# Isotope Hydrology and Source-Water Protection: an Investigation from Lafayette Parish, Louisiana

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# What is "Isotope Hydrology"

- Application of geochemical methods involving analyses of environmental isotopes (naturally occurring stable isotopes and unstable isotopes) and unstable isotopes derived from anthropogenic sources to resolve questions related to the origin, flow, mixing, and age of ground waters and surface waters.

# Isotopic Methods in Hydrology

- Widely used to differentiate between sources of water
- Delineate recharge areas and flow paths
- Estimate residence times of ground waters
- Differentiate between potential sources of contamination

Lafayette Utilities System was interested in determining risk of contamination of sands of Upper Chicot aquifer from landfills, storage tanks, pipelines, agricultural activities, etc.

# Questions Asked by LUS

- Is there evidence of modern recharge in Lafayette Parish?
- If so, how variable are recharge signatures?
- What do the isotopic signatures indicate with respect to the potential for contamination of major water producing sands of the Chicot aquifer?

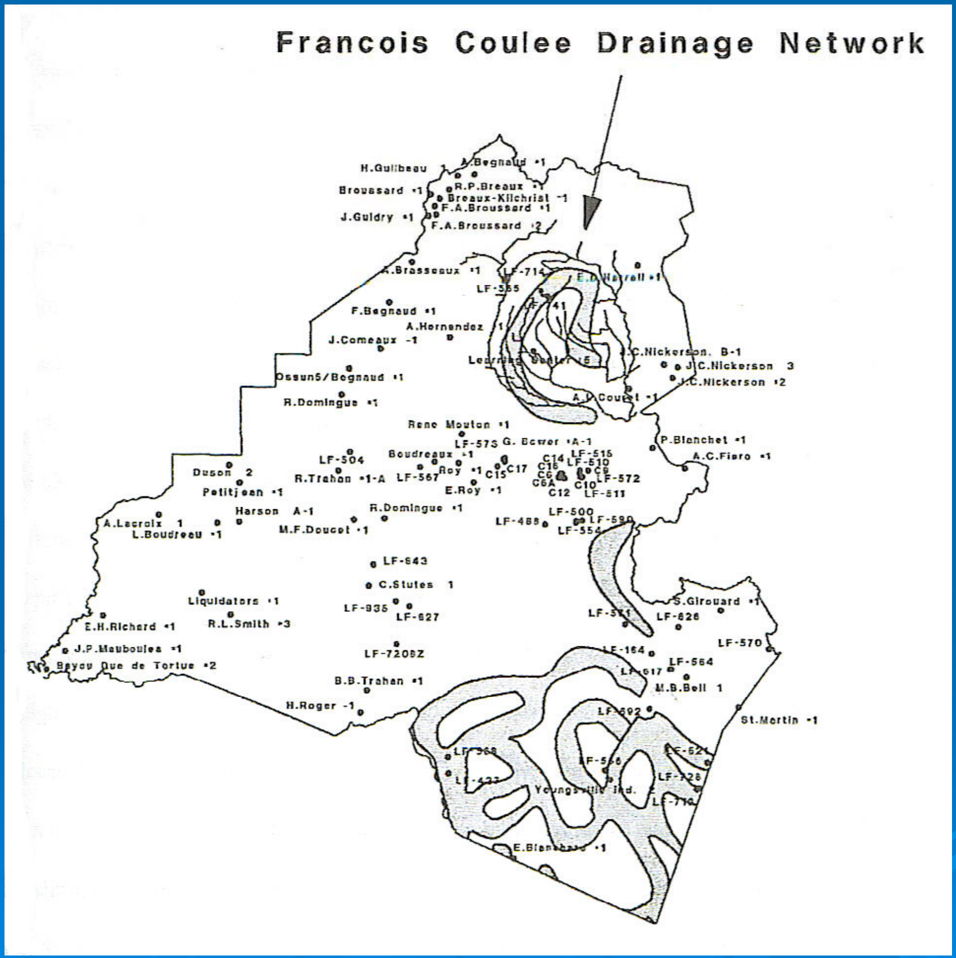
# LBG-Guyton recommended

- Collection of ground water samples for analysis of two radionuclides:
  - Carbon-14 ($^{14}C$)
  - Tritium ($^{3}H$)
- And two stable isotopes:
  - Oxygen-18 ($\delta^{18}O$)
  - Deuterium ($\delta^{2}H$)

# Sampling Program

- 13 wells
  - Nine public supply wells
  - One municipal well not used for public supply
  - Three private supply wells
  - Three upper Chicot, 10 lower Chicot
  - Upper Chicot – 65 to 270 ft
  - Lower Chicot – 452 to 567 ft
- Samples analyzed for
  - Major cations and anions
  - Tritium ($^{3}H$)
  - Carbon-14 ($^{14}C$) and Carbon-13 ($\delta^{13}C$)
  - $\delta^{18}O$ and $\delta^{2}H$

