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Joint ICTP-IAEA Workshop on Uncovering Sustainable Development CLEWS; Modelling Climate, Land-use, Energy and Water (CLEW) Interactions

30 May - 3 June, 2011

Water Resources Assessments & Their Applications to Climate, Land-use, Energy, and Water Interactions (CLEW)

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Water Resources Assessments & Their Applications to Climate, Land-use, Energy, and Water Interactions (CLEW)

Brent D. Newman, Pradeep Aggarwal, & Luis Araguas-Araguas

ICTP CLEW Course
May 31, 2011

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Session Overview

- State of global water resources
  - Current situations and concerns
- Why is IAEA involved with water?
- Water resources issues related to CLEW
  - Examples using isotope hydrology
    - How old is groundwater?
    - Where are the recharge (renewal) zones?
    - How important is mixing between different water bodies?

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State of Global Water Resources

- **70% of Earth is covered by water**
- **Only 2.5% of the Earth's water is fresh**
  - **Over 70% of the fresh water is in glaciers and ice sheets**
  - **Much of the remainder is in groundwater**

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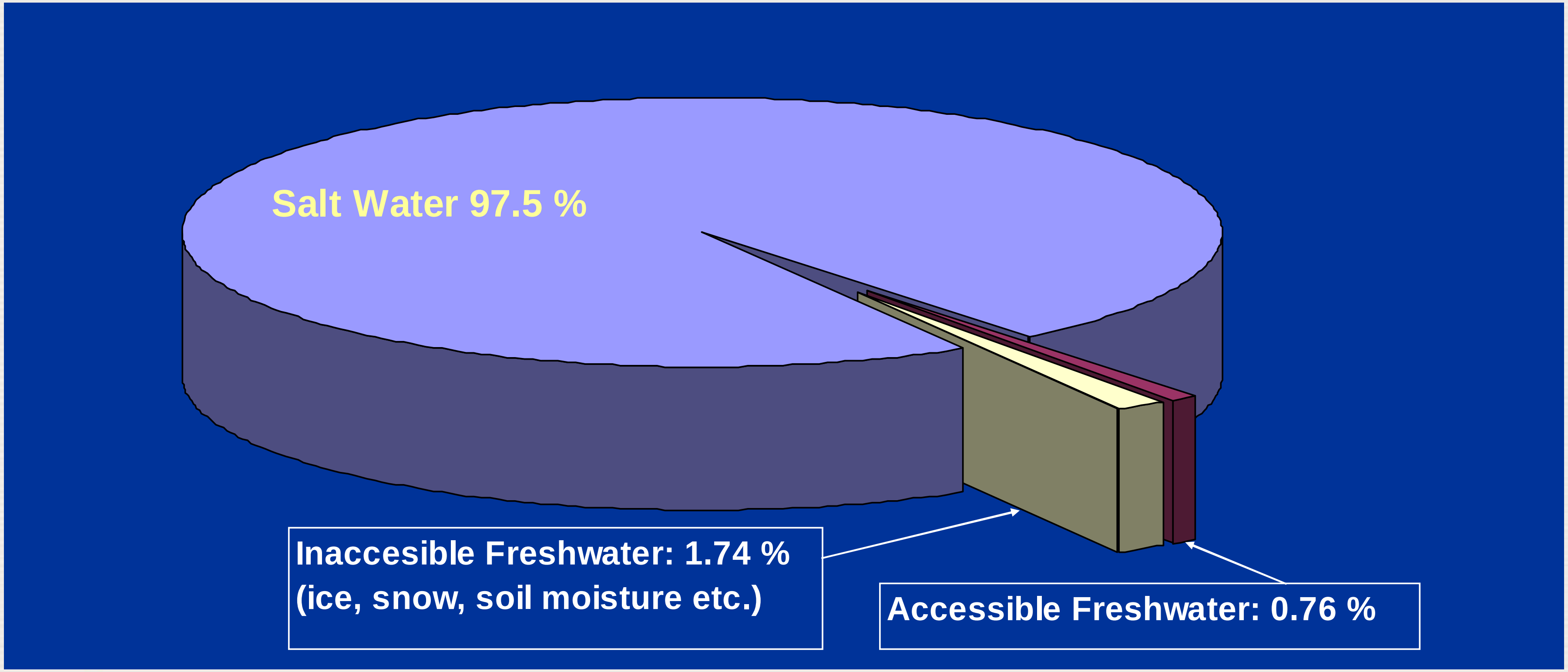
Credit: C. Young

State of Global Water Resources

- Only about 0.76% of water on the Earth is fresh & accessible for use.
- It is also unequally distributed with respect to population



(Data sources: P. Gleick, Sci. Am. Feb. 2001; UN-World Water Development Report, 2003)

Water Scarcity

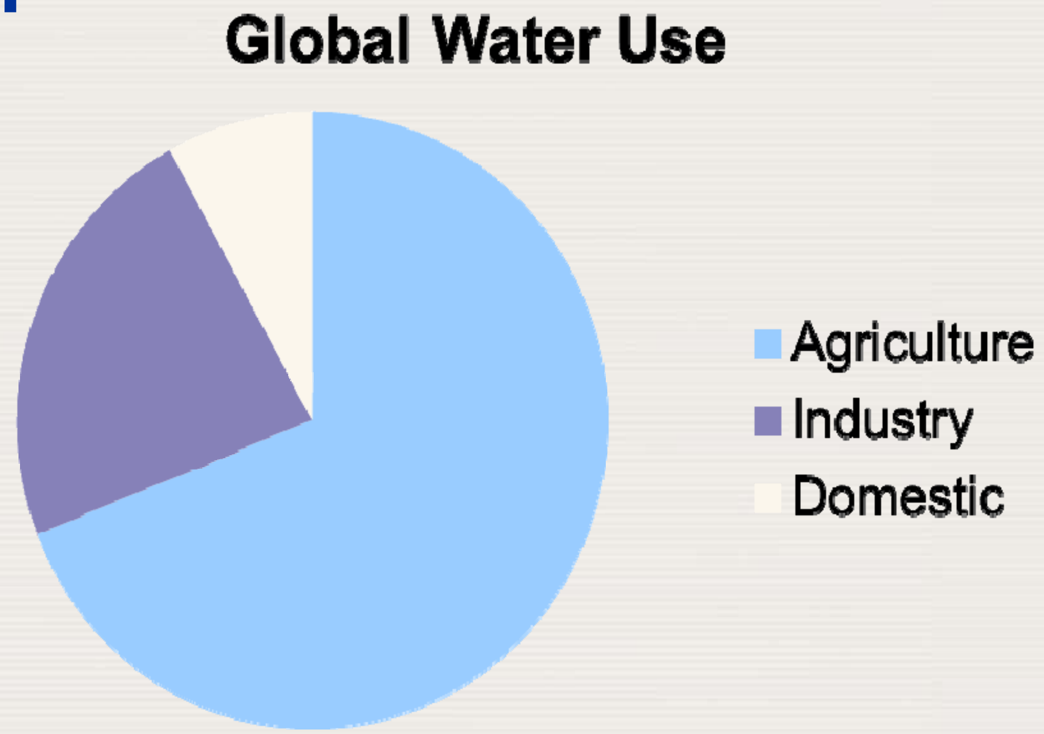
•Photo: www.wateryear2003.org

- **World population tripled in the last century**
- **Water use has increased six-fold**
  - **Half of all wetlands have disappeared**
  - **20% of freshwater fish are endangered**
- **By 2050 between 1.7 and 7 billion people will face water scarcity**
- **Shortages will not be felt uniformly**

Global Water Use

Humans currently appropriate 54% of accessible freshwater

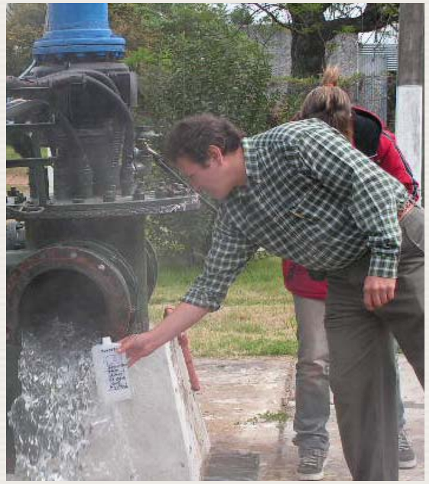
- **By 2025, 70%**
- **By 2050, 90%**



Credit: C. Young

State of Global Water Resources

- Internationally recognized need
- United Nations Millennium Goal to “halve by 2015 the proportion of people without sustainable access to proper drinking water”



- The 2010 Millennium Development Goals Report and the Dushanbe Declaration (Tajikistan)
  - noted significant progress
  - but, progress has been uneven, & some large regions still have less than 60% access
  - also an increasing concern that improvements in water quality have not kept up with improved water access.

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State of Global Water Resources

- Groundwater provides 50-90% of freshwater supplies
- Assessment and management remain a challenge in most developing countries as aquifer characterizations are generally incomplete
- Increased need to use groundwater

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Why is IAEA Involved with Water?

- A United Nations' Specialised Agency
- IAEA has 3 Mandates

  1- Nuclear non-proliferation

  2- Nuclear safety

  3- Peaceful uses of nuclear/isotope technologies

  - Agriculture, Human Health, Industrial Applications and…………..Water!

- IAEA has been involved with developing & promoting the use of isotope hydrology since the late 1950's
- Maintains & distributes stable isotope standards used for water analyses worldwide

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Key Features of the IAEA Water Resources Programme

- Responds to scientific aspects of the Global Water Agenda arising out of international initiatives

  - Improved understanding of the water cycle
  - Sustainable exploitation of water resources
  - Improved data and capacity for monitoring the quantity and quality of water resources

- Achieved through promotion of isotope and nuclear applications

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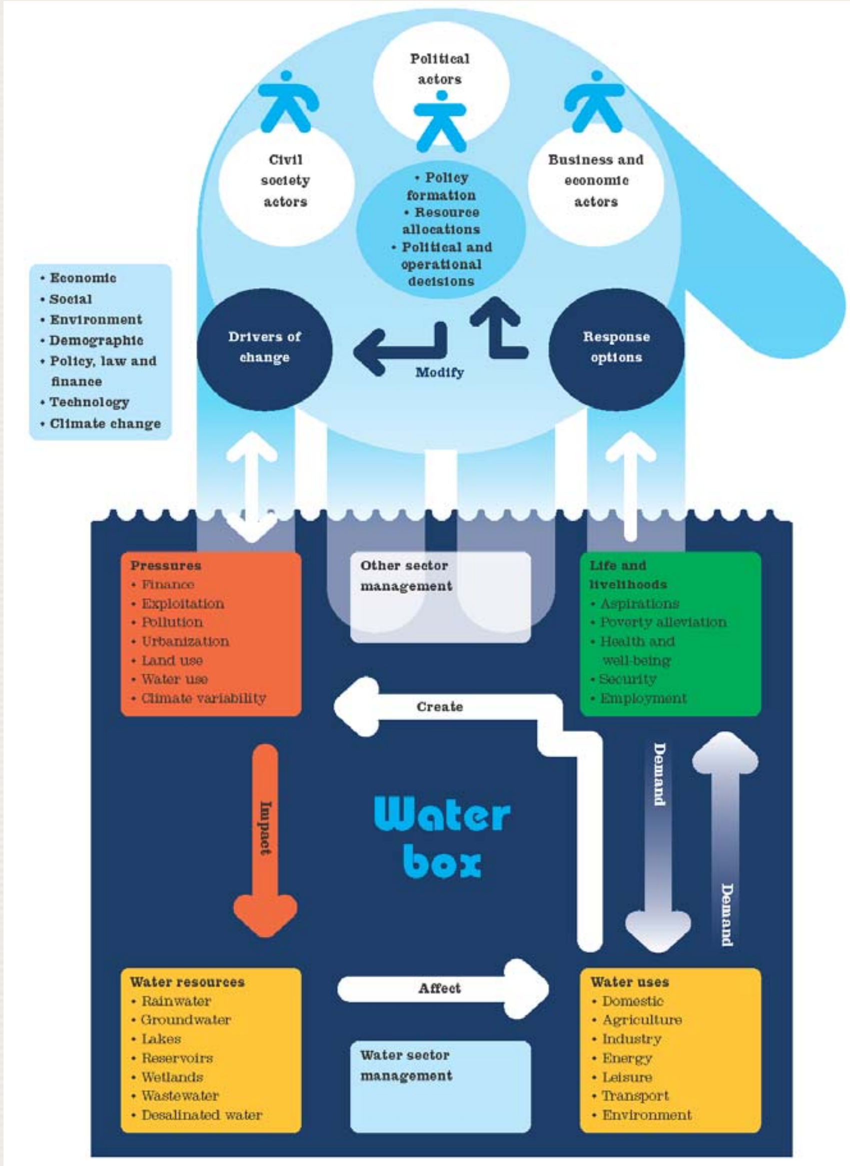
The Water Box & CLEW

The water box shows many of the features, elements, and processes involving water resources including links to food production and energy

From UN World Water Development Report #3, 2009



The Water Resources Aspects of CLEW

- Two key questions for modelling climate, land-use, energy, and water (CLEW) interactions from the water resources perspective:
  - How much water do you have?
  - How long will it last?

- Associated questions:
- Where does the water come from?
- Where is it going?
- How long does it take to get there?

