HYDROGRAPH SEPARATION: GRAPHICAL AND TRACER METHODS (AND WHAT THEY REVEAL ABOUT URBAN WATERSHEDS)

19 February 2013 – Urban Hydrology

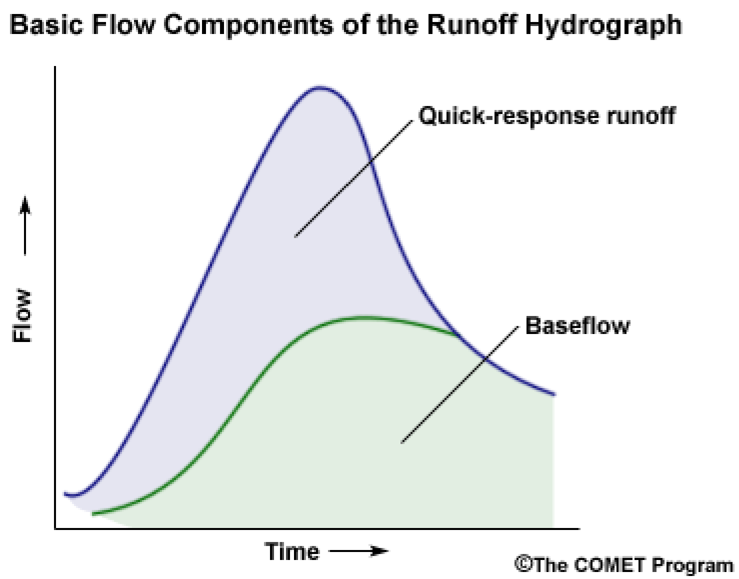
Why do hydrologists want to separate hydrographs?

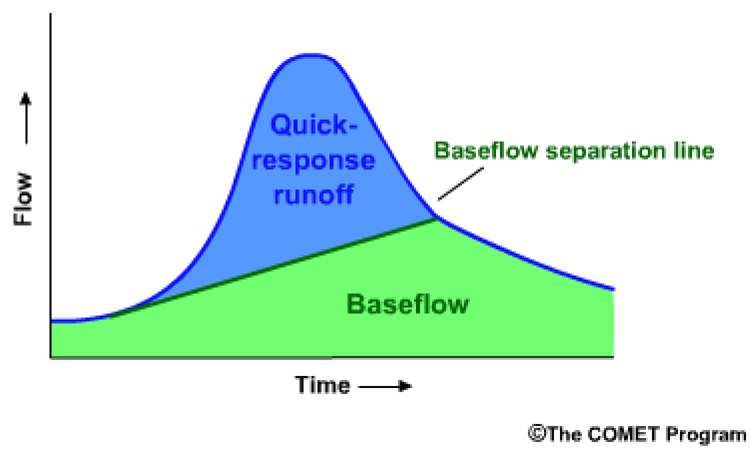
Where does surface runoff and streamflow come from?

- Hydrographs are the principal hydrologic data source available in most watersheds
  - Hydrograph contains much information about runoff sources in a watershed if we can just figure out how to separate these sources
- ***Teaser:*** Studies using isotopes to separate hydrographs revolutionized ideas about runoff in the late 1970s

Text modified from Doug Burns and Tomas Vitvar: http://www.esf.edu/hss/IsotopeWS/Burns-Vitvar%20presentation/sld001.htm

Graphical Hydrograph Separation:





- Graphical methods prevailed from the 1930s to 1960s
- Graphical methods still used by engineers and can be used as a basis for comparing runoff in different watersheds, but doesn't reveal much about processes

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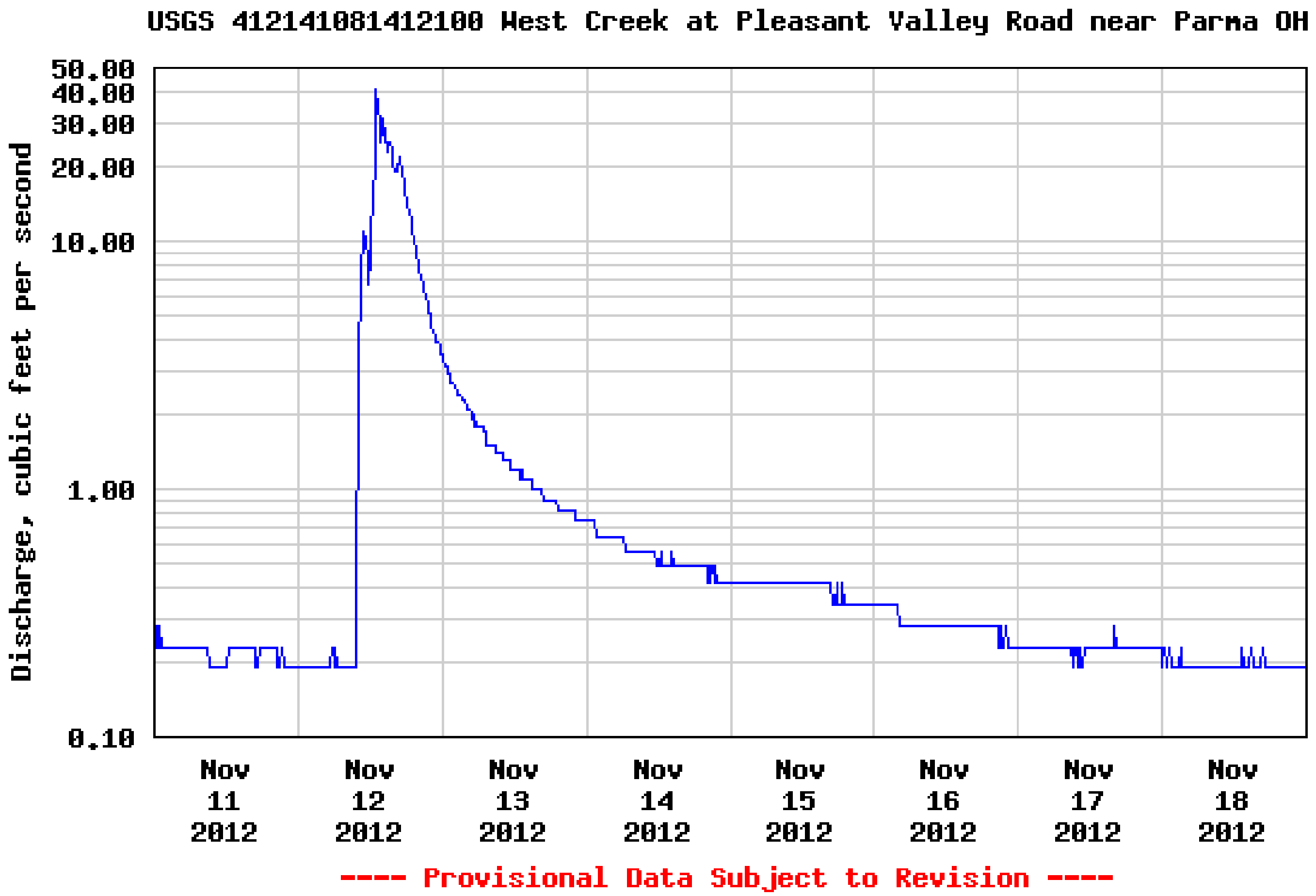
West Creek at Pleasant Valley Road

Go to: http://waterdata.usgs.gov/oh/nwis/uv/?site_no=412141081412100&PARAmeter_cd=00065,00060,00010)

Download data from November 11-18, 2012

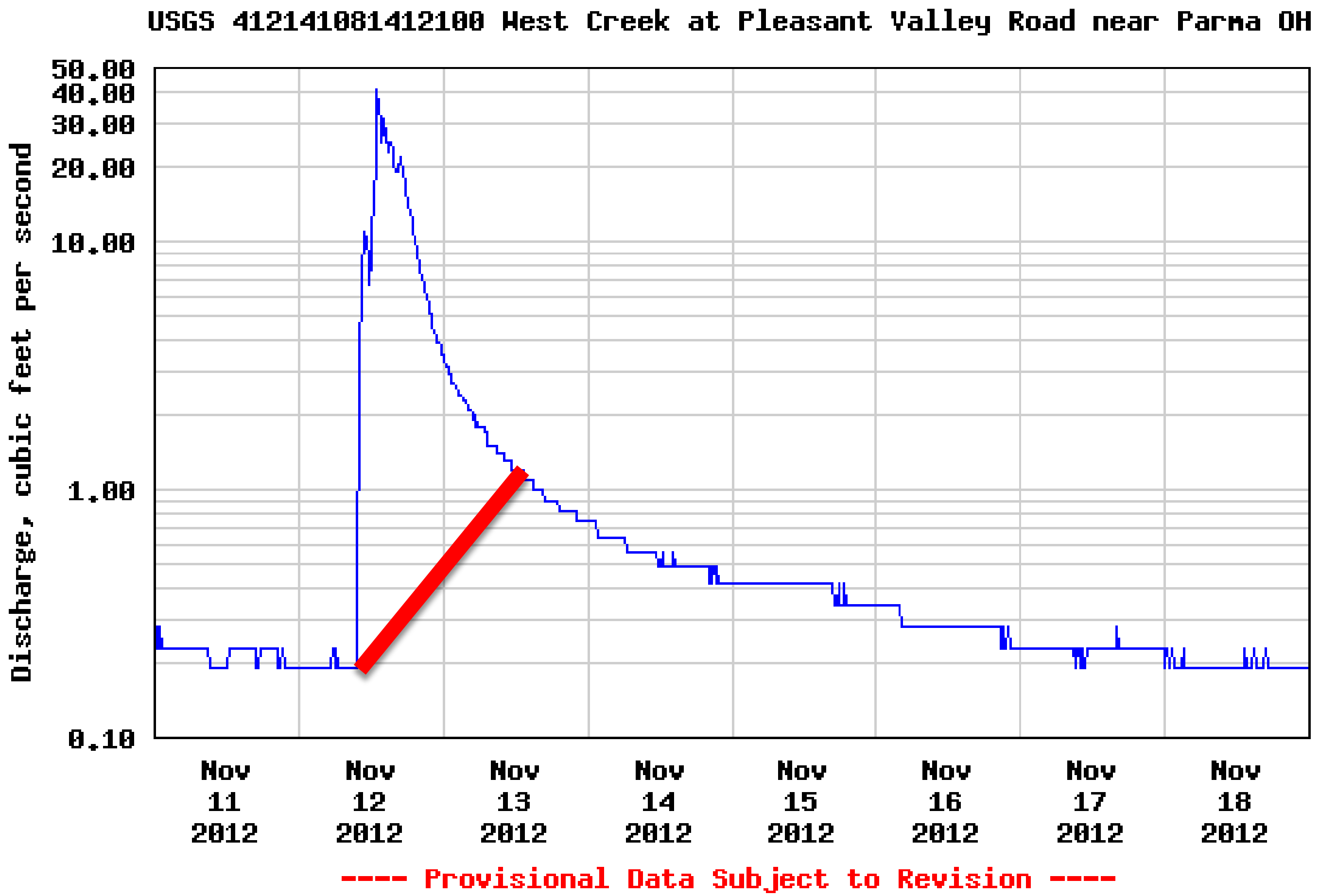


West Creek at Pleasant Valley Road

Start at start of rise, add 0.05 $ft^3/sec/mi^2/$ hour

($1.1\ mi^2 \rightarrow 0.045\ ft^3/sec/mi^2/$ hour or $0.011\ ft^3/sec/mi^2/$ 15 minutes)

