Appendix A. Summary of CFC, SF_6, and $^3H/^3He$ Tracer Samples Collected From Selected NAWQA Networks Between Fiscal Years 1992 and 2005

CFC, SF_6, and $^3H/^3He$ tracer data collected from NAWQA LUS, MAS, REF, and selected OTHER networks between fiscal years 1992 and 2005 are documented in table A1.

Appendix B. Summary of Environmental-Tracer Samples Excluded From This Compilation

Tracer data from 47 (table B1) of the 1,417 sites listed in table A1 were not compiled in this report. Reasons for exclusion of these 47 sites are given in table B1. The primary reasons for exclusion are duplication of other results or impending publication elsewhere.

Appendix C. Summary of Selected Environmental-Tracer Samples Collected Between Fiscal Years 2006 and 2007

Tracer data from 29 sites collected after fiscal year 2005 are included in this compilation. These sites and the reasons for their inclusion are listed in table C1.

Appendix D. Number of Sites with Environmental-Tracer Data Compiled in This Report

Tracer data from 1,399 sites are compiled in this report (appendixes A, B, and C). Table D1 lists the number of these sites and the types of well networks associated with the samples collected.

Appendix E. Selected Physical Characteristics of Wells Compiled in This Report

Selected physical characteristics of the 1,399 wells represented in this compilation are summarized in table E1.

Appendix F. Summary of Previously Interpreted and Published CFC, SF_6, and $^3H/^3He$ Data Collected From Selected NAWQA Networks Between Fiscal Years 1992 and 2005

Table F1 lists 618 sites from 22 NAWQA Study Units where CFC, SF_6, and $^3H/^3He$ data collected between fiscal years 1992 and 2005 have been interpreted and published elsewhere. Tracer-based piston-flow ages are associated with most of these 618 sites and are reported in table F1.

A brief overview of these previously interpreted and published data follows, organized by Study Unit and network. Study-Unit abbreviations in this appendix are defined in table A1 (appendix A). Network names in this appendix are as listed in the NAWQA DWH (available at http://infotrek.er.usgs.gov/traverse/f?p=NAWQA:HOME:0:). Information provided for each Study Unit includes the network(s) and number of wells in each network, year of sample collection, tracer(s) that were analyzed in the samples, discussion of the extent of interpretation and an indication of the thoroughness of the interpretations (where possible), cautionary notes specific to each dataset (where appropriate), and the citations to the published work.

ACAD

Samples from 21 sites in the LUSCR1 network, 9 sites in the LUSRC1 network, and 7 sites in the SUS1 network of the ACAD Study Unit were collected during 2001 (LUSCR1, SUS1) and 2002 (LUSRC1) for CFCs. CFC-based piston-flow ages were interpreted and published by Tollett and Fendick (2004) (LUSCR1), Fendick and Tollett (2004) (LUSRC1), and Tollett and others (2003) (SUS1).

Few details regarding the interpretation of the tracer data were provided by Tollett and Fendick (2004), Fendick and Tollett (2004), or Tollett and others (2003). For example, recharge temperature was not discussed. Major dissolved gases were collected, but it is not known if they were used to constrain recharge temperature. CFC-11, CFC-12, and CFC-113 concentrations were reported along with interpreted CFC-based piston-flow ages in each of these publications.

No other tracers were used to check on the interpreted tracer-based piston-flow ages. The paucity of information on the methods of interpretation and the lack of additional lines of evidence to support the interpretations suggest caution in the use of the interpretations of these tracer-based piston-flow ages.

Site identification numbers for the LUSRC1 network that were published in Appendix 5 of Fendick and Tollett (2004) differed from the site identification numbers that were published in table 1 of the same reference. The site identification numbers in table 1 were determined to be the correct site identification numbers and they were used here.

ALBE

Samples from one site in the LUSAG1 network of the ALBE Study Unit were collected during 1999 for CFCs. A CFC-based piston-flow age was interpreted and published by Tesoriero and others (2005).

Major dissolved-gas data were used to constrain recharge temperatures. Data from this one well (a dual-purpose, LUS and FPS, well) were interpreted with data from other sites along a well transect, increasing confidence in the interpretations.

ALMN

Samples from 30 sites in the LUSMI1 (mining land use study), 5 sites in the REFOT1, and 4 sites in the SUS1 networks of the ALMN Study Unit were collected during 1996 (SUS1), 1997 (LUSMI1) and REFOT1 (1998) for CFCs. Tracer-based piston-flow ages were interpreted and published by McAuley and Kozar (2006).

McAuley and Kozar (2006) provided a wealth of information about their tracer data, including their estimates of recharge temperature, recharge elevation, and excess air for each site and the analytical data for each site. However, the tracer-based piston-flow ages likely were biased old due to the presence of reducing conditions (evidenced by extensive methane occurrence, as tabulated in the report). The aquifer is composed of fractured rock, further complicating interpretation of CFC data. Because of the potential limitations associated with reducing conditions, and those associated with the interpretation of tracer data in a fractured rock aquifer, these tracer-based piston-flow ages should be treated with caution.

Of the 30 LUSMI1 sites that were sampled for CFCs, 4 were sampled for $^3H/^3He$ in addition to CFCs. These $^3H/^3He$ data were not interpreted as part of the McAuley and Kozar (2006) report. These $^3H/^3He$ data might provide useful information. (However, He and Ne data for 1 of the 4 sites were not available due to sample loss during analysis, leaving at most 3 sites with usable $^3H/^3He$ data.) Although the CFCs likely have been affected by degradation, no effort was made as part of this project to analyze the $^3H/^3He$ data because (1) the number of sites with $^3H/^3He$ data was relatively small, and (2) there is a relatively low level of focus on mining issues within the NAWQA Program.

COOK

Samples from 26 sites in the SUS1a and 4 sites in the SUS1b networks of the COOK Study Unit were collected during 1999 for $^3H/^3He$. Most sites also were sampled for CFCs. $^3H/^3He$-based piston-flow ages were interpreted and published by Glass (2001, 2002).

Glass (2001, 2002) provides some discussion of the tracer data and his interpretations. Most sites were sampled for both $^3H/^3He$ and CFCs, and Glass (2001, 2002) compared the results. CFCs may have been degraded; Glass (2001, 2002) chose to retain the $^3H/^3He$ results. It is difficult to evaluate the quality of these tracer data or the interpretations based simply upon the information provided by Glass (2001, 2002).

Two sites were dated as "<1953" based upon low 3H concentrations (0.1 TU). Other than the two "<1953" samples, the oldest tracer-based piston-flow recharge date is 1968. Three samples prior to the 1970s (1968, 1969, 1969) may have greater uncertainty, as they push the limits of the method.

Glass (2002) listed measured ^3H and interpreted tritiogenic ^3H, along with $^3H/^3He$-based piston-flow ages. The local ^3H precipitation record (International Atomic Energy Agency, 2009), along with reconstructed $^3H + ^3He$ (tritiogenic) for dated samples, are shown in figure F1. (One sample, with a $^3H/^3He$-based piston-flow recharge date of greater than 1998 was plotted at year 1998. Given the sampling date of 1999, the assignment to year 1998 introduces negligible uncertainty.)

The reconstructed $^3H + ^3He$ (tritiogenic) plot demonstrates a lot of scatter, reflecting dispersion, mixing, and possibly some errors in the tritiogenic ^3He concentrations reported by Glass (2002). However, the overall pattern of decreasing $^3H + ^3He$ (tritiogenic) concentration with increasing $^3H/^3He$-based piston-flow recharge year indicates that many of the $^3H/^3He$-based piston-flow ages are reasonable representations of relative age.

GRSL

Samples from 30 sites in the LUSRC1 network of the GRSL Study Unit were collected during 1999 for $^3H/^3He$. Tracer-based piston-flow ages were interpreted and published by Thiros (2003). The site identification number in Thiros (2003) for site #33 was incorrectly listed; the correct site identification number for site #33 is 403524111572201.

Thiros (2003) presented tracer-based piston-flow ages for 24 of the 30 sites. The 6 sites that were not dated can be considered post-1953, based upon published ^3H data (^3H concentrations greater than 2.8 TU; Thiros, 2003).

Tracer-based piston-flow ages were plotted against reconstructed initial ^3H concentrations (Thiros, 2003, fig. 21, p. 40). Of the 24 dated sites, 23 (including 2 of the 3 with pre-1970 tracer-based piston-flow recharge dates) plotted close to the local ^3H input function, suggesting that the interpretations generally were reasonable.

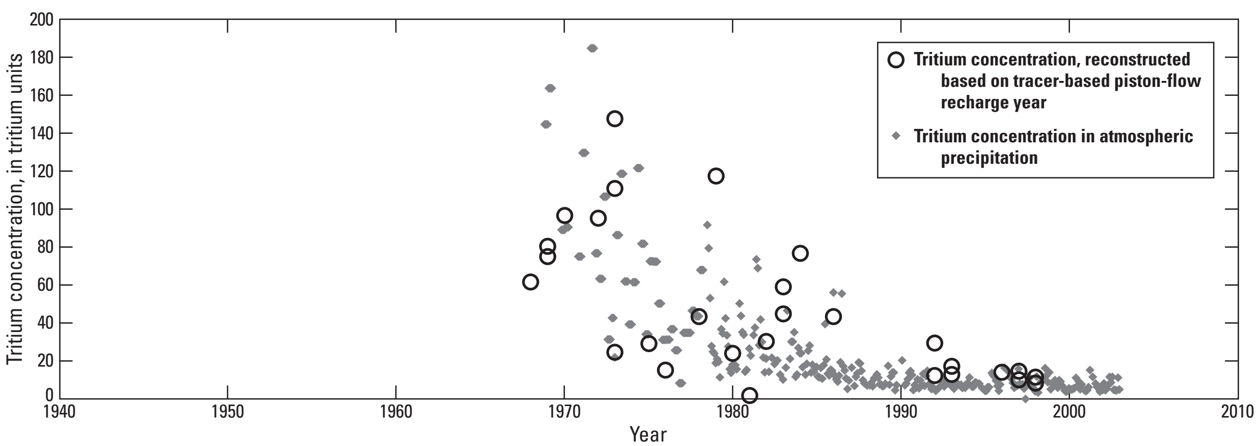

Figure F1. Reconstructed tritium concentrations and tritium in atmospheric precipitation, COOK Study Unit.

GRSL

Samples from 31 sites in an "OTHER" network of the GRSL Study Unit were collected during 2000 and 2001 for $^3H/^3He$. Tracer-based piston-flow ages were interpreted and published by Manning and others (2005).

In several cases, samples were collected in 2000 (^3H and He) and again in 2001 (^3H only). In those cases, Manning and others (2005) published interpretations based on both (1) year-2000 data and (2) year-2001 ^3H with year-2000 He data. Combining year-2001 ^3H data with year-2000 He data could introduce uncertainty associated with temporal variability in water sources. Thus, for the purposes of this compilation, tracer-based piston-flow ages based upon a complete analysis of ^3H and He were used rather than tracer-based piston-flow ages based upon combined (year-2000 and year-2001) data.

Tracer-based piston-flow ages were plotted against reconstructed initial ^3H concentrations (Manning and others, 2005). This plot indicated that many samples were composed of mixtures. These patterns are consistent with the fact that these wells were supply wells often screened over hundreds of feet (Thiros and Manning, 2004). Tracer-based piston-flow recharge dates prior to the 1970s (15 sites) may be associated with greater uncertainty than the more recent tracer-based piston-flow recharge dates because the older tracer-based piston-flow recharge dates push the limits of the method.

HPGW

Samples from 30 sites in the LUSUR1 network of the HPGW Study Unit were collected during 2000 for CFCs. Tracer-based piston-flow ages were interpreted and published by Pope and others (2002).

Pope and others (2002) provide detailed discussion about their approach to the tracer interpretations. Recharge temperature and recharge elevation were defined. Pope and others (2002) took a conservative approach with degradation, in which samples with field O_2 concentrations ≤ 0.5 mg/L were considered to have potential CFC degradation and were considered undatable.

No other tracers were used to check on the interpreted tracer-based piston-flow ages. The lack of additional lines of evidence to support the interpretations suggests caution in the use of the interpretations of these tracer-based piston-flow ages.

KANA

Samples from 25 sites in the LUSMI1 and 26 sites in the SUS1 networks of the KANA Study Unit were collected during 1997 (SUS1) and 1998 (LUSMI1) for CFCs. Tracer-based piston-flow ages were interpreted and published by McCoy and Kozar (2007). McCoy and Kozar (2007) provide a detailed discussion of their analysis of CFC and major dissolved-gas data in a challenging setting (fractured rock; some highly reducing samples). The highly reducing nature of some of the groundwater samples and the inherent difficulty of using tracers to infer groundwater age in fractured rock aquifers indicate that the interpreted tracer-based piston-flow ages should be used with caution.

CFC-12-based piston-flow ages were used in this compilation. At 3 sites, McCoy and Kozar (2007) reported CFC-12-based piston-flow ages as "nd", but this designation was not used in a consistent manner. For 2 sites, "nd" indicated non-detect in the original CFC data files; groundwater from these two sites was considered pre-1945. (These 2 sites were 373020081075601 (MER-0170) and 374908080435601 (SUM-0103)). They had 0.0 pg/kg for CFC-12 and for CFC-113, and between 0.0 and 0.3 pg/kg for CFC-11; the 0.3 pg/kg of CFC-11 likely was a small amount of sampling or analytical contamination). One sample (381048081504801 (BOO-0257)) had missing CFC-12 and CFC-113 data, CFC-11 at 2.3 pg/kg, and also high CH_4 concentrations (11.1 and 13.3 mg/L) and low Ar concentrations (0.27 and 0.31 mg/L) indicate highly reducing conditions and degassing (and gas stripping); it is not possible to know if samples from this site had CFC degradation or if they were essentially CFC-free along with a small amount of CFC-11 contamination, and the site was considered undatable.

KANA

Samples from 19 sites in the SUS2 network of the KANA Study Unit were collected during 1997 for CFCs. Tracer-based piston-flow ages were interpreted and published by Kozar and others (2001).

Kozar and others (2001) provided a detailed analysis of the tracer interpretations. Major dissolved gases (available for 12 of the 19 sites) were used to infer recharge temperatures and excess air, and these samples indicated generally oxic conditions (most field O_2 concentrations greater than 1 mg/L and all CH_4 concentrations less than 1 µg/L). However, the inherent difficulty of using tracers in fractured rock aquifers and the absence of additional tracers indicate that the interpreted tracer-based piston-flow ages should be used with caution.

LINJ

Samples from 46 sites in an OTHER network of the LINJ Study Unit were collected between 1992 and 1999 for SF_6 and(or) $^3H/^3He$. SF_6-based and $^3H/^3He$-based piston-flow ages were interpreted and published by Kauffman and others (2001). All 46 sites are considered to be FPS sites, but these are not traditional FPS wells in that they do not fall along a transect. They are more of a combination of shallow and deep LUS wells (different parts of flow system), plus some supply wells that represent integrated samples of aquifer water. Of the 46 wells, 16 serve dual purpose in the DWH (7=LUSRC1, 1=LUSFO1, 3=LUSUR1, and 5=LUSCR1), but all behave as LUS or MAS wells to some extent.

Tracer-based piston-flow ages based on $^3H/^3He$ and/or SF_6 were interpreted and published by Kauffman and others (2001) for these 46 sites. Major dissolved-gas data were available for most sites, but it is not known if these were used in the interpretations. There was no discussion of the methods used to assign tracer-based ages (e.g. recharge temperature, recharge elevation), nor even any mention of what kind of groundwater age was assigned (presumably piston-flow, but not stated). However, the tracer-based piston-flow ages were compared against flow-model particle-tracking times-of-travel, and used to calibrate model porosity. The good agreement between tracer-based piston-flow ages and particle-tracking times-of-travel with a (reasonable) porosity of 0.30 indicates that the interpreted tracer-based piston-flow ages are defensible and reasonable.

Four categories of tracer-based piston-flow ages were listed by Kauffman and others (2001):

1. 11 cases in which there were $^3H/^3He$-based piston-flow ages and no SF_6-based piston-flow ages.

2. 6 cases in which there were SF_6-based piston-flow ages and no $^3H/^3He$-based piston-flow ages.

3. 6 cases in which there were both SF_6-based and $^3H/^3He$-based piston-flow ages, and both collected on the same date; the mean of the $^3H/^3He$-based piston-flow age and the SF_6-based piston-flow age were used in this compilation.

4. 23 cases in which there were both SF_6-based and $^3H/^3He$-based piston-flow ages, but collected on different dates. We used the $^3H/^3He$-based piston-flow age for each of these sites.

MISE

Samples from 7 sites in the LUSRC1 and 3 sites in the LUSRC2 networks of the MISE Study Unit were collected during 1998 for CFCs. Tracer-based piston-flow ages were interpreted and published by Gonthier (2002).

