Lecture 4: Baseflow Analysis

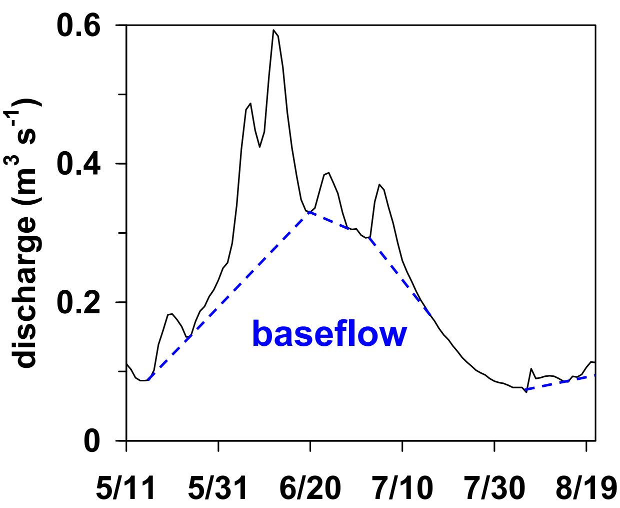
Baseflow definition and significance

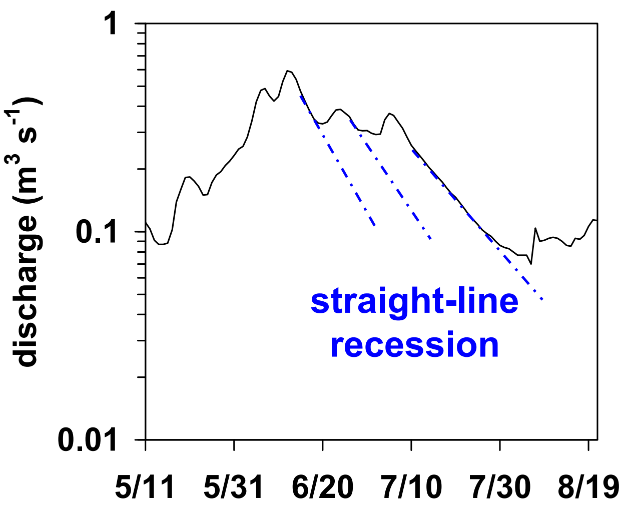
Portion of (stream) flow that comes from groundwater or other delayed sources (Tallaksen, 1995. *J. Hydrol.*, 165: 349).

Understanding of low-flow condition is important for water resource management and environmental protection.

→ Why?

In this lecture, we will review:
(1) Concept of baseflow recession
(2) Baseflow separation technique





Stream discharge gradually decreases after storm events.

Various baseflow 'separation' techniques have been proposed.

What purpose?

Regardless of sophisticated algorithms, they are all arbitrary.

Recession hydrographs commonly plot as straight lines on a semi-log graph.

$$Q(t) = Q_0 \exp(-at)$$

Q_0 : discharge at $t = 0$

a : constant (s^{-1})

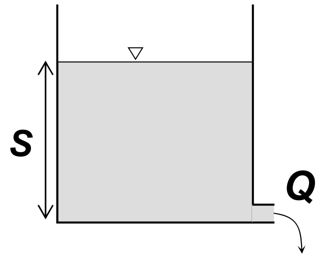
What causes the exponential behaviour?

Reservoir model for recession analysis

Exponential function is the solution of:

$$Q = aS \quad \text{and} \quad \frac{dS}{dt} = -Q \qquad \text{(linear reservoir)}$$

S: volume of water stored (m^3)



