Radiocarbon Dating and Paleohydrology of Regional Aquifer Groundwater Beneath the Pajarito Plateau, New Mexico

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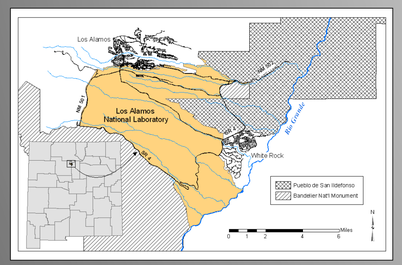
Abstract

The regional aquifer beneath the Pajarito Plateau offers a unique opportunity to investigate groundwater age and its relationship to climate change during the Holocene. The aquifer material at the regional water table is mostly free of calcium carbonate (calcite), making radiocarbon in dissolved inorganic carbon an ideal age tracer. From 2005 through 2009, 129 groundwater samples from 69 regional aquifer wells and springs were collected and analyzed for radiocarbon and other dissolved constituents including tritium, major ions, trace elements, and stable isotopes of hydrogen and oxygen. Wells and springs exhibiting background conditions do not contain tritium above 0.3 tritium units, suggesting that no post-1943 recharge has occurred at these sampling locations. Results indicate that groundwater age increases west to east from about 500 years along the mountain-front recharge zone to 10,000 years at a discharge zone at White Rock Canyon springs discharging at the Rio Grande. Distributions of average age (radiocarbon) and modern age (tritium) confirm active recharge and mixing of pre-1943 groundwater occurs beneath perennially wet canyon bottoms dissecting the Pajarito Plateau. Groundwater flow velocities calculated from points along the regional flow path and outside the areas of active recharge range from 1 to 3 m/year. Through the 10,000 year radiocarbon record, the more climate sensitive ions such as chloride and sulfate tend to increase with age with R^2 correlations of 0.687 and 0.719, respectively. Stable isotope ratios of both oxygen and deuterium correlate with age and are more positive in older waters, suggesting that the climate in northern New Mexico during the Holocene was warmer than in recent times.



Regional setting of Los Alamos National Laboratory

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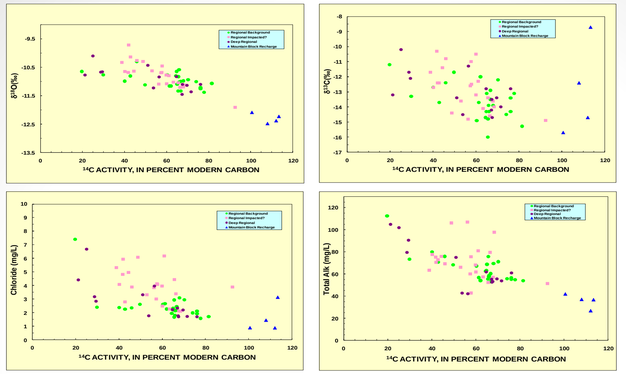
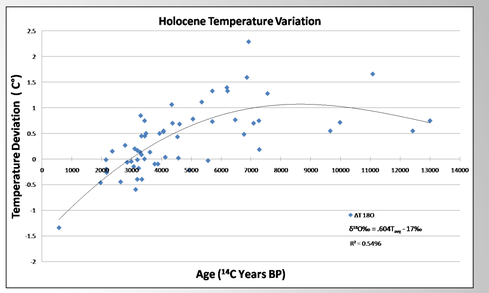
Objectives and Analytical Methods

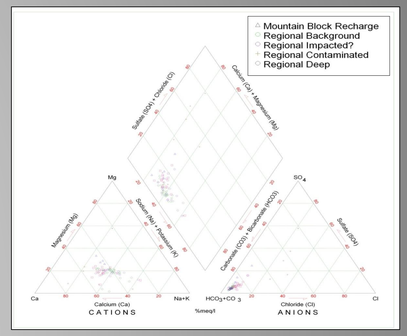
- The two objectives are to quantify average groundwater ages and establish an understanding of the groundwater flow system in the regional aquifer beneath the Pajarito Plateau (water sources, mixing relations, flow paths, and travel times) that is independent of numerical models.
- This understanding can be used either to guide the development or evaluate results of corresponding flow models.
- Of particular interest is the sustainability of water resources.
- **Carbon-14**, accelerator mass spectrometry
- **Tritium**, helium ingrowth and electrolytic enrichment
- **Stable isotopes**, isotope ratio mass spectrometry
- **Anions**, ion chromatography
- **Metals**, inductively couple (argon) plasma-optical emission spectroscopy (ICP-OES) and inductively couple (argon) plasma-mass spectrometry (ICP-MS)
- **Total carbonate alkalinity**, titration



