Tritium Age Classification: Revised Method for Minnesota

Report GW-05

December 2020

Minnesota Department of Natural Resources

Minnesota Department of Health

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A new method to determine groundwater age from tritium was developed by the United States Geological Survey (USGS). The Minnesota Department of Natural Resources (DNR) and the Minnesota Department of Health (MDH) are adopting that method with a few minor changes. For historical reasons the term groundwater residence time is used in this paper instead of groundwater age.

Tritium has been used to estimate groundwater residence time in Minnesota since the late 1980s. Alexander and Alexander (1989) proposed a method that classified a water sample into recent, mixed, or vintage tritium age based directly on the tritium unit concentration in each sample. This method worked well when tritium concentrations were fairly high in precipitation. However, most tritium deposition occurred in the United States between 1953 and 1983 (Michel and others, 2018). Three half-lives of tritium have elapsed from 1983 to 2020, resulting in tritium concentrations in precipitation that are similar to the background concentrations prior to 1953. The original Alexander and Alexander interpretation method is no longer viable because it assumes there is more tritium in precipitation than there actually is.

A new method to determine groundwater residence time from tritium is explained in two recent USGS papers (Michel and others, 2018; Lindsey and others, 2019). Michel and others mapped the variability of tritium in precipitation across the United States. They subdivided the country into 2 degree latitude by 5 degree longitude quadrangles and estimated the following for each quadrangle: 1) the tritium concentration in precipitation from 1953–2012 by month, and 2) the total tritium deposition from 1953–1983.

Lindsey and others used this data to create a method to estimate groundwater residence time. The new method takes the tritium concentration and the sample date of a groundwater sample, then compares them with the local history of tritium concentration in precipitation over time in the quadrangle. The method classifies a sample as ***modern*, *mixed*,** or ***premodern***. The main difference between this new method and the older method is that the threshold values between modern and mixed and between mixed and premodern are calculated based on geographic location and the sampling date. This accounts for the geographic variability in tritium deposition and the radioactive decay of tritium over time.

All of Minnesota, except the Northwest Angle, is included in six of Michel and others quadrangles (Figure 1).

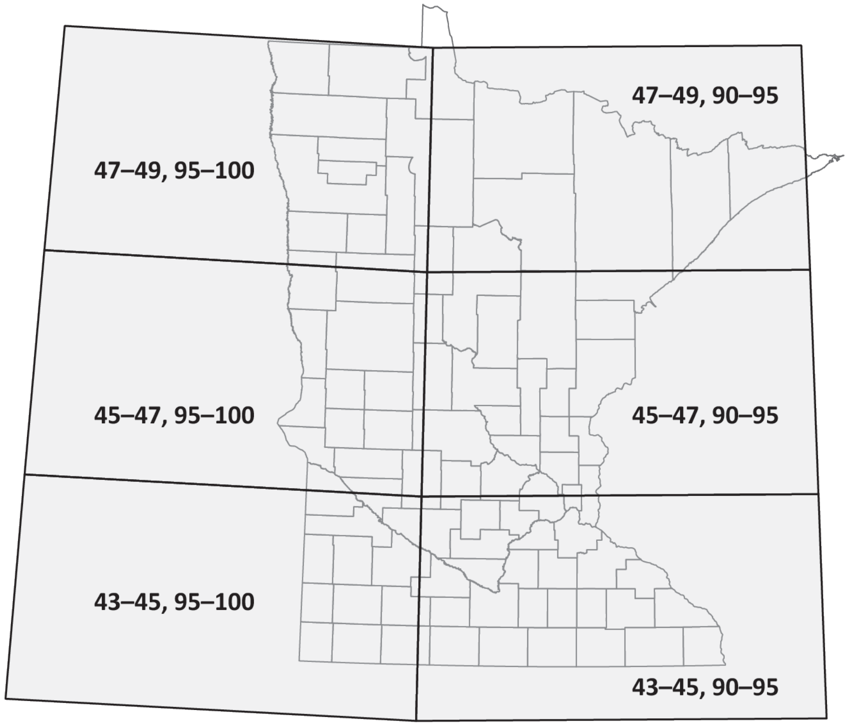

Figure 1. Michel and others quadrangles over Minnesota (2 degrees latitude by 5 degrees longitude).