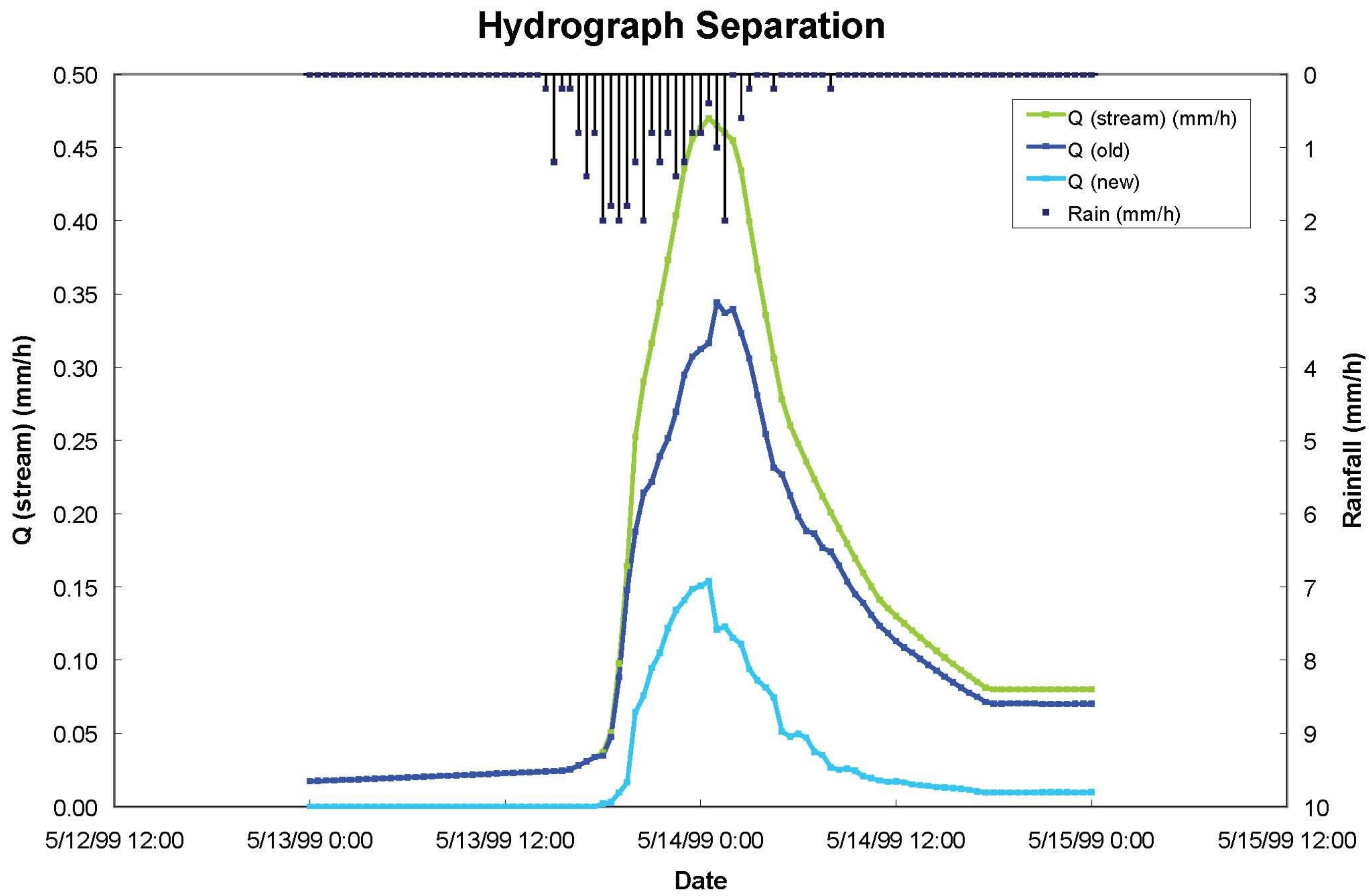
Until you intercept the falling limb



Quotes about Graphical Hydrograph Separation

- "Hydrograph separation is one of the most desperate analysis techniques in use in hydrology." -- Hewlett and Hibbert, 1967
- "Hydrograph separation appears to be little more than a convenient fiction." – Freeze, 1972

As transcribed by Doug Burns and Tomas Vitvar: http://www.esf.edu/hss/IsotopeWS/Burns-Vitvar%20presentation/sld001.htm



(data from McGlynn and McDonnell (2003)).
http://serc.carleton.edu/microbelife/research_methods/environ_sampling/stableisotopes.html

Hydrograph separation using isotope tracers

- Method takes advantage of conservative mixing of ^{18}O and ^{2}H
- Two types
  - Time source – new and old water
  - Geographic source – contributions from different landscape positions
- Punchline: Isotope methods clearly show much of stormflow or peakflow is old water stored in catchment prior to storm (*in forested watersheds*)

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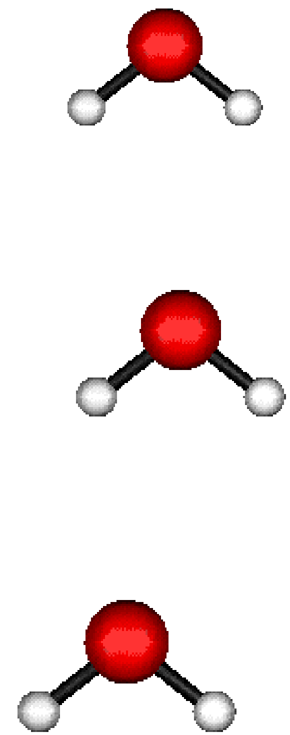
Stable Isotopes Tracing the Hydrologic Cycle

- Stable Isotopes of H_2O
  - ^{1}H, ^{2}H (^{2}D), ^{16}O, ^{17}O, ^{18}O
- Vibrational frequency (energy) differences
- Provide characteristic fingerprint of origin
- Applications in hydrogeology
  - Provenance of water
  - Identify processes that formed waters
  - Separating hydrographs into "old" and "new" water

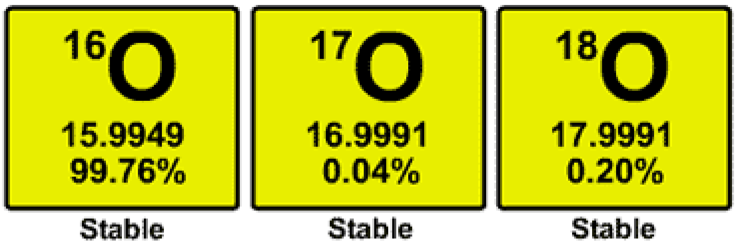


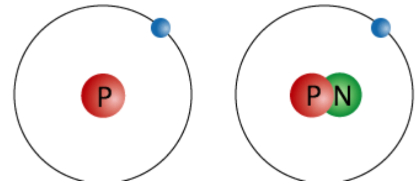
Characteristic vibrations of H_2O

Slide from E. Griffith, UT Arlington

Animations courtesy of E. Schauble (UCLA)

Isotopologues of Water





^{1}H
99.985%

$^{2}H = D$
0.015%

- **Isotopologues** are molecules that differ only in their isotopic content. *What are the isotopologues of water?*

Isotope Ratio notation

$$\delta^{18}O = \left[\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1 \right] \times 1,000$$

- δ = value ‰ 'per mil'
- O and H are normalized to SMOW – standard mean ocean water
  - $\delta^{18}O$ = 0‰, $\delta^{2}H$ = 0‰
- Positive vs. negative delta values
- Isotopically heavy vs. light

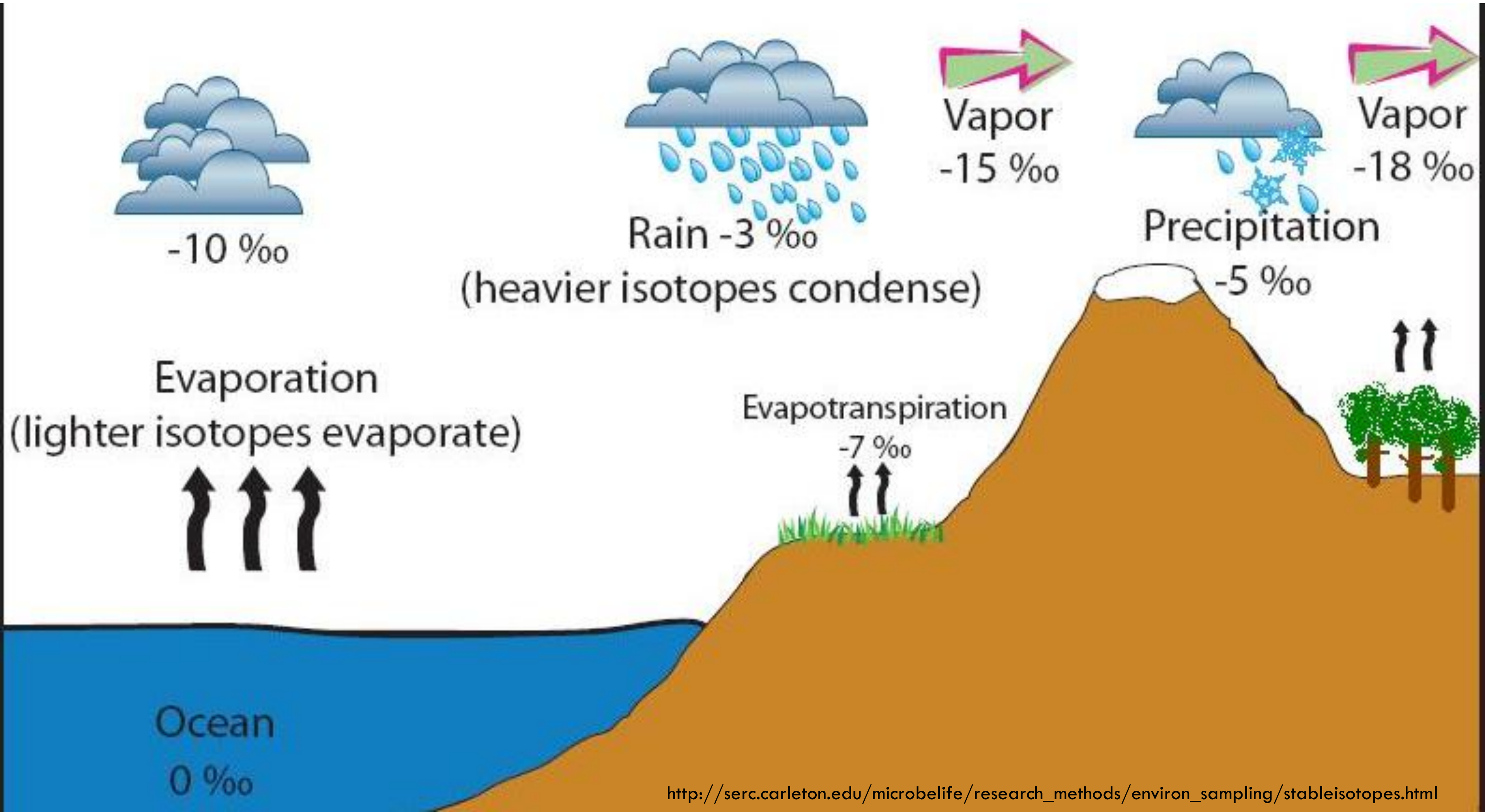
Isotopic fractionation: Detectable change in the ratio of an isotopic pair

- **Due to mass differences of isotopes**—affect vibrational frequency of atom which affects ability to make (& break) bonds w/ surrounding environment
- ^{18}O and ^{2}H content of water changes only through fractionation **associated with phase changes**
- **Conservative behavior** – once isotopes become part of water molecule, they change only through mixing