Gonthier (2002) interpreted the CFC data by taking into account recharge temperature (assumed to be equal to the mean annual air temperature), estimates of recharge elevation, and apparent CFC-113 contamination and CFC-11 degradation. Gonthier (2002) listed tracer-based piston-flow ages for 6 of the 10 sites.

The remaining 4 sites were not dated. At 2 of the 4 undated sites, the water was considered modern on the basis of the presence of CFCs. At the other 2 undated sites, the water was not assigned to pre-1945 or post-1945 timeframes because CFC-12 concentrations were near the method detection limit and CFC-113 was detected at concentrations in the tens of pg/Kg. It is not clear if the CFC-12 in these two undated samples was present in the ground water, if the CFC-12 had been introduced by sampling contamination, or if the CFC-12 was an artifact of analytical error. Similarly, the source of the CFC-113 in these 2 undated samples was not clear, but Gonthier did note that CFC-113 contamination was common in the 10 samples. Attempting to simply attribute a post-1945 or pre-1945 timeframe to samples from these 2 sites would be subject to great uncertainty.

No multiple tracers were available. The lack of additional lines of evidence to support the interpretations suggests caution in the use of these interpretations.

MOBL

Samples from eight sites in the LUSCR1 network of the MOBL Study Unit were collected during 2001 for CFCs and SF_6. CFC- and SF_6-based piston-flow ages were interpreted and published by Robinson (2003). One erroneous site identification number in Robinson (2003) was corrected using data from Robinson (2003) and data from the DWH.

Tracer-based piston-flow ages were based upon combination of CFCs and SF_6. Robinson (2003) did not mention the mechanism of estimating recharge temperature or recharge elevation. However, samples for major dissolved gases were collected and may have been used to infer recharge temperatures and excess air. The tracer-based piston-flow ages are qualitatively reasonable; Figure 14 (Robinson, 2003) shows a logical geochemical evolution with increasing tracer-based piston-flow age. However, the paucity of information on the methods of interpretation and the lack of additional lines of evidence to support the interpretations suggest caution in the use of these interpretations.

MOBL

Samples from 30 sites in the LUSRC1 network of the MOBL Study Unit were collected during 1999 and 2000 for CFCs and (or) SF_6. CFC- and SF_6-based piston-flow ages were interpreted and published by Robinson (2002). Three erroneous site identification numbers in Robinson (2002) were corrected using data in the original CFCs and SF_6 files and data from the DWH.

Interpreted tracer-based piston-flow ages were based SF_6 and CFC data as well as other information such as field O_2. Major dissolved gases were collected and may have been used to infer recharge temperatures and excess air. Tracer-based piston-flow ages were qualitatively reasonable; for example, direct correlation with pH and inverse correlation with number of pesticide detections (Robinson, 2002) provide confidence in tracer-based piston-flow ages. However, the paucity of information on the methods of interpretation and the lack of additional lines of evidence to support the interpretations suggest caution in the use of these interpretations.

NVBR

Samples from 1 site in the LUSAG1 network and 1 site in the SUS3 network of the NVBR Study Unit were collected during 1996 for CFCs. Tracer-based piston-flow ages were interpreted and published by Thomas and others (1999).

Thomas and others (1999) concluded that ground water at these 2 sites likely contained components of sewage. The likelihood of wastewater-derived CFCs in samples from these 2 sites, and the variable and often contaminant concentrations of CFCs in replicate samples from these sites preclude the establishment of tracer-based piston-flow ages for these sites using these tracer data. However, the presence of CFCs can be used to deduce the presence of modern water in samples from these sites.

OAHU

Samples from 30 sites in the SUS1 network of the OAHU Study Unit were collected during 2000 for CFCs. Tracer-based piston-flow ages were interpreted and published by Hunt (2004).

Hunt (2004) provided an in-depth discussion of the tracer data. Hunt (2004) noted a general pattern of younger tracer-based piston-flow ages in down-gradient regions and older tracer-based piston-flow ages in up-gradient regions. This occurrence pattern was attributed to irrigation practices in down-gradient locations that result in increased recharge rates (recharge rates in areas of furrow irrigation are approximately 20 times recharge rates in areas without irrigation) (Hunt, 2004). Furthermore, Hunt (2004) noted that large numbers of ground-water samples with tracer-based piston-flow recharge dates in the 1970s and early 1980s, and an absence of tracer-based piston-flow recharge dates in the 1990s, could be consistent with conversion from furrow-based to low-irrigation-rate drip-based irrigation practices in the mid-1980s. The careful analysis by Hunt of the OAHU tracer data is partially offset by uncertainties introduced by the use of wells with long screened intervals (median for the 30 wells: 104 feet, according to data presented in Hunt, 2004).

In addition to CFCs, $^3H/^3He$ data were collected. However, the $^3H/^3He$ data were not interpreted by Hunt (2004). Hunt (2004) cited problems with terrigenic He corrections for the absence of $^3H/^3He$ interpretations. Additional difficulties with the OAHU $^3H/^3He$ data include (1) aqueous ^3H concentrations were low, reflecting low ^3H inputs typical of Pacific islands where ^3H inputs tend to be diluted (low ^3H inputs result in little ^3H being available for age-dating); (2) a mantle He component appeared to be present in many samples (mantle He often contains high amounts of poorly constrained and (or) variable ^3He components); and (3) many samples were fractionated or otherwise compromised.

PODL

Samples from 28 sites in an OTHER network of the PODL Study Unit were collected during 2000 for SF_6. This network is similar to a DWGS network. Tracer-based piston-flow ages were interpreted and published by Ferrari (2002).

Major dissolved gases were used to infer recharge temperatures and excess air. Ferrari (2002) presents inferred recharge temperatures, recharge elevations, and excess air concentrations, and provides the SF_6 concentrations. SF_6 concentrations did not exhibit contaminant levels of SF_6. Tracer-based piston-flow recharge dates for the entire set of sites (collected in 2000) ranged from 1976 to 1994, within the optimal time period for the method. However, no other tracers were used to check on the interpreted tracer-based piston-flow ages. Perhaps more significantly, the wells were water supply wells; thus, the tracer-based piston-flow ages from this network may have little relation to actual ground-water age distributions for supply wells that may withdraw water from multiple flow paths.

PODL

Samples from 29 sites in the LUSCR1 network, 29 sites in the SUS1 network, and 2 sites in the REFFO1 network of the PODL Study Unit were collected during 2001, 2002, and 2003 for SF_6. Tracer-based piston-flow ages were interpreted and published by Debrewer and others, 2007.

The approach was only briefly discussed by Debrewer and others (2007). Major dissolved gases were collected and may have been used to infer recharge temperatures and excess air. Debrewer and others (2007) found statistically significant ($p<0.05$) Spearman's correlations between atrazine concentrations and tracer-based piston-flow recharge dates for both the SUS and the LUS networks, whereas Spearman's correlations between atrazine concentrations and well depths were not statistically significant; these findings provide some support for the SF_6 interpretations, insofar as tracer-based piston-flow ages would be expected to provide a better understanding of ground-water residence time than would simple physical measurements such as well depth if the tracer-based piston-flow ages are at least qualitatively correct and internally consistent. SF_6 concentrations did not exhibit contaminant levels of SF_6. Tracer-based piston-flow recharge dates for these sites (collected 2001-2003) ranged from 1974 to 2000, within the optimal time period for the method. However, no other tracers were used to check on the interpreted tracer-based piston-flow ages. The paucity of information on the methods of interpretation and the lack of additional lines of evidence to support the interpretations suggest caution in the use of the interpretations of these tracer-based piston-flow ages.

REDN

Samples from one site in the LUSAG1 network of the REDN Study Unit were collected during 1995 for CFCs. A tracer-based piston-flow age was interpreted and published by Stoner and others (1997) and Cowdery (1997).

Interpretation of the tracers was discussed in detail by Stoner and others (1997). Flow modeling and particle-tracking analysis were done for a transect of wells that included the one LUSAG1 site (a site that serves as both an LUSAG1 site and an FSS site) (Stoner and others, 1997; Cowdery, 1997). The tracer-based piston-flow age (6 years) and the particle-tracking model recharge age (2 years) had a large percentage difference, but the results of these two methods were close relative to the large uncertainties in the two methods, and thus provide support for the interpreted tracer-based piston-flow age for this site.

RIOG

Samples from 2 sites in the LUSUR1 network and 2 sites in the SUS1 network of the RIOG Study Unit were collected during 1996 (LUSUR1) and 1997 (SUS1) for CFCs, SF_6, and(or) $^3H/^3He$. The data and interpretations were published by Plummer and others (2004).

Of the 4 sites, one was datable with $^3H/^3He$. Of the 3 sites that were not datable with $^3H/^3He$, two could be attributed as pre-1940 (no detectable CFC-12) and one could be characterized as post-1940 (on the basis of contaminant levels of CFC-12). SF_6 data were not readily used because of uncertainty surrounding the extent of natural SF_6 in these aquifers.

The Middle Rio Grande project collected multiple tracer and other geochemical samples from 288 groundwater sites. As such, there was little site-specific interpretation for these four samples, but the overall patterns of tracer-based piston-flow ages across the project area lend support for the interpretations.

SOCA

Samples from eight sites in the SUS2 network of the SOCA Study Unit were collected during 2000 for $^3H/^3He$. Tracer-based piston-flow ages were interpreted and published by Hudson and others (2002). The report focused on the interpretation of the tracers, and detailed discussion was presented by Hudson and others (2002). Although tracer-based piston-flow ages were reported, Hudson and others (2002) presented evidence indicating that most of the groundwater samples were mixtures of pre-bomb and bomb water. Thus, the tracer-based piston-flow ages only approximate the relative ages of groundwater from these sites.

TENN

Samples from 9 sites in the LUSAG1 network of the TENN Study Unit were collected during 2000 for CFCs. CFC-based piston-flow ages were interpreted and published by Kingsbury (2003).

Few details regarding the interpretation of the tracer data were provided by Kingsbury (2003). The recharge temperatures and recharge elevations that were used were documented by Kingsbury (2003). Major dissolved gases were collected, but it is not clear whether the major dissolved-gas data were used in the interpretations; however, none of the samples from the 9 sites contained detectable CH_4, indicating redox conditions less reducing than methanogenic. SF_6 samples also were collected from these 9 sites, but extensive SF_6 contamination was observed and was attributed to sample caps. The limited discussion on methods of data interpretation and the lack of additional lines of evidence to support the interpretations suggest caution in the use of the interpretations of these tracer-based piston-flow ages.

UCOL

Samples from 25 sites in the LUSRC1 network of the UCOL Study Unit were collected during 1997 for CFCs. Tracer-based piston-flow ages were interpreted and published by Apodaca and others (2002).

Few details regarding the interpretation of the tracer data were provided by Apodaca and others (2002). However, recharge temperature and recharge elevation were documented. Study Unit expertise may be particularly valuable for this dataset because estimation of recharge elevations in this mountainous terrain probably benefited from local understanding.

Major dissolved gases were not collected. No other tracers were used to check on the interpreted tracer-based piston-flow ages. The paucity of information on the methods of interpretation and the lack of additional lines of evidence to support the interpretations suggest caution in the use of the interpretations of these tracer-based piston-flow ages.

UMIS

Samples from one site in the LUSRC1 network of the UMIS Study Unit were collected during 1997 for CFCs. Tracer-based piston-flow ages were interpreted and published by Andrews and others (2005).

Few details regarding the interpretation of the tracer data were provided by Andrews and others (2005). However, flow modeling and particle-tracking analysis were done for a transect of wells that included the 1 LUSRC1 site (a site that serves as both an LUSRC1 site and an FSS site). There was reasonable agreement between the tracer-based piston-flow recharge date (1990) and the particle-tracking model recharge date (1992) for the LUSRC1 site, providing support for the interpreted CFC data for this site.

USNK

Samples from 2 sites in the SUS1 network, 9 sites in the LUSCR2 network, 17 sites in the LUSCR3 network, and 11 sites in the LUSCR4 network of the USNK Study Unit were collected during 1994 and 1995 for CFCs. Of these 39 sites, 34 also were sampled for $^{3}H/^{3}He$. These data were interpreted and published by Plummer and others (2000).

The tracer data were extensively interpreted by Plummer and others (2000). CFC-113-based piston-flow ages of Plummer and others (2000) were used for the purposes of this compilation. (CFC-113 appeared to be more reliable than CFC-12 or CFC-11 in this network; Plummer and others, 2000.) Tracer-based piston-flow ages were used here to be consistent with the other tracer interpretations compiled for this project. However, Plummer and others (2000) did additional analysis of the data beyond simple piston-flow analysis. CFC, $^{3}H/^{3}He$, and stable isotope data were used to elucidate two-component groundwater mixtures and infer tracer-based piston-flow ages of the younger components. (Although many $^{3}H/^{3}He$ data were uninterpretable, owing to the presence of mantle He and to other problems, many other $^{3}H/^{3}He$ data were interpretable.) Users of USNK tracer results may wish to consult Plummer and others (2000) for these interpretations, especially if the tracer results will be used for Study-Unit-specific interpretations where comparability with results from other Study Units will not be required.

Analysis of $^{3}H/^{3}He$ and CFC data indicated that these CFC-based piston-flow ages have an old bias of up to about 10 years. This old bias appears to result from slow CFC advection through the thick unsaturated zone in this aquifer. However, CFC-based piston-flow ages were used for this compilation because $^{3}H/^{3}He$ results were available for fewer sites and were interpreted by Plummer and others (2000) in terms of mixing models.

One site (425104114283701, or local site 9) was sampled for CFCs 07-18-1994 (tracer-based recharge date 1978) and again 06-11-1995 (tracer-based recharge date 1976). The sample collected 06-11-1995 was retained because it was accompanied by NAWQA chemistry samples, whereas the 07-18-1994 sample was not sampled for NAWQA chemistry samples.

WILL

Samples from 12 sites in the LUSUR1 network of the WILL Study Unit were collected during 1997 and again (same sites) in 1998 for $^{3}H/^{3}He$. Tracer-based piston-flow ages were interpreted and published by Hinkle (2009).

Tracer-based piston-flow ages were provided for 11 of the 12 sites. At the 1 site where $^{3}H/^{3}He$ tracers did not work (due to degassing), published ^{3}H values (4.03 and 3.85 TU) indicate post-1953 water.

Tracer-based piston-flow ages were plotted against reconstructed initial ^{3}H concentrations (Hinkle, 2009). Of the 11 dated sites, 10 plotted close to the local ^{3}H input function, suggesting that the interpretations generally were reasonable. An analysis of the age gradient in relation to local recharge rates also supports the interpretations (Hinkle, 2009).

WMIC

Samples from 8 sites in the LUSAG1a network and 29 sites in the LUSAG2 network of the WMIC Study Unit were collected during 1994 for CFCs. Tracer-based piston-flow ages were interpreted and published by Saad (1997) and Saad (2009).

After publication by Saad (1997), some of the interpretations were modified (Saad, 2009). These changes have been incorporated in this report.

The approach used to interpret the CFC data was discussed in detail by Saad (1997). Part of the analysis included an attempt to account for the effects of CFC transport through unsaturated zones for sites where the assumed unsaturated zone was greater than 30 feet. This was done by using an analytical equation (Cook and Solomon, 1995) with parameters thought to be appropriate for local hydrogeologic conditions. It was some of these unsaturated-zone transport times that were subsequently modified by Saad (2009). Parameterizing models to account for CFC concentration gradients in unsaturated zones is challenging, and there were no unsaturated-zone CFC data for model calibration. However, Saad (1997) found that atrazine-plus-deethylatrazine concentration patterns were well explained by tracer-based piston-flow recharge dates and historical atrazine usage data. The changes in the CFC interpretations (Saad, 2009) do not appear to have substantively changed the relation between atrazine-plus-deethylatrazine concentrations and tracer-based piston-flow recharge dates, and the relation between atrazine-plus-deethylatrazine concentrations and tracer-based piston-flow recharge dates suggests that the interpretations of the CFC data were at least qualitatively reasonable.

Major dissolved gases were not collected. No other tracers were used to check on the interpreted tracer-based piston-flow ages. The lack of multiple lines of evidence to support the interpretations suggests caution in the use of the interpretations of these tracer-based piston-flow ages.

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Appendix G. Documentation and Analysis of Newly Interpreted CFC, SF_6, and $^3H/^3He$ Data

A total of 781 sites with newly interpreted tracer data are summarized in table 1 (in body of report). Tracer data and synopses of the tracer data, and interpretations for these 781 sites are in this appendix. Well construction, water level, and selected ancillary chemical data also are included in this appendix. These data and synopses are organized by Study Unit and network. Data are presented in tables. Data sources were discussed in the body of this report. Synopses include the network(s) and number of wells in each network, year of sample collection, tracer(s) that were analyzed in the samples, general type of aquifer materials, relevant notes about the approach used for estimating recharge temperature and (for CFCs and SF_6) excess air, a list of some of the notable advantages and disadvantages associated with the datasets, the range of water-level depths, presentation of a plot of tracer-based piston-flow age versus depth below water table (age gradient), a reconstructed ^3H plot (where ^3H data were available), and comments specific to a particular dataset (where appropriate).