Seemingly simple questions, but often big gaps in knowledge

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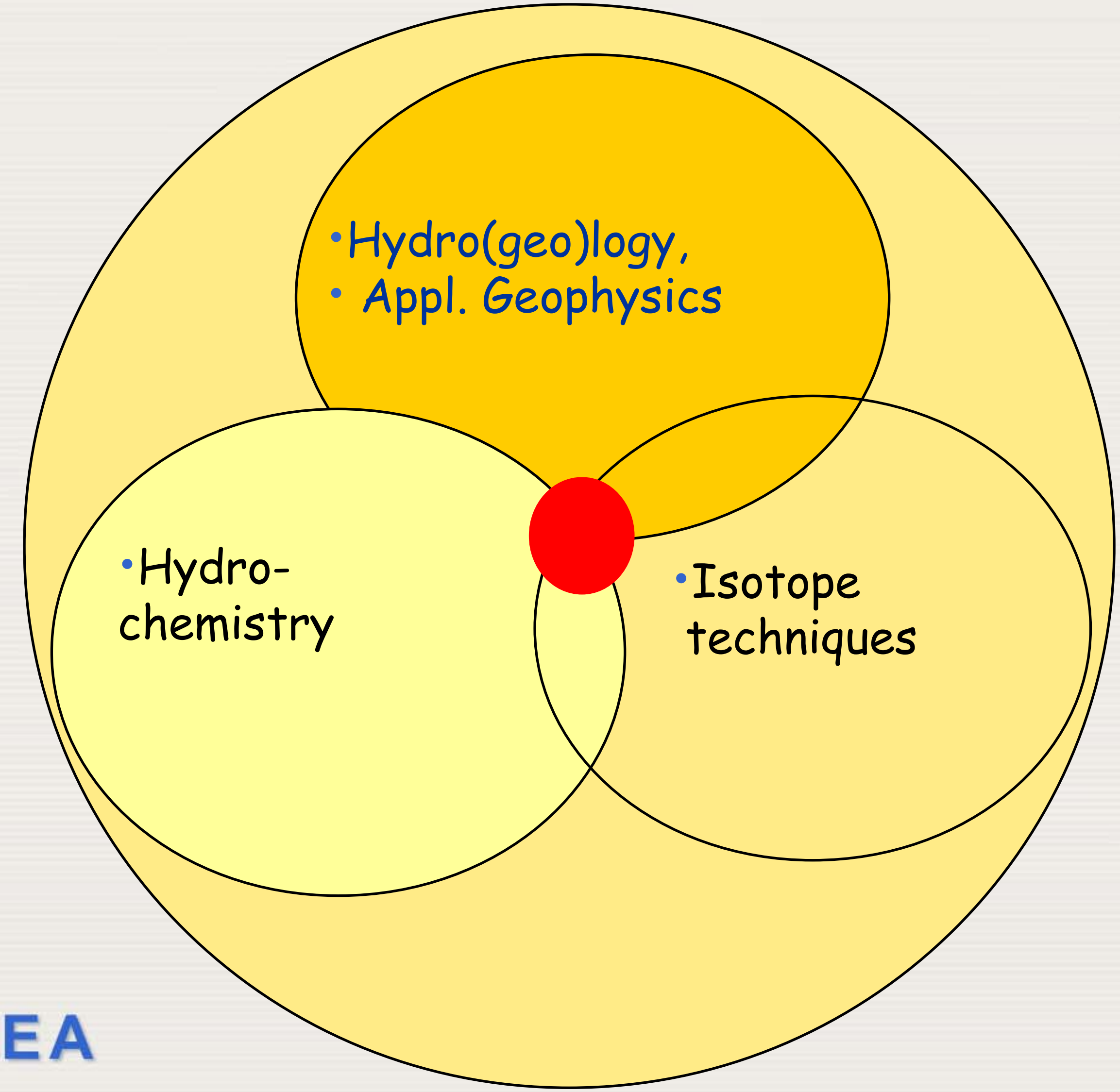
Groundwater Assessment - Complex Methodology



Why Use Isotope Techniques?

- Allow a rapid understanding of the hydrologic system that may otherwise require years or decades of monitoring
- In some cases can provide unique information
- Cost-effective

Isotope Hydrology/Isotope Geoscience

Stable and radioactive isotopes as tracers or fingerprints of:

- Source and movement of water
- Climatic conditions (atmospheric and climate change studies)
- Geochemical and/or hydrological processes
- Age/residence time
- Contamination problems
- Ecological/biogeochemical processes

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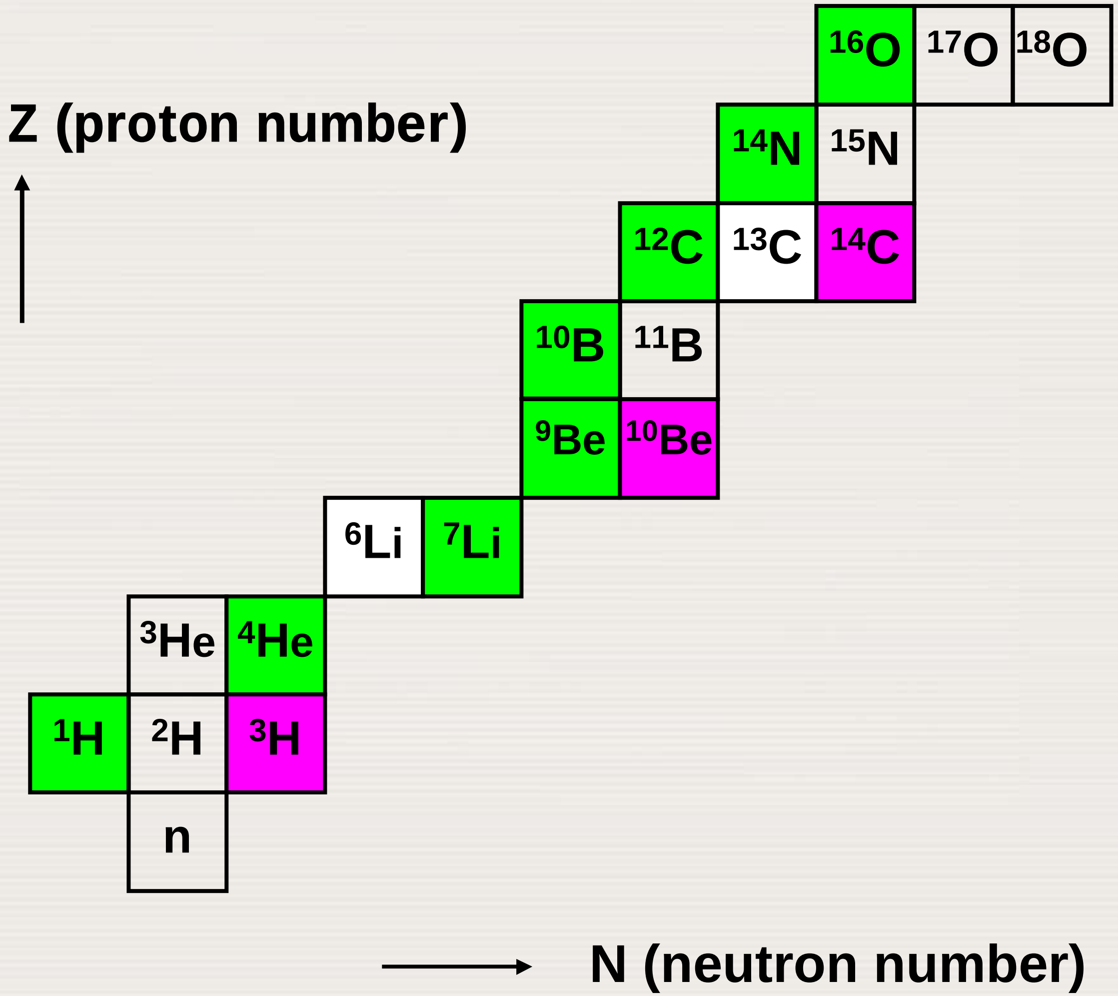
What is an Isotope?

Isotopes:

Same atomic number but different atomic mass

- **Green indicates the common or abundant stable isotope**
- **White indicates the rare stable isotope(s)**
- **Magenta indicates radioactive isotopes**

Partial Chart of the Nuclides



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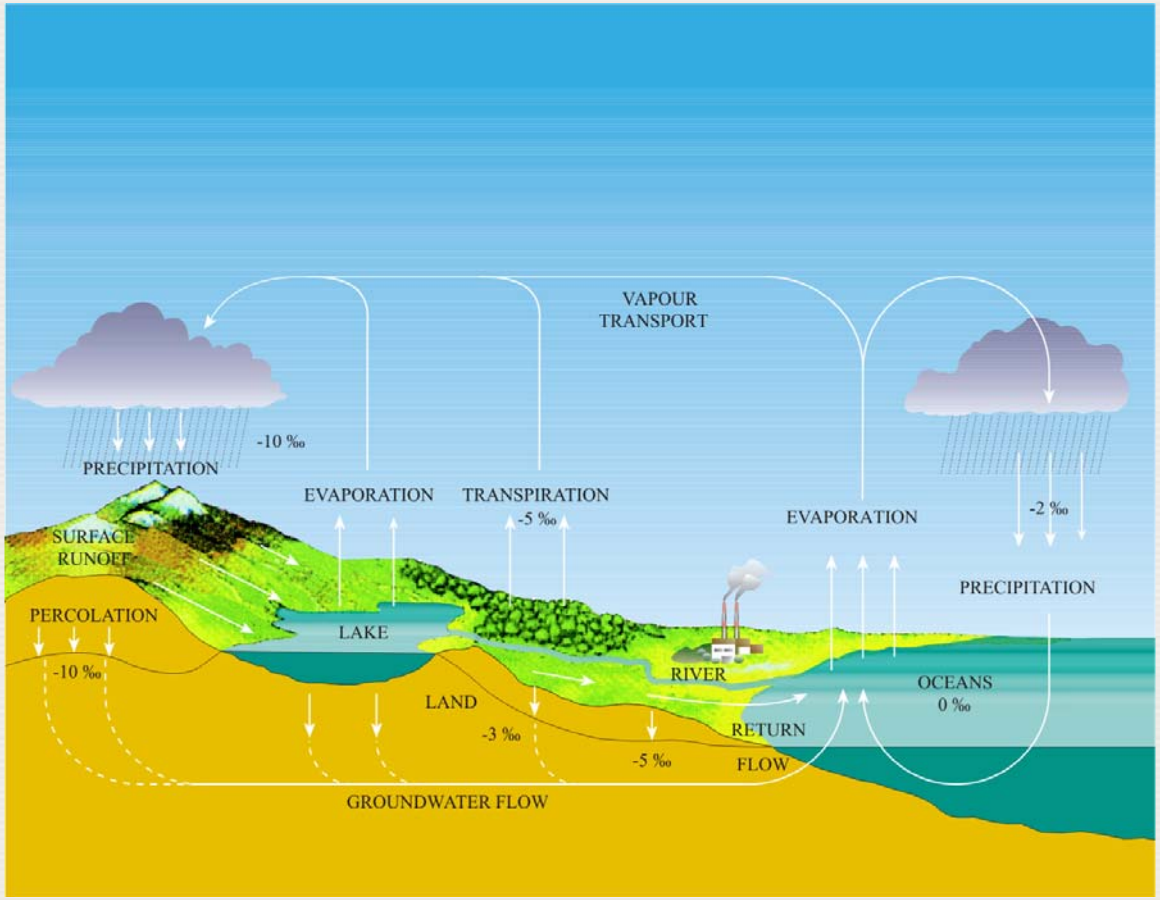
Stable Isotope Fundamentals

- **Stable isotope values <u>don't change with time</u>, they change as a result of processes**
  - **- phase changes are an example**

The water cycle & $\delta^{18}O$



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Molecular Species of Water of Practical Interest

Species		Mass
$^{1}H^{1}H\ ^{16}O$	:	18 (stable)
$^{1}H^{2}H\ ^{16}O$	:	19 (stable)
$^{1}H^{1}H\ ^{18}O$	:	20 (stable)
$^{1}H^{3}H\ ^{16}O$	:	20 (radioactive)

- Due to mass differences, these species behave differently in physical and chemical processes such as (evaporation, condensation, freezing, diffusion, chemical and biological reactions)
- As a result various sources of water can be "labeled" because they can have different isotopic signatures

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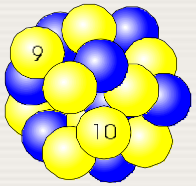
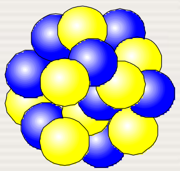
Isotope ratios are used in hydrology

Isotope (abundance) ratios are defined by the expression:

$$R = \frac{\text{abundance of rare isotope}}{\text{abundance of common isotope}}$$





$$\frac{^{18}O}{^{16}O} = \frac{1}{2000}$$

However, stable isotopes are usually reported as δ values not as R values

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What is a δ value?