$$Q(t) = Q_0 \exp(-at)$$

Q_0 : discharge at $t = 0$

higher *a* → faster recession

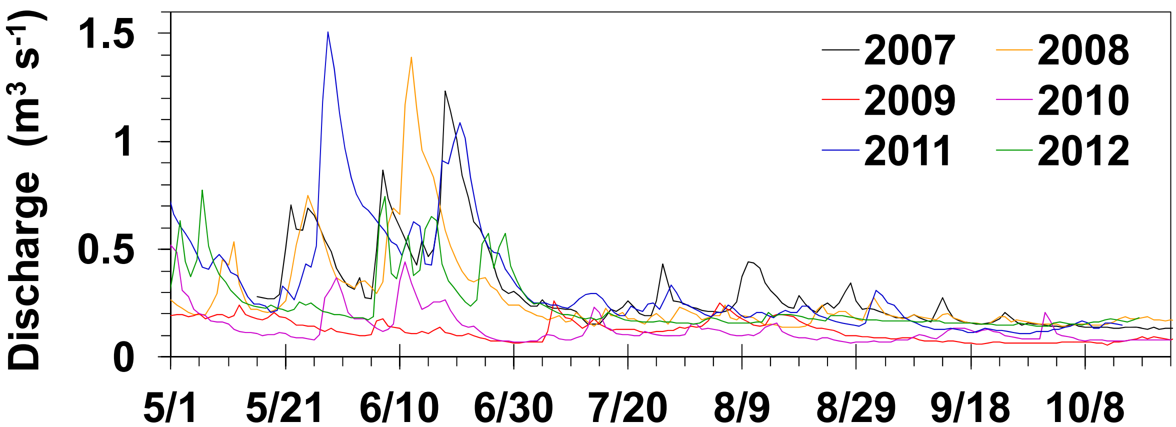
What controls *a*?

- Hydraulic conductivity of aquifer(s): *K* ($m\ s^{-1}$)
- Specific yield of aquifer(s): S_y (unitless)
- Slope of the catchment: Δ (unitless)
- Average length of slope: *L* (m)

$$a \propto \frac{K \times \Delta}{S_y \times L}$$

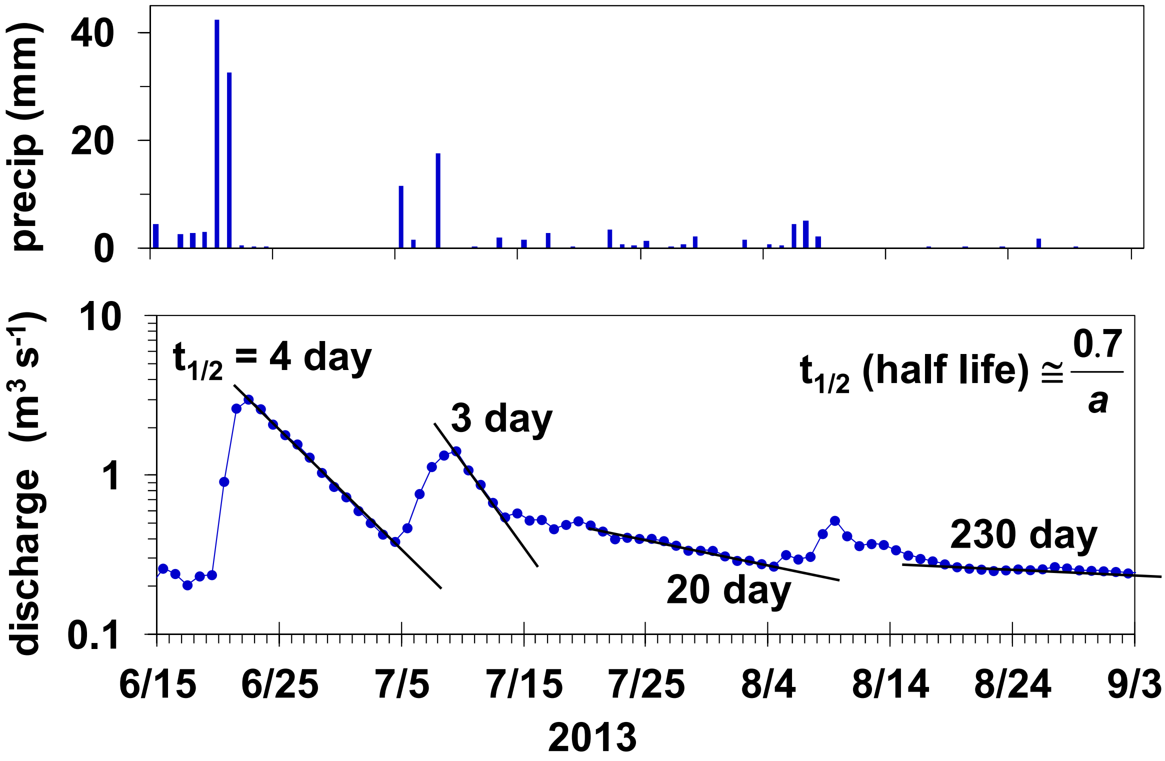
← Heuristic thinking (informal)
or
Dimensional analysis (formal)

Real Stream Example: West Nose Creek, Calgary



Hayashi and Farrow (2014. *Hydrogeol. J.* 22: 1825-1839)

Exponential Decay?