Six quadrangles cover Minnesota and portions of adjacent states. The tip of the arrowhead is included in quadrangle 47–49, 90–95. The tritium history of the Northwest Angle, which is north of the 49th parallel, is not included in Michel and others' calculations.

USGS Method to Estimate Groundwater Residence Time from Tritium

For each quadrangle Lindsey and others used the following procedure:

1. Calculate the **modern** threshold for the sample date: the minimum half-year average tritium value in precipitation after the 1960s peak decayed to the sample date.
   - Modern values (1953 and later) fall above this threshold.
2. Calculate the **premodern** threshold: the estimated value of tritium in rainfall before 1953, the start of atmospheric nuclear weapons testing.
   - Assume that the average of tritium in precipitation from 2008 to 2012 is similar to the pre-1953 tritium in precipitation.
   - Decay the assumed pre-1953 tritium values to the sample date. This becomes the premodern threshold for that date.
   - Premodern values (pre-1953) fall below this threshold.
3. Classify the **mixed** values: those that fall between modern and premodern thresholds.
   - Mixed values fall between modern and premodern thresholds.

For additional explanation, see Figure 2.

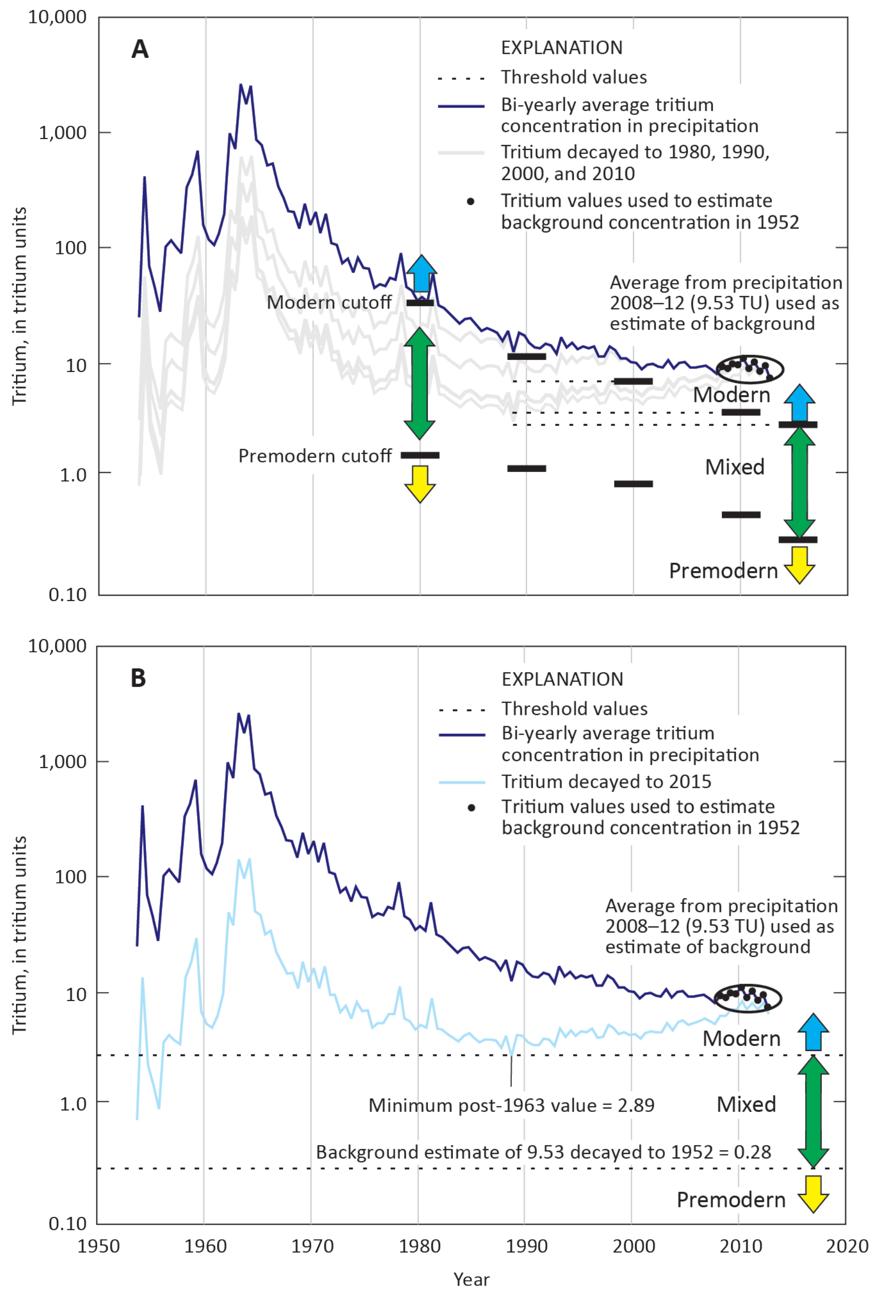

Figure 2. Tritium in precipitation from 1952 to 2012 for the quadrangle defined by latitude 41–43 degrees North and longitude 90–95 degrees West. (Modified from Lindsey and others, Figure 2.)

(A) Initial tritium in precipitation decayed to the years 1980, 1990, 2000, and 2010, and thresholds for modern, mixed, and premodern categories for tritium concentrations in groundwater measured in this region. (B) Example illustrating thresholds for the year 2015.

*Note that this example region is south of Minnesota. Similar calculations are made for each of the six quadrangle areas that cover Minnesota. The **Tritium Age Classification: Revised Method for Minnesota** smooths the tritium data with 25-month running averages instead of bi-yearly averages. This results in a slightly higher minimum post-1963 value and thus a higher modern cutoff.*

Method for Minnesota

The revision for Minnesota uses two additional categories of tritium age:

Cold War era is a reserved for modern samples that were recharged from precipitation during the late 1950s and 1960s when atmospheric tritium levels were at their peak.