- If we know R in our sample and R in a standard we can calculate "δ"

$$\delta = \frac{\text{Ratio}_{\text{sample}} - \text{Ratio}_{\text{standard}}}{\text{Ratio}_{\text{standard}}} \text{ x } 1000$$

$$\delta^2H = \frac{(^2H/^1H)_{sample} - (^2H/^1H)_{VSMOW}}{(^2H/^1H)_{VSMOW}} \text{ x } 1000$$

δ^2H = -10‰ means:

- there are 10 parts per thousand less ^{2}H in the sample than in the standard (VSMOW)

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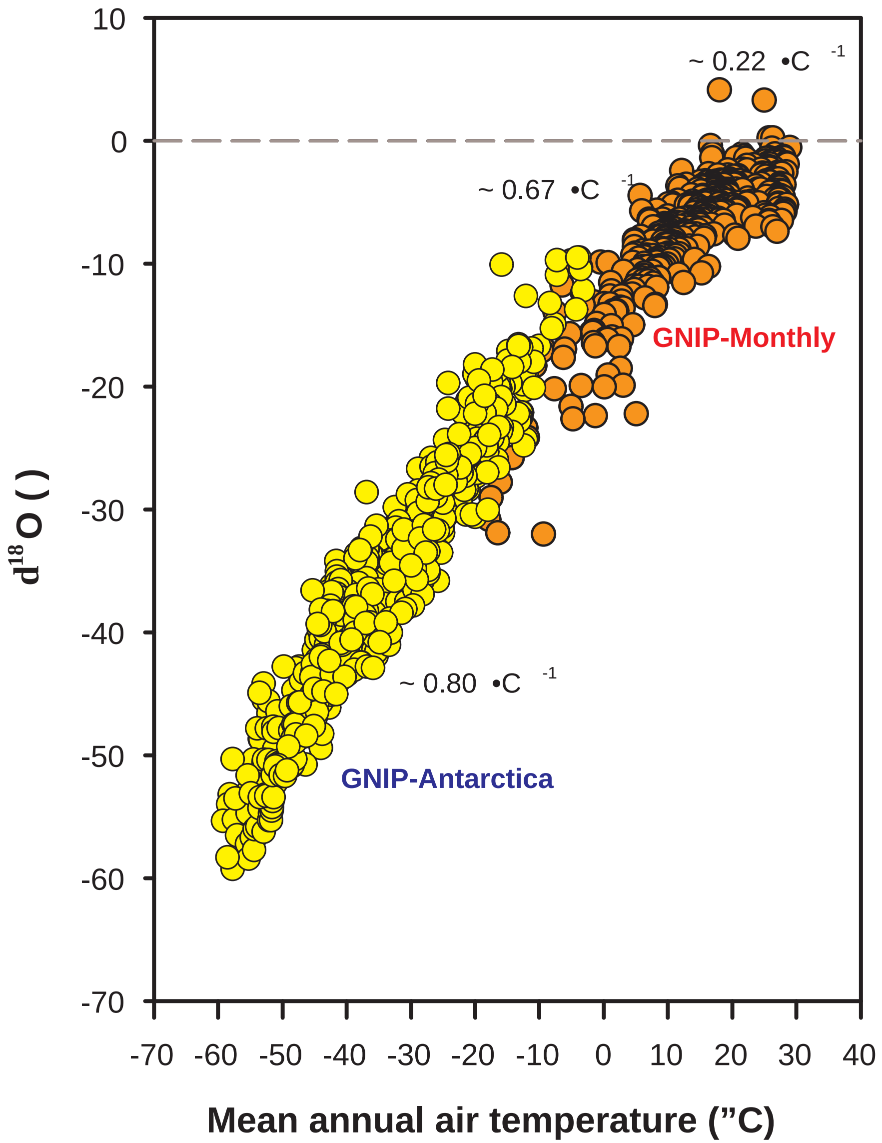
Commonly Used Stable Isotopes in Hydrology

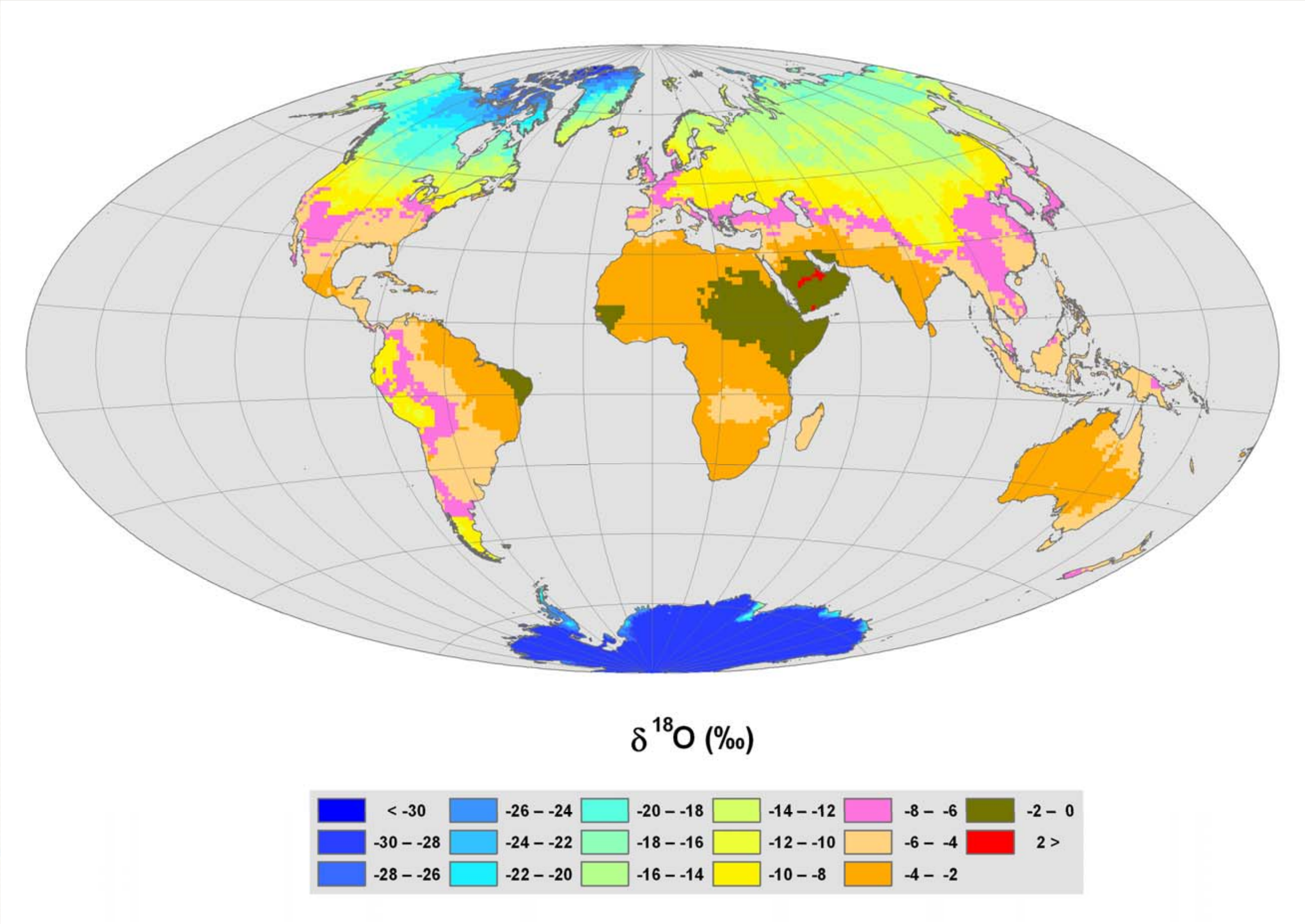
ISOTOPE	SUBSTANCE	APPLICATIONS
Deuterium (^{2}H) & Oxygen-18 (^{18}O)	• Water	➢ Origin of water & recharge ➢ Hydraulic connection, aquifer leakage ➢ Identification of paleowaters ➢ Surface water/groundwater interactions ➢ Groundwater salinization mechanism ➢ Recycling of irrigation water ➢ Geothermal water studies
Carbon-13 (^{13}C)	TDIC (water)	➢ Origin of carbon compounds ➢ Groundwater dynamics ➢ Identification of paleowaters ➢ Rock-water interaction ➢ Identification of pollution
Nitrogen-15 (^{15}N) & Oxygen-18 (^{18}O)	NO_3 (water)	➢ Origin of nitrates ➢ Identification of pollution sources ➢ Microbial denitrification processes
Sulphur-34 (^{34}S) & Oxygen-18 (^{18}O)	SO_4 (water)	➢ Identification of pollution sources ➢ Origin of groundwater salinity ➢ Geothermal water investigations
Boron-11 (^{11}B)	$B(OH)^-$ (water)	➢ Identification of pollution sources (sewage effluents)

$\delta^{18}O$/temp

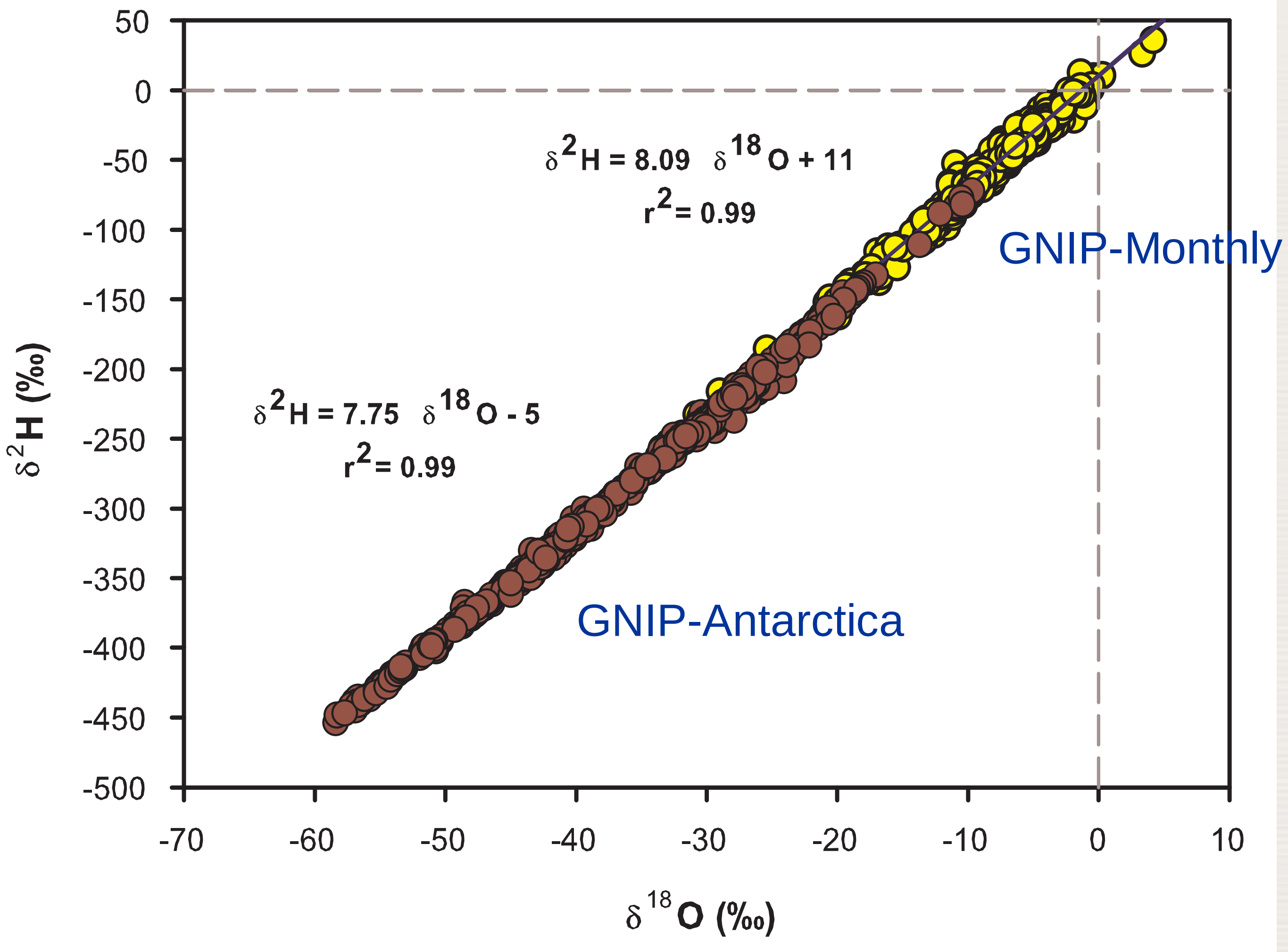


- **Temperature strongly affects stable isotope values of precipitation**
- **Helps create the unique “fingerprints” of different waters**