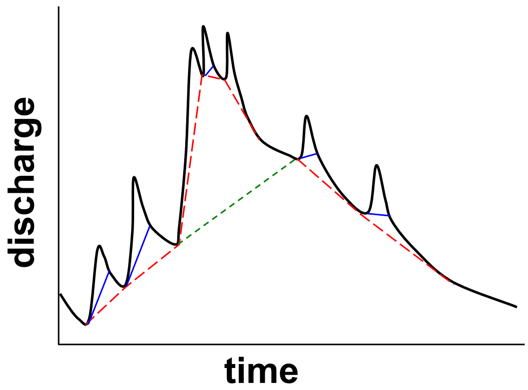


Why does the recession constant (*a*) vary?

Baseflow separation

Given a hydrograph, 'quick' flow and baseflow can be separated by a number of different methods.

- Connecting local minima
- Variation of local-minima method
- Using inflection points



All methods use arbitrary criteria for baseflow: convenient fiction.
→ See Lecture 1, slide 42.

They are also time consuming and labour intensive.

Automated techniques are at least objective and efficient for processing many data sets.

We will use a digital-filter algorithm of Arnold et al. (1995. *Ground Water*, 33: 1010) to demonstrate the usefulness and limitation of automated baseflow separation.

Recursive digital filter

The algorithm, originally described by Nathan & McMahon (1990. *Water Resour. Res.* 26: 1465), calculates the quick flow component q_i at time step i from q_{i-1} at previous time step and total flow Q_i and Q_{i-1}:

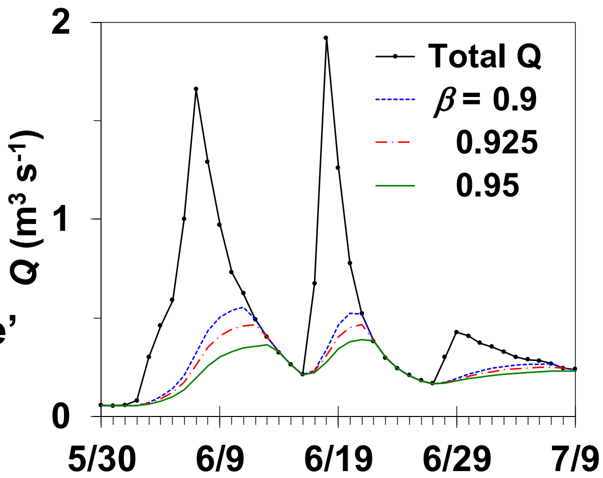
$$q_i = \beta q_{i-1} + \frac{1+\beta}{2}(Q_i - Q_{i-1})$$

where β is a filter constant ranging between 0.9 and 0.95.

Baseflow b_i is calculated as: $b_i = Q_i - q_i$

In this example from the Marmot Creek watershed in 2005, the filter was applied with three different values of β.

The case with $\beta = 0.95$ appears to have produced the most 'reasonable' separation result.



Baseflow index

By applying the digital filter to the entire 2009 summer discharge data set (May 1- September 10) for Marmot Creek, it was found that:

Total discharge = 2.48×10^6 m^3
Total baseflow = 1.77×10^6 m^3

The ratio of total baseflow to discharge is base flow index (BFI).

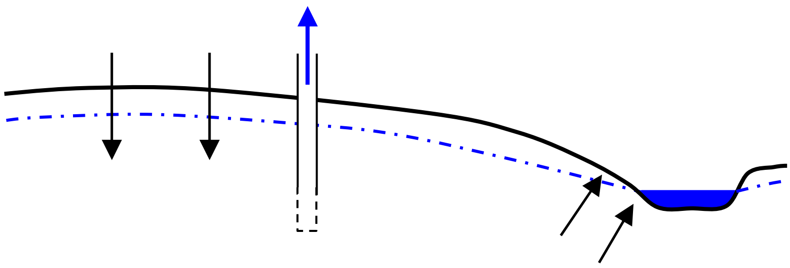
In this example, BFI = 1.77 / 2.48 = 0.76.