Fractionation effects associated with phase changes of H_2O

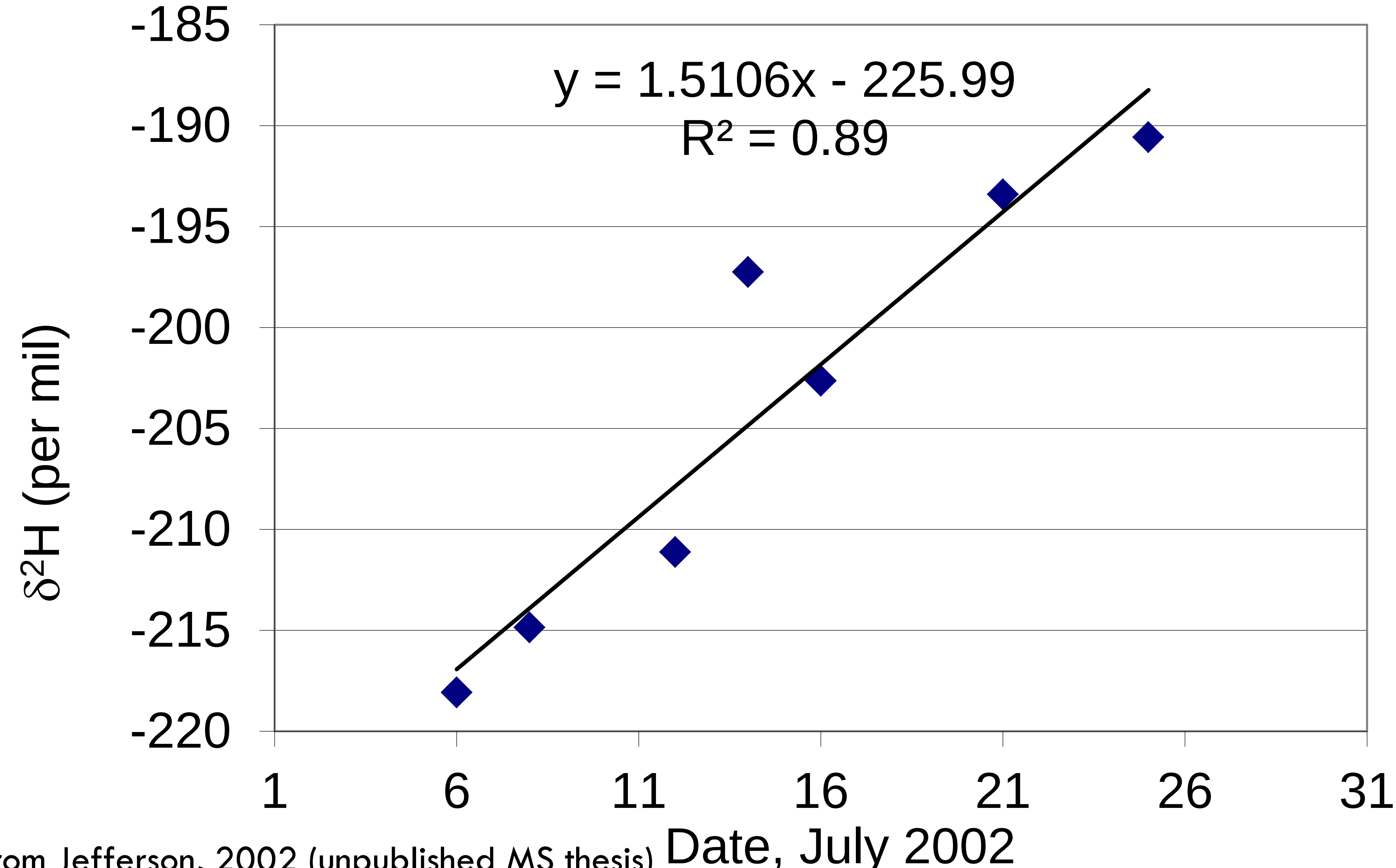
- **Evaporation** – vapor that forms is lighter than surrounding water
- **Condensation** – liquid that forms is heavier than surrounding water
- So, precipitation selectively removes ^{18}O and ^{2}H from the vapor phase
- **Snowmelt** – residual snowpack becomes isotopically heavier as light isotopes melt out first

Fractionation effects associated with phase changes of H_2O



http://serc.carleton.edu/microbelife/research_methods/environ_sampling/stableisotopes.html

July snowmelt, Stenkul Fiord, Ellesmere Island, Nunavut, Canada



From Jefferson, 2002 (unpublished MS thesis)

Geography and seasonality of ^{18}O and ^{2}H content of precipitation

- Precipitation becomes lighter as air mass moves inland
- Precipitation becomes lighter with increasing elevation – orographic effect
- Precipitation becomes lighter towards the poles and is lighter in winter than summer

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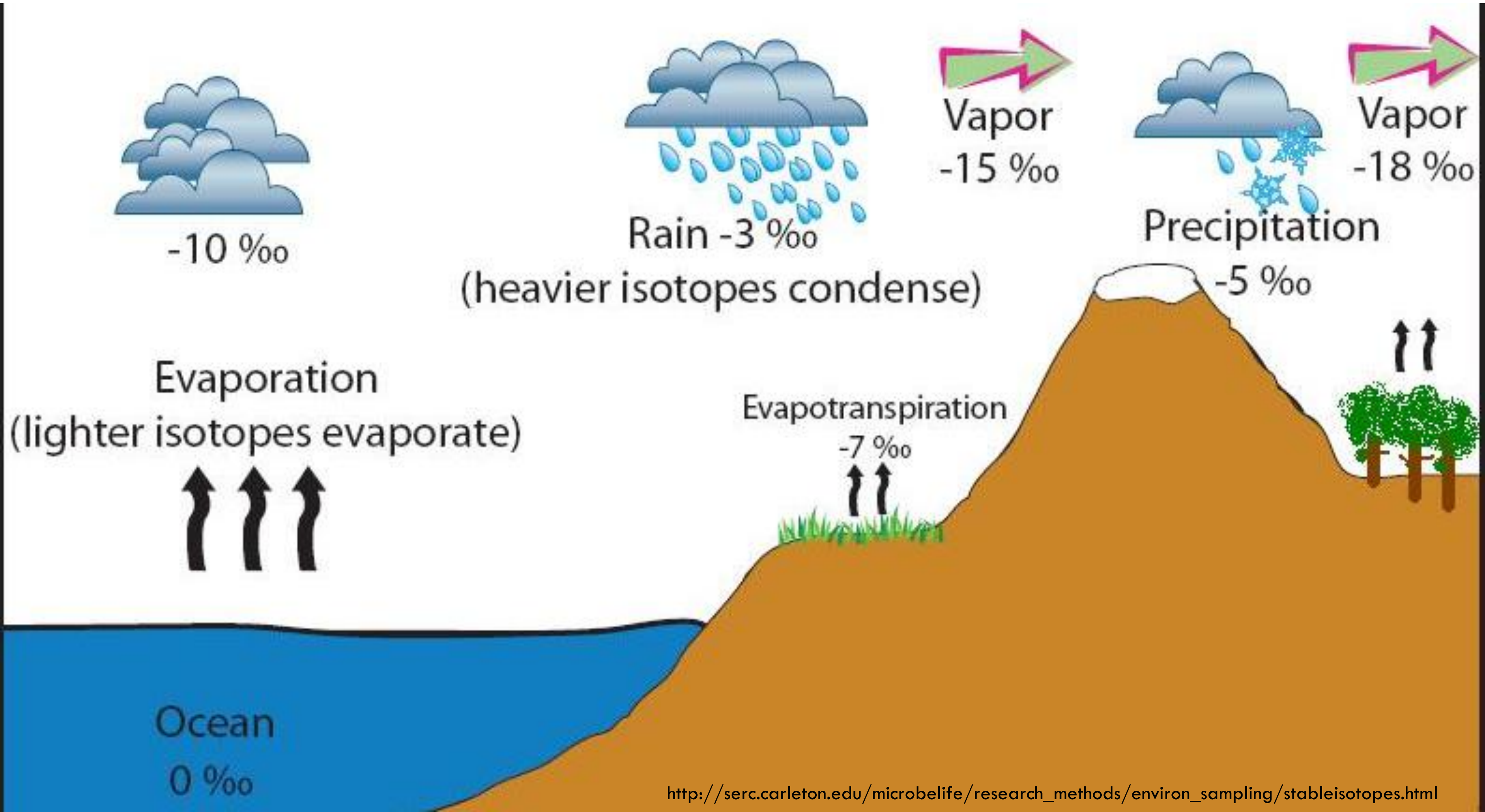
Fractionation effects associated with phase changes of H_2O



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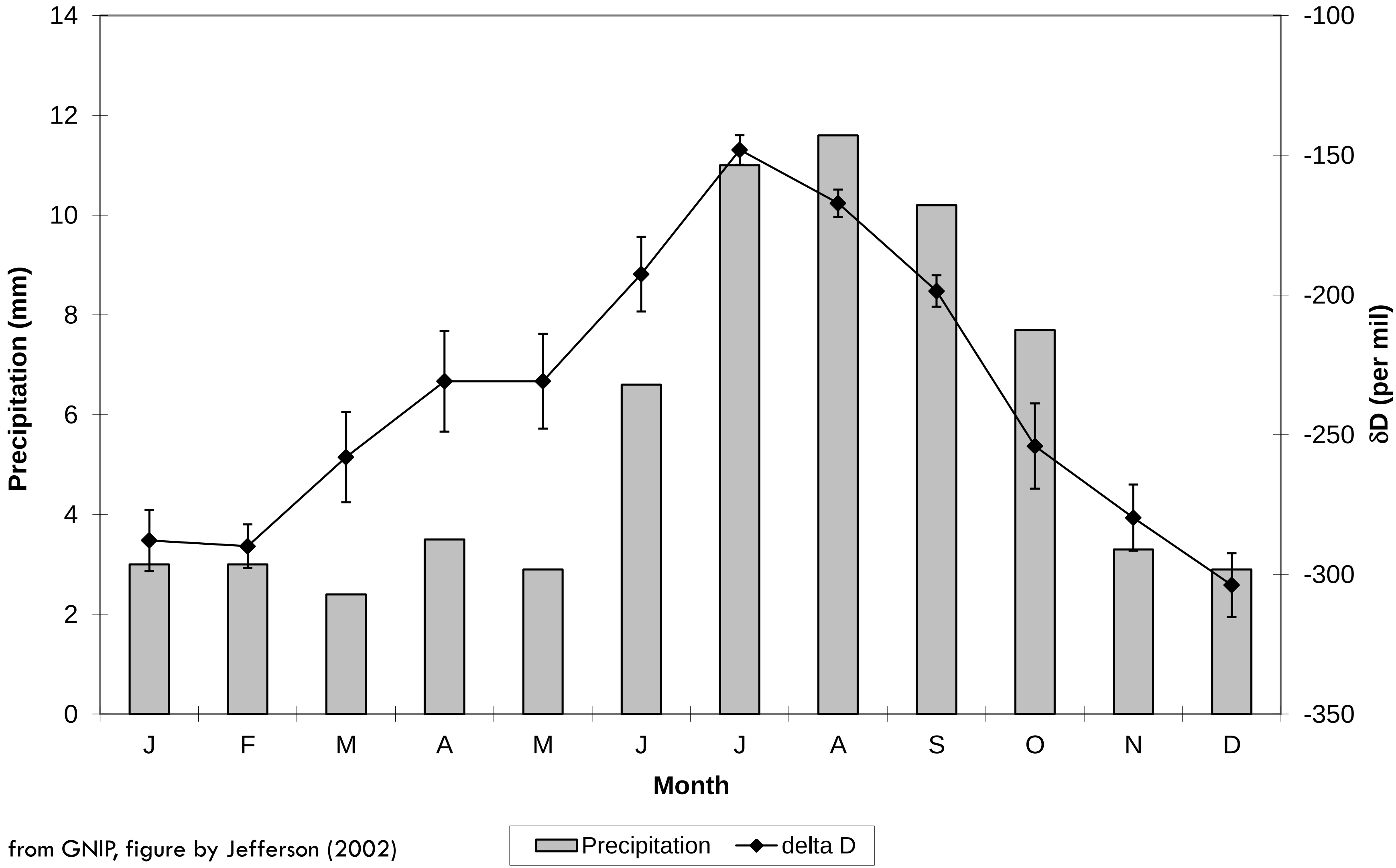
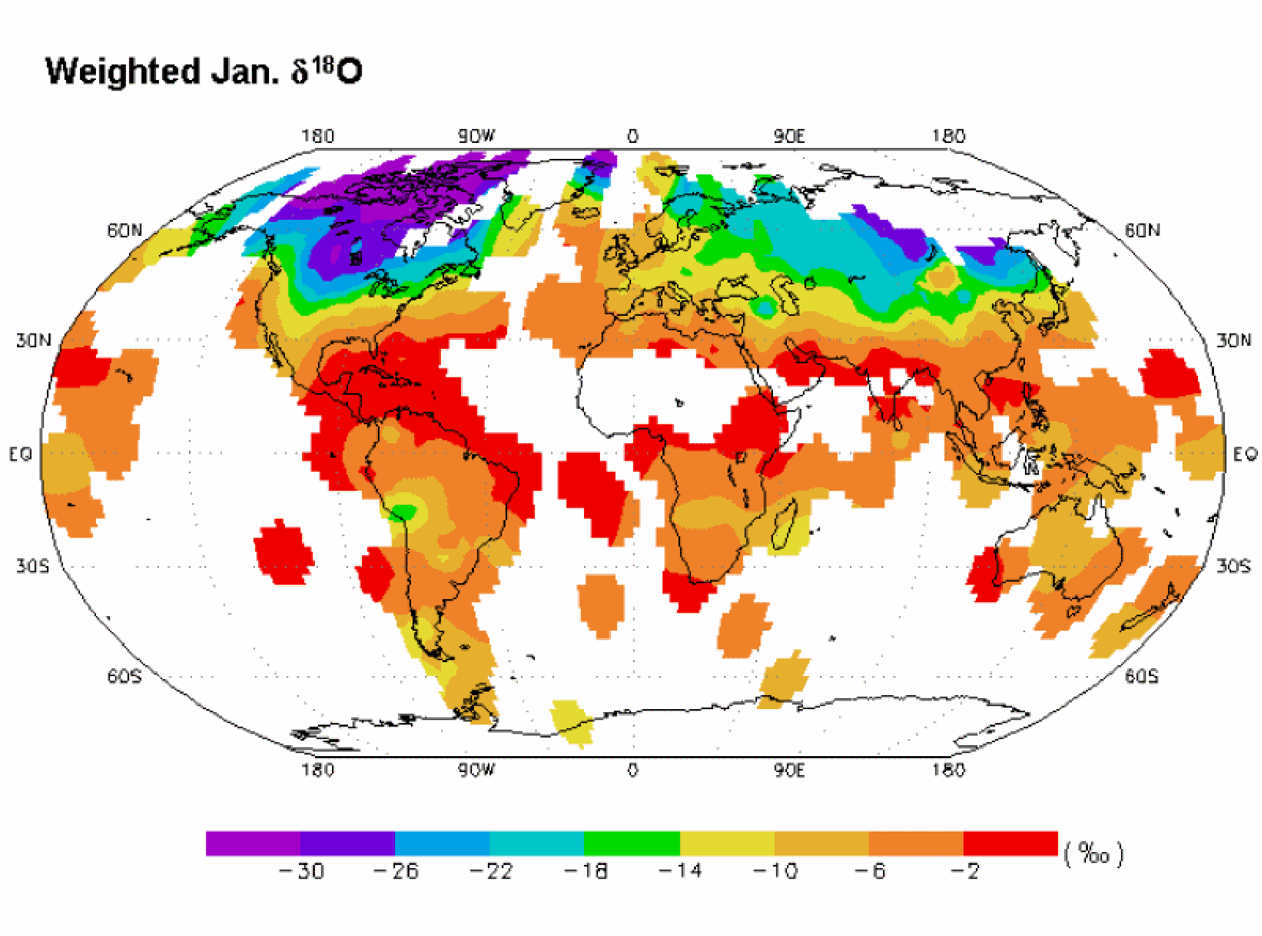
Seasonality of precipitation isotopes, Eureka, Nunavut, Canada