The range of water-level depths for a network of wells is listed to help characterize the hydrologic system and to provide context for evaluating the possible effects of unsaturated-zone thickness on CFC and SF_6 results. Data on water-level depths can be useful in evaluating CFC and SF_6 results because CFC and SF_6 concentrations at the base of thick unsaturated zones are less likely to be at equilibrium with atmospheric CFC and SF_6 concentrations than are CFC and SF_6 concentrations at the base of thin unsaturated zones, if all other factors such as climate and geology are equal (Busenberg and Plummer, 2000; International Atomic Energy Agency, 2006).

The two types of figures used in this appendix (age-gradient plots and reconstructed ^3H plots) can provide insight into age-dating interpretations and the hydrologic systems associated with the age-dating results, and can help identify outliers in need of additional investigation. An age-gradient plot simply shows tracer-based piston-flow age versus depth of center of open interval below water table for a group of wells. Unconfined, homogeneous aquifers that have simple geometries and receive uniform recharge would be expected to exhibit patterns of increasing tracer-based piston-flow age with increasing depth below the water table in recharge areas. An age gradient showing such a pattern could be construed as providing support for the relative tracer-based piston-flow ages. Where aquifer geometry and porosity are well constrained, recharge rates can be inferred from age gradients if the latter are considered reliable, or age gradients can be evaluated if reliable, independent estimates of recharge rates are available (Cook and Böhlke, 2000); however, these types of quantitative applications were beyond the scope of this report.

A reconstructed ^3H plot shows ^3H concentrations that are back-decayed, on the basis of tracer-based piston-flow ages, to original ^3H concentrations inferred to have been present at the time of recharge, and compared to historical ^3H records. In aquifers that receive recharge primarily from atmospheric precipitation, a comparison of reconstructed ^3H concentrations with historical ^3H records for precipitation can provide a consistency check on the age interpretations. Favorable agreement between reconstructed ^3H concentrations and historical ^3H records demonstrates consistency between interpreted tracer-based piston-flow ages and historical ^3H records. However, such agreement does not provide confirmation of the age interpretations. Lack of agreement between reconstructed ^3H concentrations and historical ^3H records may indicate a violation of the age-dating assumptions; tracer degradation or contamination, mixing in the aquifer or well bore, or other problems may have occurred.

In evaluating reconstructed ^3H data, the time required for ^3H to migrate from land surface to the water table (the latter being the point at which groundwater dating begins) could result in a discrepancy between the ^3H input record and reconstructed ^3H concentrations. This unsaturated-zone time lag will result in post-1960s reconstructed ^3H concentrations being shifted to the right of the ^3H input record. Dispersion of the 1960s ^3H peak in the unsaturated zone will have a similar effect. These two effects (time-of-travel and dispersion of ^3H in the unsaturated zone) generally are not observed in the datasets in this appendix, or are masked if not overwhelmed by other effects such as mixing.

Study-Unit abbreviations in this appendix are defined in table A1 (appendix A). Network names in this appendix are as listed in the NAWQA DWH (available at http://infotrek.er.usgs.gov/traverse/f?p=NAWQA:HOME:0:). Well construction, water level, and ancillary chemistry data are from the NAWQA DWH.

ACFB and GAFL LUSCR1, LUSAG1, LUSCR2, LUSFO1

Samples from 26 sites in the ACFB and 7 sites in the GAFL Study Units were collected during 1999 and 2002 for CFCs (networks and, in parentheses, number of sites):

ACFB:
LUSCR1 (8)
LUSAG1 (11)
LUSCR2 (4)
LUSFO1 (forested land use; equivalent to reference sites) (3)
GAFL:
7 LUSCR1 (7)
See table G1.

The ACFB and GAFL LUSCR1 networks are adjacent to each other and form a continuous, cross-Study-Unit LUS.

The aquifer is composed of sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, that recharge temperature was equal to the mean annual air temperature + 1 °C, and that excess air concentrations were 2 cc(STP)/Kg.

Advantages associated with these samples:

Monitoring wells, so generally low pumping stress and short well screens.

Generally oxic.

Disadvantages associated with these samples:

No major dissolved-gas data.

No tracers other than CFCs.

The 1999 samples show consistent CFC-113 contamination and/or elevated concentrations relative to the other CFCs, which may be indicative of CFC-113 contamination in the sampling equipment.

Depth to water (can affect tracer transport to water table):
Median: 28.10 feet
Mean: 29.55 feet
Minimum: 6.93 feet
Maximum: 67.25 feet

Brief analysis:
The age gradient for these sites is shown in figure G1.

The age gradient for these networks exhibits scatter, as would be expected for samples taken from a wide area. However, there is a clear general increase in tracer-based piston-flow age with increase in depth below water table.

There are 4 sites with tracer-based piston-flow ages of greater than 20 years and depth below water table of less than 5 feet. It is not clear why these 4 shallow sites have relatively old tracer-based piston-flow ages. It is possible that the tracer-based piston-flow ages for these 4 sites could be biased old, or these sites could conceivably be located in discharge areas of a flow system in spite of intentions to install such wells in areas of recharge.

ALBE LUSAG1

Samples from six sites in the ALBE Study Unit were collected during 2002 and 2003 for CFCs (network and, in parentheses, number of sites):

LUSAG1 (6)
See table G2.

The aquifer is composed of sediments.

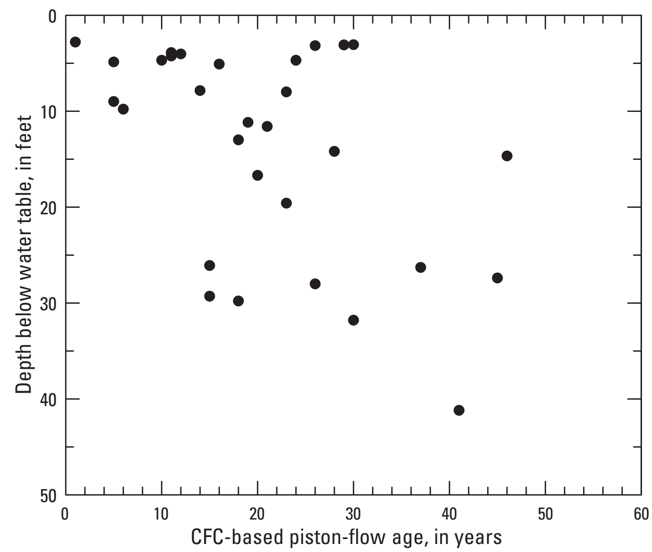

Figure G1. Age gradient for dated sites from the LUSCR1, LUSAG1, LUSCR2, and LUSFO1 networks, ACFB and GAFL Study Units.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, that recharge temperature was equal to the mean annual air temperature + 1 °C, and that excess air concentrations were 2 cc(STP)/Kg.

Advantages associated with these samples:

Short saturated open intervals (all ≤10 feet; median = 5.00 feet).

Median penetration of center of open interval into water table was 14.07 feet (sampling close to the water table, potentially minimizing mixing).

Monitoring wells, therefore low pumping stress.

Disadvantages associated with these samples:

No major dissolved-gas data.

No tracers other than CFCs.

Generally highly reducing: all field O_2 less than 1 mg/L, median Fe = 3,475 µg/L.

Depth to water (can affect tracer transport to water table):
Median: 3.78 feet
Mean: 3.68 feet
Minimum: 0.64 feet
Maximum: 7.40 feet

Brief analysis:
All of the tracer-based piston-flow ages were censored, and thus there are no data for an age gradient for these wells.

CCYK LUSOR1b and LUSAG2b

Samples from 10 sites in the CCYK Study Unit were collected during 2002 for SF_6 (networks and, in parentheses, number of sites):

LUSOR1b (5)
LUSAG2b (5)
See table G3.

The aquifer is composed of sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, that recharge temperature was equal to the mean annual air temperature + 1 °C, and that excess air concentrations were 2 cc(STP)/Kg.

Advantages associated with these samples:

- Short open intervals: median saturated open interval 5.00 feet.
- Median penetration of center of open interval into water table was 12.13 feet (sampling close to the water table, potentially minimizing mixing).
- Monitoring wells, therefore generally low pumping stress.

Disadvantages associated with these samples:

- No major dissolved-gas data.
- No tracers other than SF_6.

Depth to water (can affect tracer transport to water table):

- Median: 16.69 feet
- Mean: 29.18 feet
- Minimum: 5.38 feet
- Maximum: 67.95 feet

Brief analysis:

The age gradient for these sites is shown in figure G2.

The age gradient has a great deal of scatter. Some of this could reflect the fact that two agricultural land use studies have been combined in this analysis, but the land use studies were from similar locations within a single Study Unit. Changing irrigation practices over time, and thus changing recharge rates, could explain some of the variability. Irrigation rates in the portion of the study area where these land use studies were located increased dramatically beginning in the early 1950s in response to irrigation water availability from the Columbia Basin Irrigation Project (Jones and Wagner, 1995); increased irrigation rates probably initially increased recharge rates. Then, beginning in the 1970s, irrigation practices in portions of the study area began changing from dominantly furrow to dominantly sprinkler irrigation methods (Ebbert and Kim, 1998); these changes may have affected recharge rates. The result of these changes in irrigation practices over time would be expected to lead to nonlinear age gradients.

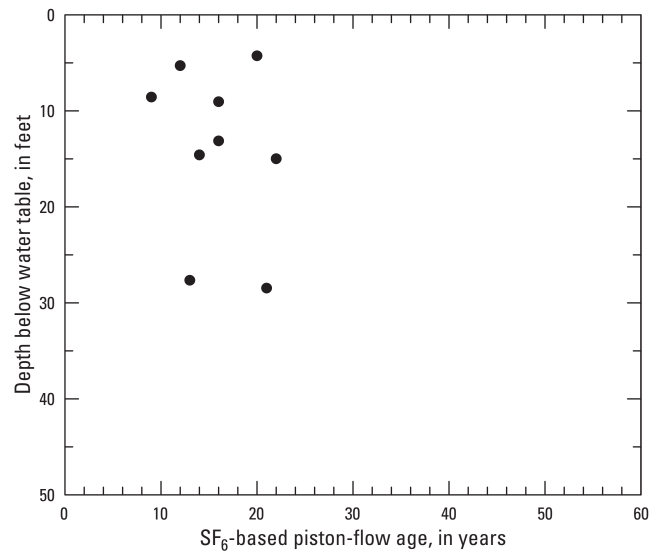

Figure G2. Age gradient for dated sites from the LUSOR1b and LUSAG2b networks in the CCYK Study Unit.

CNBR LUSCR1 and REFPA1

Samples from 22 sites in the CNBR Study Unit were collected during 2003 for CFCs (networks and, in parentheses, number of sites):

LUSCR1 (21)
REFPA1 (1)
See table G4.

The wells were installed in glacial deposit and stream-valley aquifers.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, that recharge temperature was equal to the mean annual air temperature + 1 °C, and that excess air concentrations were 2 cc(STP)/Kg.

Advantages associated with these samples:

- Short open intervals (saturated open interval ≤ 10 feet; median = 5.00 feet).
- Median penetration of center of OI into water table was 9.14 feet (sampling close to the water table, potentially minimizing mixing).
- Monitoring wells, therefore low pumping stress.
- Most sites contained $O_2 \geq 1$ mg/L (median field O_2 = 4.68 mg/L).

Disadvantages associated with these samples:

- No tracers other than CFCs.
- No major dissolved-gas data.

Depth to water (can affect tracer transport to water table):

- Median: 19.14 feet
- Mean: 23.29 feet
- Minimum: 2.10 feet
- Maximum: 62.30 feet

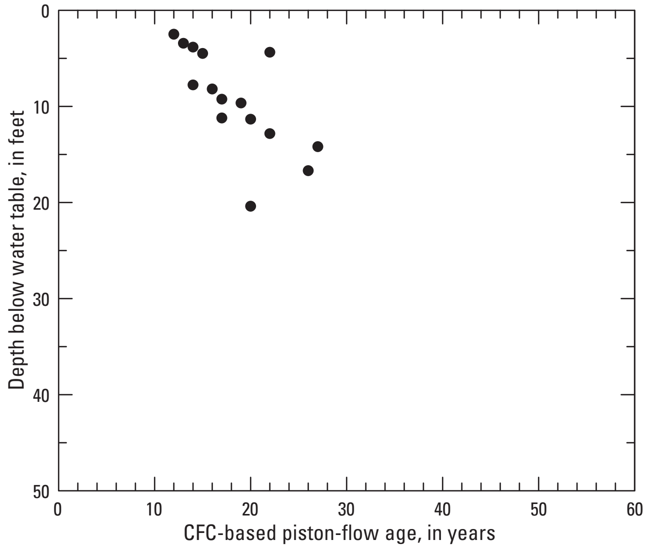

Figure G3. Age gradient for dated sites from the LUSCR1 and REFPA1 networks in the CNBR Study Unit.

Brief analysis:

The age gradient for these sites is shown in figure G3.

The age gradient for these wells shows tracer-based piston-flow age increasing with increasing depth below the water table. Although the overall pattern of increasing tracer-based piston-flow age with increasing depth is reasonable, it is possible that there is an offset towards older tracer-based piston-flow ages in at least some of these samples that could indicate a lag in the transport of CFCs through the unsaturated zone in these networks. Alternatively, it is possible that these samples represent multiple age gradients that reflect a variety of recharge rates, sediment textures, degrees of geologic heterogeneity, and directions of groundwater movement.

CONN SUS2

Samples from nine sites in the CONN Study Unit were collected during 2002 for CFCs (network and, in parentheses, number of sites):

SUS2 (9)

See table G5.

The aquifer is composed of glacial sediments.

Major dissolved-gas data were available for 8 of the 9 sites. For excess air calculations, only 4 of the 8 sites with major dissolved-gas data were oxic. Excess air concentrations for these 4 sites were sufficiently variable as to be considered insufficient for characterizing excess air for the other 5 sites. For the 4 suboxic sites that had major dissolved-gas data, as well as for the 1 site that did not have major dissolved-gas data, a typical excess air concentration of 2 cc(STP)/Kg was assumed.

Recharge temperature calculations for the 1 site (413710072553001, or CT-S-400) that did not have major dissolved-gas data were complicated by the fact that 8 sites that had major dissolved-gas data were spread over 3 states (CT, NH, VT). The mean annual air temperature for sites in these 3 states varies considerably. Thus, using the median recharge temperature from these 8 sites to represent the recharge temperature for site CT-S-400 would be problematic.

The 1 site that did not have major dissolved-gas data was in CT. The median major-dissolved-gas-inferred recharge temperature for the other 4 sites in CT was 11.10 °C. Mean annual air temperature +1°C (adjusted by lapse rate) for CT-S-400 was 11.04 °C. On the basis of these two calculations (11.10 °C and 11.04 °C), a recharge temperature of 11°C (2 significant figures) was used for CT-S-400.

Advantages associated with these samples:

Major dissolved-gas data were available for 8 of the 9 sites.

Short open intervals: For the 7 sites for which well construction data were available, the maximum saturated open interval was 8.00 feet.

Disadvantages associated with these samples:

No tracers other than CFCs.

Median penetration of center of open interval below water table was 61.85 feet (greater distance below water table possibly allowing for more mixing).

These were supply wells (more aquifer stress than with monitoring wells).

Many sites were suboxic (4 sites with field O_2 concentrations ≤0.24 mg/L), Mn-reducing (4 sites) and (or) Fe-reducing (3 sites).

Depth to water (can affect tracer transport to water table):

Median: 20.00 feet

Mean: 26.78 feet

Minimum: 6.00 feet

Maximum: 85.00 feet

Brief analysis:

Only one site was considered datable. As such, no age gradient is shown for this network.

CONN LUSRC1 and OTHER ($^3H/^3He$)

Samples from six sites in the CONN Study Unit were collected during 2003 and 2005 for $^3H/^3He$ (networks and, in parentheses, number of sites):

LUSRC1 (5)

OTHER (1)

See table G6.

The aquifer is composed of glacial sediments.

The standard procedure for $^3H/^3He$ dating that was documented in the body of the report was used for these sites. Four sites were datable (2 sites did not require a correction for terrigenic He; 2 sites did require a correction for terrigenic He), 1 site exhibited evidence of gas fractionation, and at 1 site the sample was lost during analysis.

Recharge elevation assumed equal to the elevation of the water table. For analysis of major dissolved-gas data, all six sites were oxic and all had major dissolved-gas data. However, data for 1 site (414826072290901) yielded unusual results (that is, negative excess air). Recharge elevations would have had to have been 3,000 feet (second sample) to 5,000 feet (first sample) above the water table elevation to get excess air to zero. Thus, these site-specific major dissolved-gas data were not used, and the median major dissolved-gas recharge temperature and excess air values from the other 5 sites were used to represent this 1 site.