Global average annual oxygen-18 in precipitation



δ^2H vs $\delta^{18}O$ relationship - GMWL



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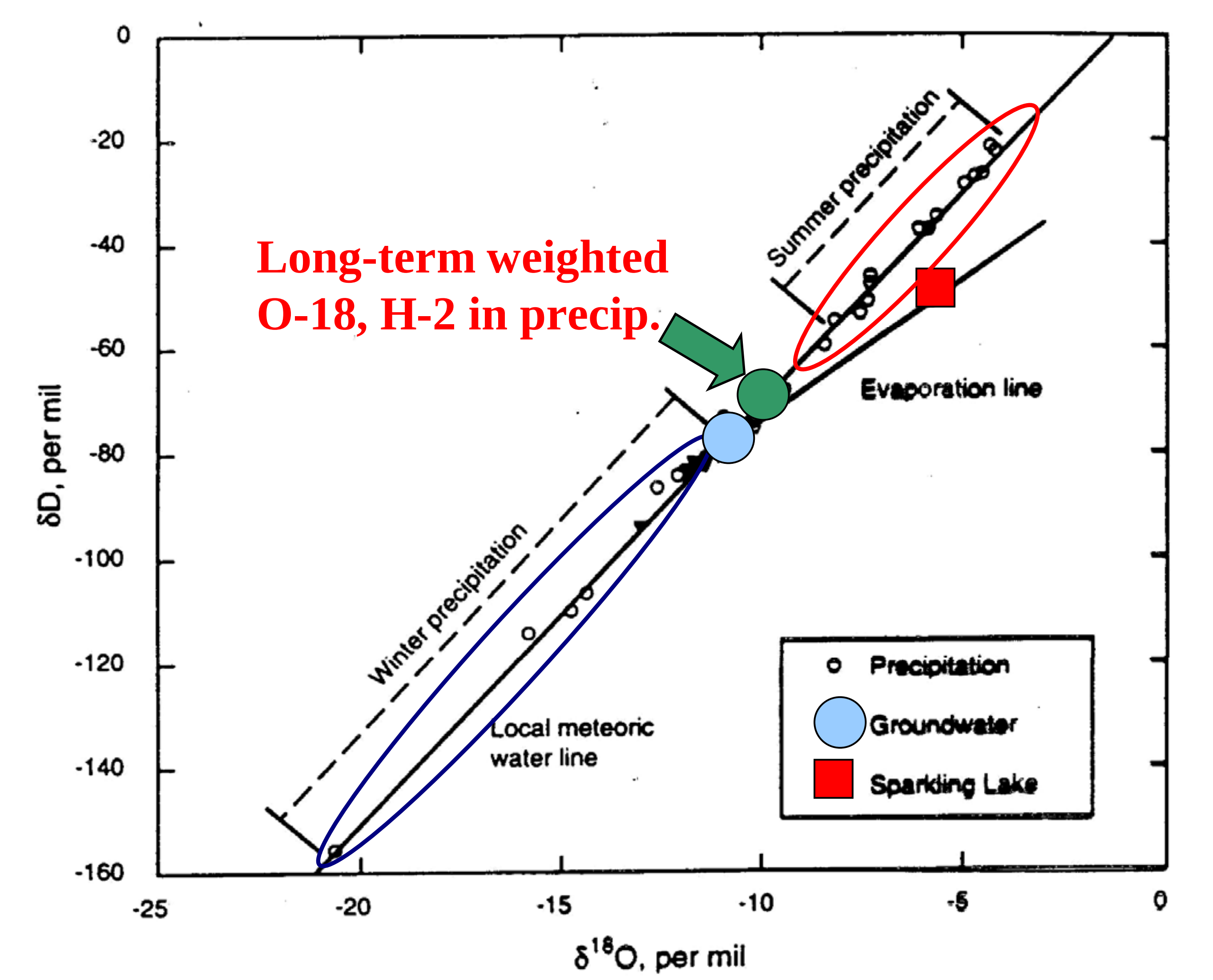
O-18 vs. H-2 relationship: seasonality of precipitation and relation to groundwater



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Altitude Effect

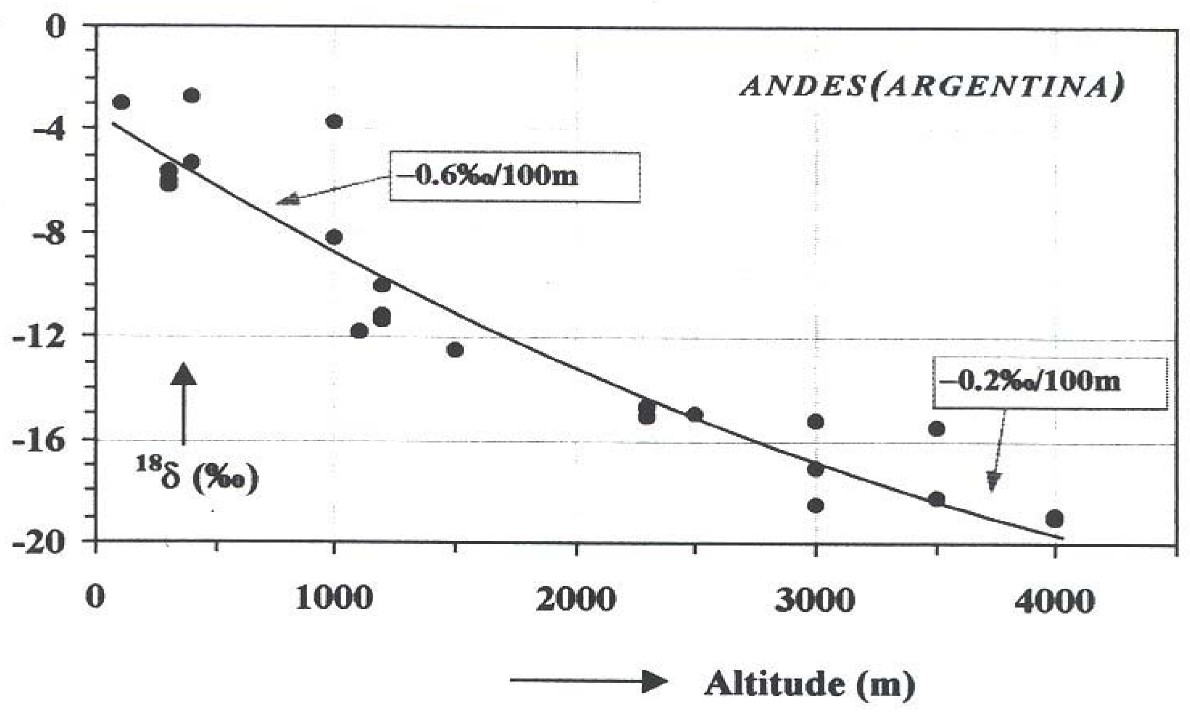
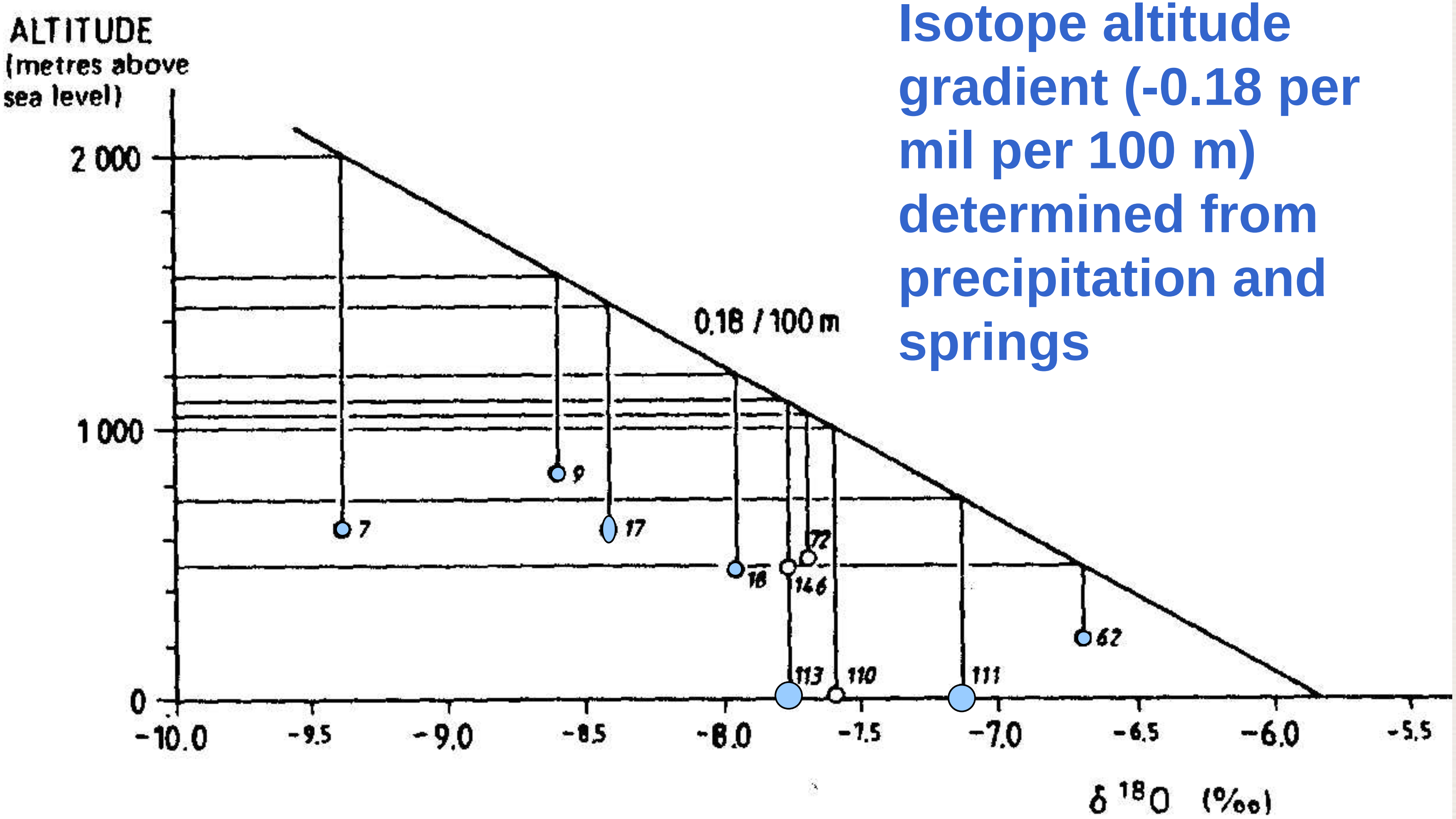


Fig.4.7 Example of the altitude effect on precipitation for the eastern slopes of the Andes mountains, as deduced from samples of undeep groundwater/soilwater, collected from springs. The magnitude of the effect is increasing from –0.2 to –0.6‰/100m (Vogel et al., 1975).

Determination of the altitude of recharge



Isotope altitude gradient (-0.18 per mil per 100 m) determined from precipitation and springs

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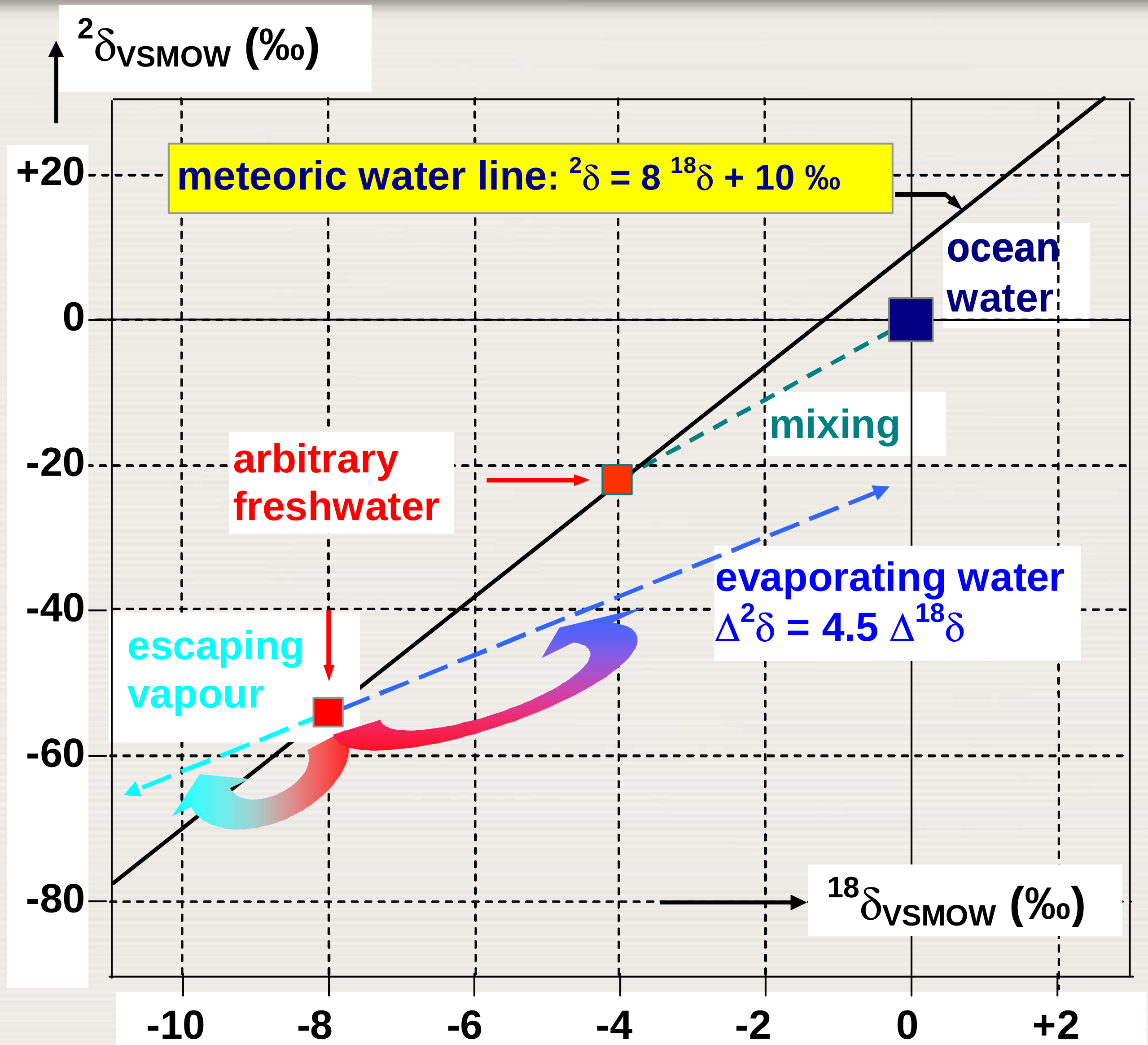
Fractionation during evaporation