Data from GNIP, figure by Jefferson (2002)

Global pattern $\delta^{18}O$ in rainwater



http://www.iaea.org/programmes/ripc/ih/iaea_waterloo_gnipmaps/iaea_waterloo.htm

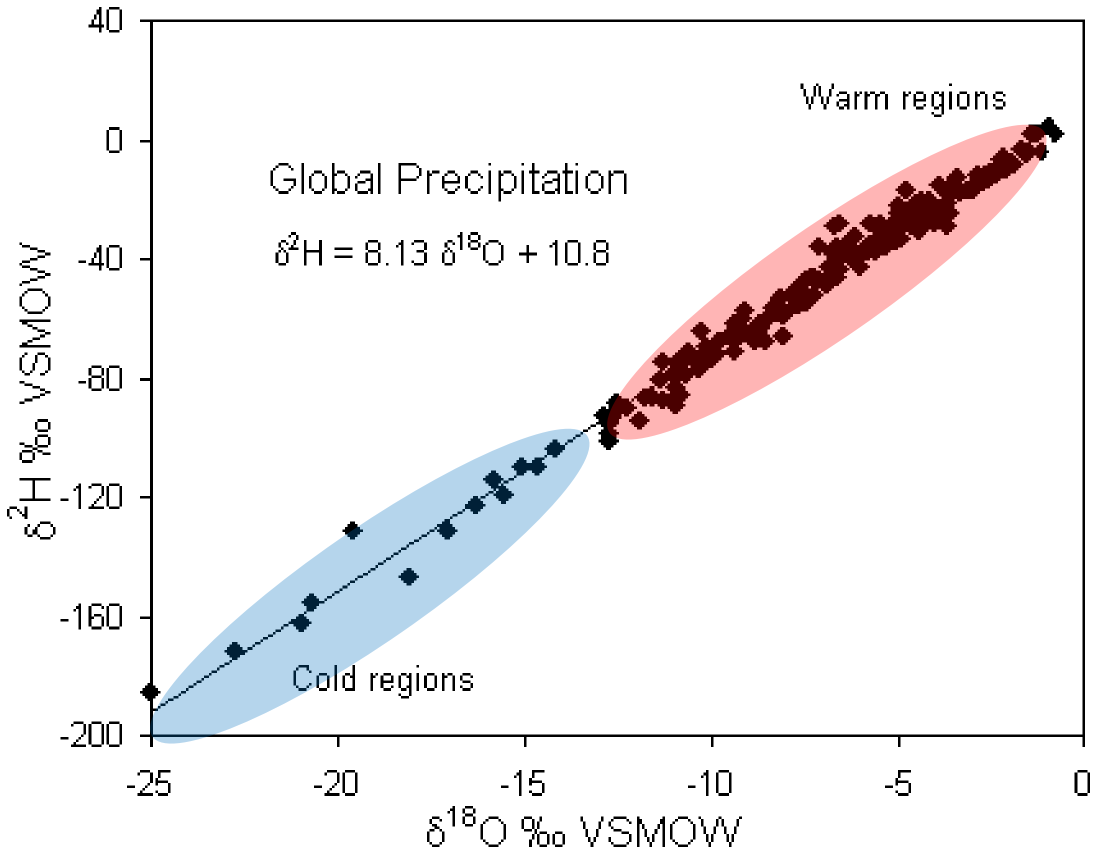
IAEA/University of Waterloo

Slide from E. Griffith, UT Arlington

Precipitation: Equilibrium & the "Global Meteoric Water Line"

Sam Epstein and Toshiko Maveda,1953

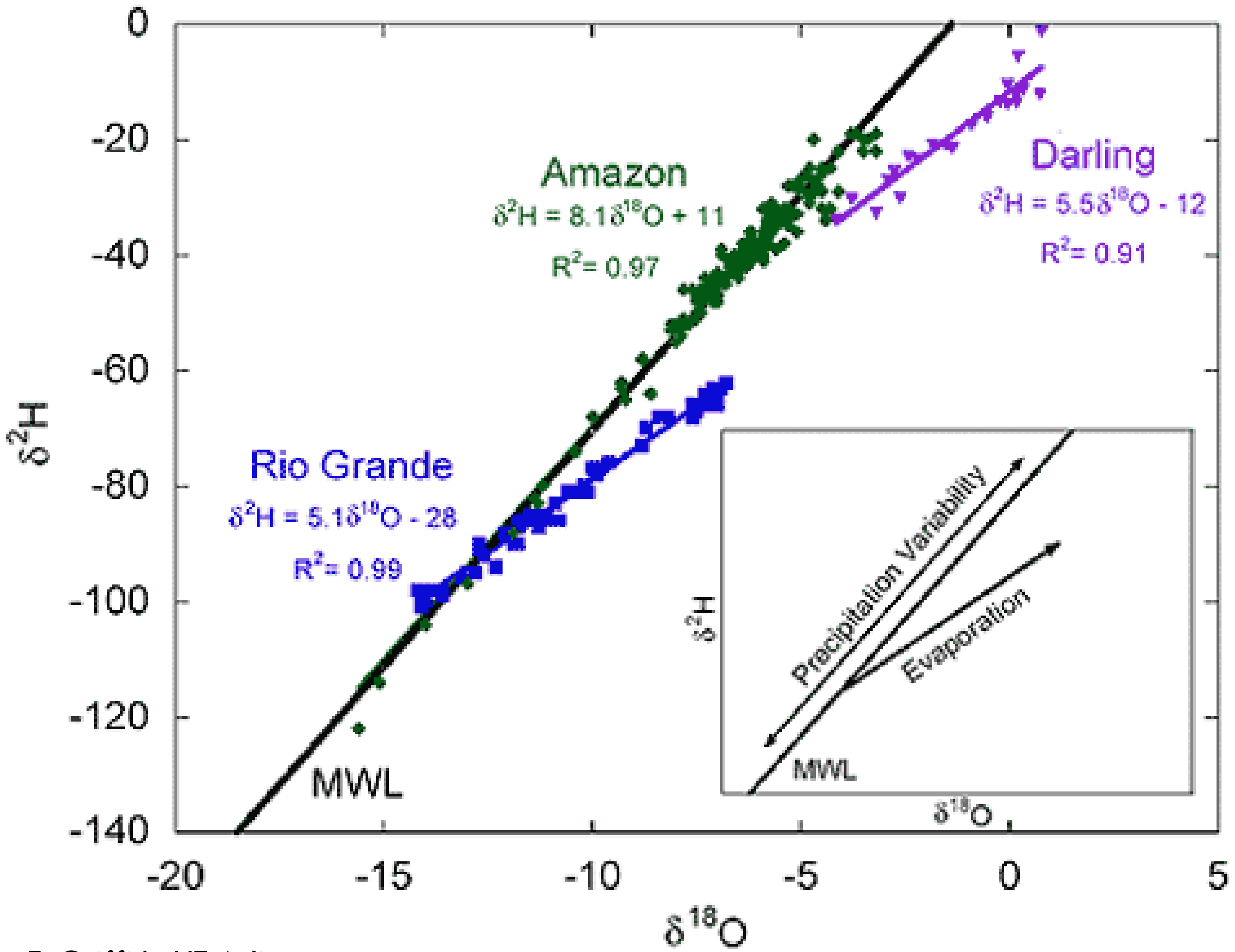
Harmon Craig (1961) defined the relationship between ^{18}O and ^{2}H in worldwide fresh surface waters.



Craig (1961); Rozanski et al. (1992)

Slide from E. Griffith, UT Arlington

Evaporation: Humidity & Local Meteoric Water Lines



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Isotopes in storm-discharge analysis

Iqbal, M.Z. 1998. Application of environmental isotopes in storm-discharge analysis of two contrasting stream channels in a watershed, *Wat. Res.*32(10): 2959-2968

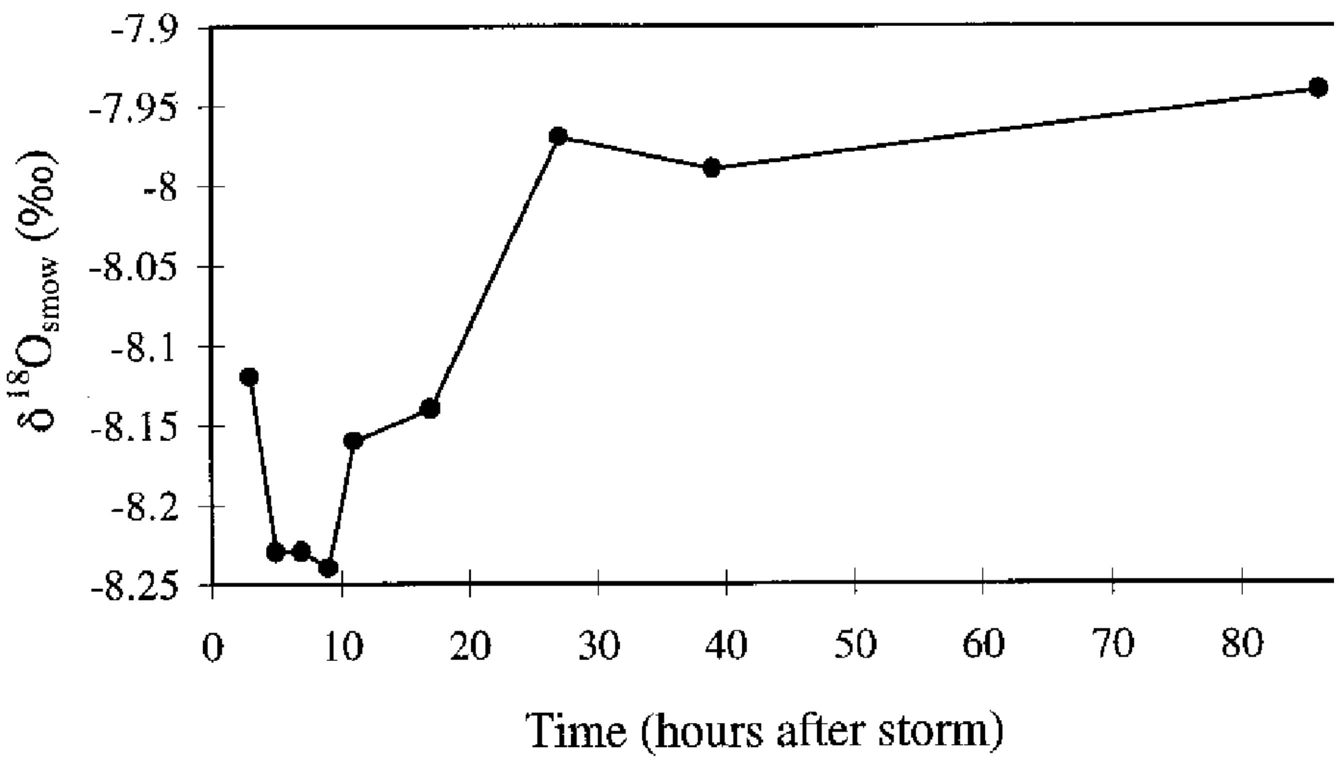

Fig. 3. Temporal variations in the oxygen isotope ratio (Cedar River).