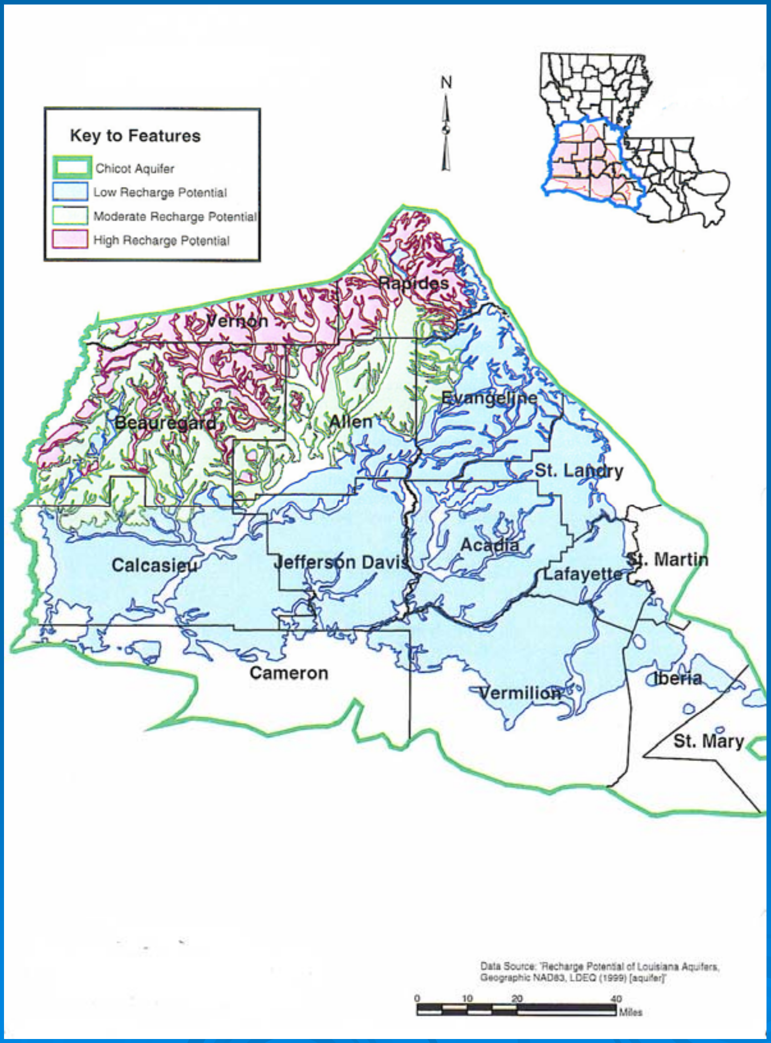
# Francois Coulee Drainage Network



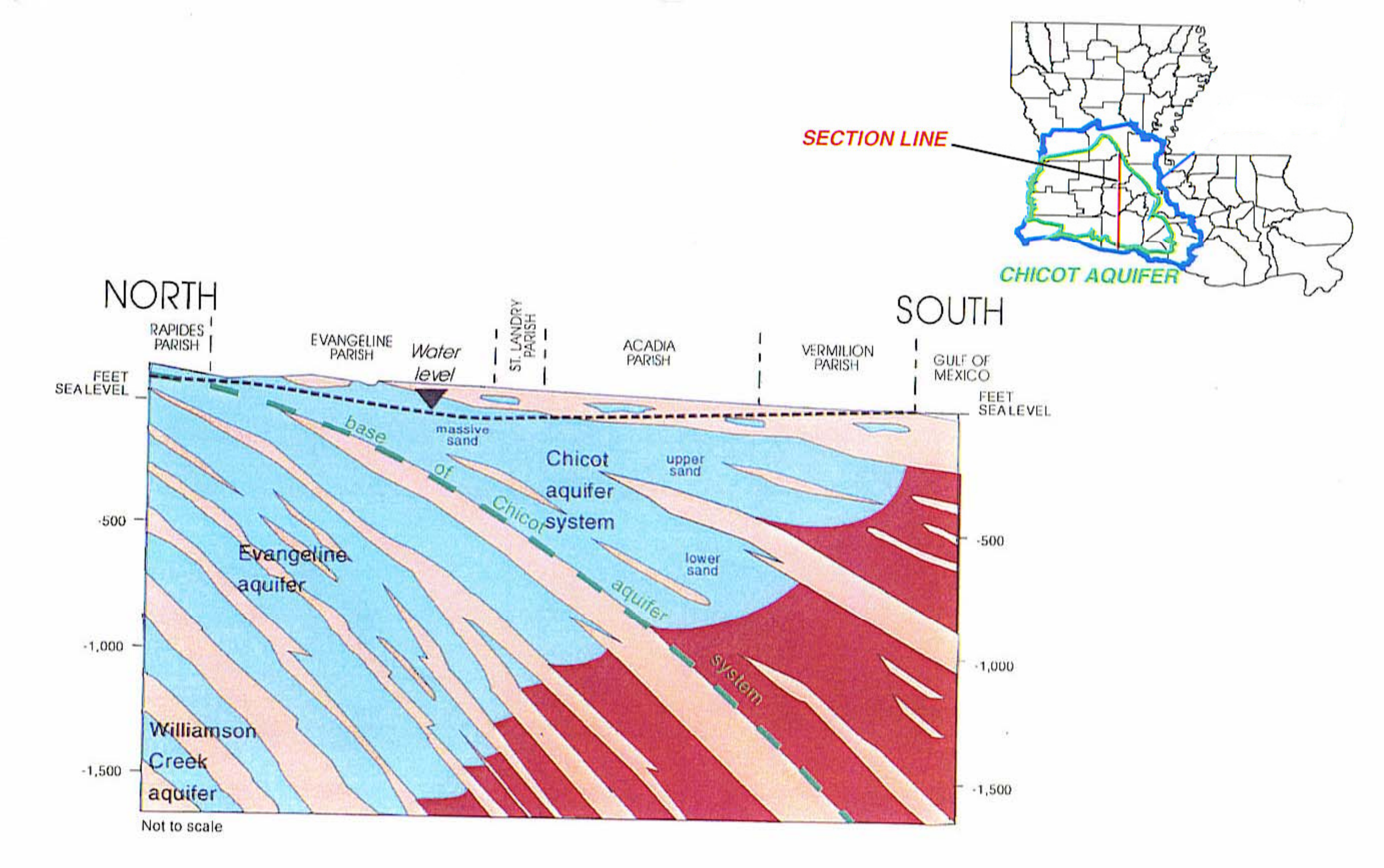

Source: A hydrogeological study of the Chicot aquifer in Lafayette Parish, Louisiana (Williams, 1996)

# Location of Wells in Lafayette Parish

# Chicot Aquifer Recharge Areas

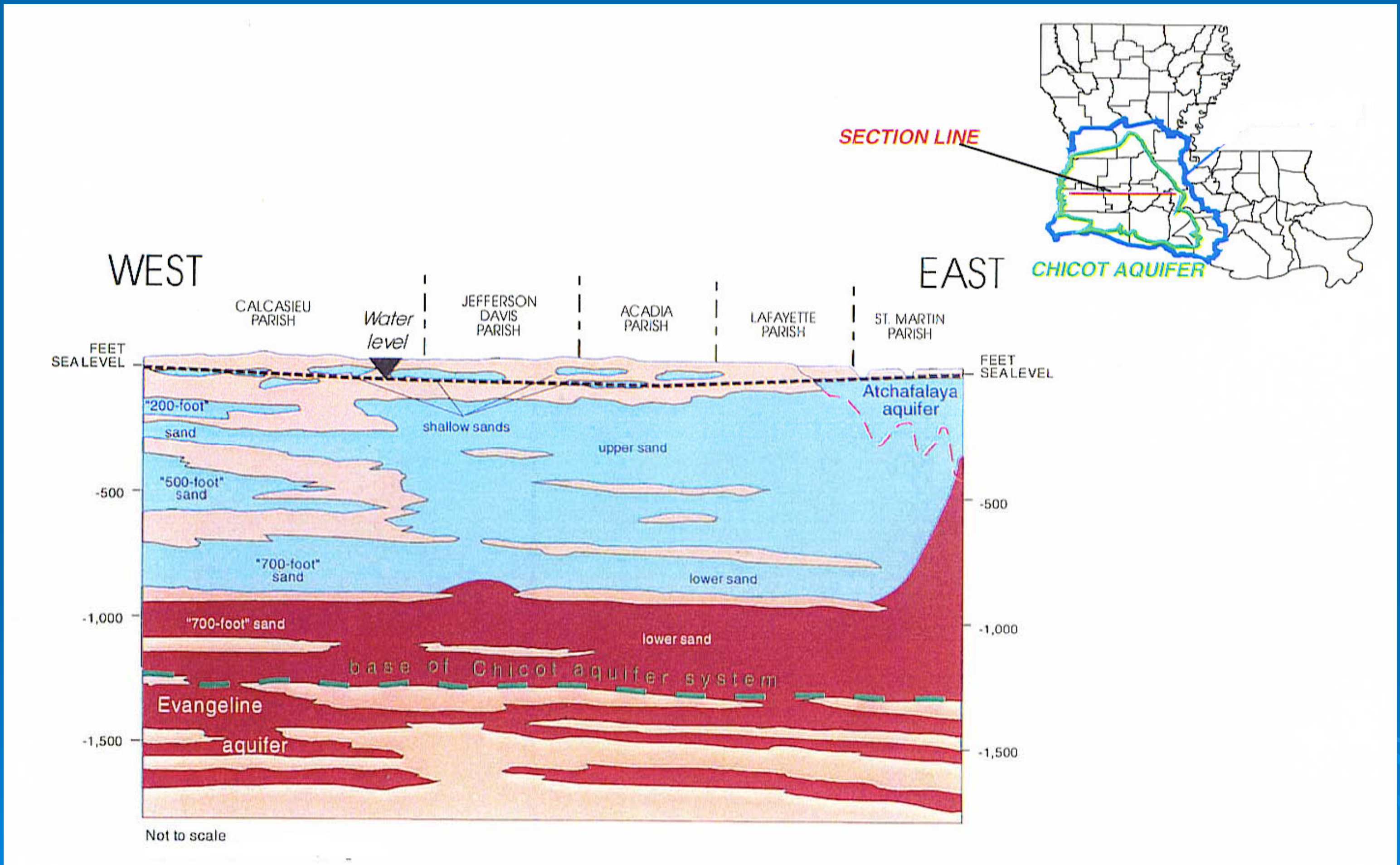


# N-S Chicot Aquifer Cross Section




Source: LaDOTD/USGS Water Resources Technical Report 66

# E-W Chicot Aquifer Cross Section




Source: LaDOTD/USGS Water Resources Technical Report 66

# Tritium – $^{3}H$

- Naturally occurring isotope of hydrogen
- Produced in upper atmosphere by interaction of Nitrogen-14 ($^{14}N$) with flux of neutrons generated by cosmic radiation:

$$^{14}N + n \rightarrow {}^{12}C + {}^{3}H$$

- Also generated by reactions associated with nuclear power plants and detonations of thermonuclear bombs
- Half-life – 12.43 years

# Tritium

- Incorporated directly into water by oxidation:

$$^{3}HHO$$

or

$$^{3}H_2O$$

- Activity measured by low-level counting by Tritium Laboratory, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami
- Effective tracer of ground waters with recharge dates of ~50 years or younger

# Tritium – $^{3}H$

- "Concentration" measured in "Tritium Units"
- A Tritium Unit is:
  - One atom of $^{3}H$ per $10^{18}$ atoms of H