Automated baseflow separation offers a convenient tool to calculate BFI for multiple watersheds having different size and geology, or for a single watershed in multiple years having different meteorological forcing or land-use practice.

We will use a computer program Baseflow with a sample data set from the Marmot Creek watershed in a computer exercise to calculate BFI.

Baseflow Separation Exercise

Water Balance for Sustainable GW Management



Recharge − Discharge − Pumping = Storage Change
(water level ↑↓)

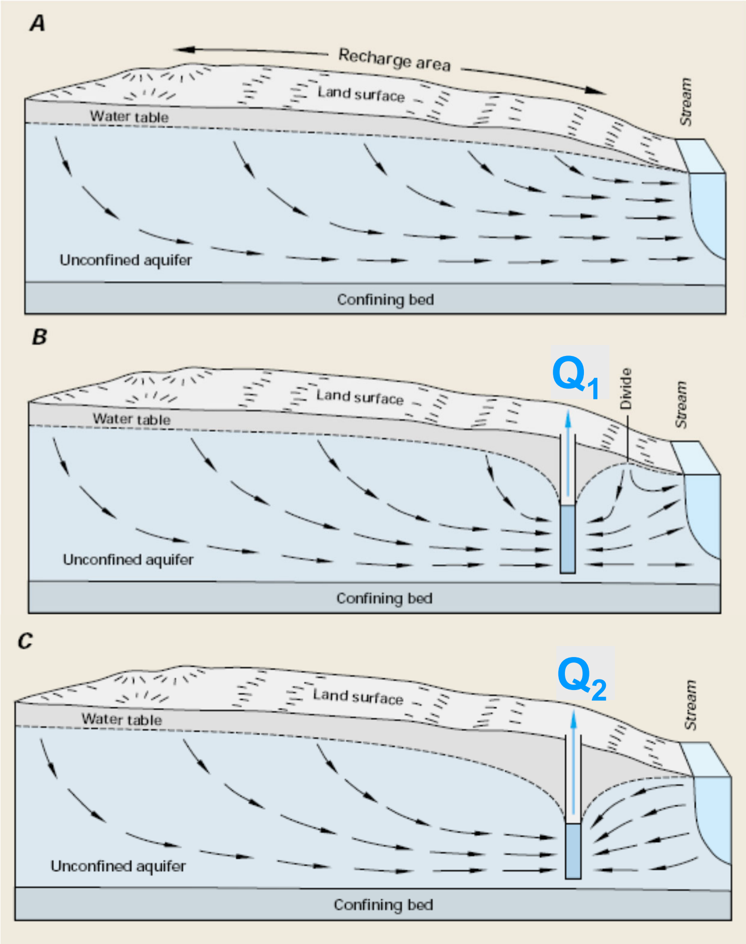
Long-term balance (dynamic equilibrium):

Recharge – Pumping ≈ Discharge

Over pumping may cause:

- **Large drawdown of groundwater level (wells going dry, land subsidence, etc.).** **storage depletion**
- **Reduction of baseflow, or drying of springs.** **surface water capture**