Isotope Hydrograph Separation: How is it done?

- Simple mass balance expression
- Streamflow = new water + old water
- $Q_s\delta_s = Q_n\delta_n + Q_o\delta_o$
- Rearrange to solve for the new water discharge at any point in time
- $Q_n = Q_s \times (\delta_s - \delta_o)/(\delta_n - \delta_o)$

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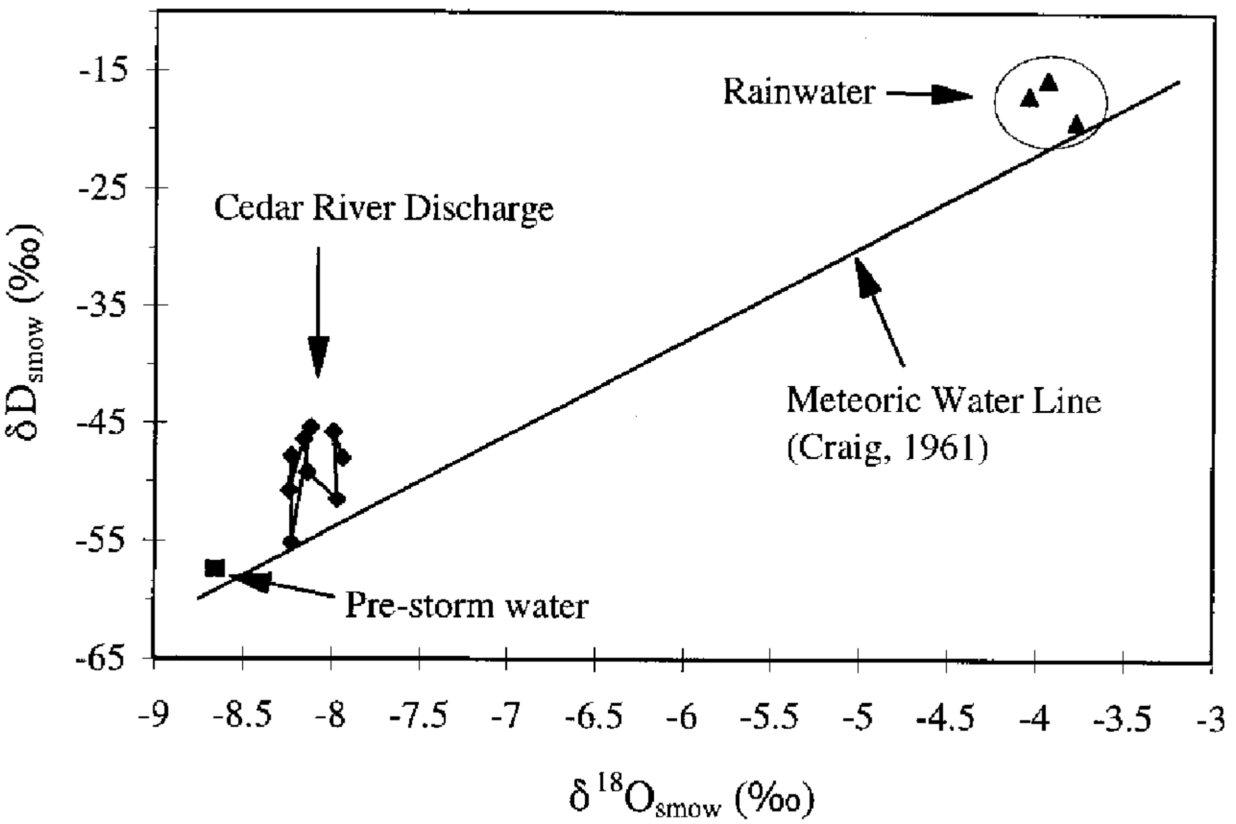

g. 4. Isotopic evolution of instantaneously discharged water in Cedar River by simple mixing

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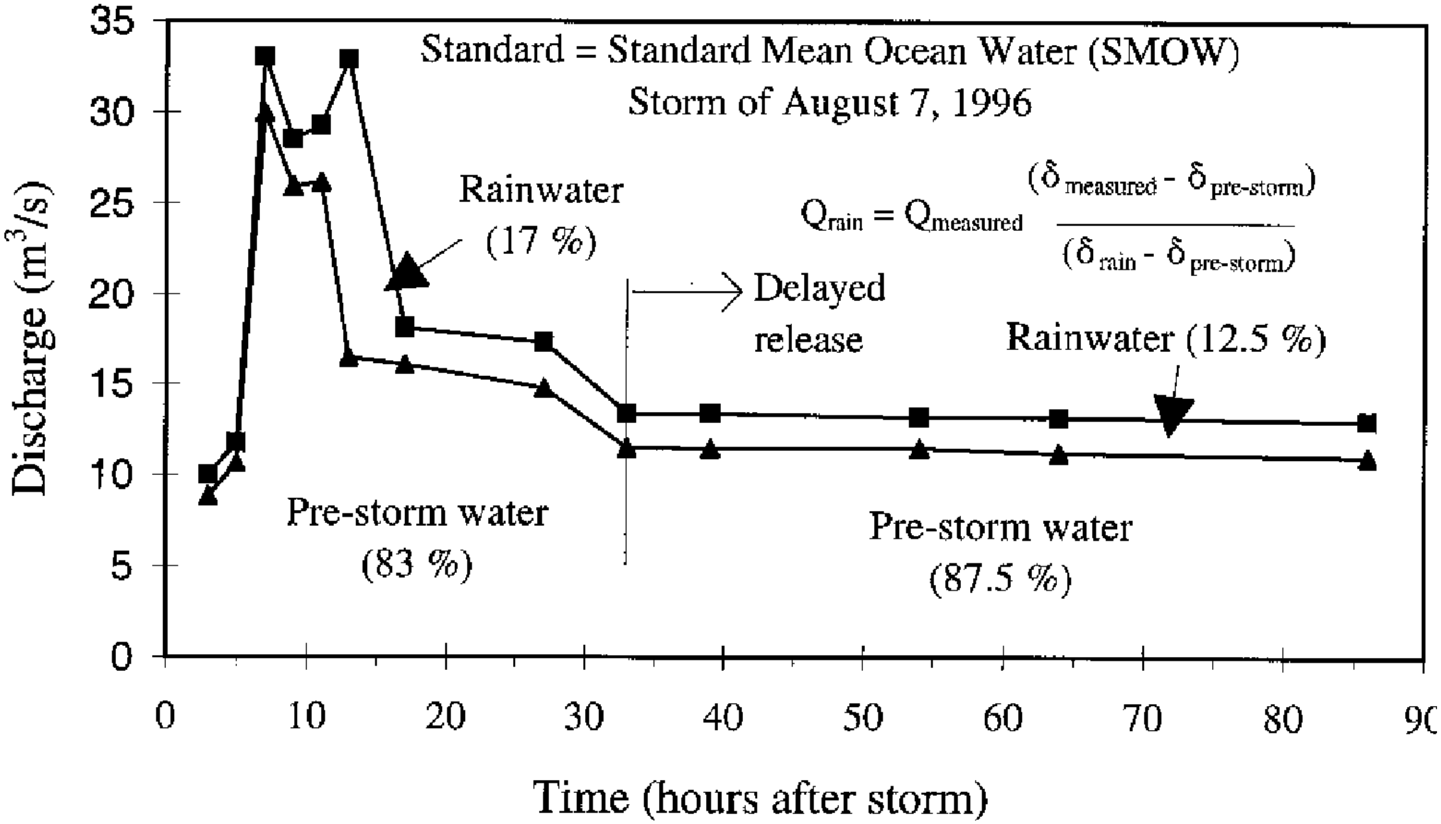

Storm hydrograph separation of the Cedar River using two-component mixing model oxygen isotope data).

Assumptions of Isotope Hydrograph Separations

- Significant differences in isotopic content of new and old water
- New and old water content has a constant isotopic content in space and time, or variation can be accounted for
- Contributions of water with with isotopic content different from old water negligible – soil water, stored surface water, multiple sources of gw

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General results of hydrograph separation studies

- Old water is typically >50% of peakflow, 60-80% of total storm runoff at most sites (but humid, forested site bias)
- Agricultural and **urban watersheds** are dominated by new water at peak flow
- Wetlands and impoundments promote high proportion of old water in stormflow

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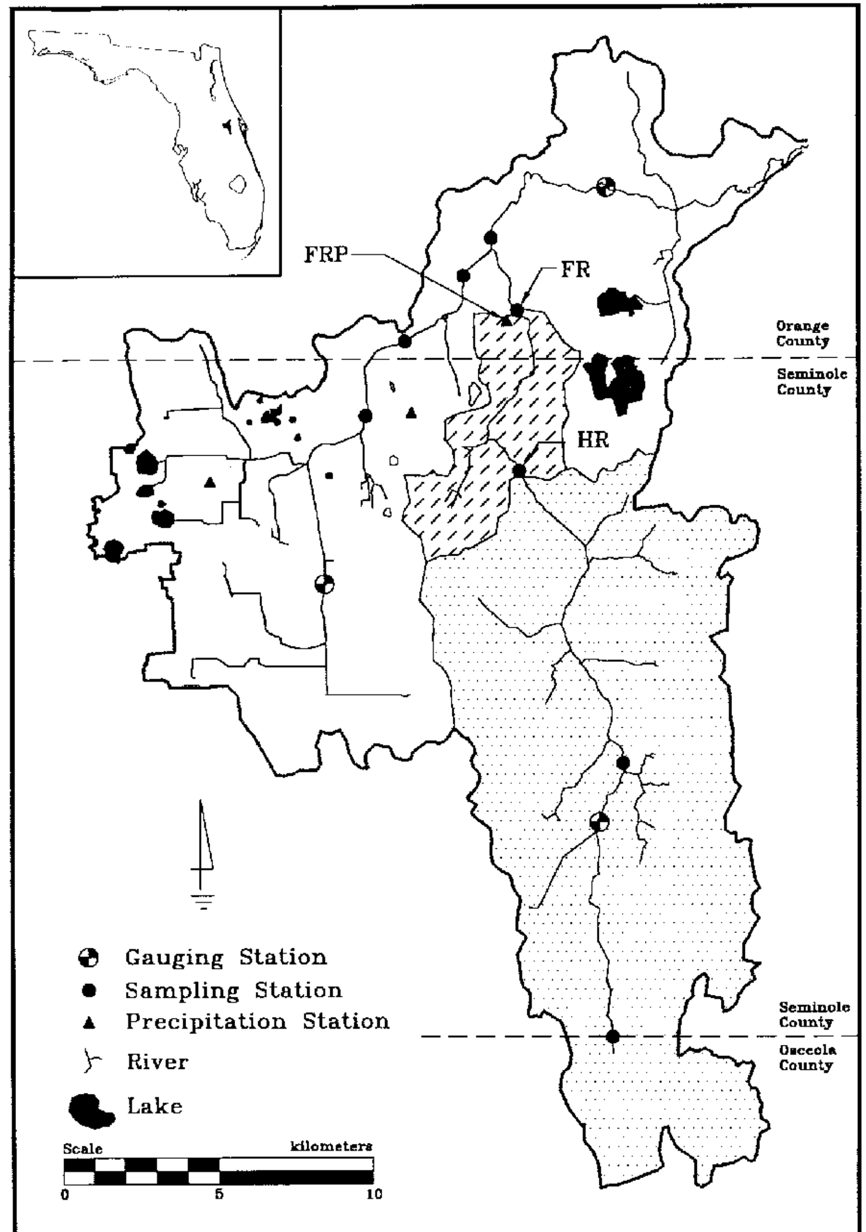
How does urbanization show up in isotope hydrograph separation?