Advantages associated with these samples:

Major dissolved gases were available for estimation of recharge temperatures.

Of the four datable wells, three had short open intervals (saturated open intervals ≤ 5.00 feet) and were monitoring wells with low pumping stress. The fourth well was a supply well with a saturated open interval of 15.00 feet.

Disadvantages associated with these samples:

The only substantial limitations specific to these sites are discussed in the next section.

Brief analysis:

The age gradient for these sites is shown in figure G4.

The age gradient for these networks is affected by the inclusion of a supply well with the relatively long well screen. This sample may reflect effects associated with well pumping, where young water may be drawn down to the well screen. If this well is removed from consideration, the age gradient is well defined for the three monitoring wells, all screened in sand and gravel and with short well screens.

The deepest of the four sites shown in the figure, above, also was dated with SF_6 (summarized separately). The SF_6-based piston-flow age was 3 years, compared with the $^3H/^3He$ -based piston-flow age of 6 years. These results could be consistent with a young bias in the SF_6-based piston-flow ages (discussed in the SF_6 summary). The $^3H/^3He$-based piston-flow age for this well probably is more reliable than the SF_6-based piston-flow age.

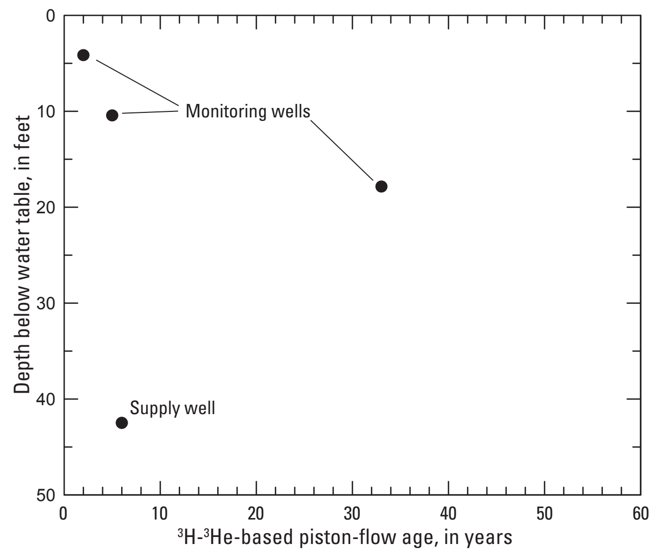

Figure G4. $^3H/^3He$-based age gradient for dated sites from the LUSRC1 and OTHER networks in the CONN Study Unit.

One of the monitoring wells in the figure above (the shallowest) also was dated with SF_6, but on a different sampling date. The SF_6-based piston-flow age for this well was 7 years, and the $^3H/^3He$-based piston-flow age was 2 years. However, these different tracers were collected on different sampling dates, complicating analysis of multiple tracers. Note that the chemistry was very different on the two sampling dates (e.g. nitrite-plus-nitrate 0.13 mg N/L versus 8.6 mg N/L), suggesting that the water sampled on the different dates was different. If one tracer-based piston-flow age is to be chosen to represent this site, the $^3H/^3He$-based piston-flow age probably is more reliable than the SF_6-based piston-flow age.

The reconstructed ^3H plot is shown in figure G5.

The 3 relatively modern samples plot near the ^3H input function for the wells, consistent with piston-flow conditions. The sample with a tracer-based piston-flow recharge date of 1972 appears to be affected by mixing processes, or possibly the large amount of excess air in the sample.

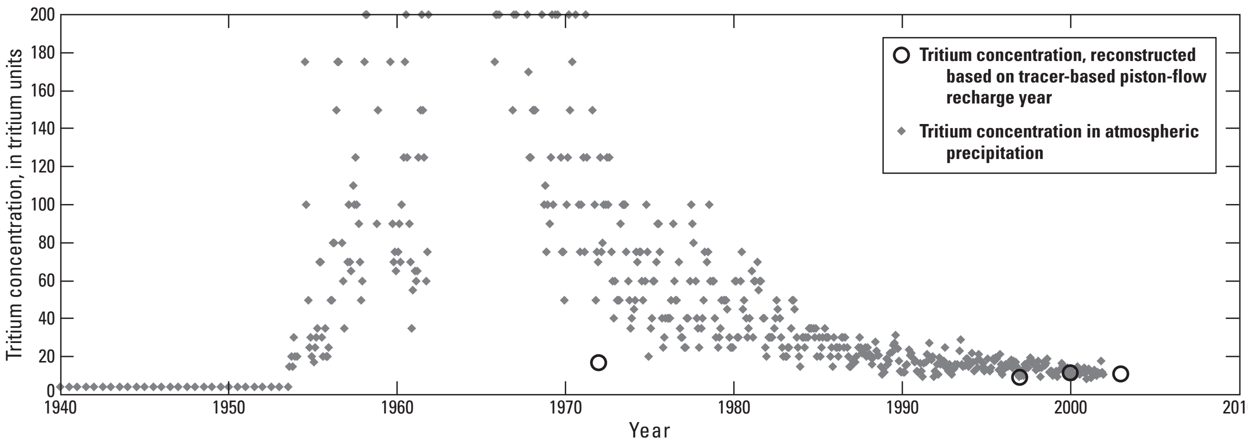

Figure G5. Reconstructed tritium concentrations (reconstruction based on $^3H/^3He$) and tritium in atmospheric precipitation, LUSRC1 and OTHER networks, CONN Study Unit.

CONN LUSRC1 and OTHER (SF_6)

Samples from 10 sites in the CONN Study Unit were collected during 2003 for SF_6 (networks and, in parentheses, number of sites):

LUSRC1 (7)
OTHER (3)
See table G7.

The aquifer is composed of glacial sediments.

Major dissolved-gas data were available for 5 of the 10 sites. Of these 5 sites, 3 were oxic and 2 were suboxic.

For the 3 oxic sites with major dissolved-gas data, the major dissolved-gas data were used to infer recharge temperature and excess air. However, these 3 samples were insufficient to characterize typical excess air concentrations for the other sites. Thus, for the 2 suboxic sites with major dissolved-gas data, a typical excess air concentration of 2 cc(STP)/Kg was used to constrain the calculations for recharge temperature.

For the 5 sites without major dissolved-gas data, the median major-dissolved-gas-inferred recharge temperature from the 5 sites that had major dissolved-gas data was used, and a typical excess air concentration of 2 cc(STP)/Kg was used.

Several of the sites yielded SF_6 atmospheric mixing ratios that were slightly elevated above the atmospheric mixing ratio for the dates of sampling. Although SF_6 contamination from natural or anthropogenic sources is not uncommon, it is possible that bias in estimated recharge temperatures or estimated excess air concentrations contributed to elevated estimates of SF_6 atmospheric mixing ratios. Several alternative approaches were evaluated, but no reasonable and defensible approaches for resolving these interpretations were identified. However, the problem may have sources other than assumptions about recharge temperatures or excess air. SF_6 concentrations in samples from the monitoring wells (n=7) exhibited greater variability among replicates than is typically seen in SF_6 data. Analyzing serial replicates (2 to 4 samples per site), the ratio of the highest SF_6 concentration to the lowest SF_6 concentration was 141, 152, 157, and 168 percent for four of these sets of replicates. Such variability, possibly indicating problems with well purging, sample collection, or sample analysis, complicates data interpretation and may partially explain the elevated atmospheric mixing ratios in some samples.

Advantages associated with these samples:

- Major dissolved-gas data were available for 5 of the 10 sites.
- Short open intervals: of the 9 wells for which well construction data were available, the median saturated open interval was 4.35 feet.
- Of the 9 wells for which well construction data were available, the median penetration of center of open interval into water table was 5.85 feet (sampling close to the water table, potentially minimizing mixing).
- Mostly monitoring wells (7 of the 10), therefore generally low pumping stress.

Disadvantages associated with these samples:

- Possible natural SF_6 present in some of these samples.

Depth to water (can affect tracer transport to water table):

- Median: 9.32 feet
- Mean: 19.18 feet
- Minimum: 4.00 feet
- Maximum: 60.95 feet

Brief analysis:

Many samples contained contaminant levels of SF_6. Only three samples were datable. The age gradient, although represented by only three sites, is shown in figure G6.

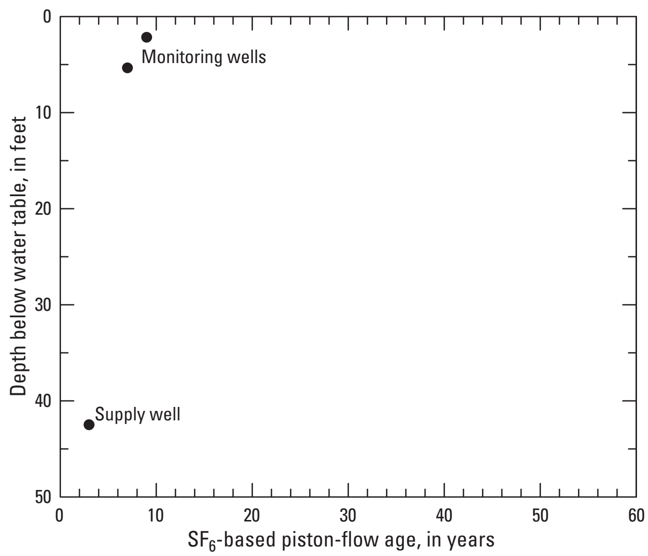

Figure G6. SF_6-based age gradient for dated sites from the LUSRC1 and OTHER networks in the CONN Study Unit.

The three data points yield an age inverse gradient, in which tracer-based piston-flow ages becoming younger with increasing depth. It is possible that for the deeper sample, which is a supply well, pumping stress draws young water to greater depth than would otherwise be found at those depths. Alternatively, the inverse age gradient could indicate the presence of a natural source of SF_6 in the aquifer, such that longer times of travel allow for greater concentrations of SF_6. Certainly, conclusions based on so few data points cannot be drawn, but the age gradient does suggest that these tracer based piston-flow ages be treated with caution.

The deepest of the three sites shown in the figure, above, also was dated with $^3H/^3He$ (summarized separately). The $^3H/^3He$-based piston-flow age was 6 years, compared with the SF_6-based piston-flow age of 3 years. These results could be consistent with a young bias in the SF_6-based piston-flow ages. The $^3H/^3He$-based piston-flow age for this well probably is more reliable than the SF_6-based piston-flow age.

One of the two monitoring wells in the figure above (the deeper of the two) also was dated with $^3H/^3He$, but on a different sampling date. The $^3H/^3He$-based piston-flow age for this well was 2 years, and the SF_6-based piston-flow age was 7 years. The fact that the SF_6-based piston-flow age was greater than the $^3H/^3He$-based piston-flow age is difficult to reconcile with other evidence suggesting a possible young bias in SF_6-based piston-flow ages, but the fact that different tracers were collected on different sampling dates adds uncertainties to any such analysis. Note that the chemistry was very different on the two sampling dates (e.g. nitrite-plus nitrate 0.13 mg N/L versus 8.6 mg N/L), suggesting that the water sampled on the different dates may have been different. If one tracer-based piston-flow age is to be chosen to represent this site, the $^3H/^3He$-based piston-flow age probably is more reliable than the SF_6-based piston-flow age.

The reconstructed ^3H plot (^3H data were available for only one site) is shown in figure G7.

This single reconstructed ^3H sample plots below the ^3H input function. A sample that plots below the ^3H input function can be an indication of a sample mixture. Mixing of different groundwater components would be consistent with particle-tracking simulations for this supply well (Starn and Brown, 2007). However, the combination of the low reconstructed ^3H concentration and the SF_6-based piston-flow recharge date of 2000 are not easily explained by mixing scenarios, especially if one accepts the distribution of simulated times-of-travel (about 0 to about 20 years; Starn and Brown, 2007). A more reasonable explanation for the observed pattern could be bias in the SF_6-based piston-flow age (for example, young bias due to the presence of natural SF_6 sources in the aquifer), and possibly analytical bias in the SF_6 or ^3H determinations.

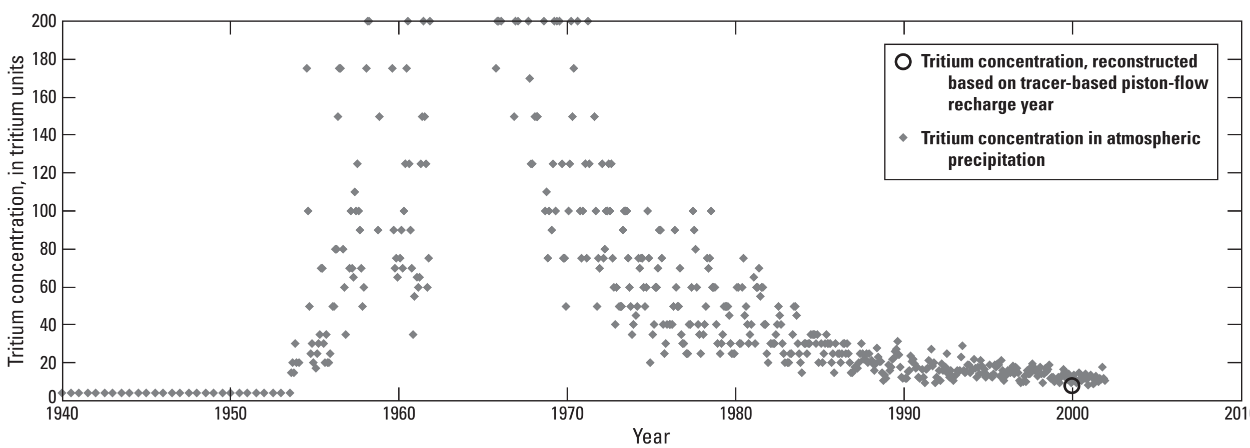

Figure G7. Reconstructed tritium concentrations (reconstruction based on SF_6) and tritium in atmospheric precipitation, LUSRC1 and OTHER networks, CONN Study Unit.

DELR SUS1

Samples from 18 sites in the DELR Study Unit were collected during 1999 for $^3H/^3He$ (network and, in parentheses, number of sites):

SUS1 (18)
See table G8.

The aquifer is a fractured rock aquifer.

The standard procedure for $^3H/^3He$ dating that was documented in the body of the report was used for these sites. Of the 18 sites, 16 were datable (8 sites did not require a correction for terrigenic He, and 8 sites did require a correction for terrigenic He). The other 2 sites exhibited evidence of gas fractionation

Advantages associated with these samples:

These samples exhibited few problems with fractionation, with low-^3H samples beyond the dating range, or with high He concentrations.

Disadvantages associated with these samples:

These wells have long saturated open intervals.

Brief analysis:

The age gradient for these sites is shown in figure G8.

The age gradient for this network has a great deal of scatter. The deepest site (400808075210401) does have the oldest tracer-based piston-flow age. However, of the 16 datable wells, this site (400808075210401) was the only site that was not a domestic well (it was a commercial well with a 408-foot open interval), and it is possible that the depth of the center of the open interval may be biased deep relative to the location of the water-bearing interval. If this one sample is removed from the age gradient plot, the age gradient for the remaining sites (fig. G9) shows slightly improved structure. However, the youngest samples are in relatively deep locations (see plot below). One of these samples had high ΔHe and ΔNe and a low sample weight indicating that there may have been air contamination and thus problems with the tracer interpretation, however, the other two samples are not affected by this problem. The scatter in the age gradient is consistent with mixing occurring due to the long well screens in the sampled wells.

The reconstructed ^3H plot is shown in figure G10.

Overall, these samples plot towards the lower part of, if not below, the ^3H input function, possibly indicating the effects of mixing. Alternatively, differences between the assumed $^3He/^4He$ ratio of terrigenic He and the actual $^3He/^4He$ ratio of terrigenic He in the study area (as discussed in the body of the report) may have introduced bias in the estimation of tracer-based piston-flow ages.

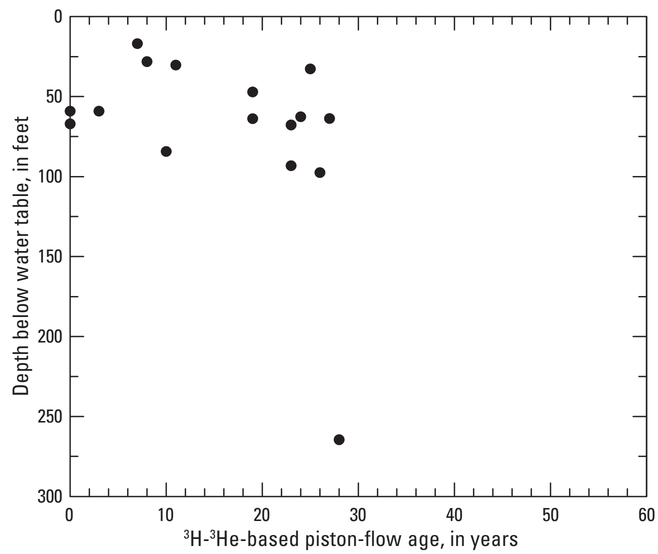

Figure G8. Age gradient for dated sites from the SUS1 network in the DELR Study Unit.