Mostly premodern identifies predominantly premodern samples that might contain small amounts of modern or mixed water.

Additional information describing how these categories are determined is provided in the following section.

Minnesota Categories

Cold War era

This category is not included in Lindsey and others, but Minnesota classifies groundwater samples collected in the current year or previous year with more than 15 TU as Cold War era samples. Groundwater with tritium concentrations at these levels must have been recharged from precipitation during the peak atmospheric tritium levels during the late 1950s and 1960s. Cold War era is an ephemeral classification that only applies in years near the sample date. It implies a specific residence time that would be incorrect at a later date.

Modern

The threshold is determined using the method of Lindsey and others but uses monthly tritium in precipitation data instead of the half-year average. The monthly tritium data are calculated from the Michel and others monthly tritium data smoothed through a 25-month running average. This results in a slightly higher modern tritium-age threshold than the Lindsey and others calculation.

Mixed

This classification is taken directly from Lindsey and others and includes sample results that fall between the modern and premodern threshold values.

Mostly premodern

This category was developed because of analytical limitations of the standard enriched tritium method most commonly used by Minnesota state agencies. The detection limit for this method of 0.8 TU is often higher than the premodern classification threshold for a given place and time, resulting in an ambiguous determination. Samples analyzed using the enriched tritium method that have no detectable tritium (< 0.8 TU) are classified as mostly premodern if the premodern threshold is below 0.8 TU. The premodern tritium upper threshold value in Minnesota is currently between 0.2 and 0.25 TU, and will decrease over time because of radioactive decay. Samples that fall into this new category are dominated by premodern water, but could include a relatively small component of younger water that falls short of the mixed cutoff of Lindsey and others. It should be noted that ultra-low-level tritium analysis is available with a detection limit of 0.1 TU, but it is rarely used because it is very expensive and turnaround times are long. For additional information on the basis for this category, see Figures 3 and 4 and Table 1.