Effects of GW Pumping on Stream Flow

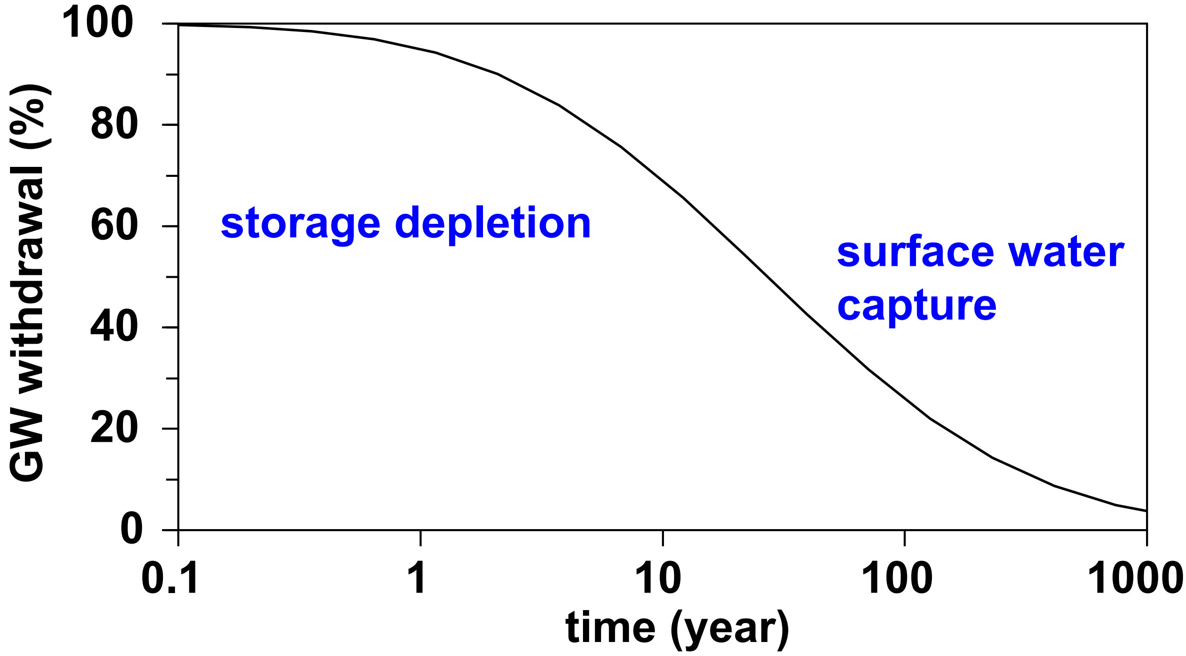


GW discharges to the stream under undisturbed conditions.

At relatively low pumping rates (Q_1), pumping from a well captures GW that would otherwise have discharged to the stream.

At higher pumping rates (Q_2), in addition to the GW capture above, pumping induces infiltration of streamflow into aquifer.

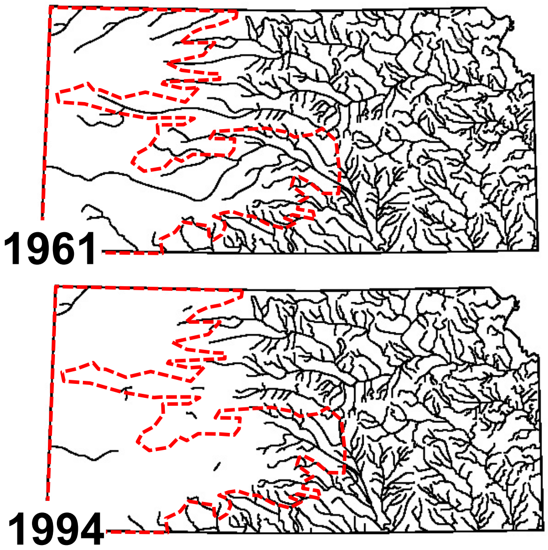
Transition from Storage Depletion to Surface Water Capture



M. Sophocleous (2000. *J. Hydrol.*, 235: 27-43)

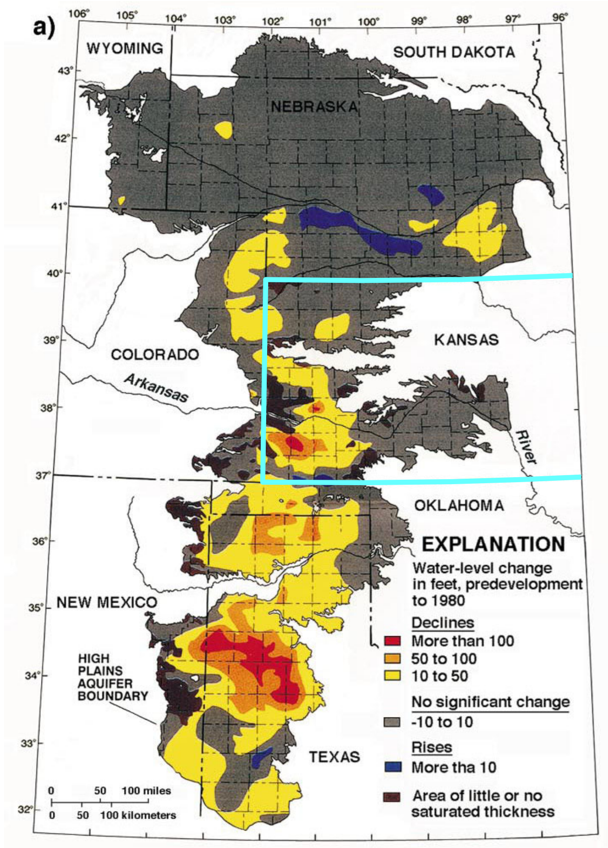
Long-Term Effects of Groundwater Extraction
Example from Kansas, U.S.