# Thermonuclear Bombs -
# Principal Anthropogenic Sources of Tritium

# Operation Ivy, Shot Mike
# Yield – 10 Mt, Date: November 1, 1951

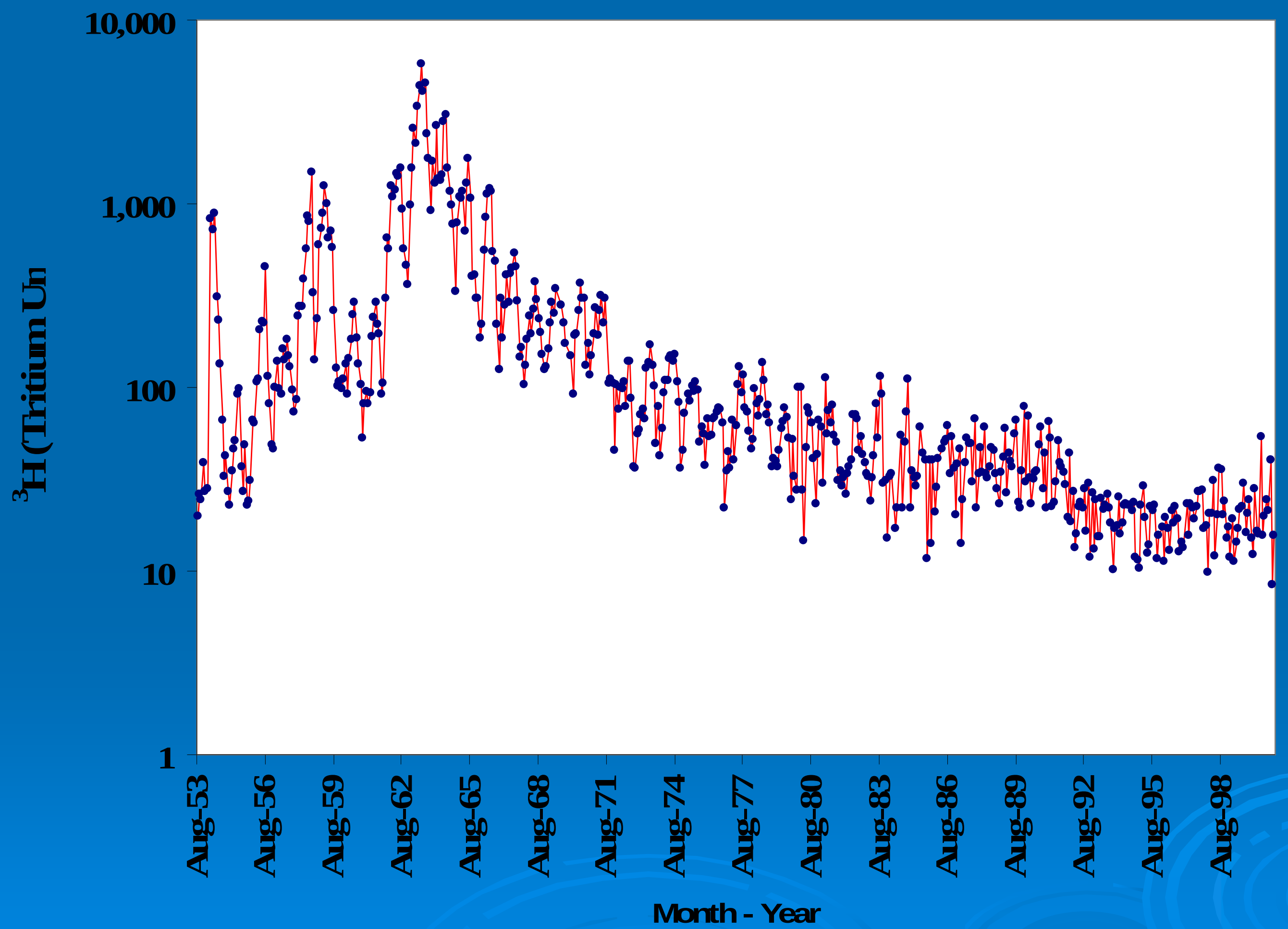
Detonations of Atomic Bombs and Especially Thermonuclear Bombs Generated Tritium far in Excess of Tritium from Natural Processes

“Pre-bomb” levels of $^3H$ in North Hemisphere were estimated to be 5 TU per year.

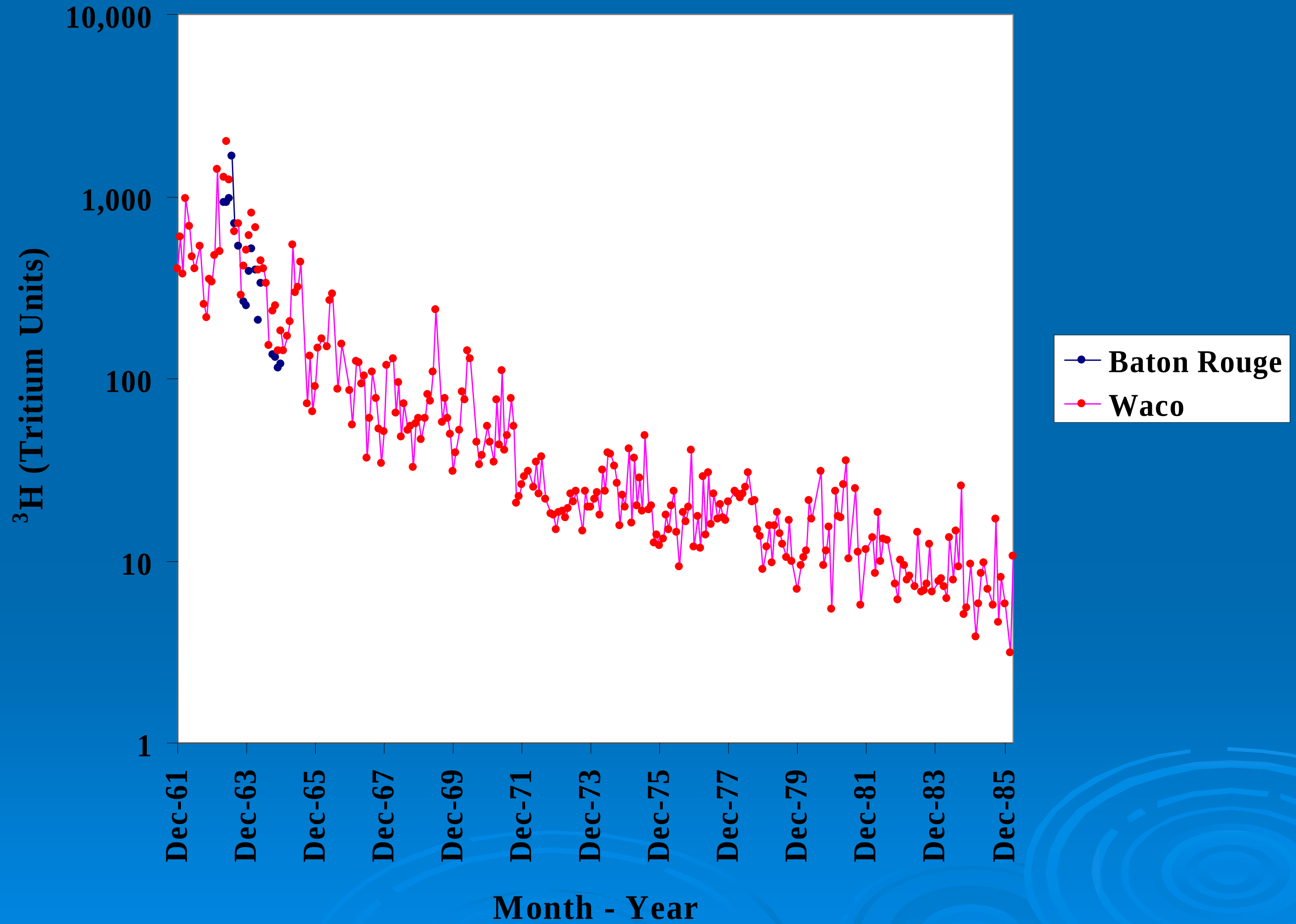
Generation of $^3H$ during period of above-ground testing of thermonuclear bombs rose to more than 2,000 TU by 1963.

Since 1963, the amount of $^3H$ has decreased to nearly pre-bomb levels.