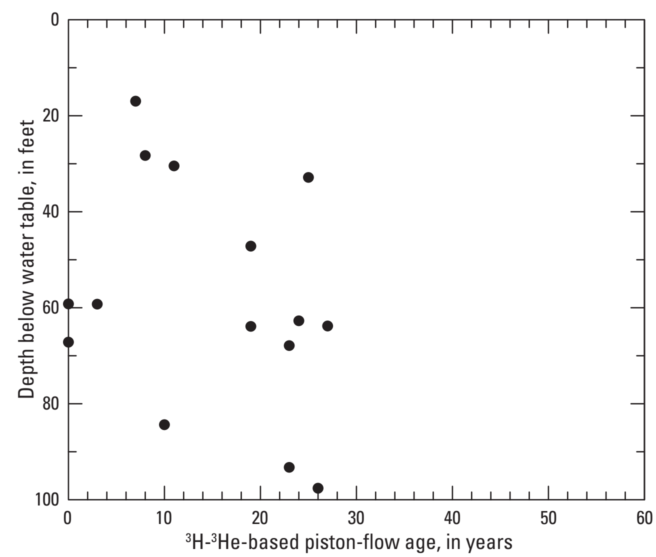

Figure G9. Age gradient for dated sites from the SUS1 network in the DELR Study Unit, with the one deep sample removed.

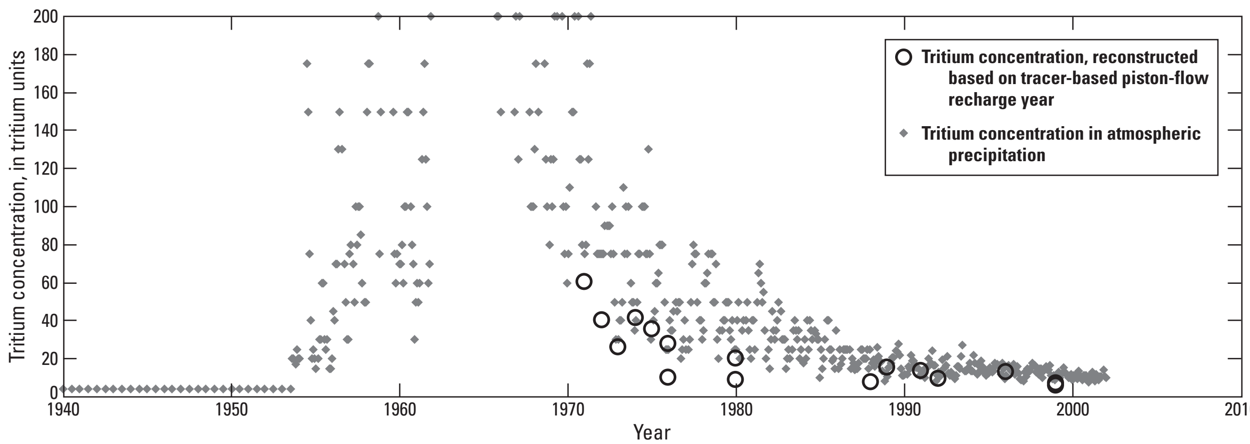

Figure G10. Reconstructed tritium concentrations and tritium in atmospheric precipitation, SUS1 network, DELR Study Unit.

EIWA OTHER

Samples from 27 sites in the EIWA Study Unit were collected during 1998 for CFCs (network and, in parentheses, number of sites):

OTHER (27) (1 site has dual designations as both OTHER and REFCR1)
See table G9.

The aquifer is composed of glacial sediments.

Recharge elevation assumed equal to the elevation of the water table. For analysis of major dissolved-gas data, only 3 sites were considered oxic (but 1 site had obvious analytical problems and was not used to infer recharge temperature or excess air); major dissolved-gas data were used to constrain recharge temperature and excess air for these two usable oxic sites. For the other 21 sites at which major dissolved-gas data were available, excess air was assumed to be 2 cc(STP)/Kg and major dissolved-gas data were used to infer recharge temperatures. For the 3 sites at which no major dissolved-gas data were available, and for the 1 site at which major dissolved-gas data were problematic, excess air was assumed to be 2 cc(STP)/Kg and recharge temperature was assumed to be equal to the mean annual air temperature + 1°C.

Advantages associated with these samples:

Major dissolved-gas data were available for 24 of the 27 sites.

These were monitoring wells, with generally low pumping stress and short well screens.

Disadvantages associated with these samples:

No tracers other than CFCs.

Generally highly reducing conditions. Only 3 sites contained greater than 1 mg O_2/L (field O_2). Of the 24 sites with major dissolved-gas data, 16 contained detectable CH_4.

Depth to water (can affect tracer transport to water table):

Median: 4.35 feet
Mean: 4.68 feet
Minimum: 2.35 feet
Maximum: 16.00 feet

Brief analysis:
Only three sites were considered datable. To be consistent with other network presentations, the age gradient is shown (fig. G11). However, the small number of data points and the lack of substantial vertical spread in those data limit the value of the age gradient figure.

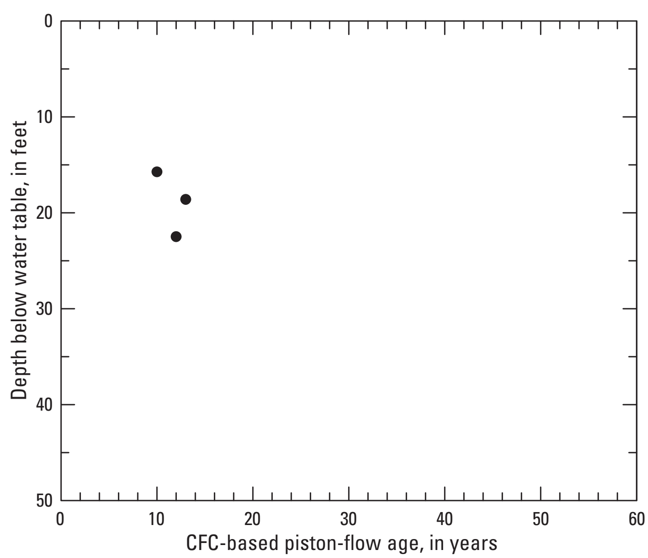

Figure G11. Age gradient for dated sites from the OTHER network in the EIWA Study Unit.

EIWA LUSCR1

Samples from 29 sites in the EIWA Study Unit were collected during 1999 for CFCs (network and, in parentheses, number of sites):

LUSCR1 (29)
See table G10.

The aquifer is composed of glacial sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites. There were three exceptions to this procedure. (1) Site 414208092312601 had anomalous major dissolved-gas data and yielded negative excess air; thus, the median recharge temperature and median excess air estimates from the usable oxic sites were used at this site. (2) One site did not have major dissolved-gas data, so the median recharge temperature and median excess air estimates from the usable oxic sites were used. (3) Site 422629092345001, considered oxic, had a major-dissolved-gas-inferred recharge temperature of 32.8 °C and an inferred excess air of 8.4 cc(STP)/Kg. The apparently elevated inferred recharge temperature and excess air could reflect unrecognized denitrification, but an assumption of denitrification leads to a major-dissolved-gas-inferred recharge temperature of 21.4 °C, still greater than the major-dissolved-gas-inferred recharge temperatures of all the other sites in this network. Additionally, there was only one major dissolved-gas sample for this site, thus the major dissolved-gas data were not reproduced. The site-specific major dissolved-gas data were not used for this site, and the median major-dissolved-gas-inferred recharge temperature and excess air from the usable oxic sites were used for this site.

Advantages associated with these samples:

- Major dissolved-gas data were available for 28 of the 29 sites.
- The saturated open intervals were ≤5 feet.
- These wells were shallow. The median penetration of the center of the open interval into the water table was 9.90 feet (sampling close to the water table, potentially minimizing mixing).
- These were monitoring wells, with low pumping stress.
- Most sites contained O_2 ≥ 1 mg/L (median field O_2 = 3.46 mg/L).

Disadvantages associated with these samples:

- No tracers other than CFCs.
- CH_4 was detected at 7 of the 28 sites.
- Many sites contained contaminant levels of CFCs.

Depth to water (can affect tracer transport to water table):

- Median: 6.35 feet
- Mean: 6.80 feet
- Minimum: 1.15 feet
- Maximum: 13.60 feet

Brief analysis:
The age gradient for datable sites in this network (fig. G12) shows little structure. The age gradient could reflect hydrologic variability. However, the poorly defined age gradient, in combination with the other limitations of the results from this network (for example, extensive contamination) suggests that these tracer-based piston-flow ages have substantial uncertainty.

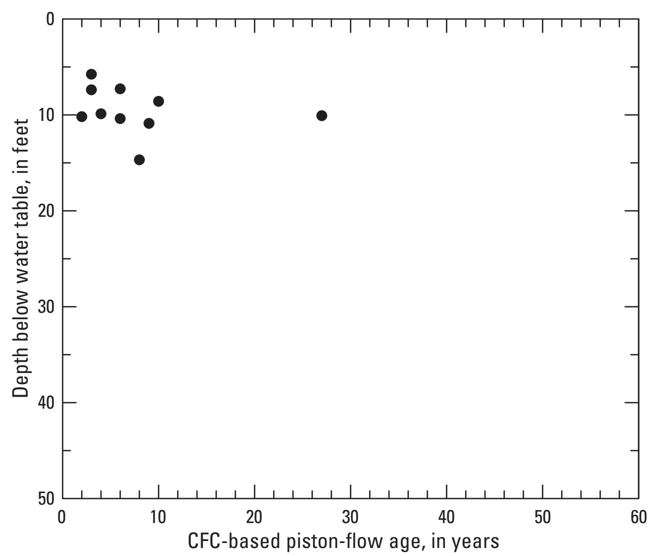

Figure G12. Age gradient for dated sites from the LUSCR1 network in the EIWA Study Unit.

LERI LUSRC1

Samples from five sites in the LERI Study Unit were collected during 1996 for $^3H/^3He$ (network and, in parentheses, number of sites):

LUSRC1 (5)
See table G11.

The aquifer is composed of glacial sediments.

The standard procedure for $^3H/^3He$ dating that was documented in the body of the report was used for these sites. Four sites were datable (1 site did not require a correction for terrigenic He; 3 sites did require a correction for terrigenic He). One site exhibited evidence of gas fractionation and thus was not datable.

Brief analysis:
The age gradient for this network is shown in figure G13. With only 4 data points, few conclusions can be drawn. However, the pattern of generally increasing tracer-based piston-flow age with increasing depth below the water table provides some support for these interpretations.

The reconstructed ^3H plot is shown in figure G14.

Three samples (2 attributed to the 1990s, 1 to the 1970s) have tracer-based piston-flow ages and reconstructed $^3H + {}^3He$ values that are consistent with ^3H inputs to the study area. One sample (1960s) plots lower than the ^3H input function would indicate for piston flow conditions. This sample had high terrigenic He and probably contains a component of pre-bomb water.

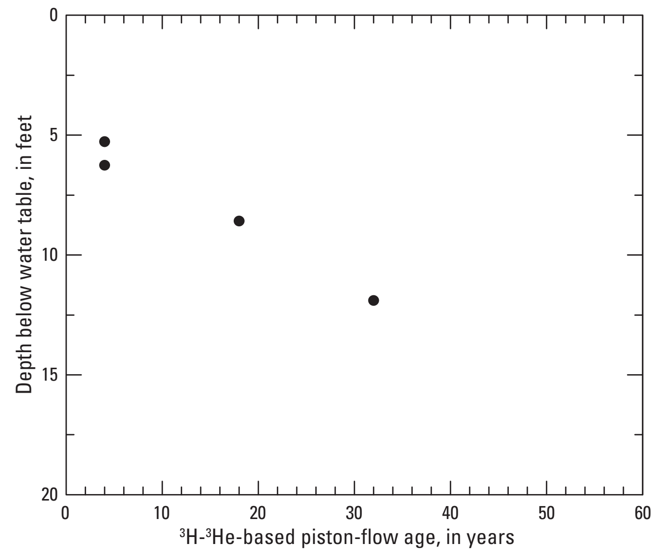

Figure G13. Age gradient for dated sites from the LUSRC1 network in the LERI Study Unit.

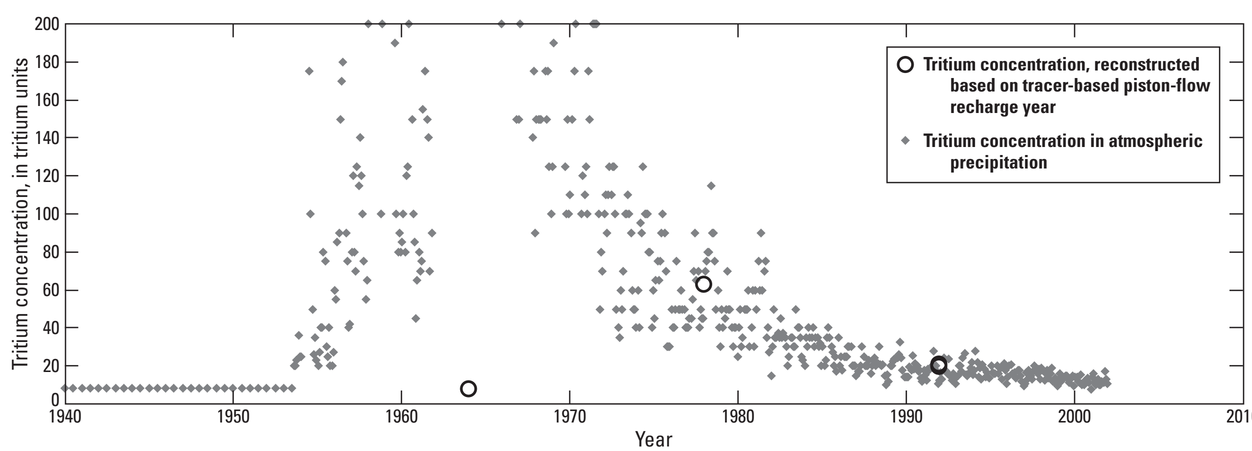

Figure G14. Reconstructed tritium concentrations and tritium in atmospheric precipitation, LUSRC1 network, LERI Study Unit.

LIRB LUSRC1

Samples from 20 sites in the LIRB Study Unit were collected during 2005 for SF_6 (network and, in parentheses, number of sites):

LUSRC1 (20)
See table G12.

The aquifer is composed of glacial sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, that recharge temperature was equal to the mean annual air temperature + 1 °C, and that excess air concentrations were 2 cc(STP)/Kg. Although 20 sites were sampled, 7 sites contained contaminant levels of SF_6, and 5 sites were not datable because both of the bottles for each of these sites were cracked. Thus, only 8 sites were datable.

Advantages associated with these samples:
- Short open intervals: median saturated open interval 5.00 feet.
- Median penetration of the center of the open interval into water table was 14.70 feet (sampling close to the water table, thus potentially minimizing mixing).
- These were monitoring wells, associated with generally low pumping stress.

Disadvantages associated with these samples:
- No tracers other than SF_6.
- No major dissolved-gas data.

Depth to water (can affect tracer transport to water table):
- Median: 11.71 feet
- Mean: 12.35 feet
- Minimum: 2.37 feet
- Maximum: 31.13 feet

Brief analysis:
The age gradient for these sites is shown in figure G15.

The age gradient has a great deal of scatter.

The site closest to the water table has a tracer-based piton-flow age of 23 years. This well was screened across the top 2.98 feet of the water table (the figure shows the location of the center of the saturated part of the open interval, and thus shows the point at 1.49 feet). It is possible that the relatively old tracer-based piston-flow age for the sample from this well could be related to the lithology of these sites. This 1 site was screened in silt; the other 7 wells were screened in sand.

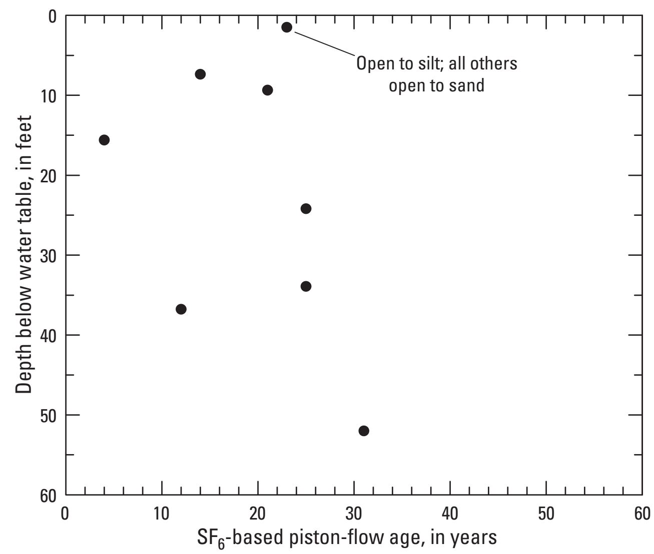

Figure G15. Age gradient for dated sites from the LUSRC1 network in the LIRB Study Unit.