Table I. Land use in subcatchments of the Econlockhatchee River basin, Florida (Source: Wanielista *et al.*, 1992)

Land use	Upstream from station HR (%)	Subcatchment between HR and FR (%)
Urban	5	23
Agricultural	26	30
Upland forest	36	21
Wetlands and open water	33	26



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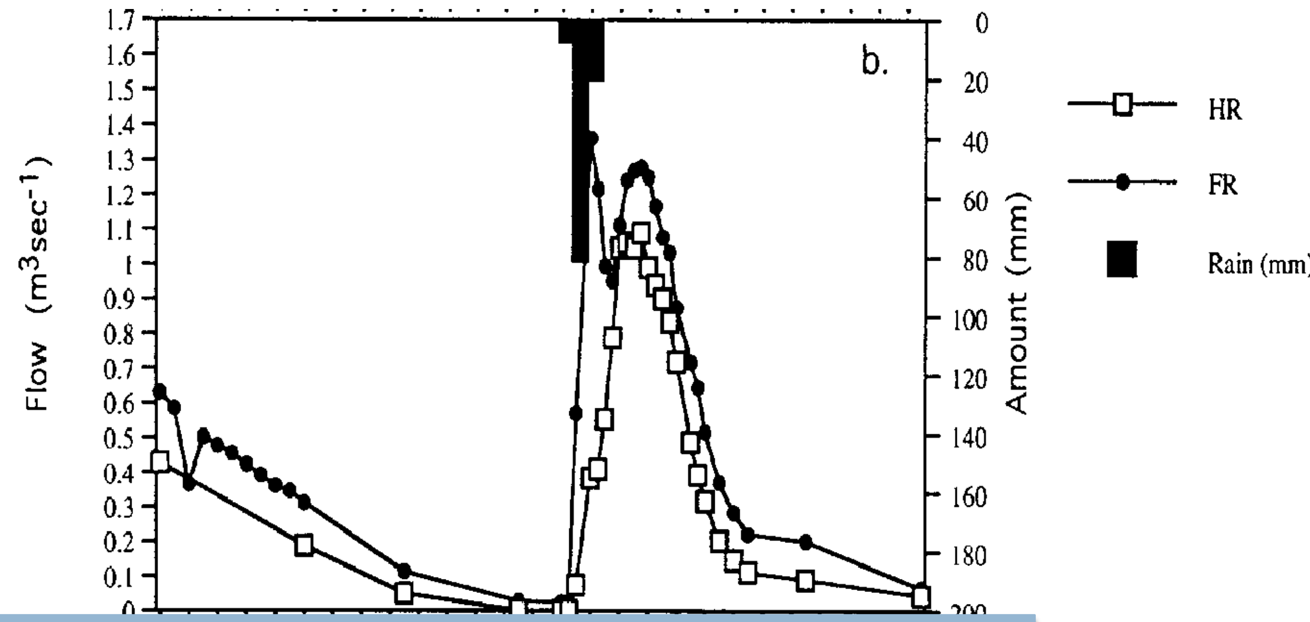

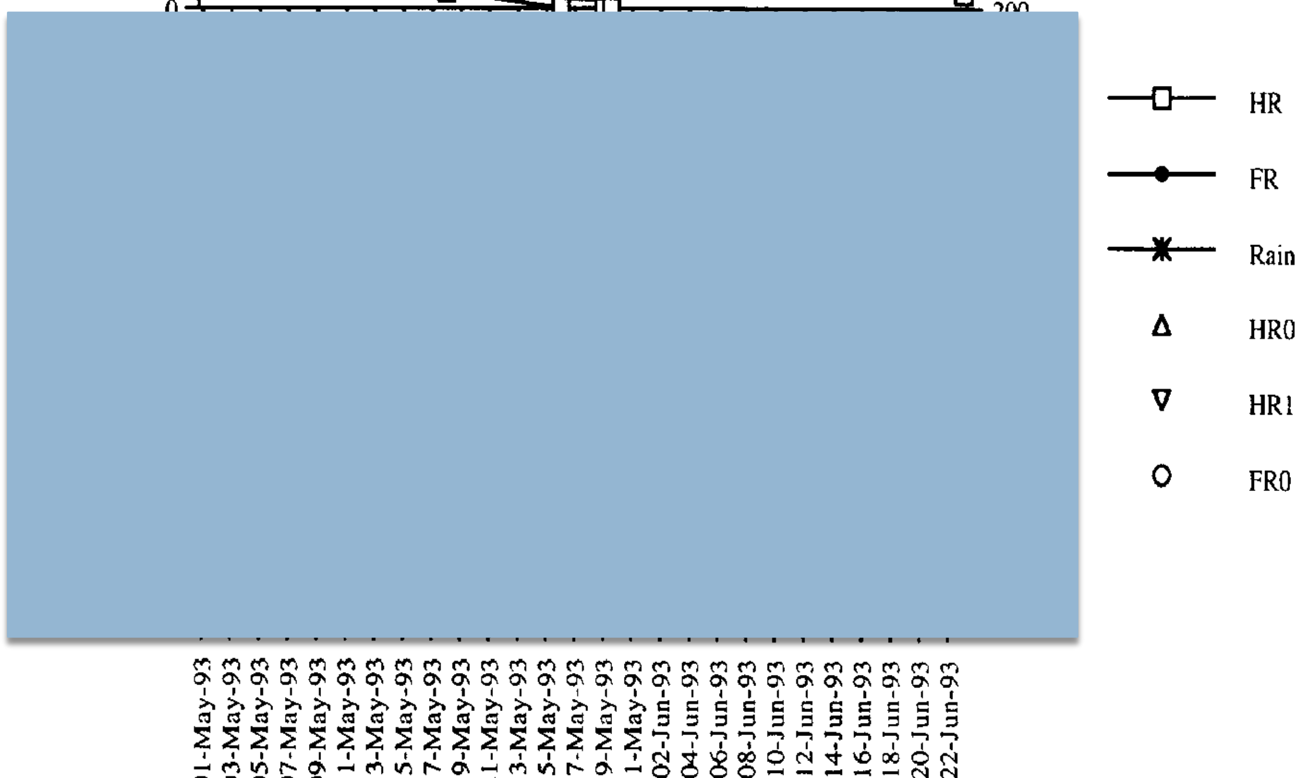

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Urbanizing Florida watershed

Downstream of urbanizing subcatchment

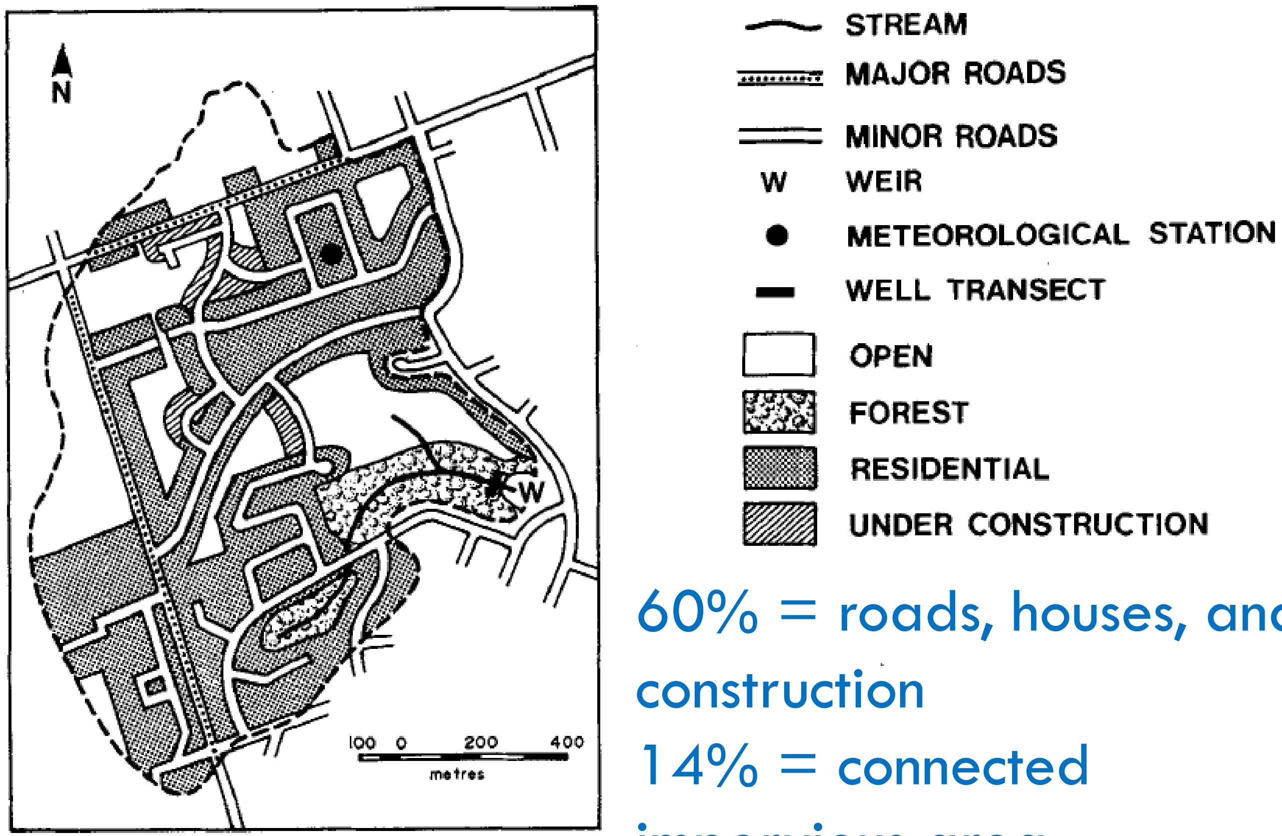
- 76% of river flow was "old" water
- Only 47% of water entering river in the urbanizing subcatchment was "old" water
- *Why are these the "expected" results?*

Why is hard to find isotope hydrograph separations in urban watersheds?

Gremillion et al. 2000. Application of alternative hydrograph separation models to detect changes in flow paths in a watershed undergoing urban development, Hydrol. Process. 14: 1485-1501.