# $^3H$ Measured in Precipitation at Ottawa, Canada (1953 – 2000)

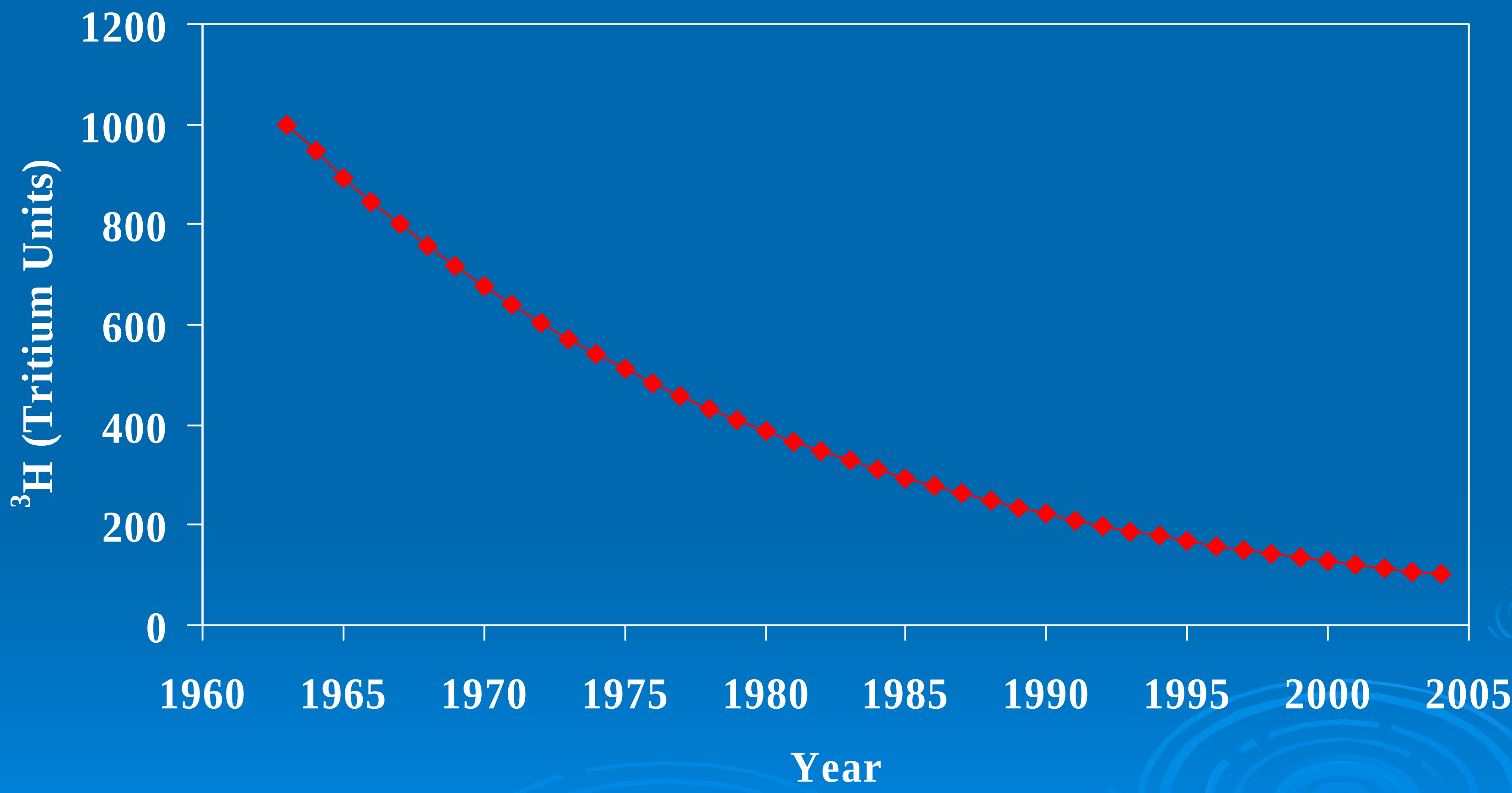


# $^{3}H$ Measured in Precipitation at Baton Rouge, LA and Waco, TX

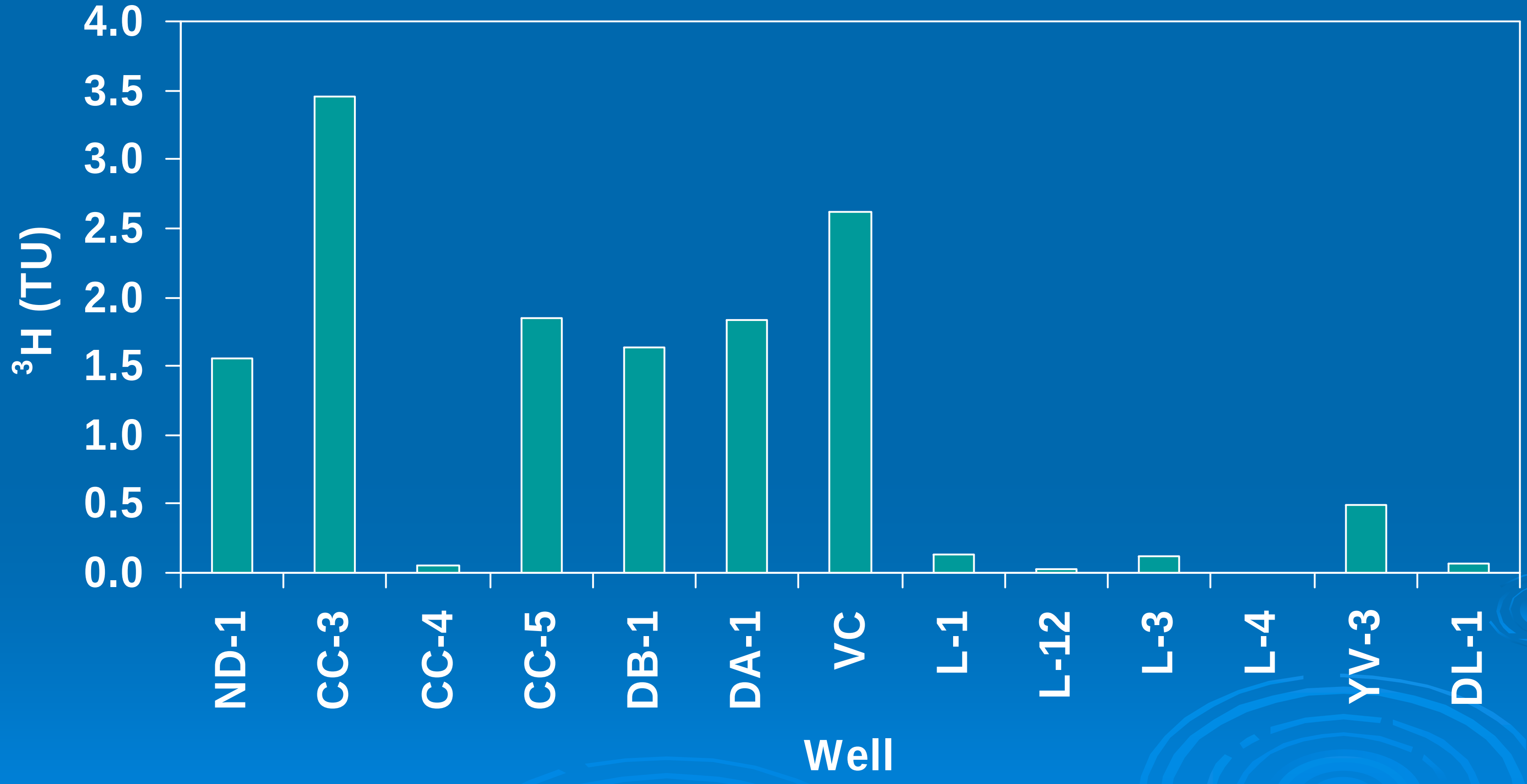



Source: IAEA's Global Network of Isotopes in Precipitation Database

# Decay Curve Based on $^{3}H$ in Precipitation at Baton Rouge, 1963



# Results of Analyses for Tritium in samples of ground water from Lafayette Parish wells



# Tritium Analyses Indicate

- Demonstrably "bomb" to "post-bomb" values for wells with depths 150 ft or less
- Probably "pre-bomb" values for wells greater than 150 ft
- Possibly vertical leakage of younger water into deeper sands as result of gradients imposed by pumping
- "Youngest" waters occur in northern and eastern areas of Lafayette Parish

# Radiocarbon – $^{14}C$

- Naturally occurring isotope of carbon
- Formed in upper atmosphere by interaction of $^{14}N$ with neutrons generated by cosmic radiation:

$$^{14}N + n \rightarrow ^{14}C + H$$

- Also generated by complex reactions associated with with nuclear power plants and detonations of thermonuclear bombs
- Half-life – ~5,540 years

# Radiocarbon – $^{14}C$

- Becomes incorporated as a dissolved constituent of water as follows:

$$^{14}CO_2 + H_2O \rightarrow H_2{}^{14}CO_3$$

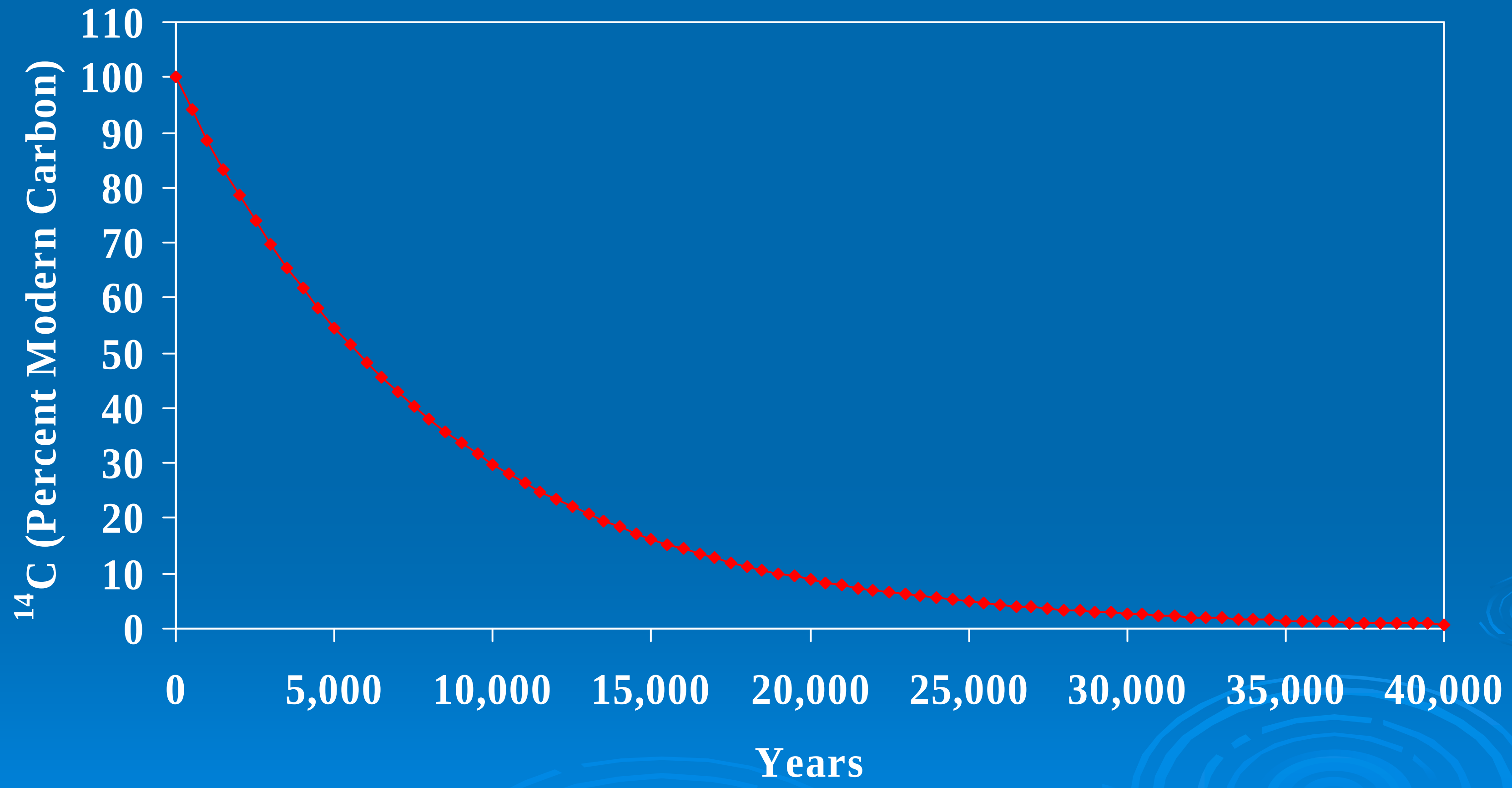
then

$$H_2{}^{14}CO_3 \rightarrow H^+ + H^{14}CO_3^-$$

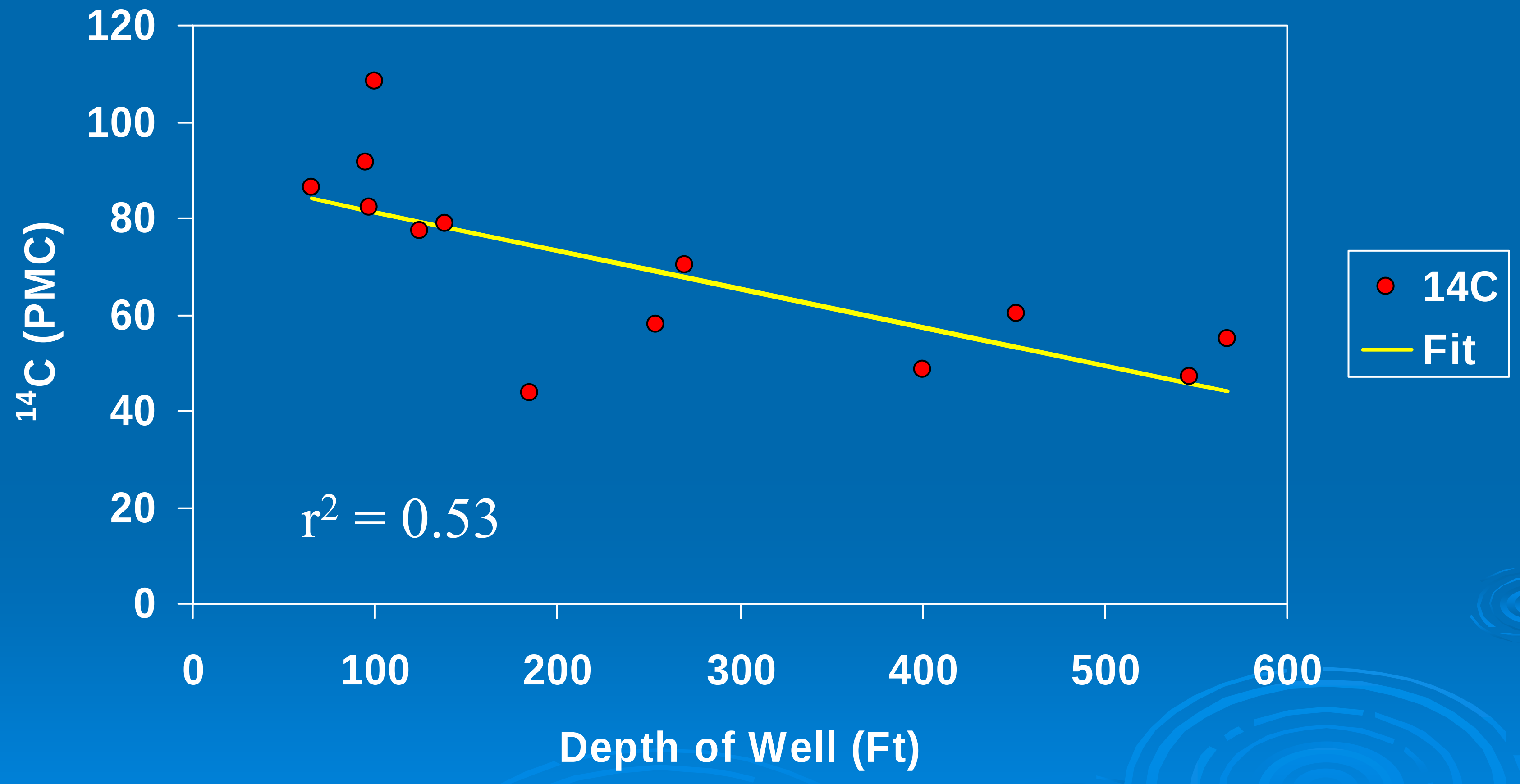
# Radiometric Decay Equation

- $A = A_o e^{-\lambda t}$
  - A = Activity of sample
  - $A_o$ = Initial activity of sample
  - $\lambda$ = Decay constant (ln(2)/half-life of isotope)
  - t = Time elapsed since initiation of decay