Premodern

This category is calculated using Lindsey and others' methods. Such samples are considered to include predominantly pre-1953 water (little to no modern or mixed). Note that the threshold for premodern varies over time. Figures 3 and 4 show tritium in precipitation in 1952 decayed to year on x-axis in Quadrangle 47–49, 95–100 and Quadrangle 43–45, 95–100, respectively.

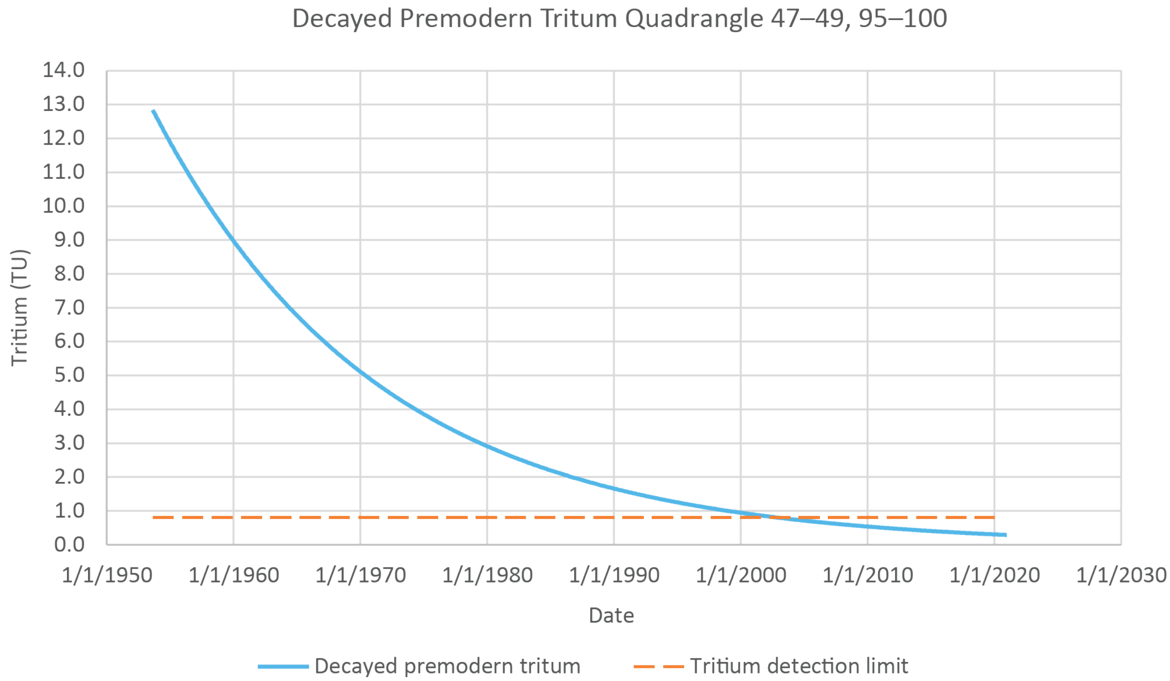

Figure 3. Decayed premodern tritium for Quadrangle 47–49, 95–100 compared to the enriched tritium detection limit of 0.8 TU.

This quadrangle had the highest tritium deposition in Minnesota. The premodern tritium threshold becomes less than the detection limit in November 2002.