NECB SUS1 and SUS2

Samples from 57 sites in SUS1 and SUS2 networks in the NECB Study Unit were collected during 1999 and 2000 for CFCs.

See table G13.

The aquifer is composed of fractured rock.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites.

One site did not have major dissolved-gas data, so the median recharge temperature and median excess air estimates from the oxic sites were used.

One site (435858070475901) was anomalous. The reducing conditions at this site suggested a need to allow for potential denitrification. However, this resulted in negative recharge temperatures. If denitrification was not allowed, then excess air was greater than typically observed: 7.87 and 7.73 cc(STP)/Kg in the duplicate samples. Given these uncertainties, the median recharge temperature and median excess air estimates from oxic sites were used for this site.

Advantages associated with these samples:
- Major dissolved-gas data were available for 56 of the 57 sites.

Disadvantages associated with these samples:
- These samples were primarily suboxic. The median field O_2 was 0.40 mg/L.
- Long open intervals (median saturated open interval 214 feet).
- No tracers other than CFCs.
- Some of the CFC data were problematic, with "ERR" reported in a concentration field (sometimes accompanied by a note about "peak interference").

CFC concentrations were more variable among samples than is usually seen, perhaps reflecting the nature of fracture flow to long-screened wells or perhaps due to purging problems.

Depth to water (can affect tracer transport to water table):
Median: 20.80 feet
Mean: 21.86 feet
Minimum: 0.00 feet
Maximum: 81.85 feet

Brief analysis:
The age gradient for these sites is shown in figure G16.

Scatter in these data reflect, in part, the wide geographic diversity of these eight sites (large parts of NH and ME) and the generally greater hydrologic heterogeneity that is found in fractured rocks than is found in sediments. The general pattern of increasing tracer-based piston-flow age with increasing depth below the water table, albeit with scatter, provides some support for the few datable sites.

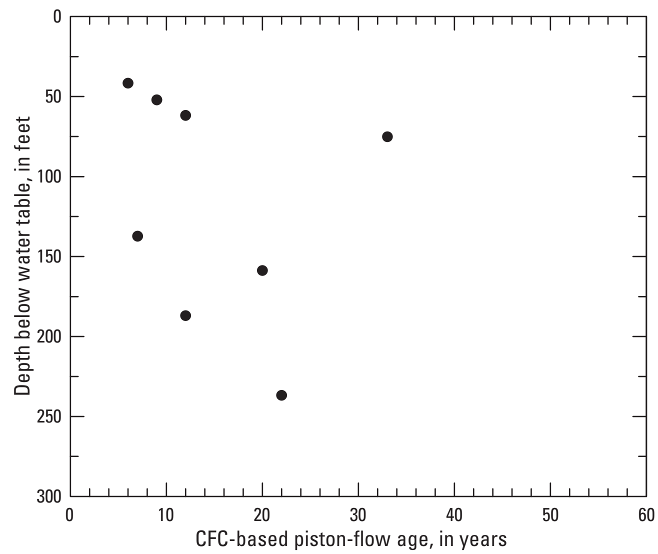

Figure G16. Age gradient for dated sites from the SUS1 and SUS2 networks in the NECB Study Unit.

NECB SUS3

Samples from 11 sites in the SUS3 network in the NECB Study Unit were collected during 2001 for CFCs.

See table G14.

The aquifer is composed of glacial sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites.

Advantages associated with these samples:
Major dissolved-gas data were available for all 11 sites.

Disadvantages associated with these samples:
Supply wells, possibly with large pumping rates and thus an increased potential for groundwater mixing.

Lots of CFC contamination present.

Although ^{3}H data were available for 3 sites, none of these 3 sites were datable.

Depth to water (can affect tracer transport to water table):
Median: 19.60 feet
Mean: 21.04 feet
Minimum: 14.30 feet
Maximum: 36.50 feet

Brief analysis:
Tracer-based piston-flow age was plotted against depth below water table (fig. G17). Only 3 sites were datable, and 1 of these did not have well construction data. The 2 data points are insufficient to draw conclusions about the age gradient for this network.

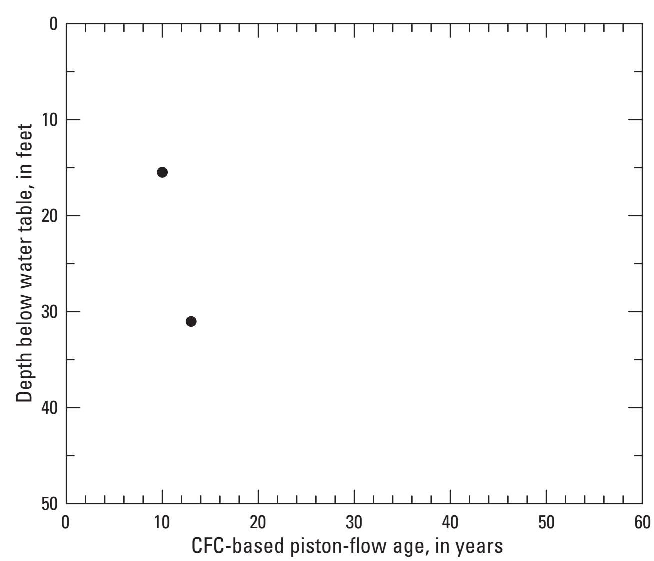

Figure G17. Age gradient for dated sites from the SUS3 network in the NECB Study Unit.

NECB LUSRC1

Samples from 29 sites in the LUSRC1 network in the NECB Study Unit were collected during 1999 for CFCs.

See table G15.

The aquifer is composed of glacial sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites.

At three sites (420249071035801, 420607070515501, 423527071120601), major dissolved-gas data exhibited evidence of degassing. Argon concentrations were unusually low (<0.6 mg/L), CH_4 concentrations were elevated (up to 9.3 mg/L), and inferred recharge temperatures were high (>20 °C). For these sites, the median recharge temperature and excess air from the oxic sites were used.

Advantages associated with these samples:

Major dissolved-gas data were available for all 29 sites.

These wells were monitoring wells, and as such, subject to generally low pumping stress.

Disadvantages associated with these samples:

Multiple tracers were not collected.

Depth to water (can affect tracer transport to water table):

Median: 12.45 feet
Mean: 14.32 feet
Minimum: 2.00 feet
Maximum: 31.87 feet

Brief analysis:

Tracer-based piston-flow age was plotted against depth below water table in figure G18. The narrow range of depths represented by these samples limits this analysis.

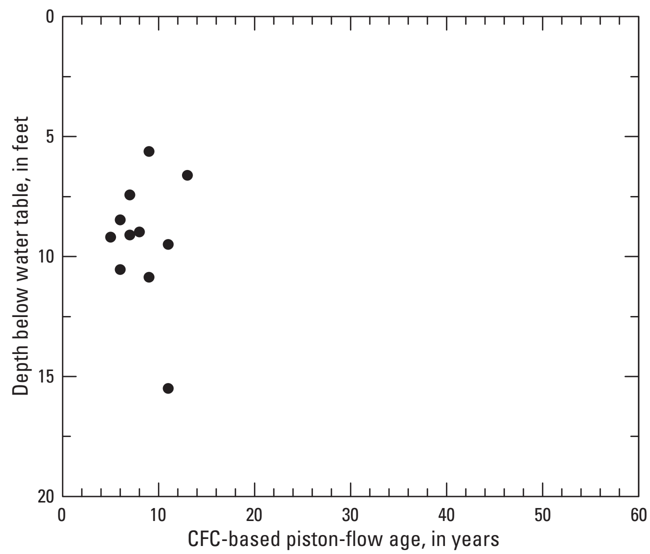

Figure G18. Age gradient for dated sites from the LUSRC1 network in the NECB Study Unit.

NROK SUS2

Samples from seven sites in the NROK Study Unit were collected during 2001 for SF_6 (network and, in parentheses, number of sites):

SUS2 (7)
See table G16.

The aquifer is composed of sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, and to estimate recharge temperature and excess air based upon major dissolved-gas data. Exceptions were made for two sites: 465741114110601 (#6) and 465838114074501 (#17). The major dissolved-gas data were problematic for these two sites. At site #6, the major-dissolved-gas-inferred recharge temperature (2.0 °C) and major-dissolved-gas-inferred excess air (8.4 cc(STP)/L) were anomalous. At site #17, the major-dissolved-gas-inferred recharge temperature (-1.4 °C) was anomalous. These anomalous results suggest the existence of sampling problems, and the median major-dissolved-gas-inferred recharge temperature and major-dissolved-gas-inferred excess air values from the other sites in the network (all of which were oxic) were used at these 2 sites.

Advantages associated with these samples:

Major dissolved-gas data were available for all 7 sites.

Mostly wells had short open intervals. Of the 7 sites, 5 were open-bottom wells (saturated open interval essentially zero for these 5 sites).

Disadvantages associated with these samples:

The median penetration of the center of the open interval into water table was 50.07 feet; at these depths, the magnitude of hydrodynamic dispersion tends to be greater than for wells screened near the water table.

Depth to water (can affect tracer transport to water table):

Median: 42.50 feet
Mean: 45.03 feet
Minimum: 12.07 feet
Maximum: 72.93 feet

Brief analysis:

The age gradient for these sites is shown in figure G19.

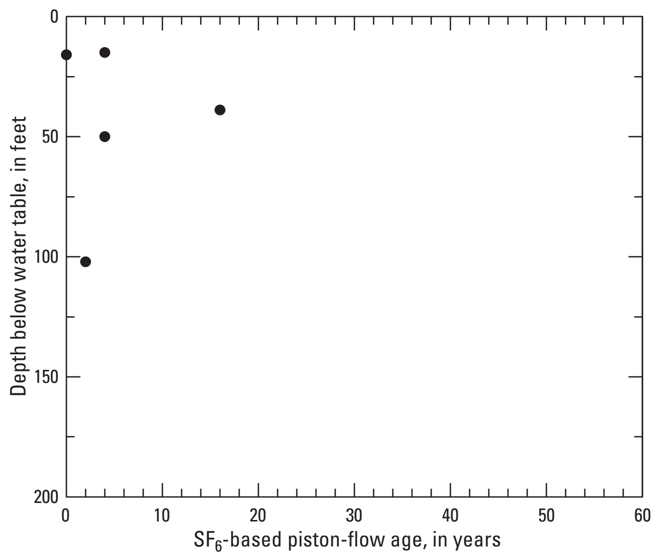

Figure G19. Age gradient for dated sites from the SUS2 network in the NROK Study Unit.

The steep age gradient for these wells might reflect strong vertical gradients. Alternatively, the steep age gradient could be an artifact of the tracers (for example, if some of the SF_6 is from natural sources, the tracer-based piston-flow ages would be biased young, steepening the age gradient).

Six of the 7 sites had ^3H data, and of these 6 sites, 5 were datable. The reconstructed ^3H plot is shown in figure G20.

For the most part, the tracer-based piston-flow ages are consistent with the ^3H input function. One exception is the youngest sample, which plots below the majority of the ^3H values and this could indicate a problem with either the SF_6 or the ^3H data for this site.

NVBR LUSRC1 LUSUR2 and SUS2

Samples from 15 sites in the NVBR Study Unit were collected during 2002 and 2003 for CFCs (networks and, in parentheses, number of sites):

LUSRC1 (9)
LUSUR2 (1)
SUS2 (5)
See table G17.

The aquifer is composed of sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, that recharge temperature was equal to the mean annual air temperature + 1 °C, and that excess air concentrations were 2 cc(STP)/Kg.

There is uncertainty in these estimates of recharge temperature and recharge elevation, in part because recharge may largely be from mountain-front and mountain-block recharge. To evaluate the effect of variable recharge temperature and recharge elevation on these tracer-based piston-flow ages, a comparison of results was made using (1) recharge temperatures based on mean annual air temperature + 1°C and recharge elevations based on static water levels, and (2) cooler recharge temperatures and greater recharge elevations based on Study Unit guidance. This comparison showed no substantial differences for these particular data, largely because all of the dated sites had tracer-based piston-flow recharge dates prior to the 1980s, a time when atmospheric CFC concentrations were increasing rapidly and thus a time period where sensitivity to recharge temperature and recharge elevation was small. Thus, the standard approach of using mean annual air temperature + 1°C and static water level elevations was used (consistent with the approach used with most other networks lacking major dissolved-gas data).

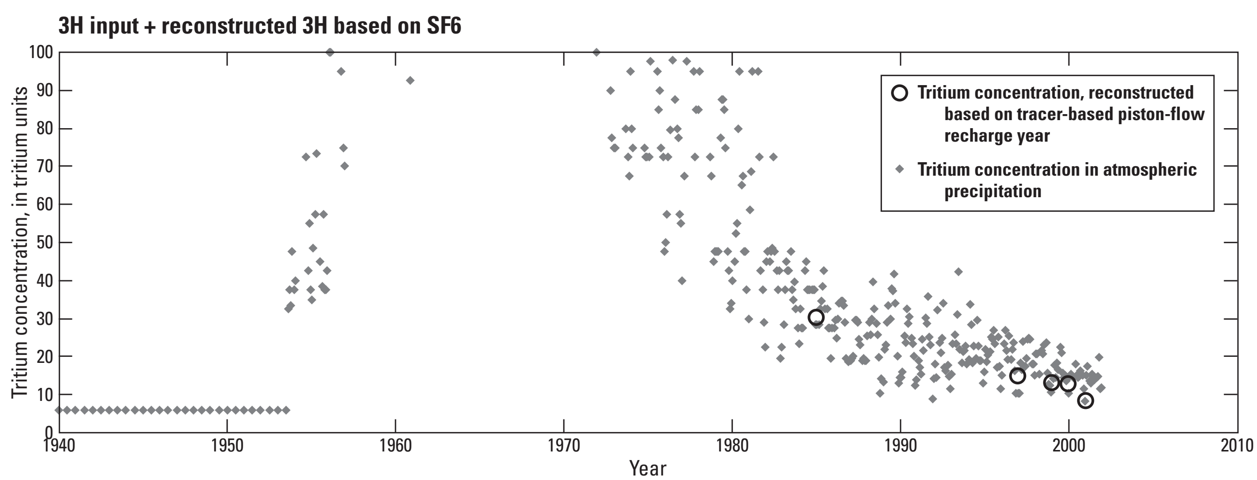

Figure G20. Reconstructed tritium concentrations and tritium in atmospheric precipitation, SUS2 network, NROK Study Unit.

Advantages associated with these samples:

Primarily monitoring wells, so generally low pumping stress and short well screens.

Primarily oxic conditions (DWH redox classification for 13 of the 15 sites was "O_2").

Disadvantages associated with these samples:

No major dissolved-gas data available.

Depth to water (can affect tracer transport to water table):

Median: 68.77 feet
Mean: 73.80 feet
Minimum: 4.30 feet
Maximum: 298.40 feet

Brief analysis:

The age gradient for these sites is shown in figure G21. One site did not contain a static water level measurement, and thus is not shown. The age gradient appears to be offset towards older tracer-based piston-flow ages. Such offset of the age gradient sometimes can indicate degradation or can indicate the presence of low CFC concentrations in unsaturated zone air near the water table. These sites are O_2-reducing (O_2 present), contraindicating CFC degradation. Sites with thicker unsaturated zones do not have greater offset in the age gradient than do sites with thinner unsaturated zone. It is possible that the age gradient reflects mixing of old (pre-CFC) mixtures with components of modern water.

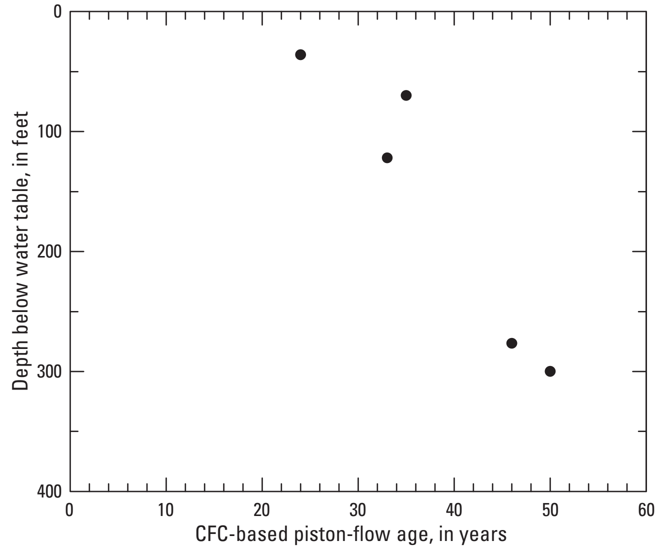

Figure G21. Age gradient for dated sites from the LUSRC1, LUSUR2 and SUS2 networks in the NVBR Study Unit.