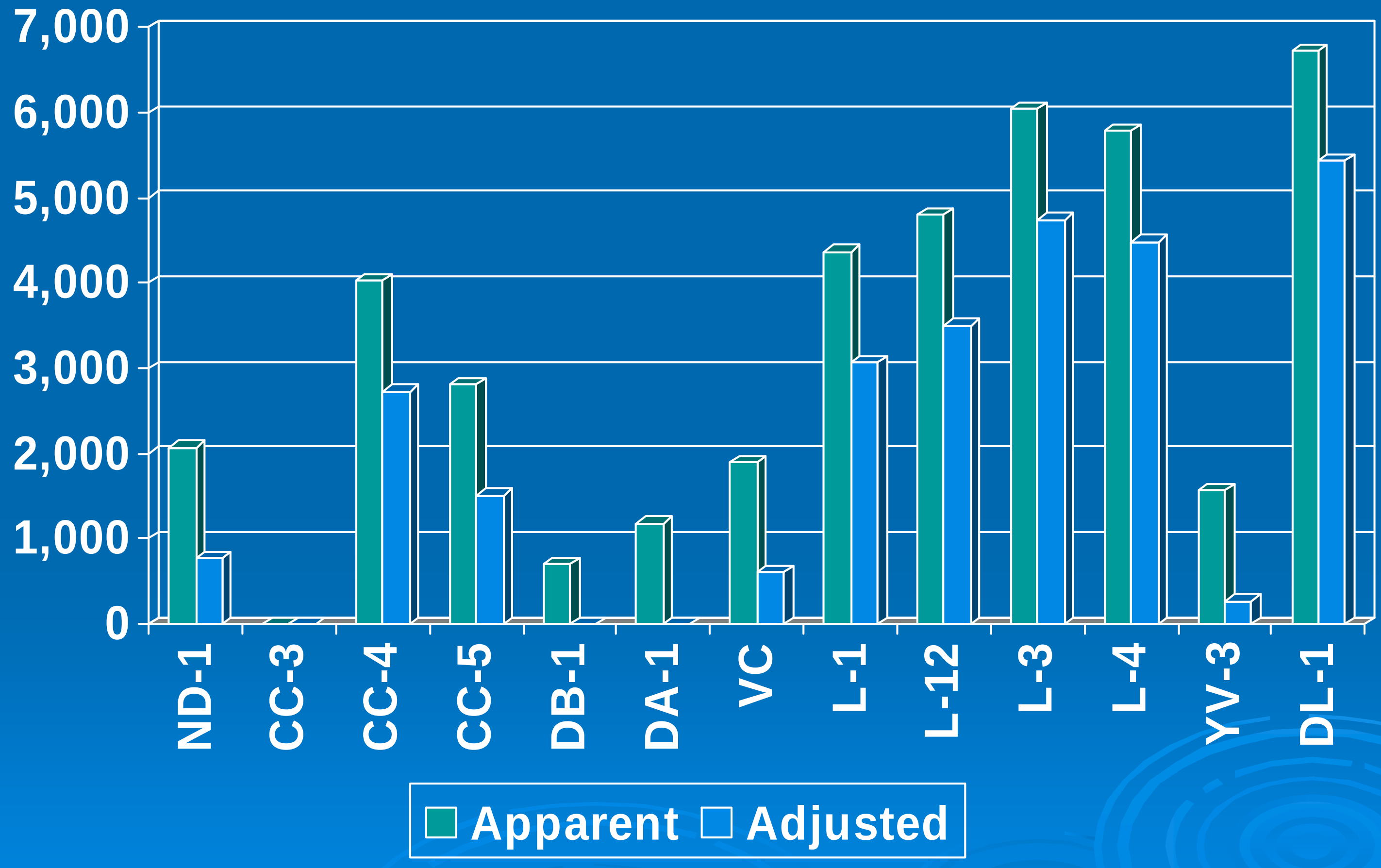
# $^{14}C$ Decay Curve



# $^{14}C$ as a Function of Depth in Lafayette Parish Wells



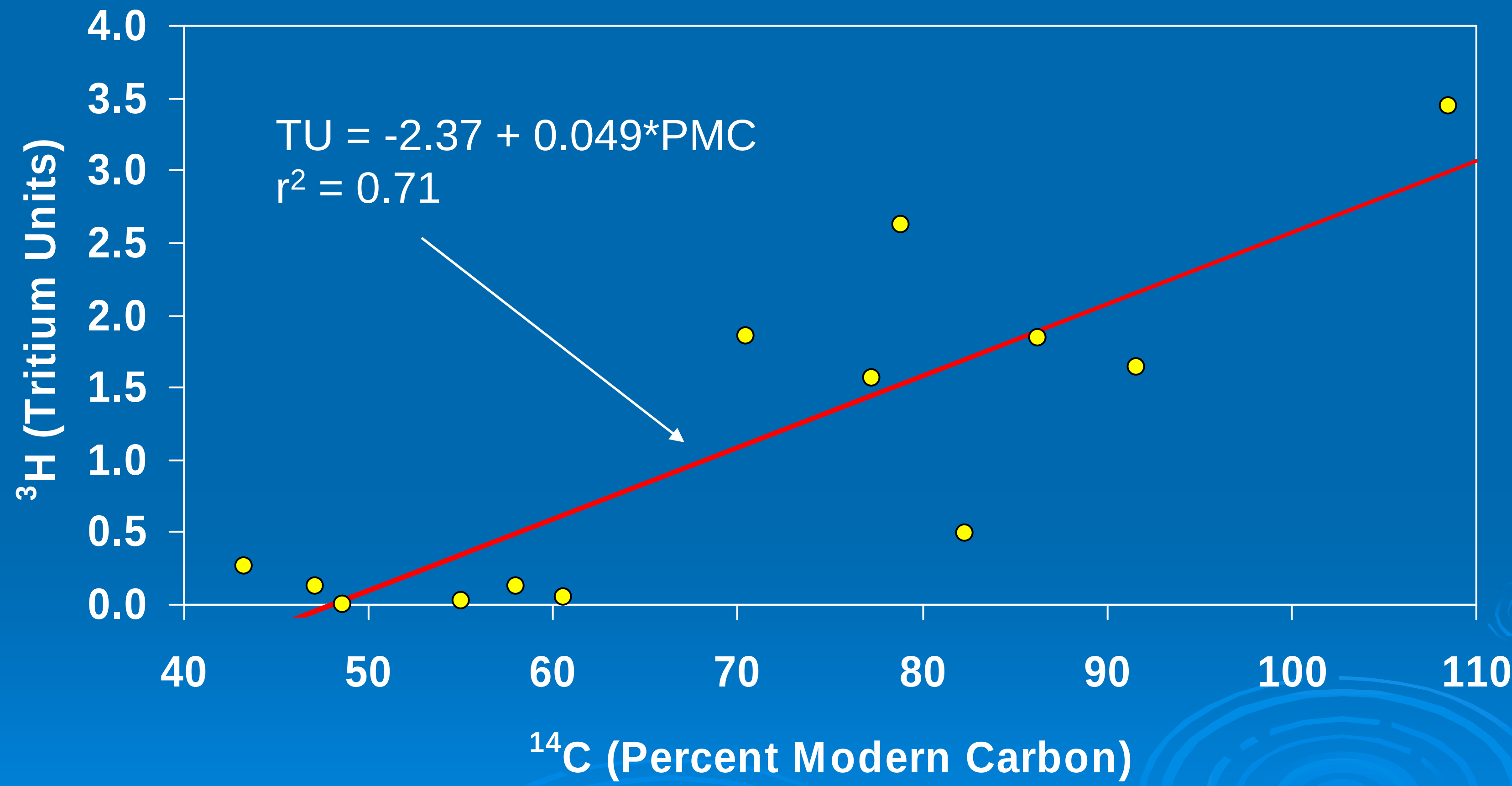
# Apparent and Adjusted $^{14}C$ Ages



# $^{14}C$ Analyses Indicate

- Ages ranging from modern to between 4,000 and 6,000 years
- Youngest $^{14}C$ ages associated with bomb/post-bomb $^{3}H$
- Oldest $^{14}C$ ages associated with deeper wells

# Correlation between $^{3}H$ and $^{14}C$ in Lafayette Parish Ground Waters



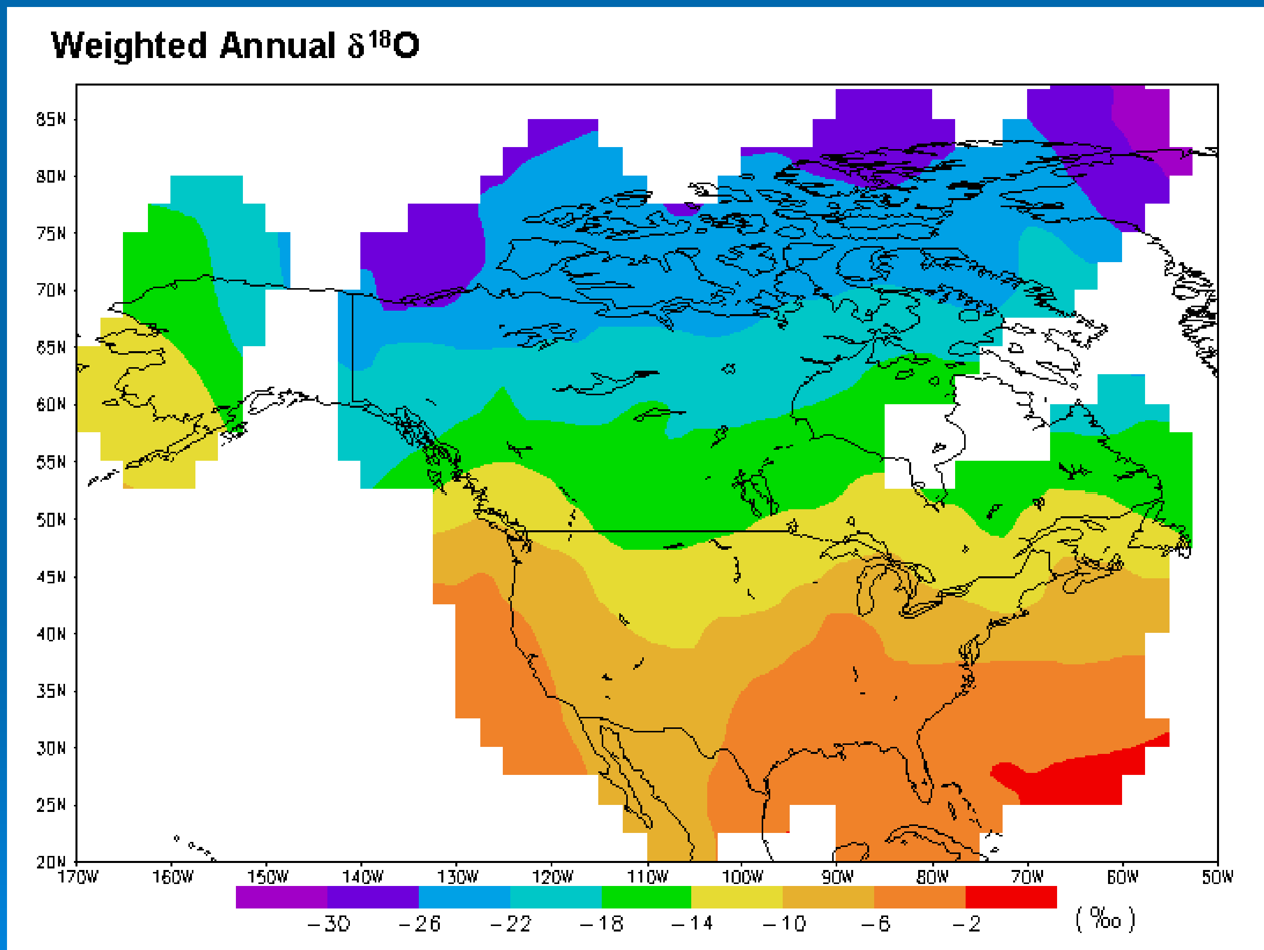
# Combined $^{3}H$ and $^{14}C$ Analyses Indicate