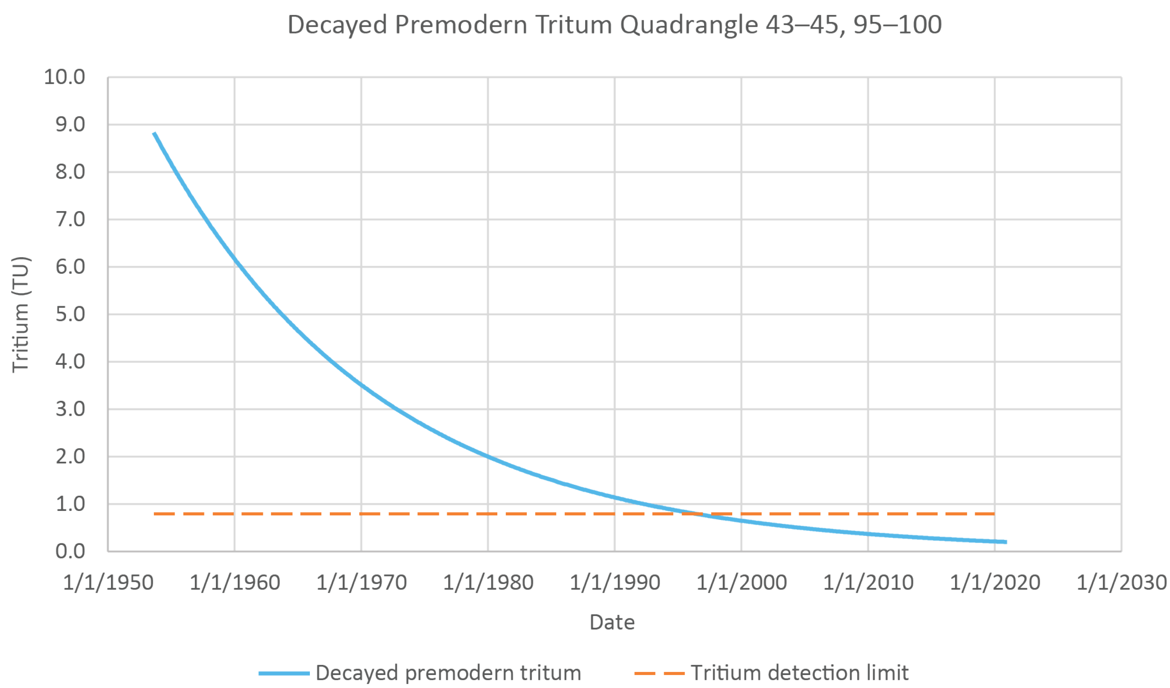

Figure 4. Decayed premodern tritium for Quadrangle 43–45, 95–100 compared to the enriched tritium detection limit of 0.8 TU.

This quadrangle had the lowest tritium deposition in Minnesota. The premodern tritium threshold becomes less than the detection limit (0.8 TU) in March 1996.

Table 1. Undecayed premodern tritium values in precipitation by quadrangle and date when value decays to 0.8 TU.

Quadrangle	Undecayed Premodern Tritium in Precipitation (TU)	Tritium Decayed to 0.8 TU
47–49, 95–100	13.68	November 2002
47–49, 90–95	13.16	March 2002
45–47, 95–100	10.62	May 1998
45–47, 90–95	11.63	December 1999
43–45, 95–100	9.41	March 1996
43–45, 90–95	10.48	February 1998

In Table 1, the undecayed premodern tritium value for precipitation for each quadrangle is the average of monthly data for 2008 to 2012 from Michel and others (2018). Northern quadrangles in Minnesota had more tritium deposition than southern quadrangles.

Non-detect enriched tritium samples collected after the decay curve falls below 0.8 TU cannot be unambiguously categorized by Lindsey and others (2019) methods. These samples might be premodern or might be mixed. The new method creates a new category of mostly premodern for these samples.

References

Alexander, S.C., and Alexander, E.C., Jr., 1989, Residence times of Minnesota groundwaters: Minnesota Academy of Sciences Journal, v. 55, no.1, p. 48–52.

Lindsey, B.D., Jurgens, B.C., and Belitz, K., 2019, Tritium as an indicator of modern, mixed, and premodern groundwater age: U.S. Geological Survey, Scientific Investigations Report 2019-5090, 18 p.

Michel, R.L., Jurgens, B.C., and Young, M.B., 2018, Tritium deposition in precipitation in the United States, 1953–2012: U.S. Geological Survey, Scientific Investigations Report 2018-5086, 11 p.