Ogallala Aquifer

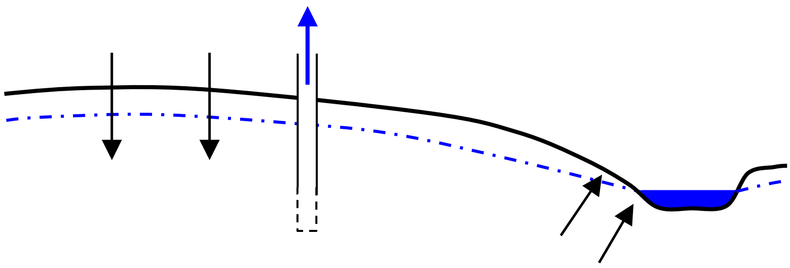


Major perennial streams in Kansas.

Sophocleous (2000. *J. Hydrol*., 235: 27)



Water Balance under Long-Term Equilibrium

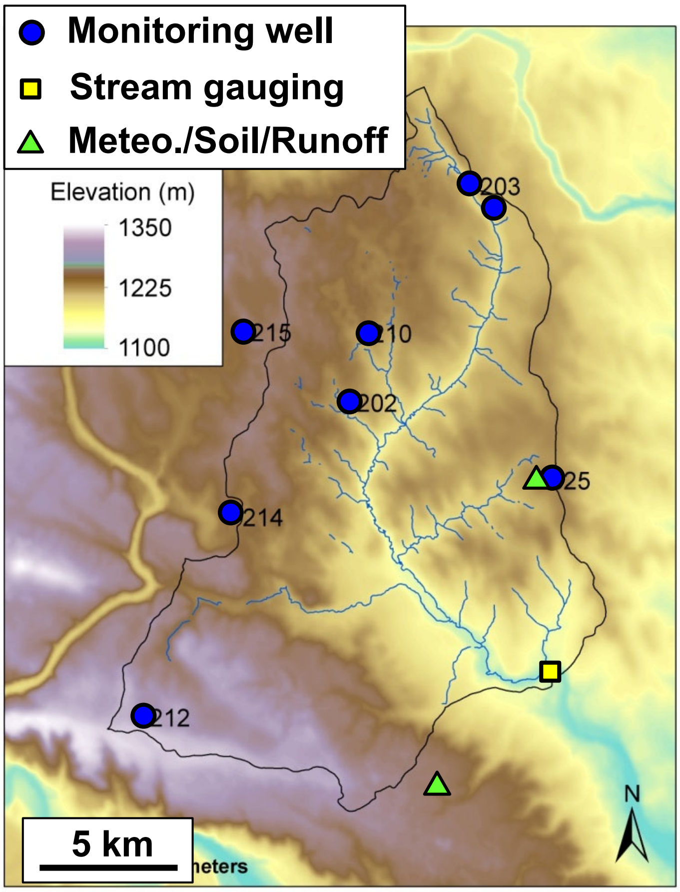


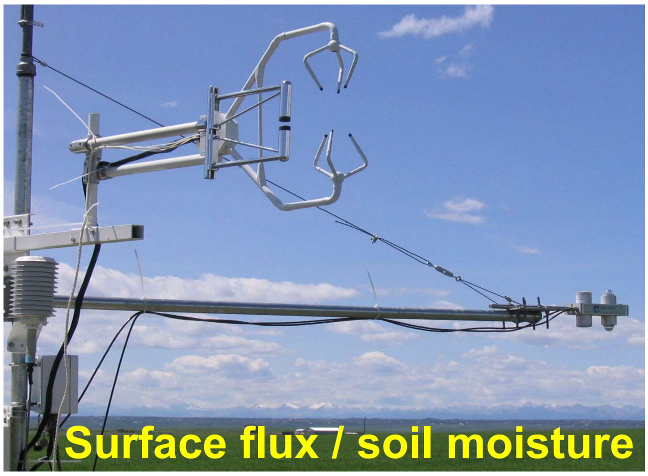
Recharge – Pumping – Discharge ≈ 0

