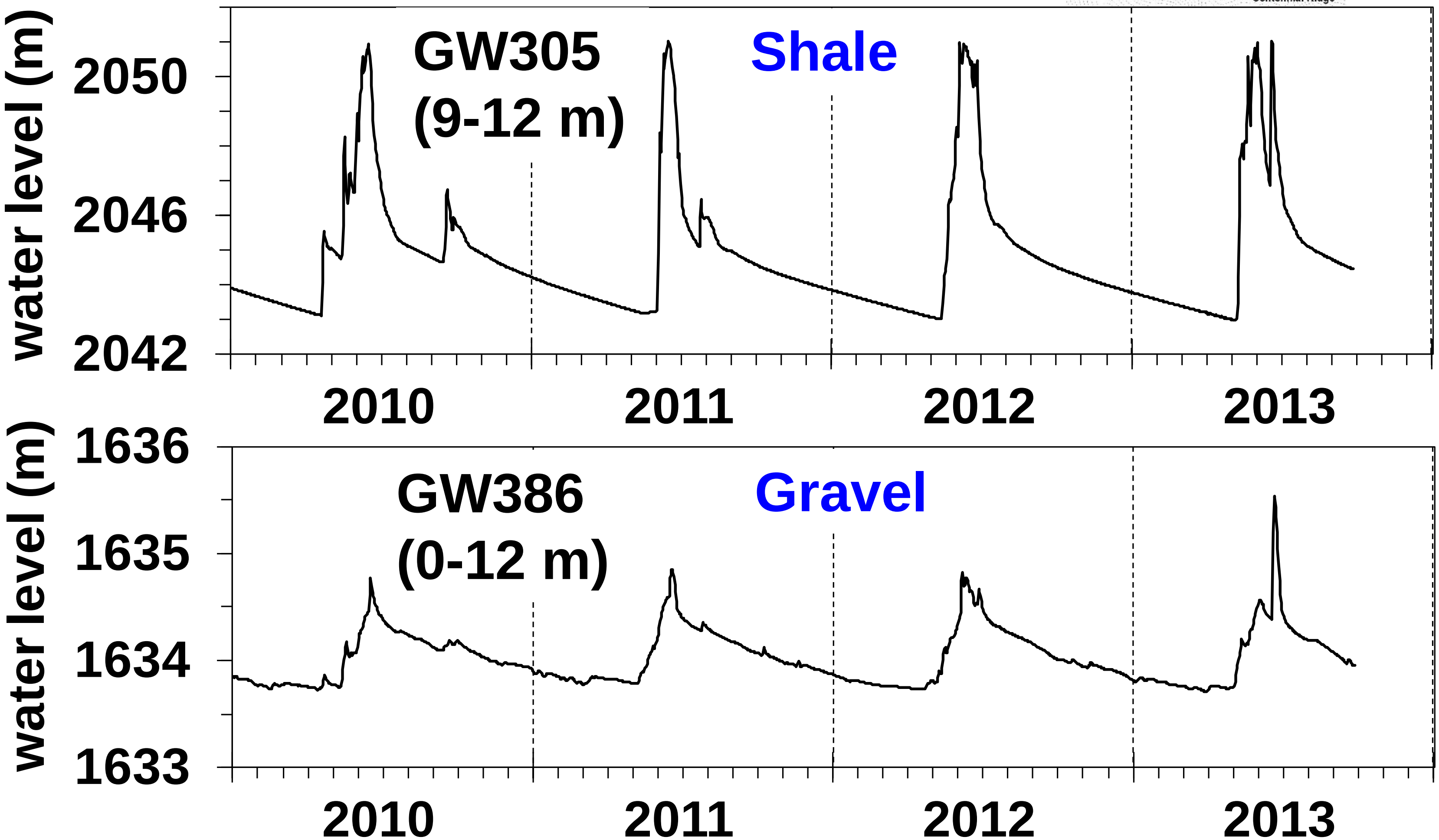

Photo provided by John Pomeroy



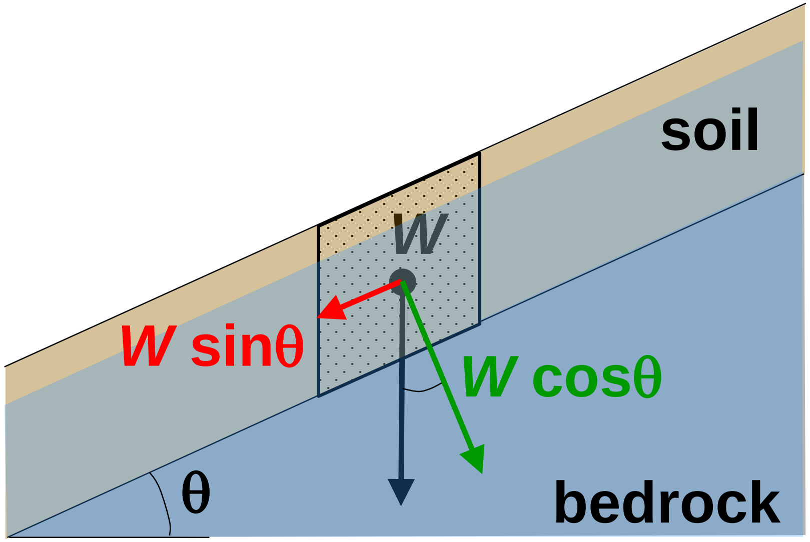

Fang et al. (2013. *Hydrol. Earth System Sci*. 17: 1635)

# EDRD GW Observation Wells



# Groundwater Effects on Slope Stability
# Simple Conceptual Framework




*W*: Material weight [N m$^{-2}$]

Downslope force = $W \sin\theta$

Shear strength ∝ $W \cos\theta - P$

*P* : Pore pressure [N m$^{-2}$]

Dunne & Leopold (1978)


Rapid rise in the water table may trigger slope failure.

→ Debris Flow


Evan-Thomas Creek, Kananaskis

# Key Points

1. **Majority of river flow is provided by subsurface water, even during storm events. Mountains have built-in detention mechanisms.**
2. **Storage of storm water in alluvial aquifers provide natural flood detention, but also causes basement floods.**
3. **Rapid water table rise in mountain slopes can trigger slope failures.**
4. **Can we utilize groundwater detention mechanisms for flood risk mitigation?**

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