The reconstructed ^3H plot for the 6 datable sites is shown in figure G22.

For this figure, some of the ^3H samples were collected on different sampling dates than was the case for the CFC samples associated with the ^3H samples, but all ^3H samples were collected in the same calendar year as were the CFC samples. Thus, the overall patterns demonstrated in this figure can still be used to evaluate the CFC interpretations. The reconstructed ^3H plot indicates that these samples probably are mixtures of pre- and post-bomb water. The calculated tracer-based piston-flow ages might have meaning in a relative sense (greater tracer-based piston-flow ages containing relatively less post-bomb water), but the calculated tracer-based piston-flow ages probably have little meaning in an absolute sense (that is, the samples probably do not contain water of piston-flow origin and the tracer-based piston-flow ages probably do not represent the mean age of the samples).

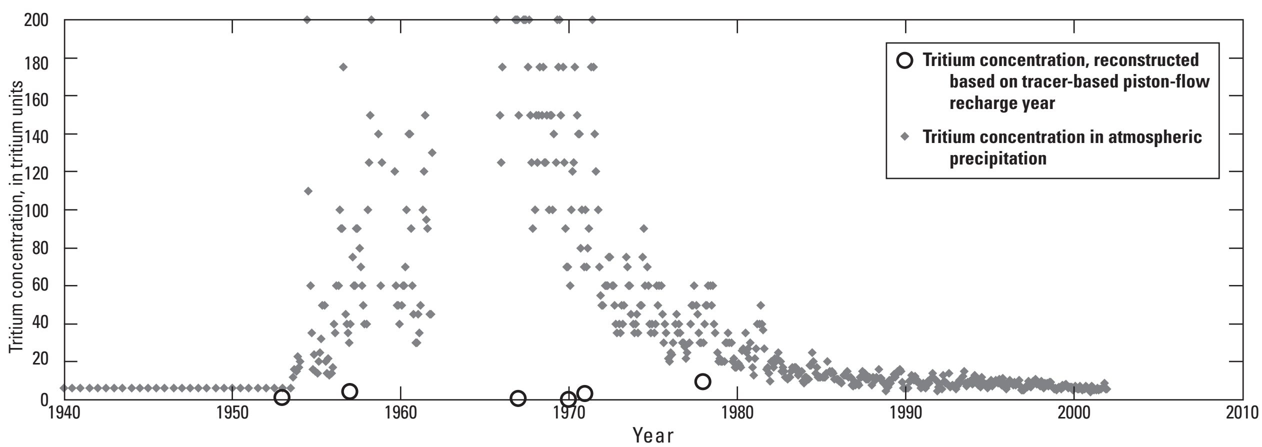

Figure G22. Reconstructed tritium concentrations and tritium in atmospheric precipitation for the LUSRC1, LUSUR2 and SUS2 networks, NVBR Study Unit.

PODL LUSRC1 and REFFO2

Samples from 8 sites in the PODL Study Unit were collected during 2003 for SF_6 (networks and, in parentheses, number of sites):

LUSRC1 (7)
REFFO2 (1)
See table G18.

The aquifer is composed of fractured rock.

Recharge elevation was assumed equal to the elevation of the water table. Recharge temperature and excess air at the one oxic site was based upon major dissolved-gas data. With only one oxic site in these networks, the approach of using the median excess air from the oxic sites to constrain suboxic sites was not feasible. The approach used for recharge temperatures and excess air at the seven suboxic sites was to constrain the major dissolved-gas analysis with an assumption that excess air concentration in this fractured rock aquifer was 3 cc(STP)/Kg. The value of 3 cc(STP)/Kg was similar to the (limited) results from other fractured rock aquifers in this project. In constraining excess air to 3 cc(STP)/Kg, it was assumed that N_2 gas in excess of air-water solubility plus that associated with 3 cc(STP)/Kg of excess air was derived from denitrification. However, for sites that initially contained less than 3 cc(STP)/ Kg of excess air, denitrification was held to zero and excess air was not adjusted.

In this analysis, with excess air constrained to 3 cc(STP)/Kg, there were 4 sites without an excess air adjustment (1 oxic and 3 suboxic sites), and 4 sites that did have an excess air adjustment (all 4 being suboxic). The median inferred recharge temperature for the 4 sites that did not have an excess air adjustment was 13.8 °C, similar to the median inferred recharge temperature of 12.6 °C for the 4 sites that did have an excess air adjustment. This analysis leads to inferred denitrification at 4 sites, at concentrations up to 2.2 mg N_2/Kg. All 4 sites with inferred denitrification also contained detectable CH_4, whereas the other 4 sites (no inferred denitrification) contained no detectable CH_4. The similarity between inferred recharge temperatures among different sites and the association of denitrification with more reduced conditions supports the assumption of 3 cc(STP)/Kg of excess air.

Advantages associated with these samples:

- Major dissolved-gas data were available for all 8 sites.
- These were monitoring wells, thus, associated with low pumping stress.

Disadvantages associated with these samples:

- No tracers other than SF_6.
- Fractured rock aquifers often have increased potential for mixing.
- Although these wells were monitoring wells, they were not as close to the water table as many NAWQA monitoring wells are; the median penetration below water table was 31.22 feet, probably reflecting the challenges of obtaining water from a fractured rock aquifer.

Depth to water (can affect tracer transport to water table):

Median: 15.91 feet
Mean: 14.70 feet
Minimum: 0.05 feet
Maximum: 29.55 feet

Brief analysis:

The age gradient for these sites is shown in figure G23.

Four of the eight sites were undatable due to the presence of SF_6 contamination. The remaining four data points provide very limited information about the age gradient for these networks. There is some structure to the age gradient, in which tracer-based piston-flow age tends to increase with increasing depth.

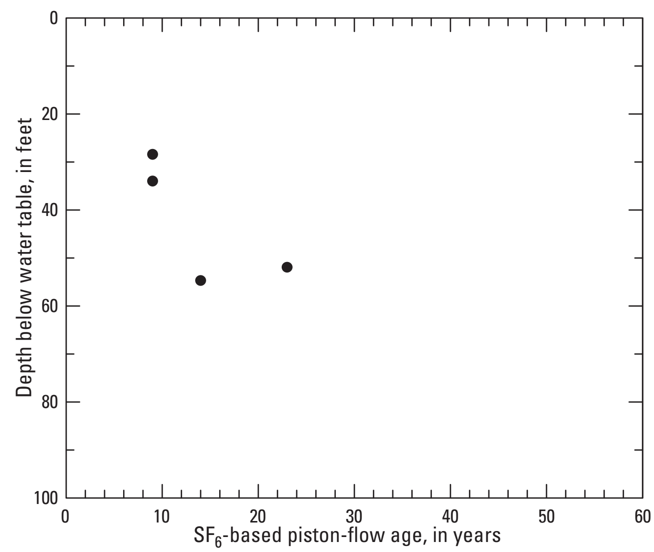

Figure G23. Age gradient for dated sites from the LUSRC1 and REFFO2 networks in the PODL Study Unit.

PODL LUSAG1 and REFFO1

Samples from 13 sites in the PODL Study Unit were collected during 2000 and 2002 for SF_6 (networks and, in parentheses, number of sites):

LUSAG1 (12)
REFFO1 (1)
See table G19.

This is a karst aquifer.

Recharge elevation was assumed equal to the elevation of the water table. Recharge temperature and excess air at the oxic sites based upon major dissolved-gas data. Recharge temperature and excess air at the 1 suboxic site was constrained based upon median excess air at the 12 oxic sites.

At one site (394828077545701), the replicate SF_6-samples yielded SF_6 concentrations of 306 fg/kg and 213 fg/kg (tracer-based piston-flow ages of 0.9 and 7.4 years). The large differences between replicate samples are unusual. It is possible that the sample with the larger SF_6 concentration had a leak or some sample contamination. Certainly, a young tracer-based piston-flow age of 0.9 years seems less likely than a tracer-based piston-flow age of 7.4 years, considering the center of the open interval was 93 feet below the water table, and thus the older tracer-based piston-flow age was chosen.

Advantages associated with these samples:
- Major dissolved-gas data were available for all 13 sites.

Disadvantages associated with these samples:
- Karst aquifer (increased potential for mixing; increased potential for air-water contact within caverns in aquifer).
- Median penetration of center of open interval into water table was 64.10 feet (for the 10 wells that had well construction data); these samples are, for the most part, not located near the water table, increasing the potential for mixing.
- Supply wells with long open intervals (median saturated open interval, for the 10 sites with well construction data: 91.38 feet).
- No tracers other than SF_6.

Depth to water (can affect tracer transport to water table):
- Median: 49.99 feet
- Mean: 63.19 feet
- Minimum: 23.66 feet
- Maximum: 134.40 feet

Brief analysis:
The age gradient for these sites is shown in figure G24.

The age gradient for these wells exhibits scatter that is typical of wells that are dispersed over a large geographic area. However, there is some structure to the relation, indicating a general increase in SF_6-based piston-flow age with depth, and the SF_6-based piston-flow age of 2 years at the shallowest site provides some support for the interpretations.

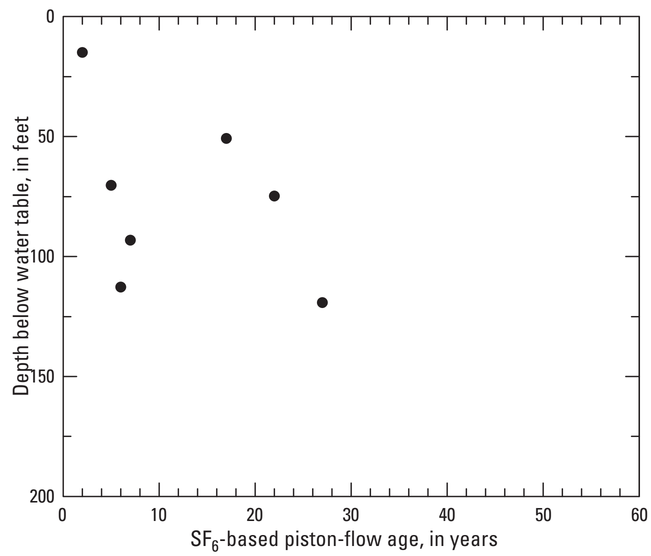

Figure G24. Age gradient for dated sites from the LUSAG1 and REFFO1 networks in the PODL Study Unit.

PUGT LUSCR1 and REFCR1

Samples from 23 sites in the PUGT Study Unit were collected during 2006 and 2007 for SF_6 (networks and, in parentheses, number of sites):

LUSCR1 (22)
REFCR1 (1)
See table G20.

The aquifer is composed of sediments.

Recharge elevation was assumed equal to the elevation of the water table; recharge temperature and excess air at oxic sites were based upon major dissolved-gas data; and recharge temperature and excess air at suboxic sites were constrained based upon the median excess air at the oxic sites. Two exceptions were made: 485755122253901 (AG-05) and 490012122240001 (FT7-22). These 2 sites appear to have had degassing in the aquifer or during sample collection. They had the lowest Ar concentrations (consistent with degassing) and the highest inferred recharge temperatures (elevated inferred recharge temperatures result if ground water degasses). Degassing would be consistent with the chemistry: these 2 sites have the highest CH_4, Fe, and Mn concentrations, and the lowest field O_2 concentrations, of the 23 sites, indicating reducing conditions that could lead to gas super saturation and degassing. Thus, for these 2 sites, the site-specific major dissolved-gas data were not used, and the median major-dissolved-gas-inferred recharge temperature and the inferred excess air from the set of robust oxic sites were used.

Tracer-based piston-flow ages were initially calculated with corrections for excess air, and subsequently calculated without corrections for excess air. These different approaches are discussed below.

Advantages associated with these samples:

Major dissolved-gas data were available for all 23 sites.

These wells had short open intervals: median saturated open interval 5.00 feet.

The median penetration of the center of the open interval into water table was 10.83 feet (sampling close to the water table, potentially minimizing mixing).

Most of the wells (19 of the 23) were monitoring wells, leading to generally low pumping stress.

Disadvantages associated with these samples:

The only tracer other than SF_6 was a single ^3H sample.

Depth to water (can affect tracer transport to water table):

Median: 14.64 feet
Mean: 17.79 feet
Minimum: 6.34 feet
Maximum: 76.12 feet

Brief analysis:

The age gradient for the initial interpretation is shown in figure G25. This interpretation includes the standard correction for excess air.

Two sites, AG-05 and FT7-22, are apparent outliers. These 2 sites likely lost gases to degassing (discussed above). Because SF_6 is only sparingly soluble, SF_6 is easily lost during degassing. Samples from AG-05 and FT7-22 probably have an old bias due to SF_6 loss. Tracer-based piston-flow ages for these 2 samples are considered to be maximum estimates. The other tracer-based piston-flow ages yield an approximately linear age gradient.

The age gradient as a whole (minus AG-05 and FT7-22) is not aligned with the origin, suggesting the possibility that these piston-flow ages could have an old bias. These data could conceivably be affected by fractionation during recharge, a process that favors loss of SF_6 from solution owing to the low solubility of SF_6. An old bias in tracer-based piston-flow ages could be consistent with $^3H/^3He$ data from Wassenaar and others (2006). Wassenaar and others (2006) present $^3H/^3He$ interpretations from some wells in the PUGT study area, including 5 LUSCR1 wells that were also sampled by the USGS for SF_6. The $^3H/^3He$-based piston-flow ages for these 5 sites, along with SF_6-based piston-flow ages for LUSCR1 sites that were sampled for SF_6 (except sites AG-05 and FT7-22, which were omitted because of degassing problems) are shown in figure G26 below. The age gradient of the $^3H/^3He$ data appears to have a generally similar slope to that of the SF_6 data, but appears to intersect the graph near the origin, suggesting that the SF_6 data indeed might have an old bias.

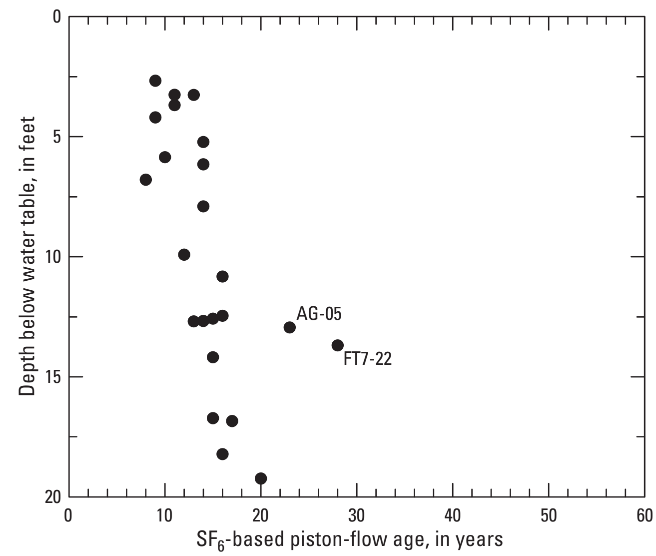

Figure G25. Age gradient for dated sites from the LUSCR1 and REFCR1 networks in the PUGT Study Unit. The tracer-based piston-flow ages were calculated by the standard approach of correcting for the presence of excess air.

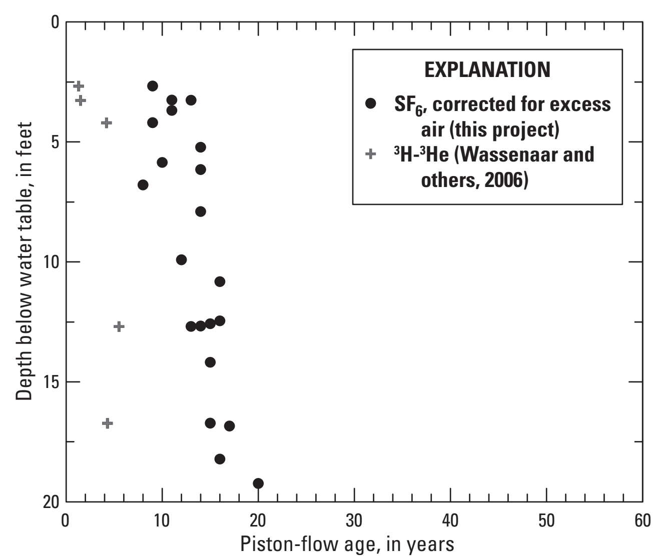

Figure G26. Age gradient for dated sites from the LUSCR1 and REFCR1 networks in the PUGT Study Unit. The tracer-based piston-flow ages were calculated by the standard approach of correcting for the presence of excess air. Two outliers that were shown in figure G25 have been removed. The $^3H/^3He$-based age gradient of Wassenaar and others (2006) is shown for comparison.