Recharge ≈ Discharge + Pumping

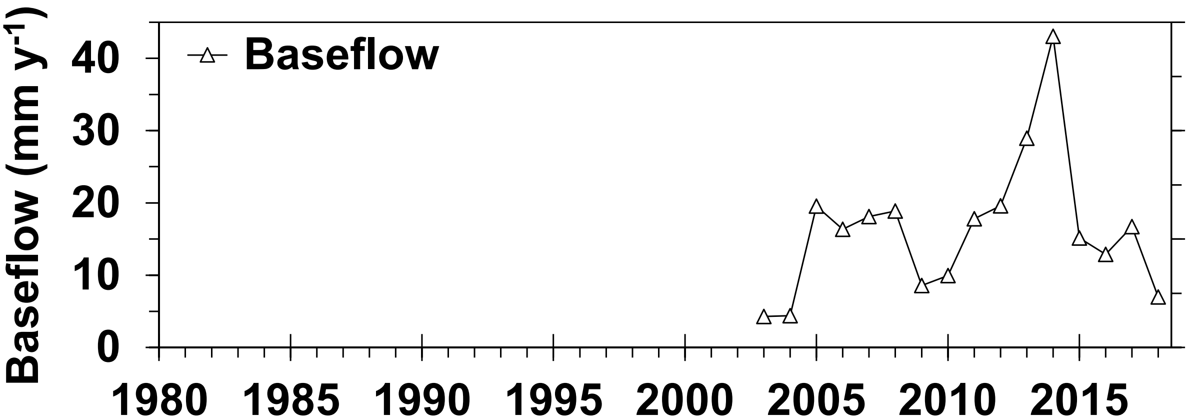
Use baseflow to estimate watershed-scale recharge.

West Nose Creek Hydrological Observatory



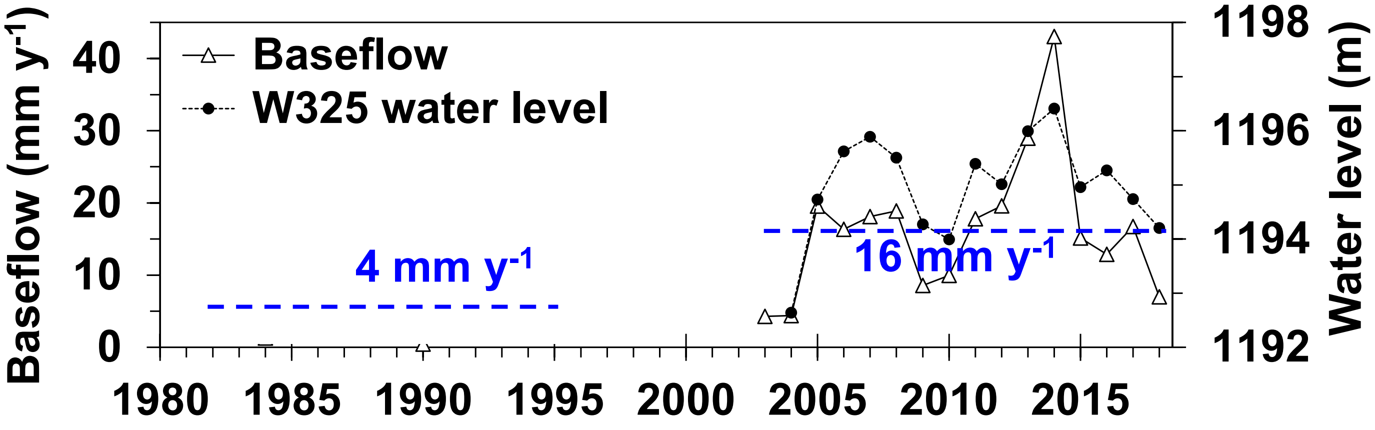


West Nose Creek Baseflow



Hayashi and Farrow (2014. *Hydrogeol. J.* 22: 1825-1839)