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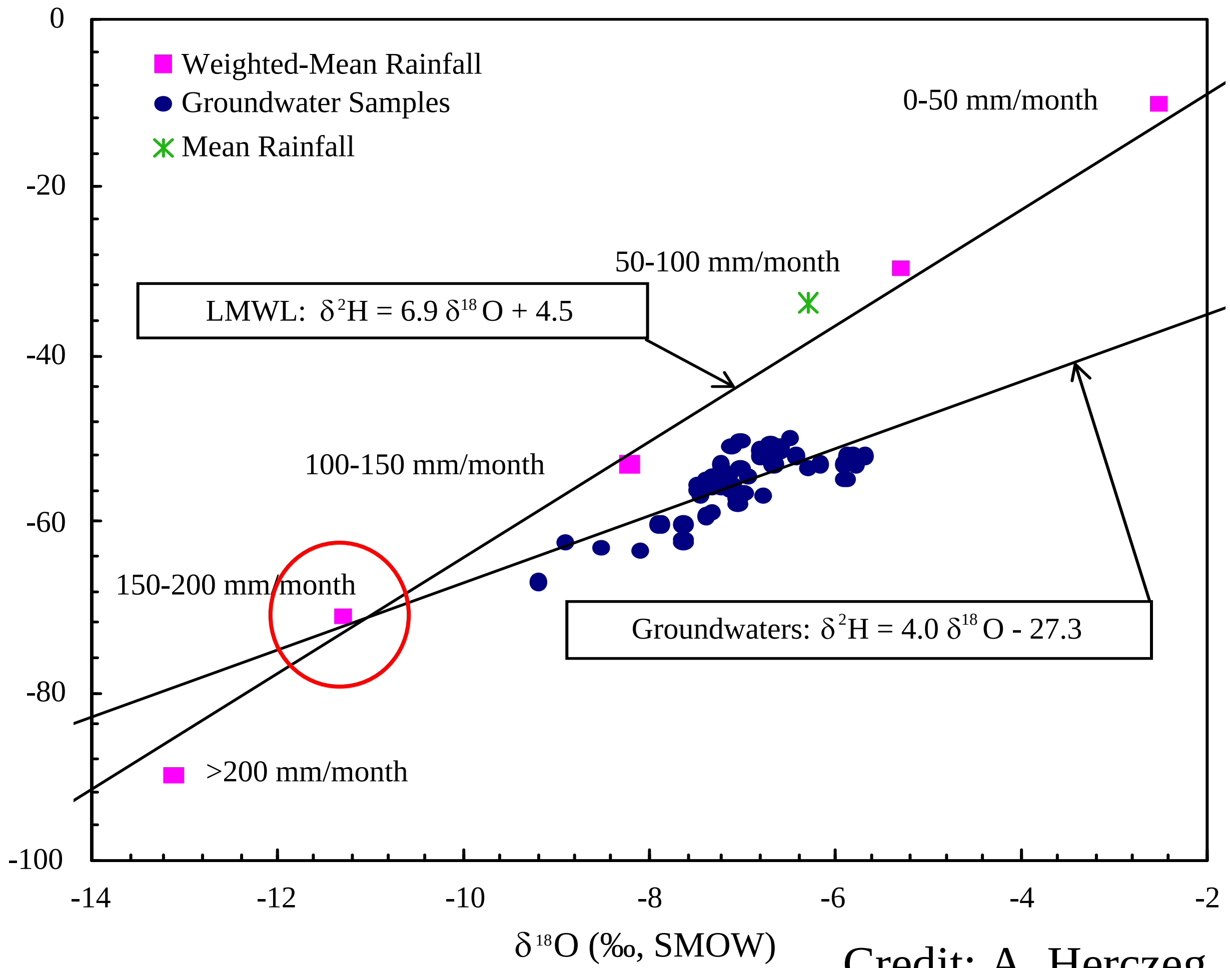
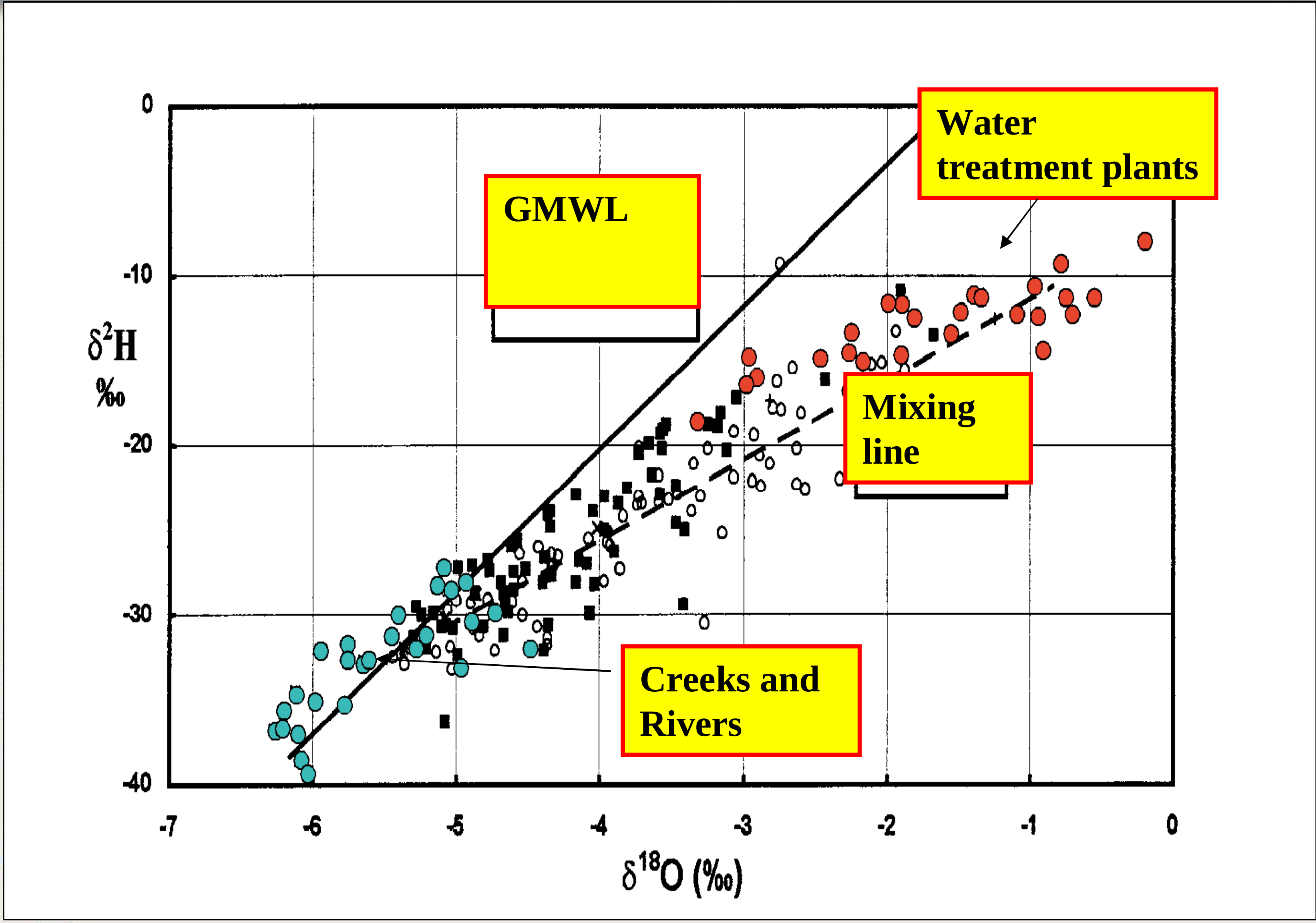
Event recharge: Ti-Tree basin, central Australia

Recharge by intermittent heavy floods

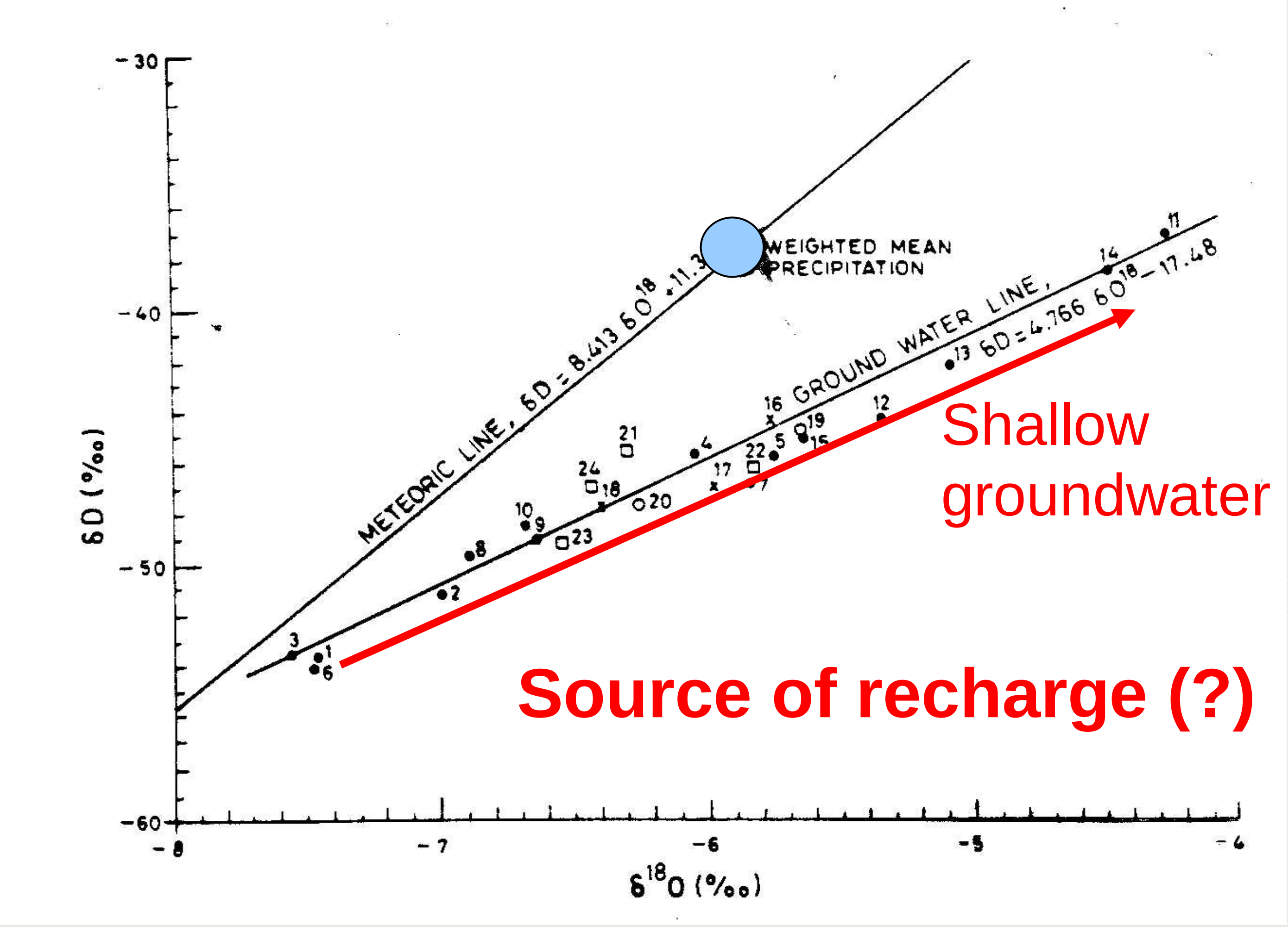


Credit: A. Herczeg

Recharge sources urban aquifer of Caracas, Venezuela (Seiler, 2000). Surface Water/Groundwater Interactions