Isotope hydrograph separation in a suburban watershed (during snowmelt)

Buttle et al., 1995, Applicability of isotopic hydrograph separation in a suburban basin during snowmelt, Hydrological Processes, 9: 197-211

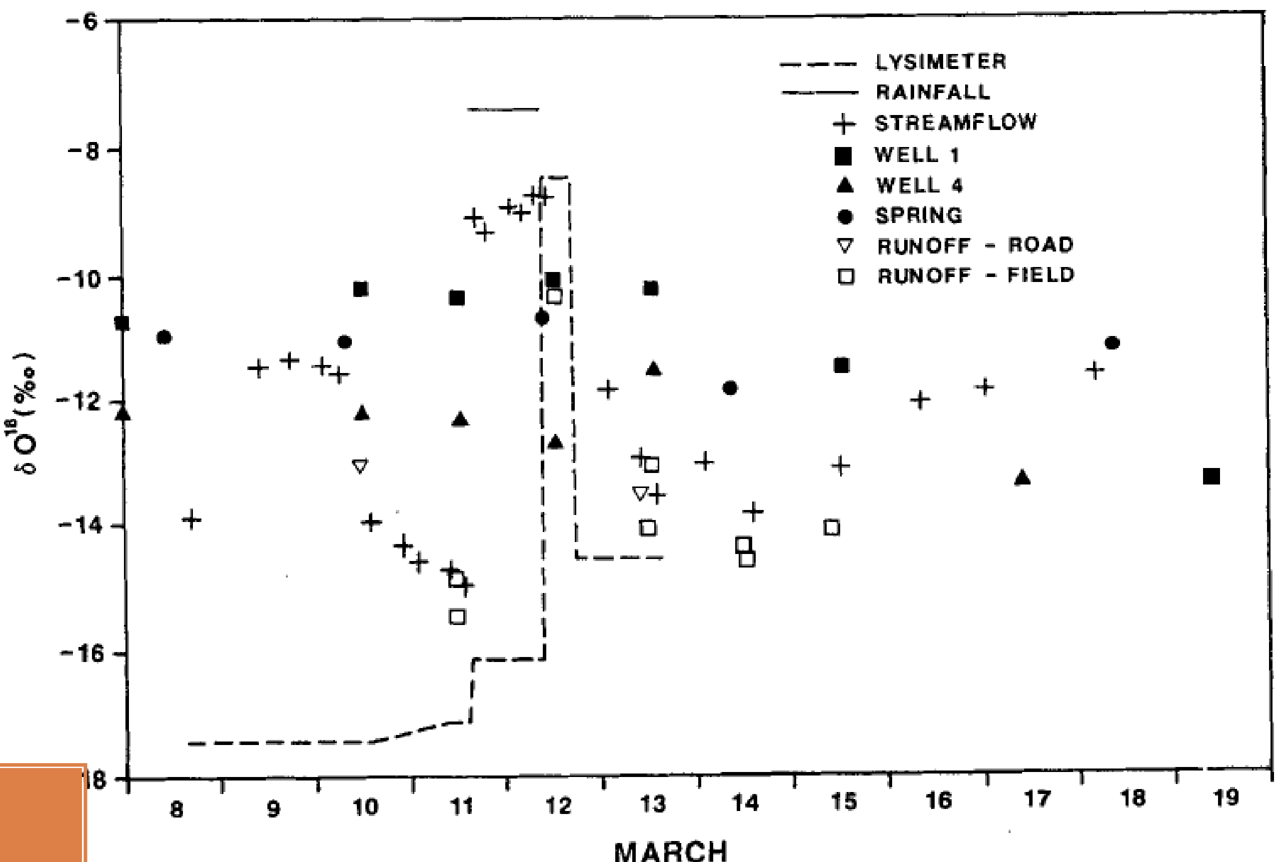


60% = roads, houses, and construction

14% = connected impervious area

Isotope hydrograph separation in a suburban watershed (during snowmelt)

- Problem 1: What to use as pre-event isotope content?
  - Baseflow – maybe none in an urban watershed?
  - Near stream groundwater – not well mixed?



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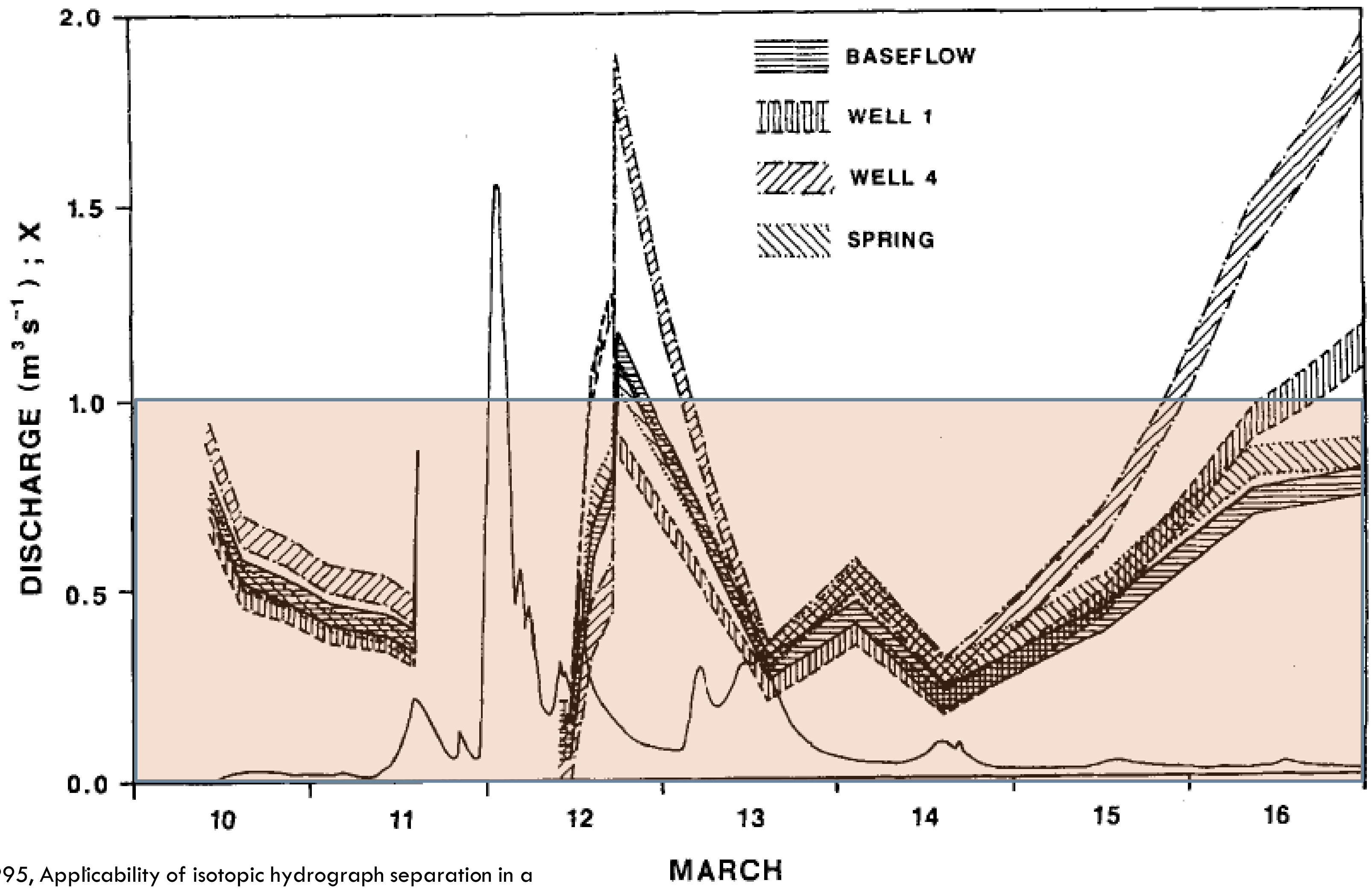
Poor constraint of pre-event water can lead to impossible results



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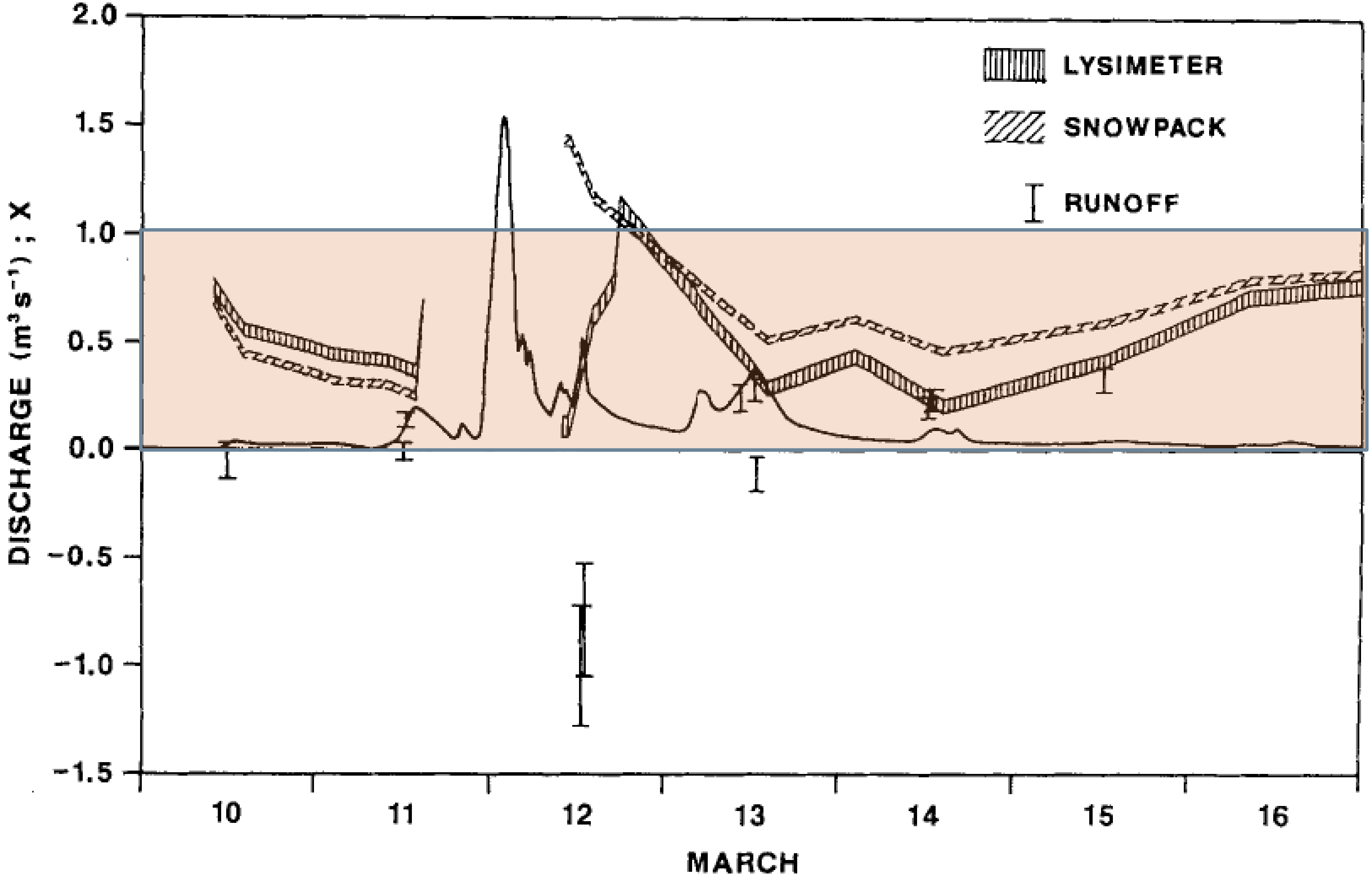
Isotope hydrograph separation in a suburban watershed (during snowmelt)

- Problem 2: What to use as event isotope content?
  - Rainfall?
    - But also snowmelt
  - Pre-event snowpack? Or a snowmelt time series?
    - But not even distribution, % melted, % directly connected to stream
  - Runoff to storm sewer?
    - Still need to worry about spatial variability