West Nose Creek Baseflow



Recharge ≈ Discharge + Pumping

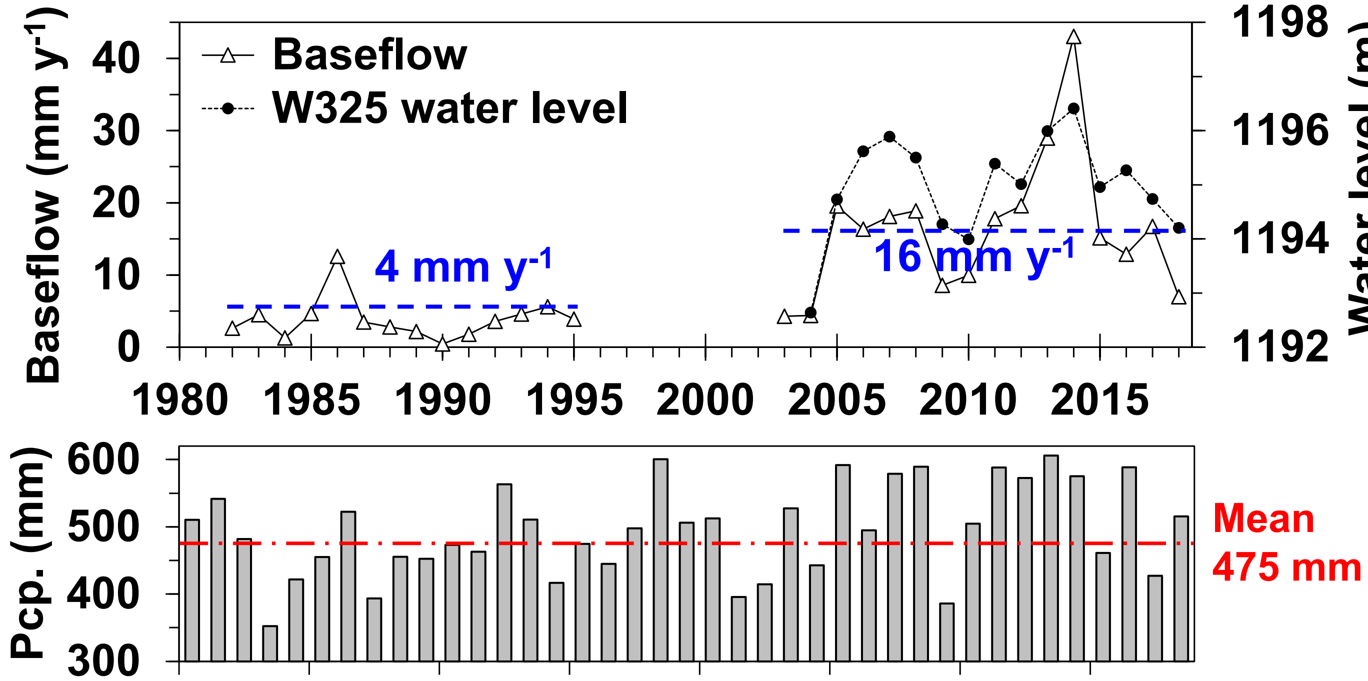
Total groundwater extraction ≈ 2-3 mm y^{-1}

Recharge ≈ 6-7 mm y^{-1} in 1982-1995

18-19 mm y^{-1} in 2003-2018

Hayashi and Farrow (2014. *Hydrogeol. J.* 22: 1825-1839)

West Nose Creek Baseflow



Present recharge ≈ 18-19 mm y^{-1}, much larger than GW extraction rate of 3 mm y^{-1}.

→ What if the drier condition of the 1980s returns?

Hayashi and Farrow (2014. *Hydrogeol. J.* 22: 1825-1839)