Alluvial aquifer in a semi-arid part of India



Artificial recharge - Effectiveness of Verchum Dam to recharge groundwater

The dam is very effective for increasing groundwater recharge

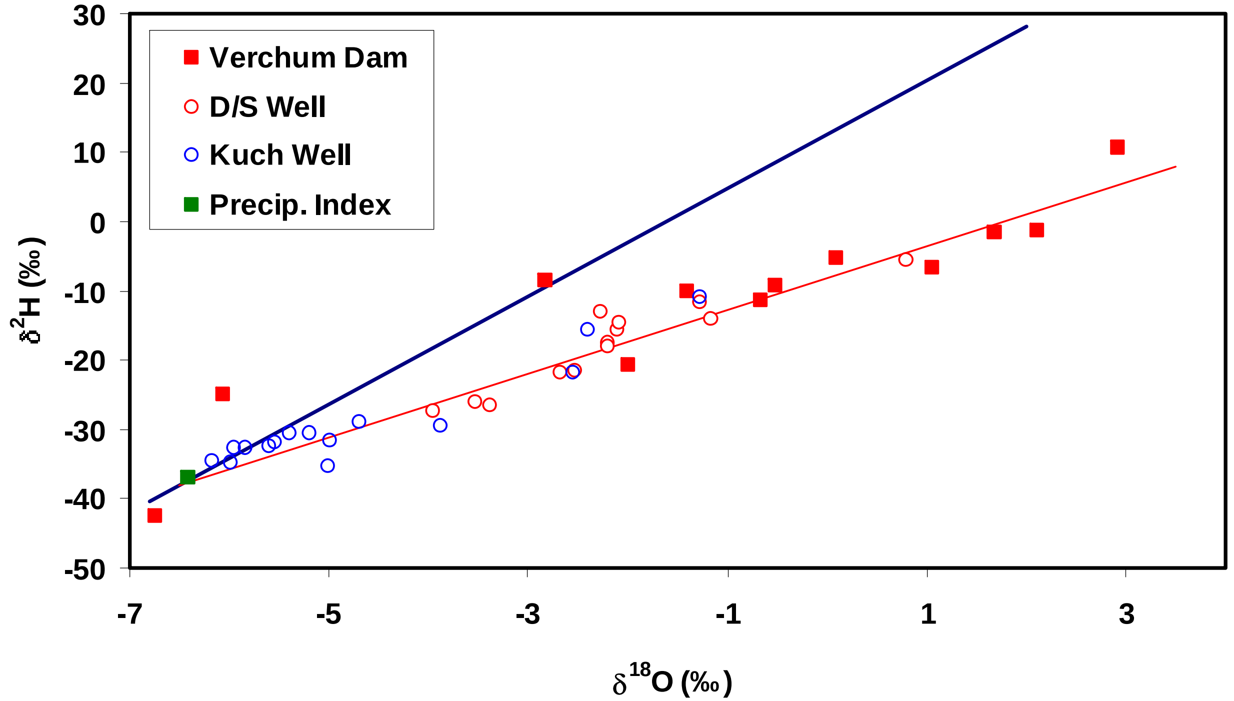


Fig. . $\delta^{18}O$ vs δ^2H of Verchum Dam and downstream Wells

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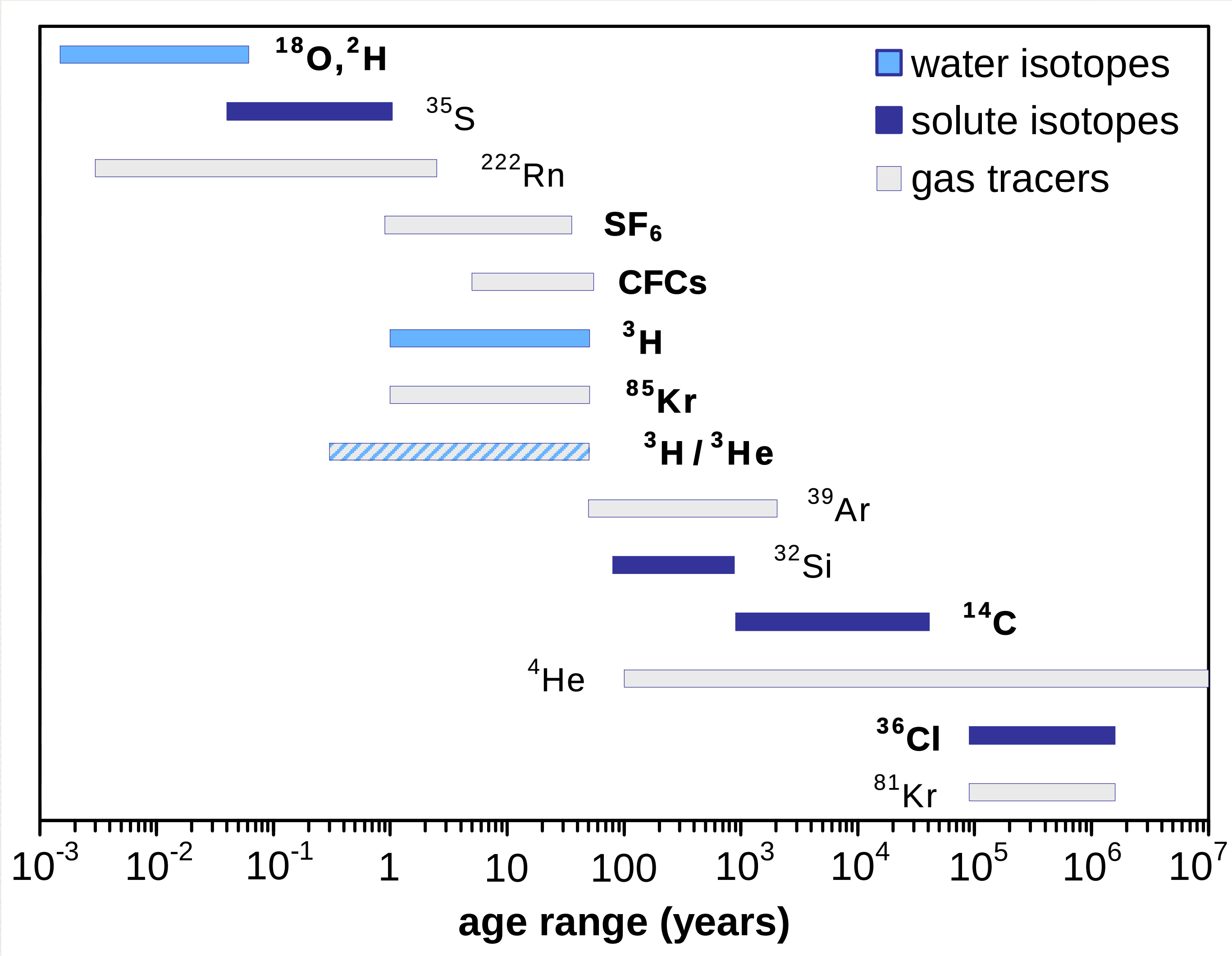
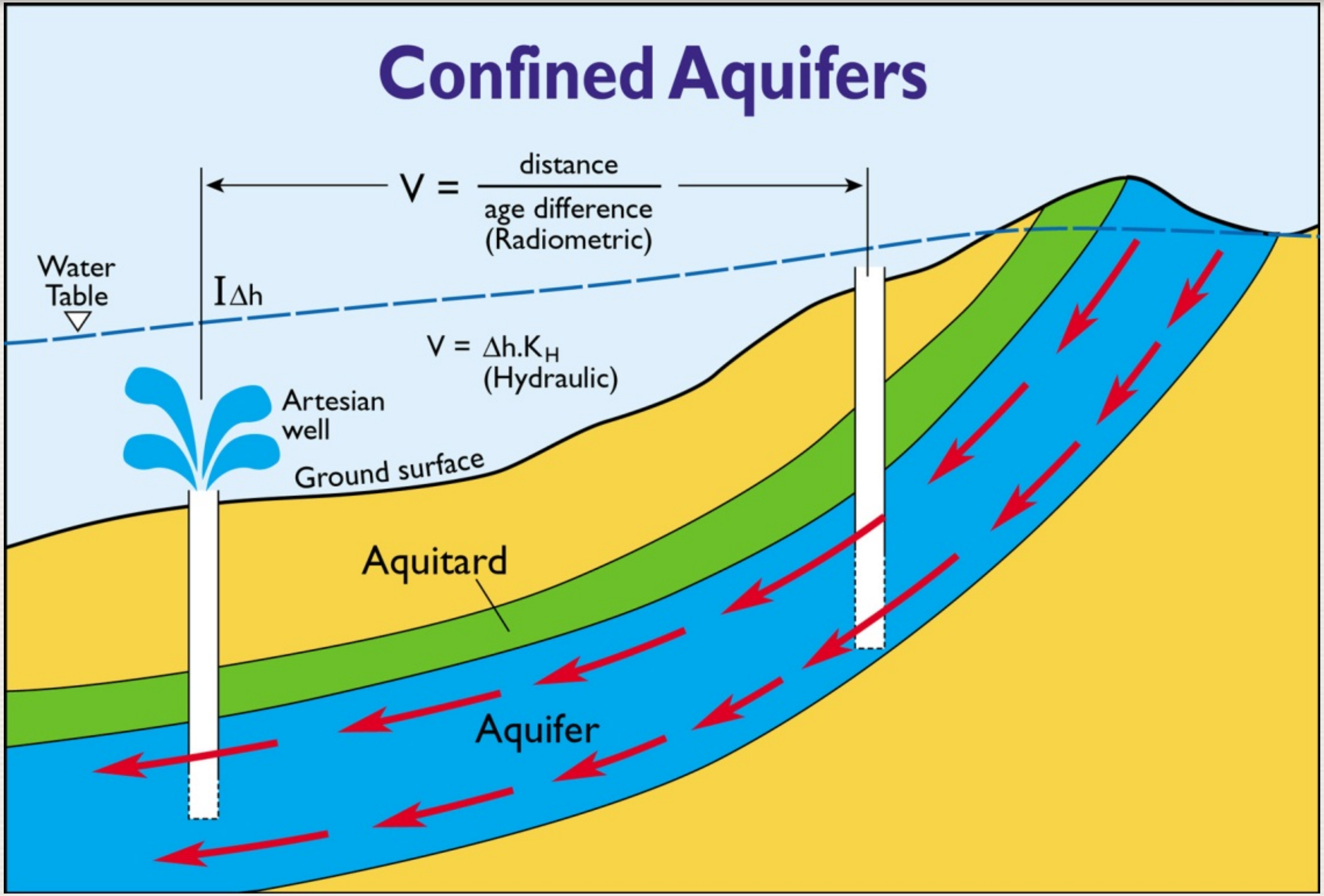
Age Dating with Isotope Tracers



Newman et al., 2010

Confined Aquifers



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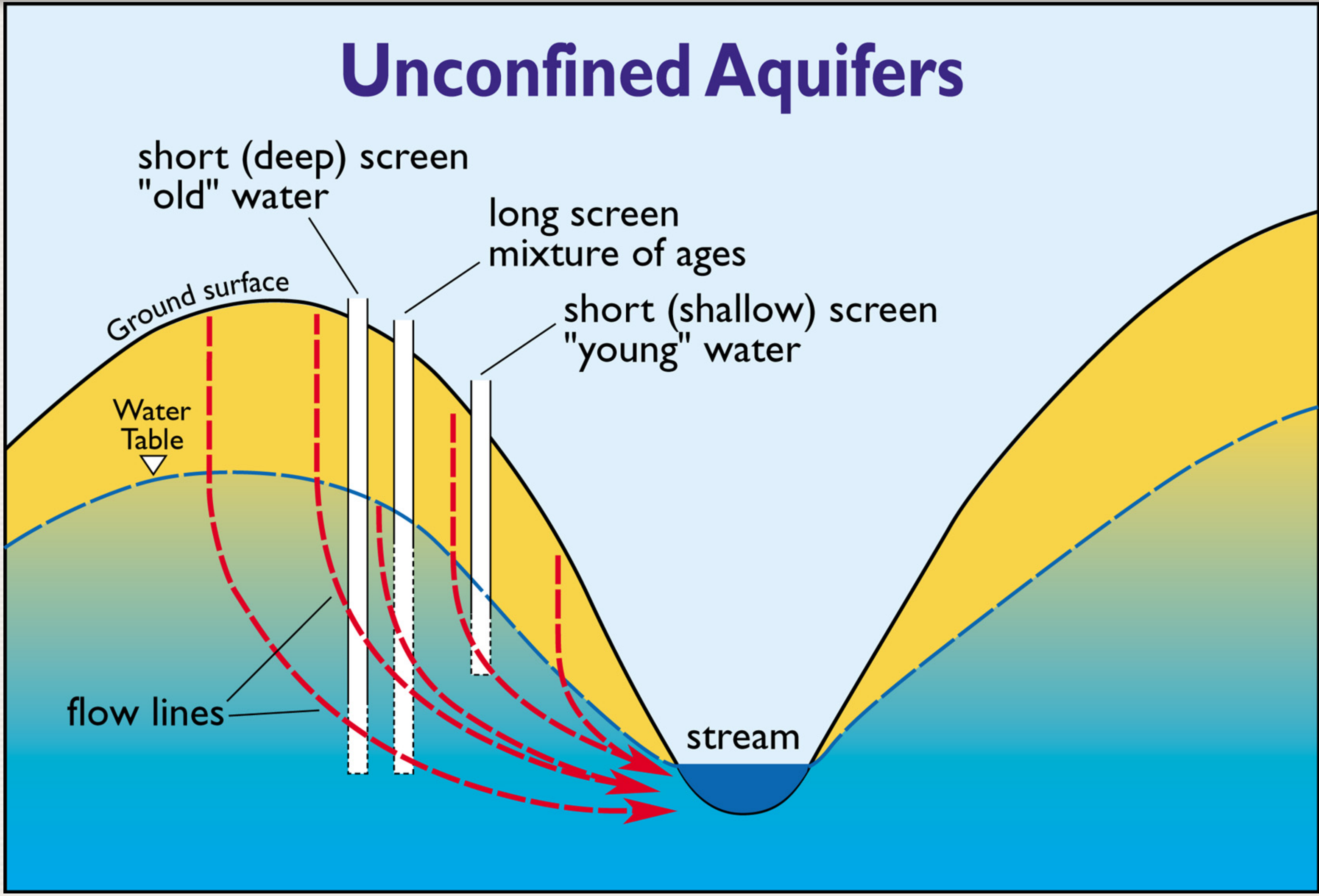
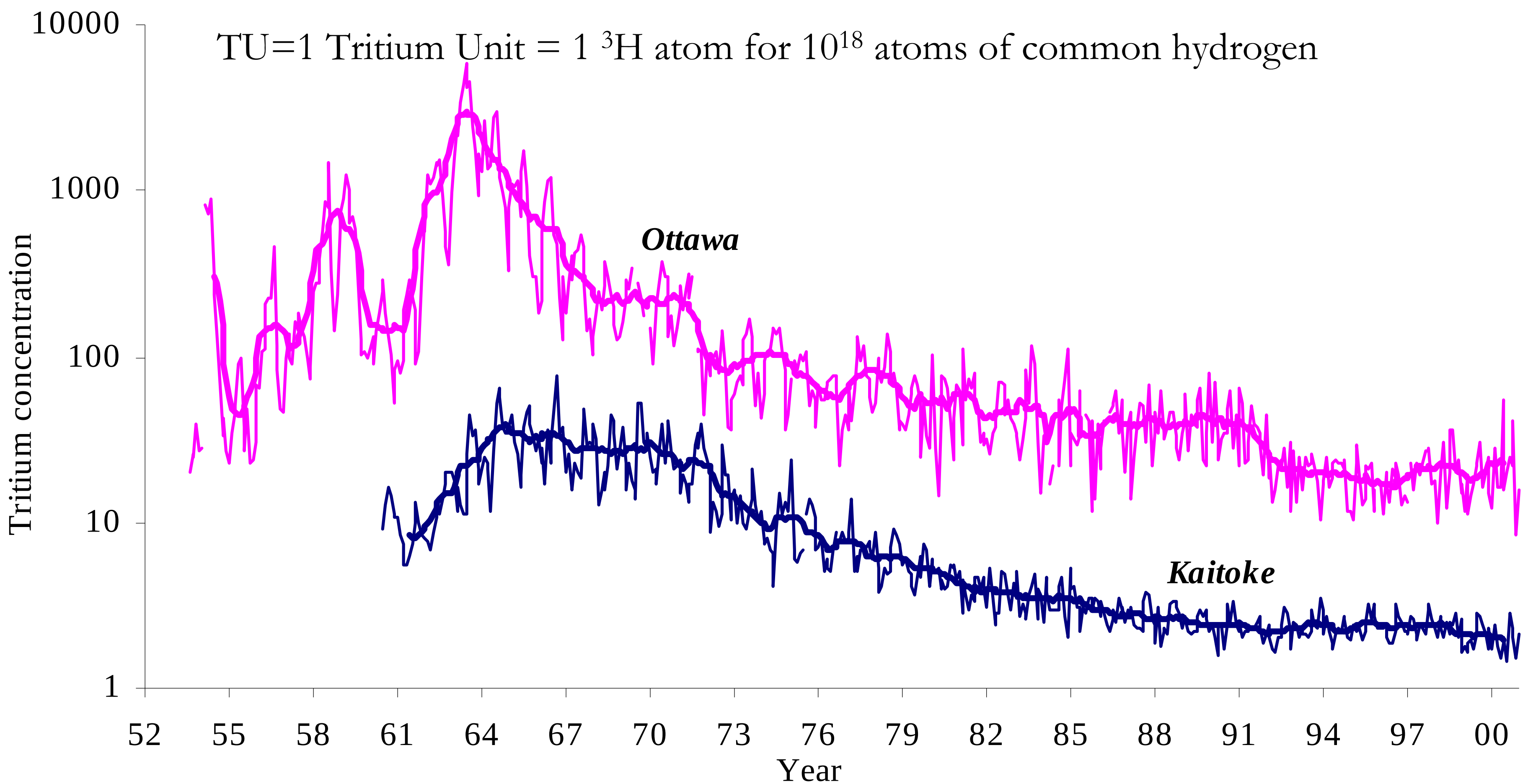
Unconfined aquifers