- Reasonable correlation between $^{3}H$ and $^{14}C$
- Probable mixing between bomb/pre-bomb and post-bomb waters
- Youngest waters typically occur in shallow sands of northern and eastern areas of Lafayette Parish
- Oldest waters tapped by deeper supply wells
- Best strategy to minimize threat of contamination is to drill municipal supply wells to sands of lower Chicot aquifer

# Stable Isotopes of Oxygen and Hydrogen

- Oxygen-18 ($^{18}O$)
  - Abundance reported as $\delta^{18}O$ – Standard Mean Ocean Water (SMOW)
- Deuterium ($^{2}H$)
  - Abundance reported as $\delta^{18}O$ – SMOW
- Abundances vary according to fractionation processes associated with temperature of precipitation, amount of precipitation, evaporation, elevation, and distance from source

# Annual Mean $\delta^{18}O$ in Precipitation over North American Continent

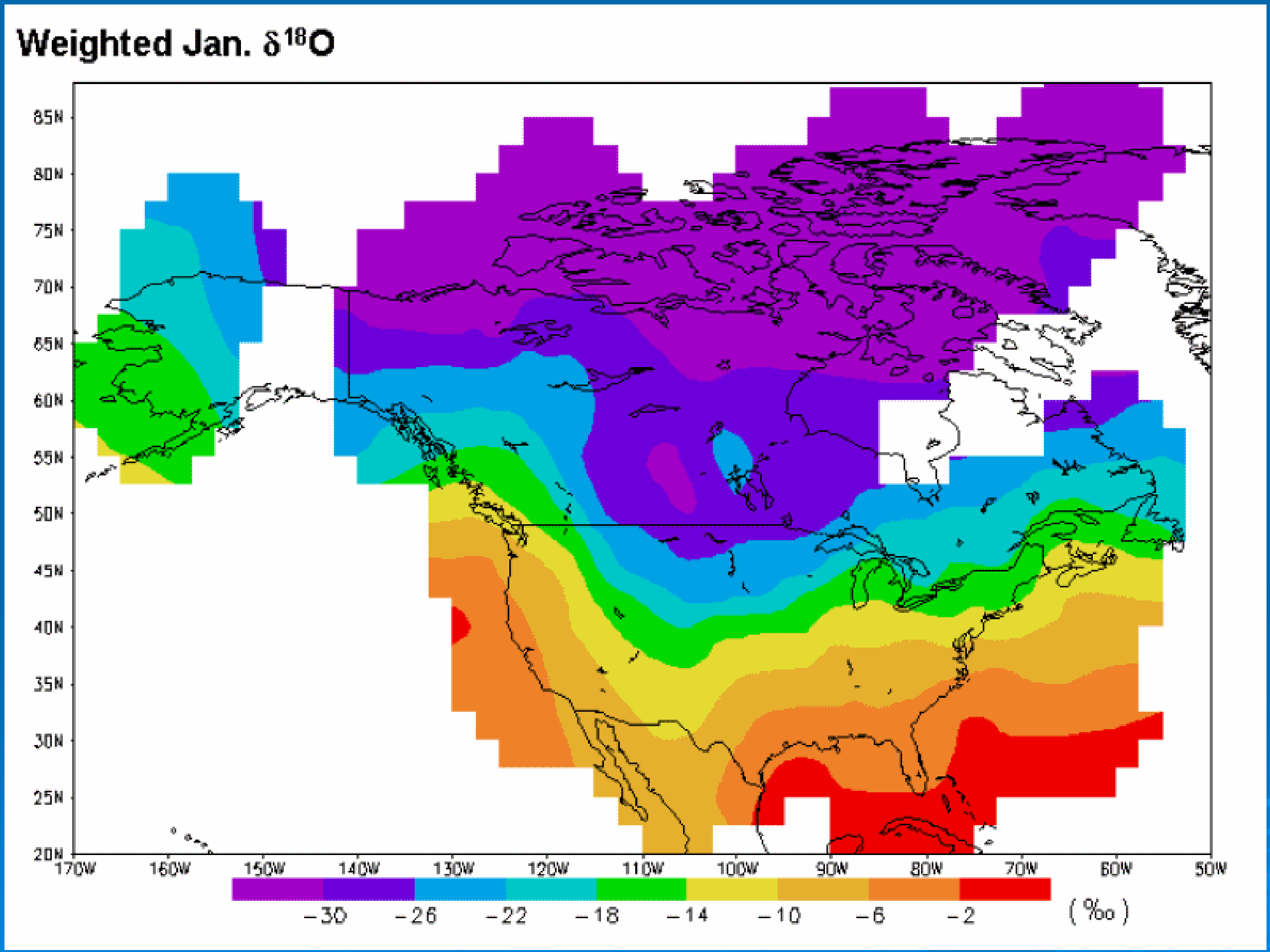



Source: Global Network of Isotopes in Precipitation Database

# For $^{18}O$ and $^{2}H$

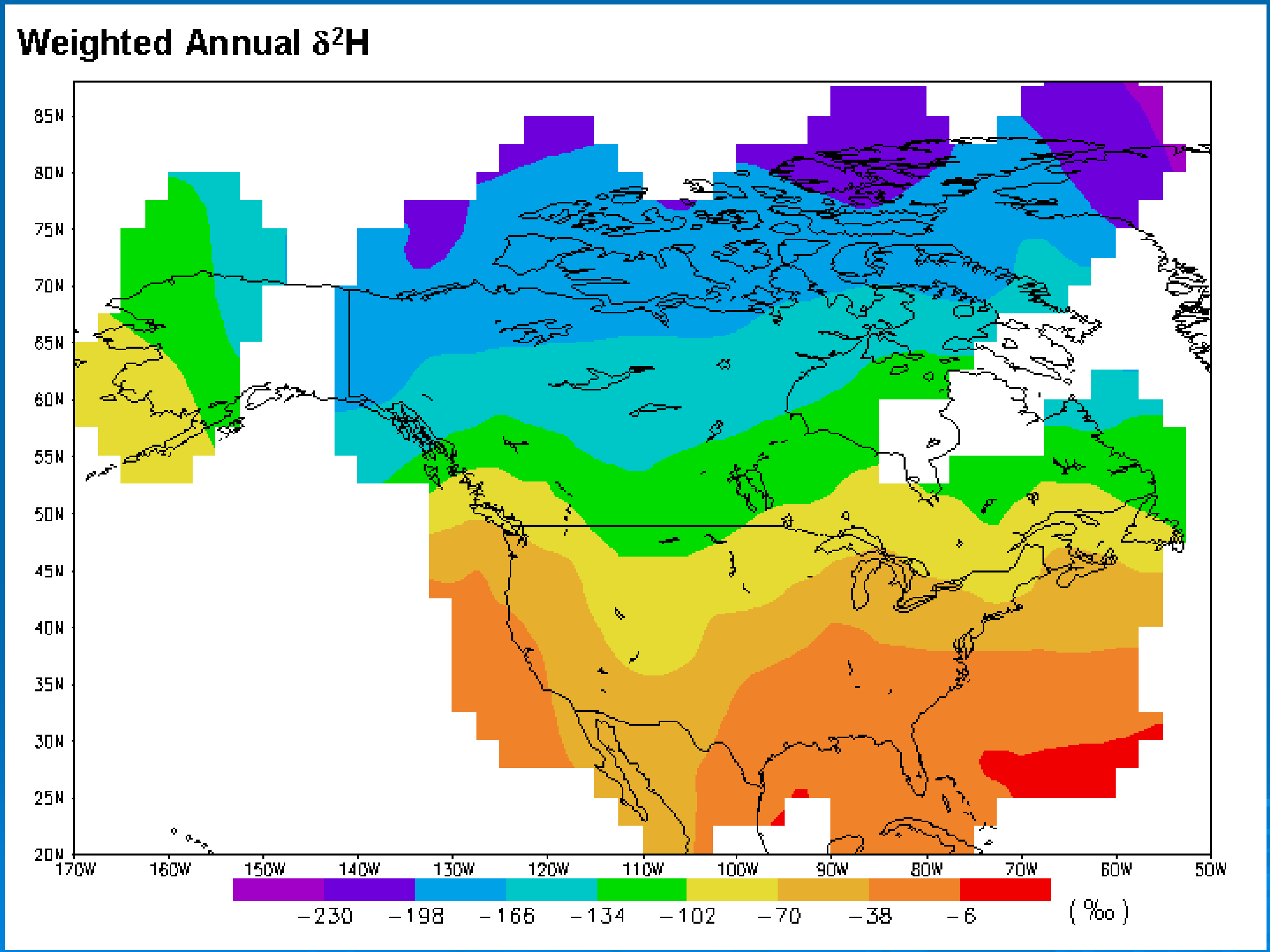
- Precipitation becomes increasingly depleted in both isotopes toward the higher latitudes in the northern hemisphere
- Weighted means vary from month to month
- During glacial epochs, precipitation was more depleted