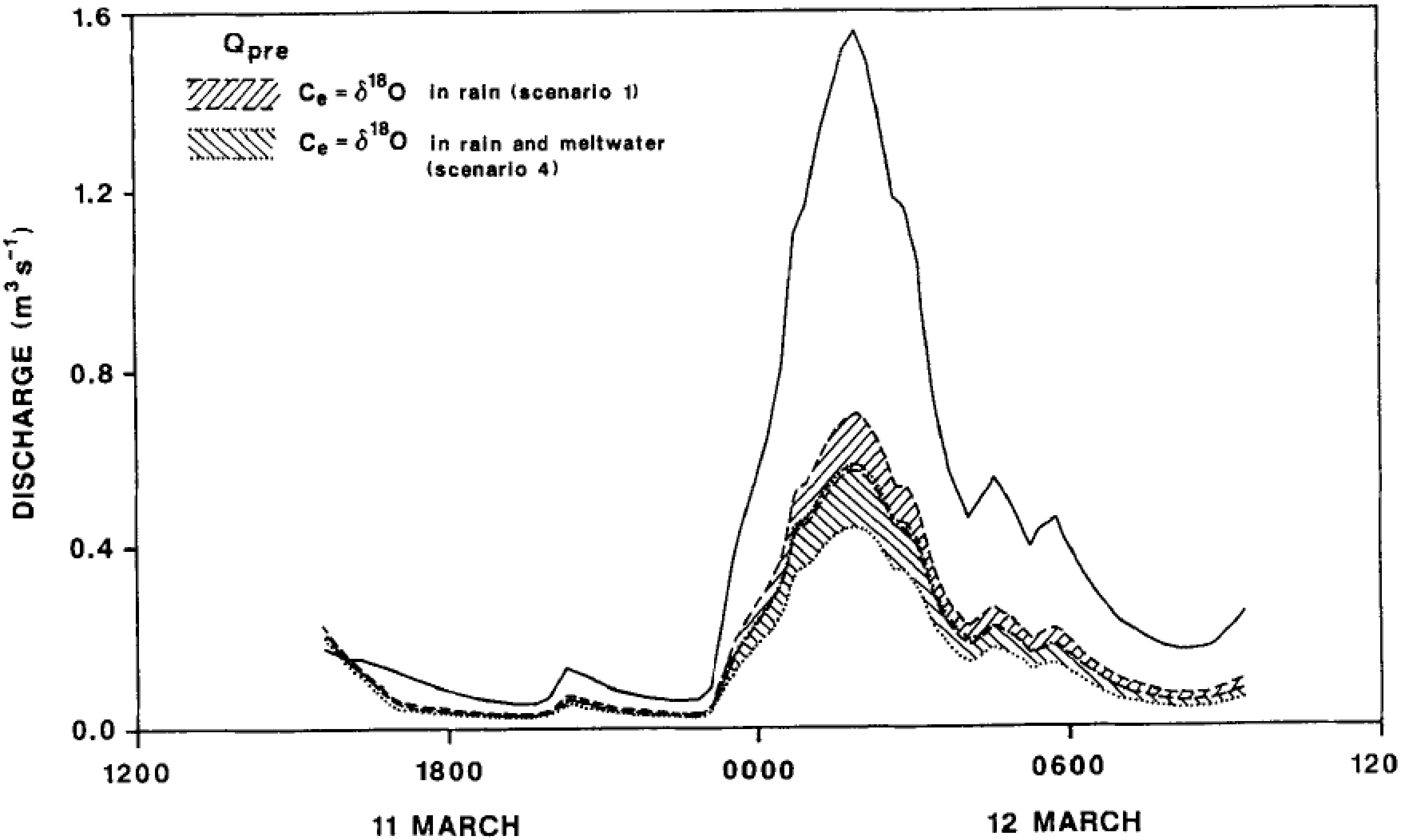
Buttle et al., 1995, Applicability of isotopic hydrograph separation in a suburban basin during snowmelt, Hydrological Processes, 9: 197-211

Poor constraint of event water can lead to impossible results.



Buttle et al., 1995, Applicability of isotopic hydrograph separation in a suburban basin during snowmelt, Hydrological Processes, 9: 197-211

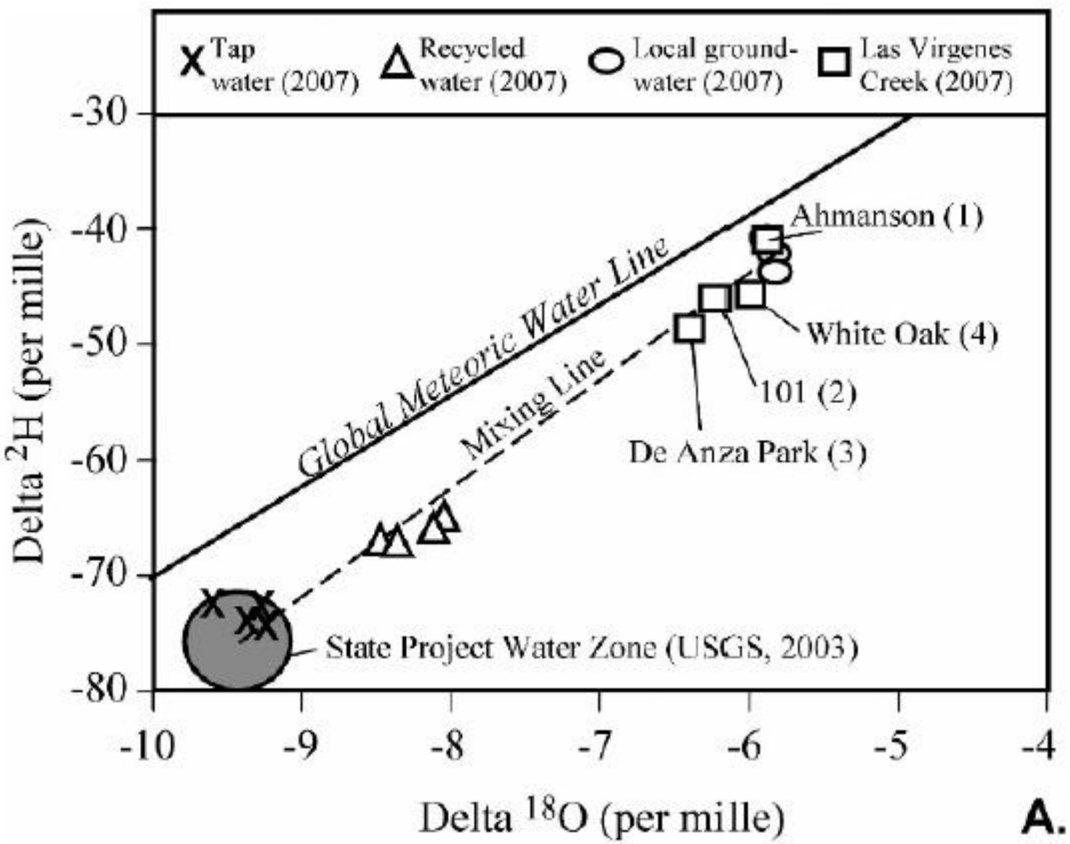
55-63% of peak flow was “new” water. 48-55% of total runoff during melt.



Buttle et al., 1995, Applicability of isotopic hydrograph separation in a suburban basin during snowmelt, Hydrological Processes, 9: 197-211

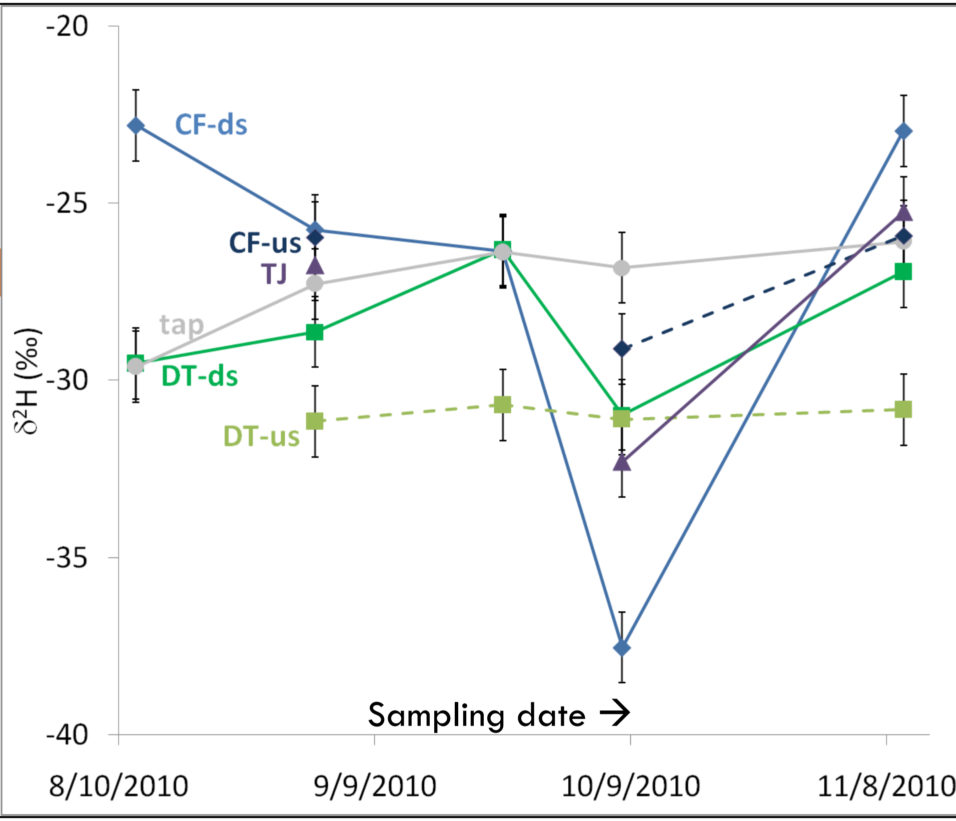
Challenges for using isotopes as urban hydrology tracers

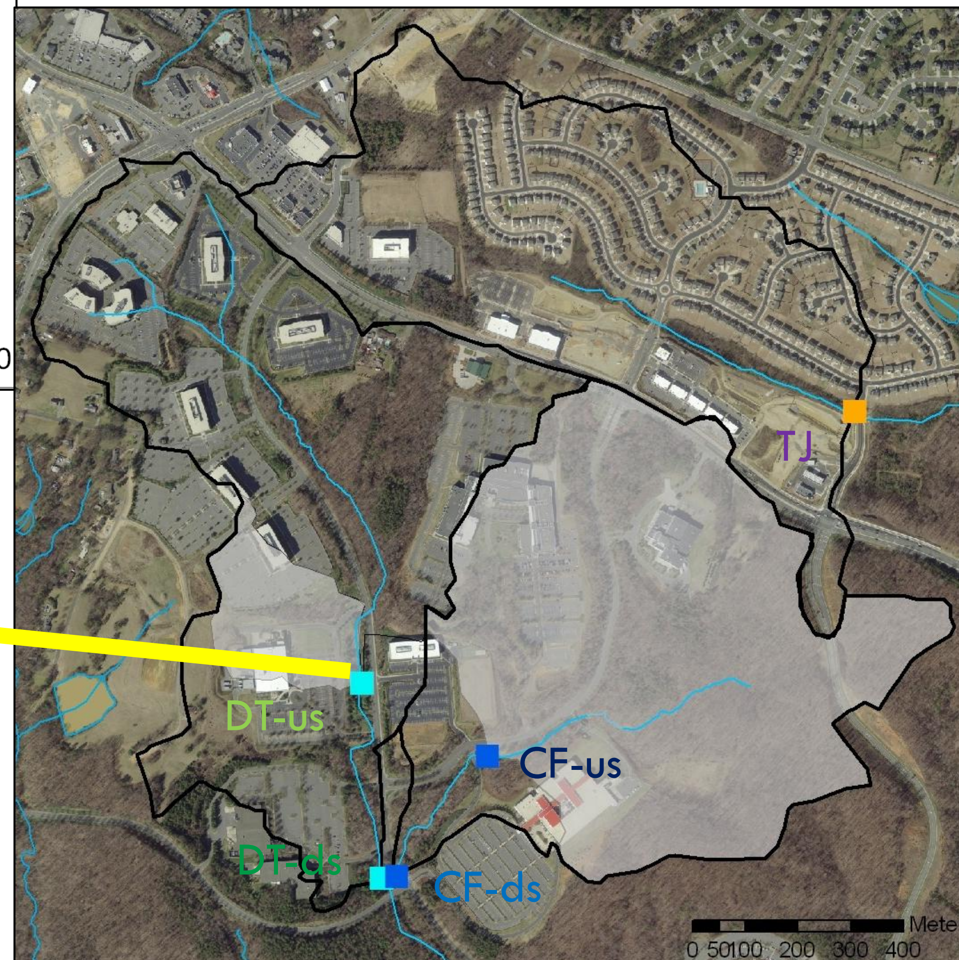
- Role of connected and disconnected impervious surfaces
- Potential for imported water from leaky pipes, irrigation, & wastewater effluent
- But these challenges can also make them useful "forensic" tools



Hibbs et al. 2012 Origin of Stream Flows at the Wildlands-Urban Interface, Santa Monica Mountains, California, USA, Environmental and Engineering Geosciences, 18(1): 51-64.

Heterogeneity in small (~0.5 km^2) watersheds





Jefferson, unpublished data

New methods and approaches

- More applications in disturbed settings
- Can use solute tracers – but conservative mixing assumption may not be met
- End-member Mixing Analysis (EMMA) – more complex methods of separating hydrographs using multiple tracers simultaneously

→ *The readings by Sidle and Pellerin are great examples of applying isotopes & tracers to problems in urban hydrology*

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