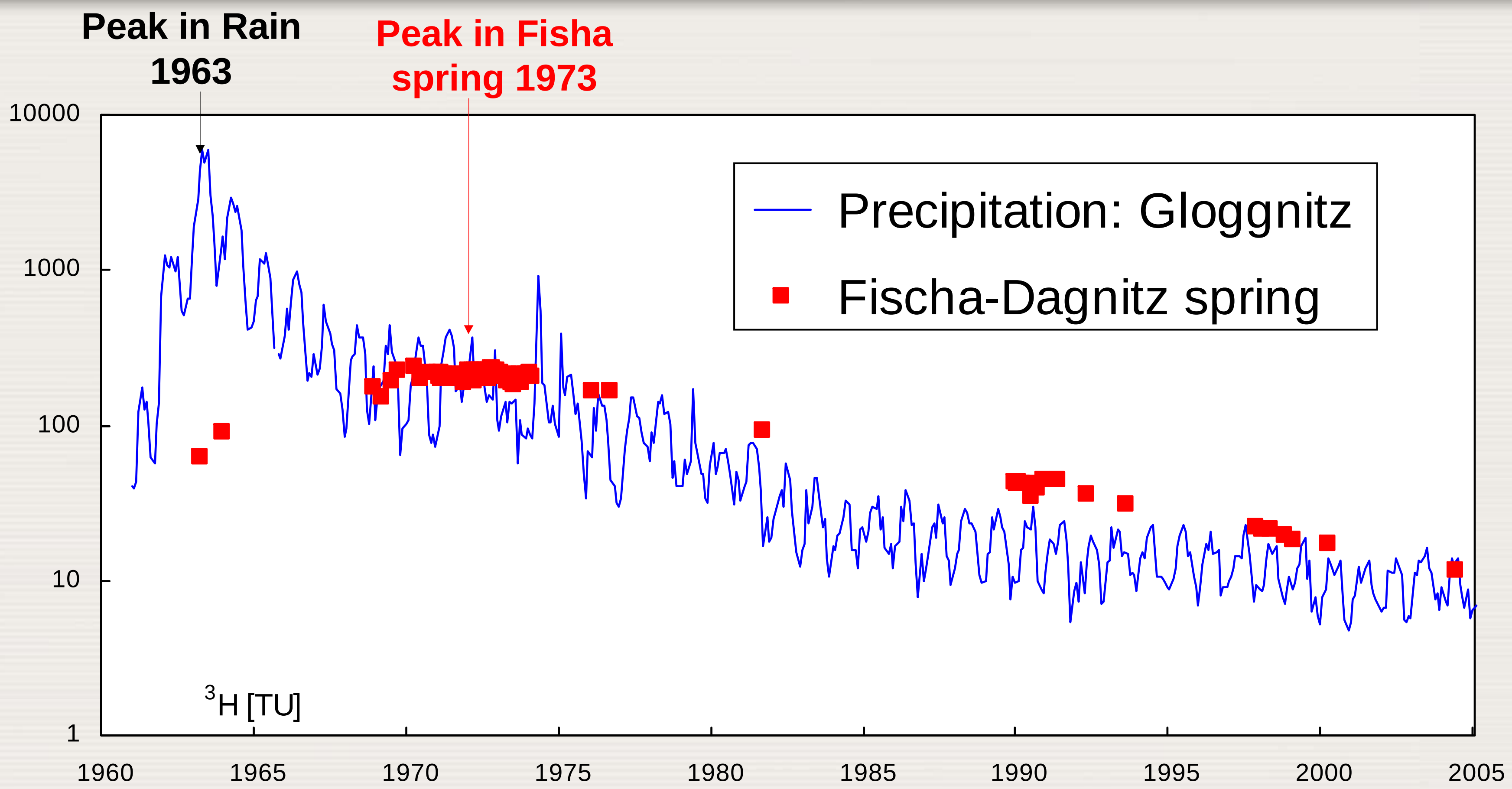


Tritium in precipitation



Ref. IAEA

Following shifts in Tritium peaks
Example from the Vienna basin



15 km groundwater from recharge area to spring

10 years old (difference of peaks 1973-1963)

Horizontal flow velocity is up to 1500 m/year

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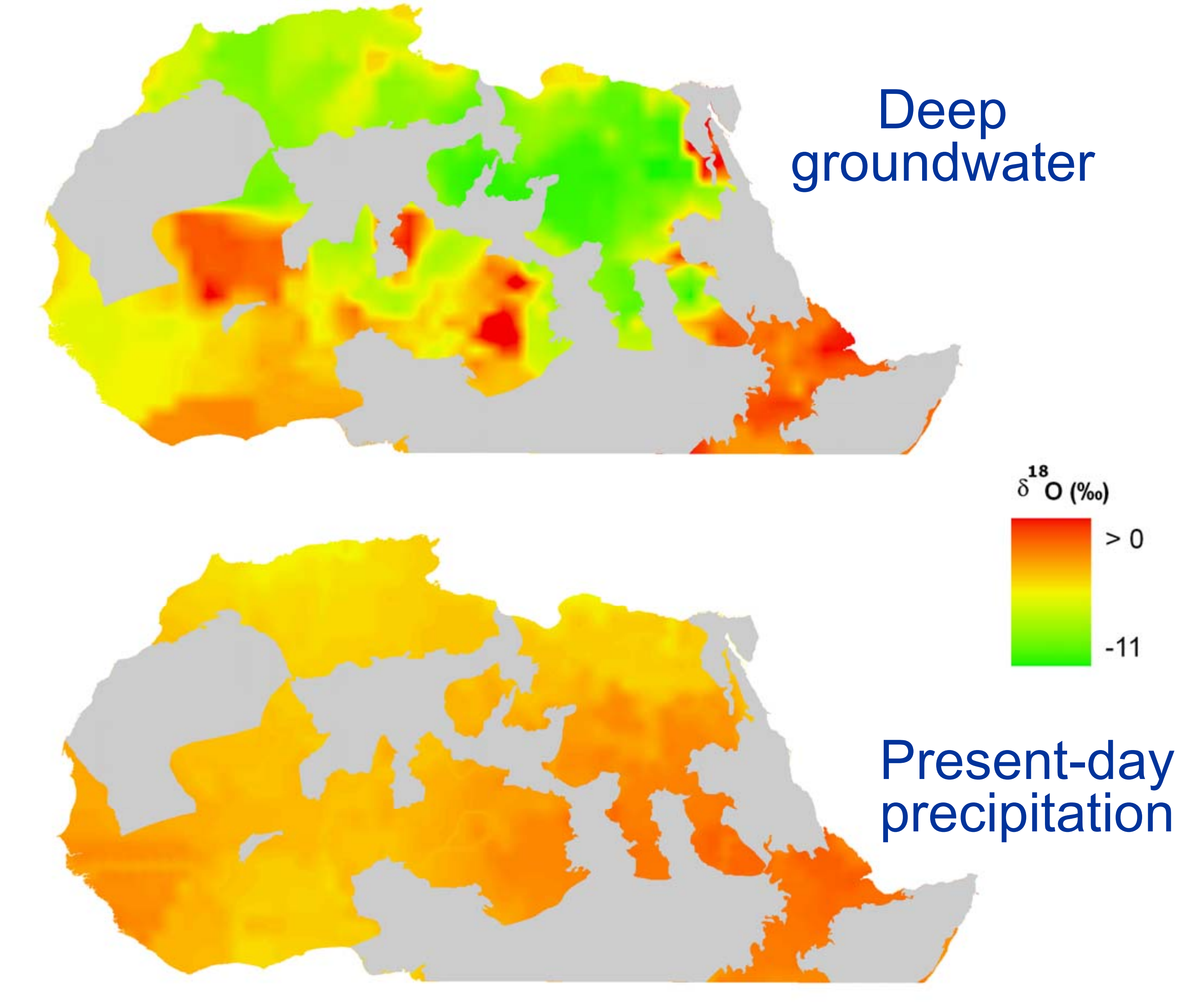
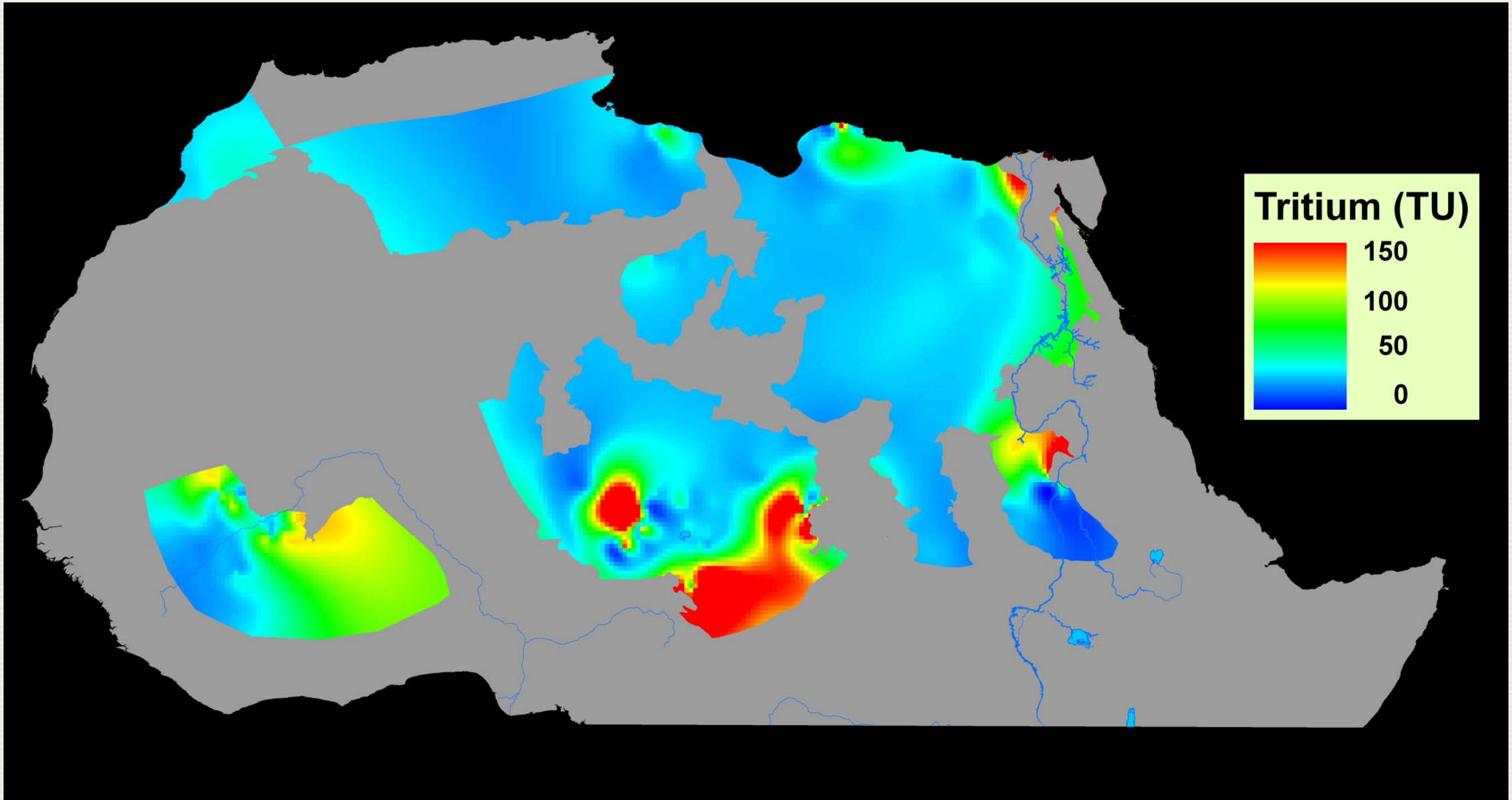
Ref: IAEA

Climate Change in northern Africa?