# Weighted Monthly $\delta^{18}O$ in Precipitation over North American Continent



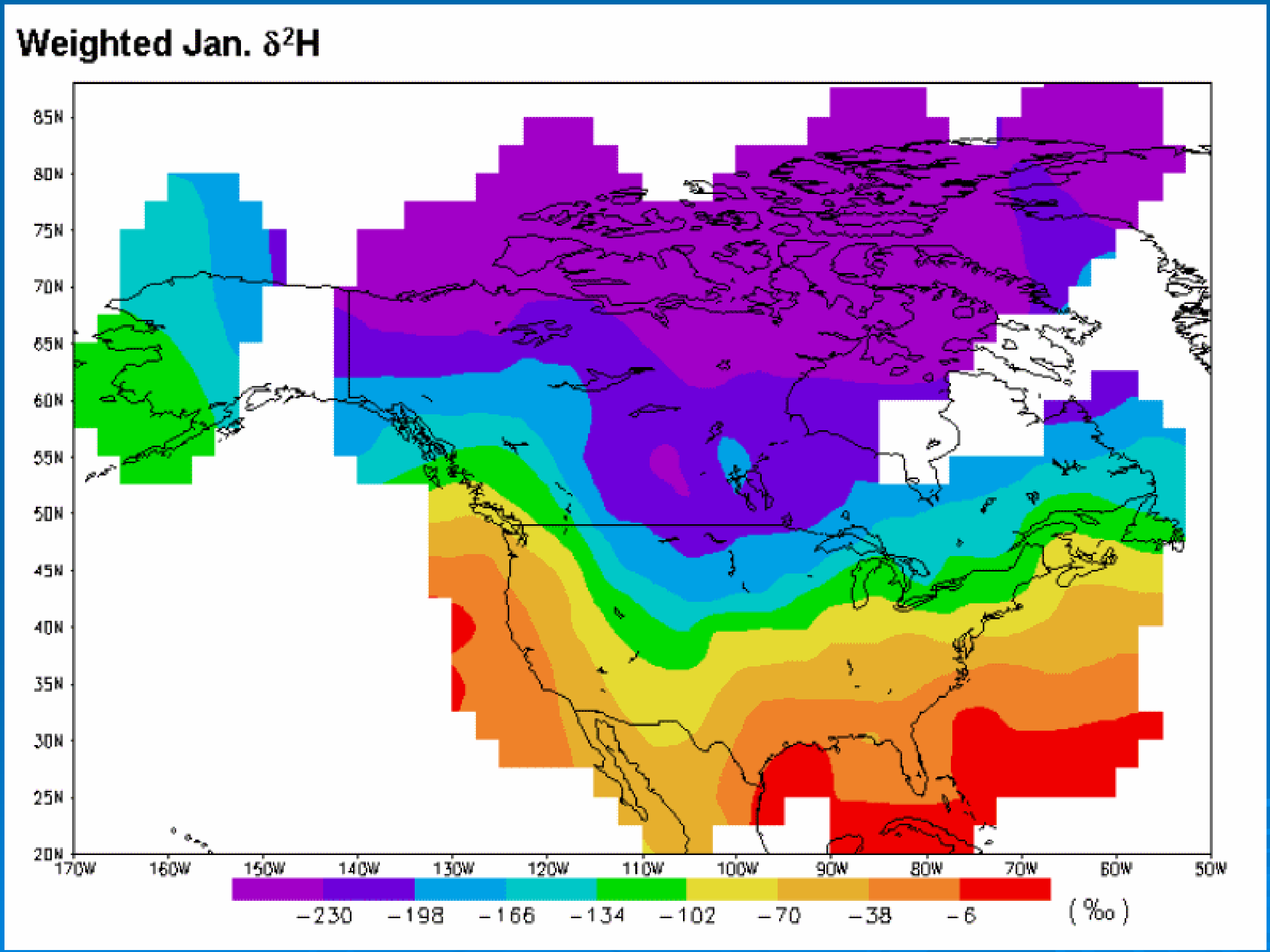

Source: Global Network of Isotopes in Precipitation Database

# Annual Mean δ²H in Precipitation over North American Continent



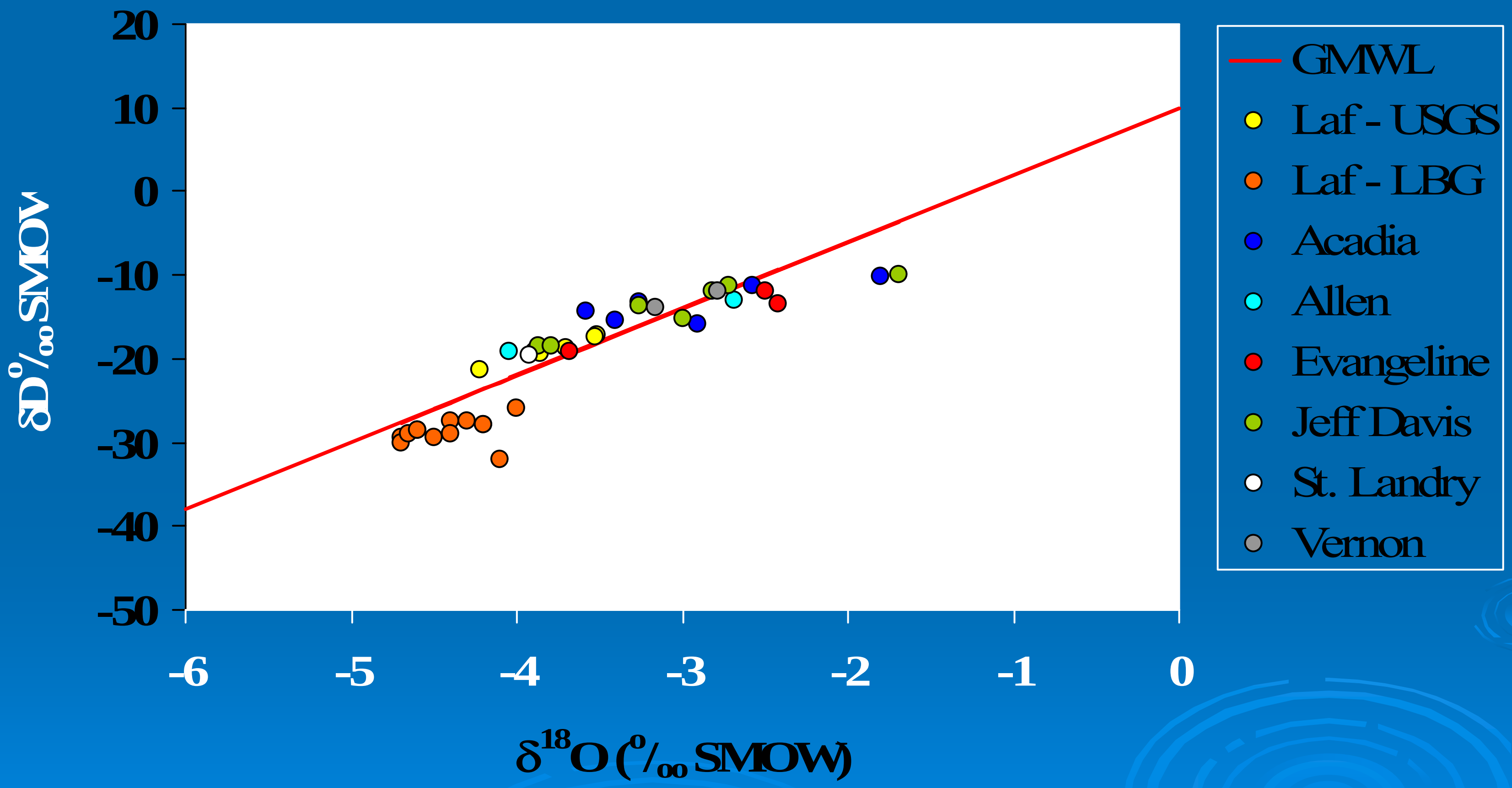

Source: Global Network of Isotopes in Precipitation Database

# Weighted Monthly $\delta^2H$ in Precipitation over North American Continent




Source: Global Network of Isotopes in Precipitation Database

# Distribution of Stable Isotopes in Ground Waters of Southern Louisiana



# $\delta^{18}O$ and $\delta^{2}H$ of Chicot Aquifer Waters

- Are consistent with normal abundances for the region
- Are not indicative of precipitation in colder and wetter climatic regime
- Do not manifest patterns indicative of evaporative enrichment

# Conclusions

- Shallow ground waters are demonstrably modern
- Ages increase (often sharply) with depth
- François coulee area of northern Lafayette Parish appears to have greatest potential for recharge
- Safest strategy for LUS and other suppliers of public water is to complete wells in lower Chicot sand