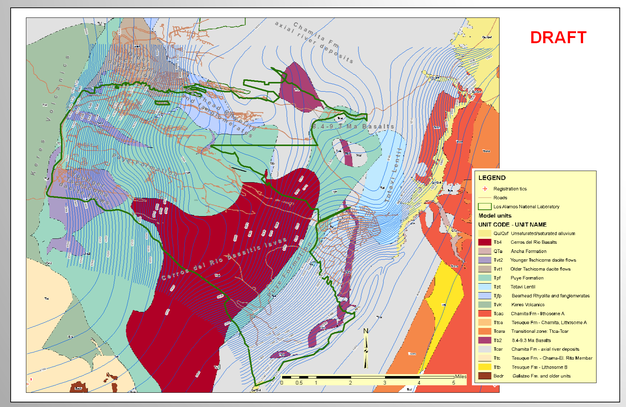
Bivariate plots illustrating the relationship between percent modern carbon (pmC), or groundwater age, and the stable isotope $\delta^{18}O$ in water, $\delta^{13}C$ in dissolved organic carbon, chloride, and total alkalinity. Note how stations with lower pmC (older groundwater) values tend to be less depleted, or heavier, with respect $\delta^{18}O$ and contain higher concentrations of chloride and total alkalinity than that of more recent groundwater.



Average annual atmospheric temperature deviation calculated from shifts in $\delta^{18}O$ relative to a reference temperature from ~ 5 yr old mixed recharge waters. $\delta^{18}O$ temperature dependence taken from Phillips et al., 1986 using the local meteoric water line from Vuataz and Goff, 1985. $\delta^{18}O$ record indicates warmer temperature during middle Holocene with recent cooling.

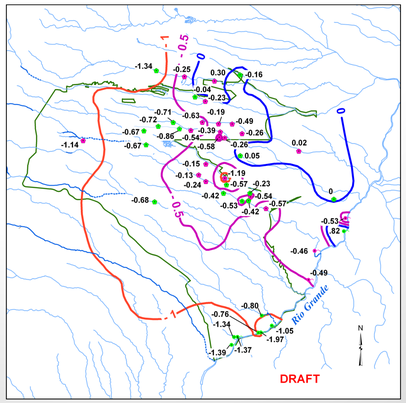


Piper diagram illustrating major ion chemistry from wells and springs in the study area. Contaminated regional aquifer groundwaters have higher concentrations of sulfate, chloride, and other tracers compared to background stations.

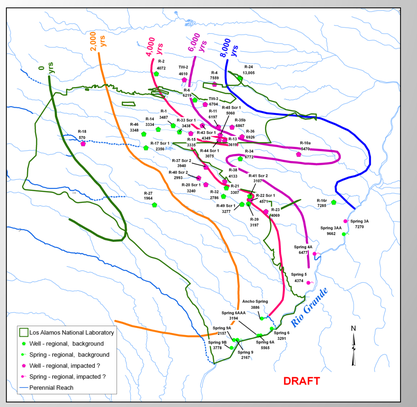


Geology at the water table and water-table elevation contours

From "The 2009 three-dimensional, geologic models of the Los Alamos National Laboratory site, southern Española basin, and Española basin", Cole and others, 2010, LA-UR-09-03701
Water contours from LANL, 2009 and INTERA, 2006



Saturation index map for $CaCO_3$ (calcite) for the regional aquifer. In most areas, groundwater at the regional aquifer water table is undersaturated with respect to calcite.



Inferred distribution of groundwater age in years before present at the regional water table beneath the Pajarito Plateau based on unadjusted ^{14}C ages

Conclusions

- The regional aquifer beneath the Pajarito Plateau contains both submodern (background) water and a component of mixed submodern and recent recharge water. Submodern water is characterized by pre-1943 radiocarbon ages, tritium levels below 0.3 TU, and background levels of major ions (chloride, etc). The mixed component includes elevated levels of tritium and major ions (chloride, etc.) in relation to submodern water.
- Average ages for the regional aquifer range from 570 to 13,005 years based on unadjusted ^{14}C age results.
- Groundwater with younger unadjusted ^{14}C ages appears to be associated with canyon bottom recharge.
- Younger regional aquifer groundwater has lighter $\delta^{18}O$ values, suggesting different recharge elevations and/or cooler climate for precipitation. Older regional aquifer groundwater (background) has higher concentrations of chloride and total alkalinity, suggesting more water-rock interactions within the Santa Fe Group.
- Radiocarbon ages in association with climate sensitive elements or "climate proxies" in groundwaters spanning the Holocene Epoch suggest a warmer climate followed by gradual cooling to present day.
- Most of the regional aquifer groundwater samples are undersaturated with respect to calcite suggesting that dilution of ^{14}C by bicarbonate is not a significant process. Most of the unadjusted ^{14}C ages probably do not need to be adjusted for calcite dissolution based on $\delta^{13}C$ values.
- In conjunction with hydrogeologic data such as water-level measurements, the data and findings provided by this work will be used to determine the sustainability of water resources in the Los Alamos area.