Recent recharge to deep aquifers in northern Africa (since 1960's)



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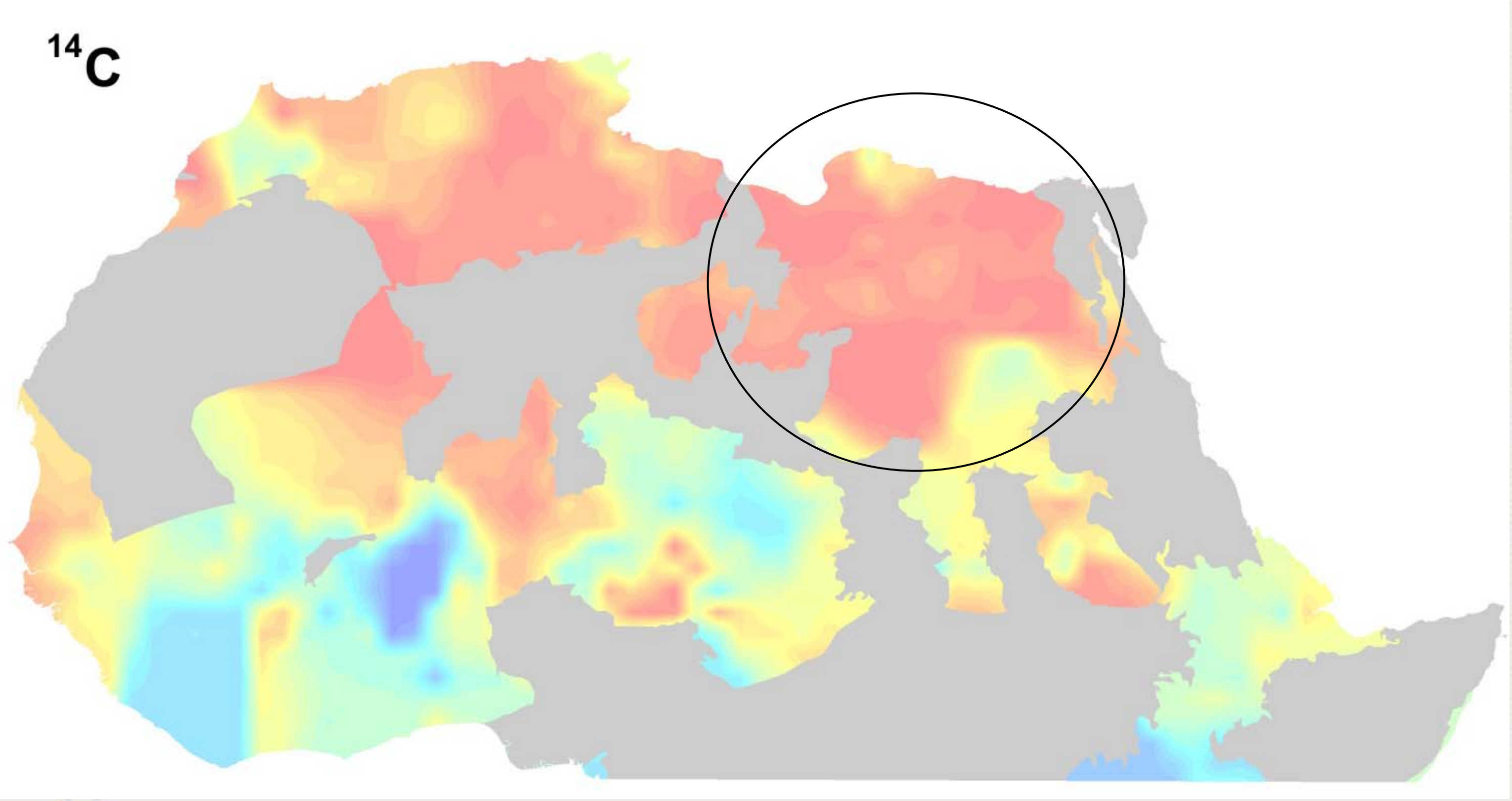
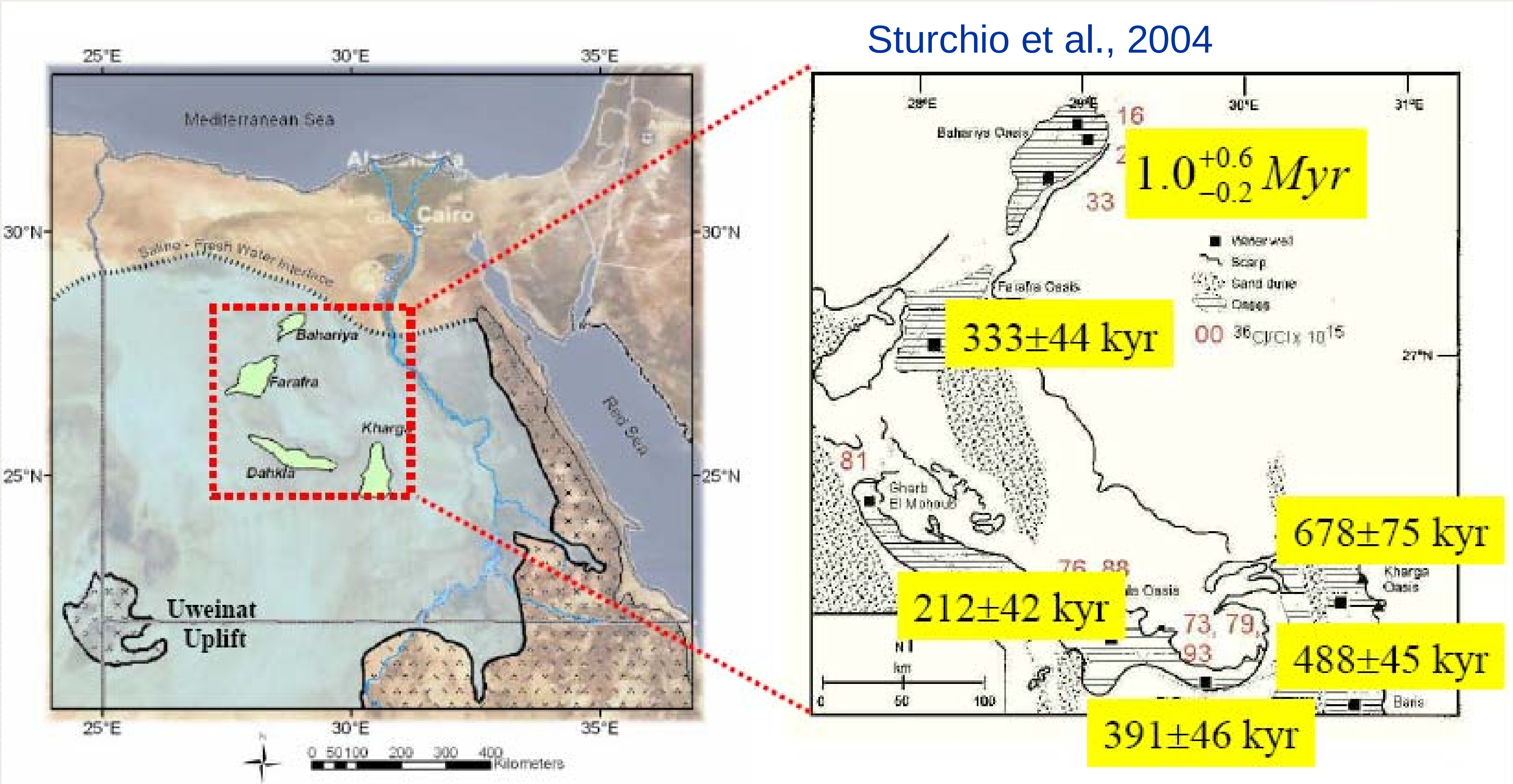
Carbon-14 in Northern Africa

- Carbon-14 indicates groundwater in much of northern Africa is >10,000 years old
  - Hot colors very low pmc (<20%)
  - Cold colors high pmc



Nubian Aquifer Ages using Krypton-81

Krypton-81 ages range from 200,000 to one million years old!



Groundwater ages derived from Cl-36 ($T_{1/2}$=300.000a) and hydrodynamic model ages at the Great Artesian Basin, Australia

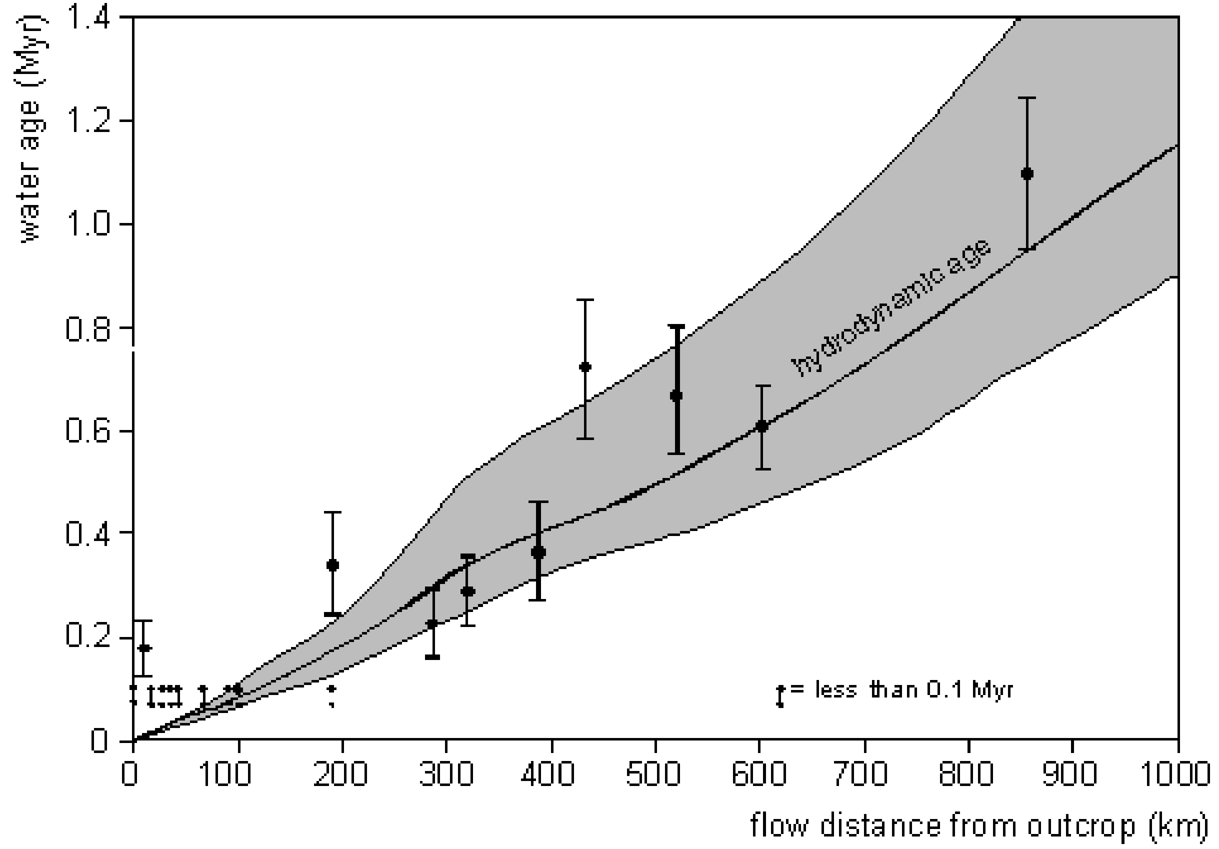


Fig.5.40 Concordant ^{36}Cl ages and geohydraulically estimated groundwater ages along the southern flow line in the Great Artesian Basin in Australia (after Bentley et al. 1986).

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Conclusions

Remember the three key groundwater questions:

- **Where did it (does it) come from?**
- **Where it is going?**
- **How long does it takes to get there?**

The answers are absolutely critical for building reliable conceptual models & for computer modelling of water resource use.

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Thank You!

If you want to use these techniques consult an isotope hydrologist about the best approaches. IAEA also has lots of materials that can help.

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