Where SF_6 samples have undergone substantial fractionation, tracer-based piston-flow ages without a correction for excess air will be a closer representation of time-of-travel than those with a correction for excess air. The age gradient for these sites, without an excess air correction, is shown in figure G27 (sites AG-05 and FT7-22 omitted).

The age gradient for this analysis (i.e. no correction for excess air) is closer to that of Wassenaar and others (2006), and appears to approximately intersect the origin. These SF_6-based piston-flow ages (uncorrected for excess air) have been retained for these networks.

One site had a ^3H analysis. The ^3H concentration, adjusted for radioactive decay by the SF_6-based piston-flow age of the sample, plots in the expected field on the ^3H input function for the study area (figure G28). However, the existence of just one ^3H analysis and its position on an approximately flat part of the ^3H curve provide little support for the SF_6 analysis. (The SF_6-based piston-flow age shown in the reconstructed ^3H analysis was based on calculations without a correction for excess air, but the calculation with a correction for excess air does not substantially alter the results of the reconstructed ^3H analysis.)

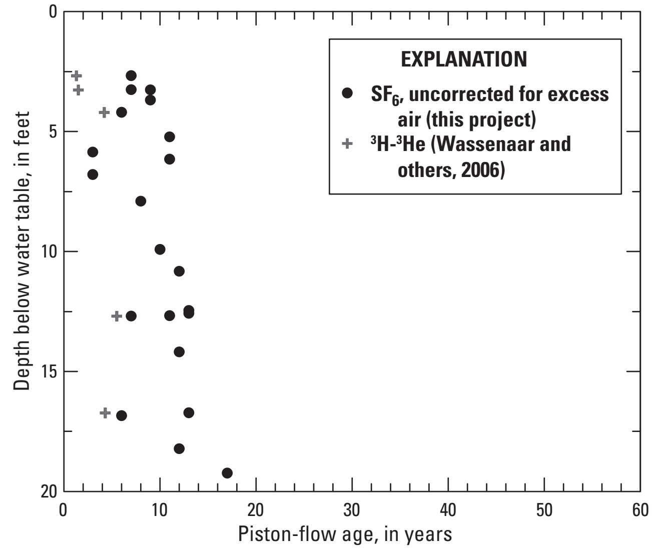

Figure G27. Age gradient for dated sites from the LUSCR1 and REFCR1 networks in the PUGT Study Unit. The tracer-based piston-flow ages were calculated without a correction for the presence of excess air. Two outliers that were shown in figure G25 have been removed. The $^3H/^3He$-based age gradient of Wassenaar and others (2006) is shown for comparison.

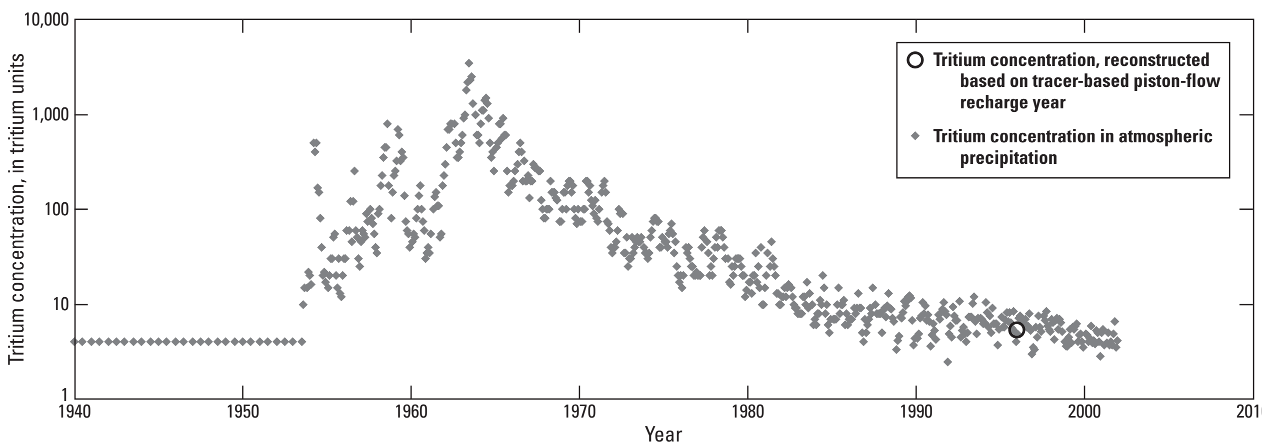

Figure G28. Reconstructed tritium concentrations and tritium in atmospheric precipitation for the LUSCR1 and REFCR1 networks, PUGT Study Unit.

RIOG LUSCR1

Samples from 33 sites in the RIOG Study Unit were collected during 2000 for CFCs (network and, in parentheses, number of sites):

LUSCR1 (33)
See table G21.

The aquifer is composed of sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, that recharge temperature was equal to the mean annual air temperature + 1°C, and that excess air concentrations were 2 cc(STP)/Kg.

Advantages associated with these samples:

- Short saturated open intervals (all saturated open intervals were ≤ 10.09 feet).
- Median penetration of the center of the open interval into water table was 4.15 feet (sampling close to the water table, possibly reducing mixing).
- Monitoring wells, therefore low pumping stress.
- Mostly oxic (median field O_2 = 3.40 mg/L).

Disadvantages associated with these samples:

- No tracers other than CFCs.
- No major dissolved-gas data.

Depth to water (can affect tracer transport to water table):

- Median: 10.63 feet
- Mean: 12.33 feet
- Minimum: 3.70 feet
- Maximum: 39.16 feet

Brief analysis:
The age gradient for these sites is shown in figure G29.

The age gradient for this network shows little structure. These wells are located near the water table in areas of irrigated agriculture, and thus there is periodic recharge. However, this aquifer is not a typical aquifer in which there is diffuse recharge and in which discharge occurs primarily at or near surface-water bodies, at wells, or by ground water outflow. Most groundwater discharge in this aquifer is by evapotranspiration (Anderholm, 1996). Thus, relations between tracer-based piston-flow ages and depth below water table would not necessarily be expected to reflect the dynamics of simpler flow systems.

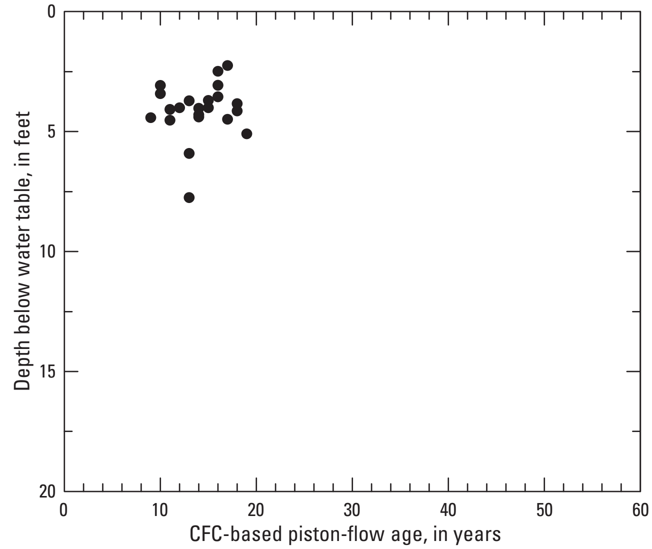

Figure G29. Age gradient for dated sites from the LUSCR1 network in the RIOG Study Unit.

Flow dynamics in this aquifer are particularly complicated. Abundant recharge from irrigation, hydraulic perturbations caused by irrigation pumping, and substantial discharge via evapotranspiration, all contribute to groundwater mixing. As an illustration of the effect that mixing can have on tracer-based piston-flow ages, consider the fact that the CFC concentrations for the datable sites contained 78 percent ± 11 percent (mean and standard deviation) of atmospheric concentrations at the time of sampling. Given these CFC concentrations, the sites represented here could reflect mixtures dominated by relatively young (days to years old) recharge with small amounts of old (decades or centuries old) recharge. Although such scenarios are possible for many groundwater samples, the particular hydrologic regime in this network and the clustering near the water table of data points in the age gradient plot are reasons to suspect that these tracer based piston-flow ages do not reflect the true complexity of flow represented by these samples.

One of the datable sites also had ^3H data. The reconstructed ^3H plot is shown in figure G30 for consistency, but has limited value on account of the single ^3H analysis.

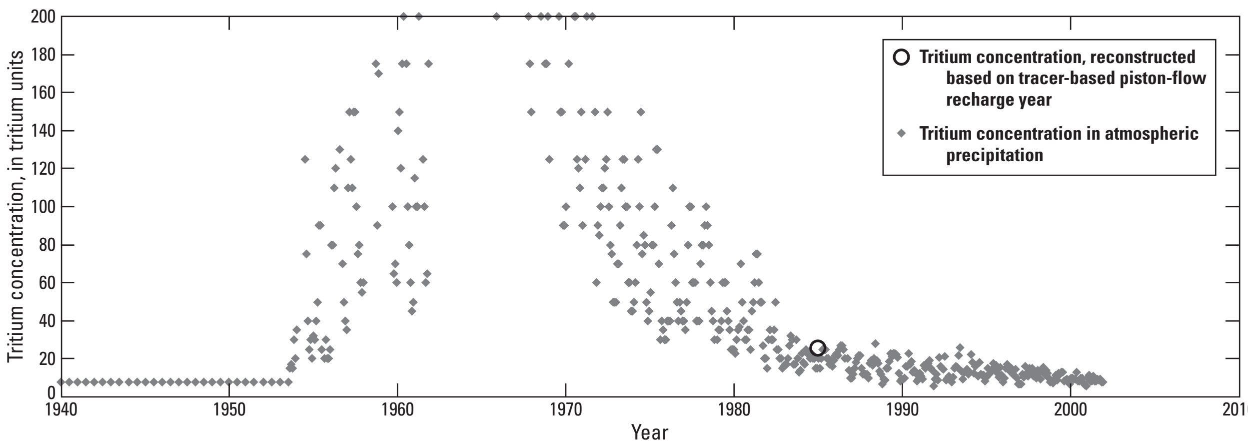

Figure G30. Reconstructed tritium concentrations and tritium in atmospheric precipitation for the LUSCR1 network, RIOG Study Unit.

SACR LUSRC1

Samples from 19 sites in the SACR Study Unit were collected during 1998 for $^3H/^3He$ (network and, in parentheses, number of sites):

LUSRC1 (19)
See table G22.

The aquifer is composed of sediments.

The standard procedure for $^3H/^3He$ dating that was documented in the body of the report was used for these sites. Seven sites were datable (1 site did not require a correction for terrigenic He; 6 sites did require a correction for terrigenic He), 6 site exhibited evidence of gas fractionation, 3 sites were beyond the dating range, and at 3 sites the samples were lost during analysis.

Advantages associated with these samples:

The wells were monitoring wells with low pumping stress and short open intervals.

Disadvantages associated with these samples:

Many samples showed evidence of fractionation. Samples for three of the sites had loose bolts or crimps, which may have contributed to sample fractionation in some samples.

Brief analysis:

The age gradient for these sites is shown in figure G31.

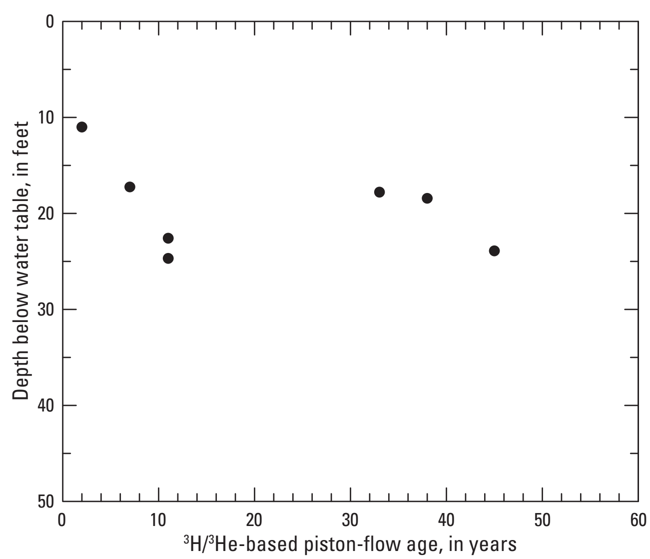

Figure G31. Age gradient for dated sites from the LUSRC1 network in the SACR Study Unit.

Wells with relatively young ages are spread out throughout the network. These sites are located in different geologic deposits and should not necessarily have consistent age-depth gradients. The 3 wells with tracer-based piston-flow ages greater than 30 years, but similar depths to wells with younger ages, are likely affected by mixing. These wells have low concentrations of VOCs and pesticides, as well as mixed redox indicators for 2 of the samples, indicative of mixing of young and old waters.

The reconstructed ^3H plot is shown in figure G32.

The 3 samples with tracer-based piston-flow recharge dates older than 1970 have reconstructed ^3H concentrations that are consistent with higher concentrations during the 1950s and 1960s. Three of the more modern samples appear to be relatively unmixed and represent piston-flow transport, while the fourth one appears to be affected by mixing processes or diffusive ^3He loss. The samples that were beyond the dating range for the $^3H/^3He$ method all have very low ^3H concentrations, are all oxygenated, all have deeper water tables and required mud rotary drilling, and are all located in North Sacramento in the Turlock Lake Formation. These wells had only one VOC detection, had no pesticide detections, and only one had an elevated nitrate concentration. Despite the fact that the $^3H/^3He$ dating could not be used for these wells, the ^3H information alone is useful in determining that the water in these locations is old and is consistent with the minimal occurrence of anthropogenic indicators such as VOCs or pesticides.

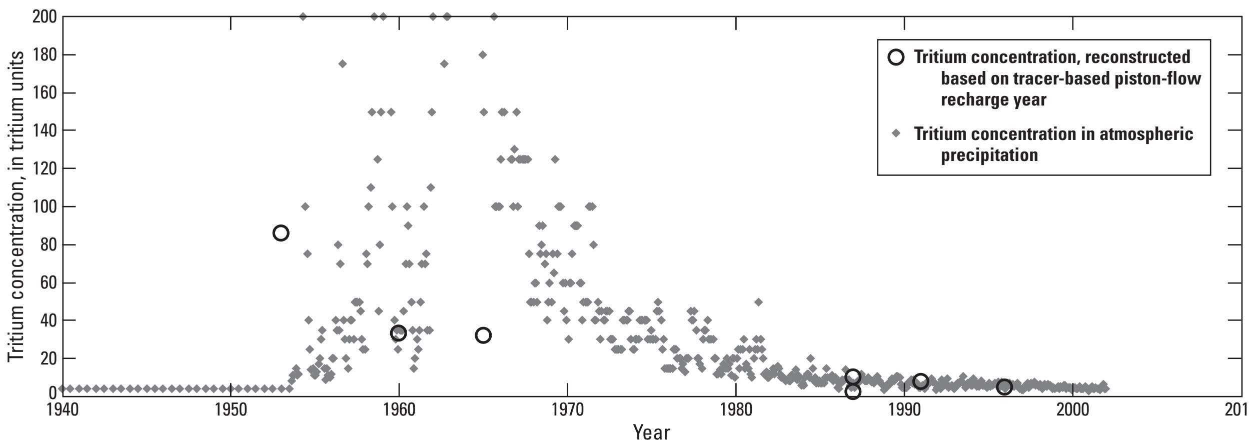

Figure G32. Reconstructed tritium concentrations and tritium in atmospheric precipitation for the LUSRC1 network, SACR Study Unit.

SANJ LUSOR1

Samples from 9 sites in the SANJ Study Unit were collected during 1996 for CFCs (network and, in parentheses, number of sites):

LUSOR1 (9)
See table G23.

The aquifer is composed of sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites.

Advantages associated with these samples:

Major dissolved-gas data were available for all 9 sites that had CFC analyses.

Of the 9 wells, 6 were monitoring wells (low pumping stress for these 6 sites).

Mostly oxic redox conditions (median field O_2 = 3.80 mg/L).

Disadvantages associated with these samples:

No tracers other than CFCs.

Median saturated open interval was 10 feet and ranged up to 50 feet.

The median penetration of the center of the open interval into the water table was 54.67 feet; at these depths, the magnitude of hydrodynamic dispersion tends to be greater than for wells screened near the water table.

Depth to water (can affect tracer transport to water table):

Median: 43.65 feet
Mean: 45.32 feet
Minimum: 28.26 feet
Maximum: 57.00 feet

Brief analysis:
The age gradient for these sites is shown in figure G33. The age gradient, although limited to only 4 datable samples, shows a general pattern of increasing tracer-based piston-flow age with increasing depth below the water table.

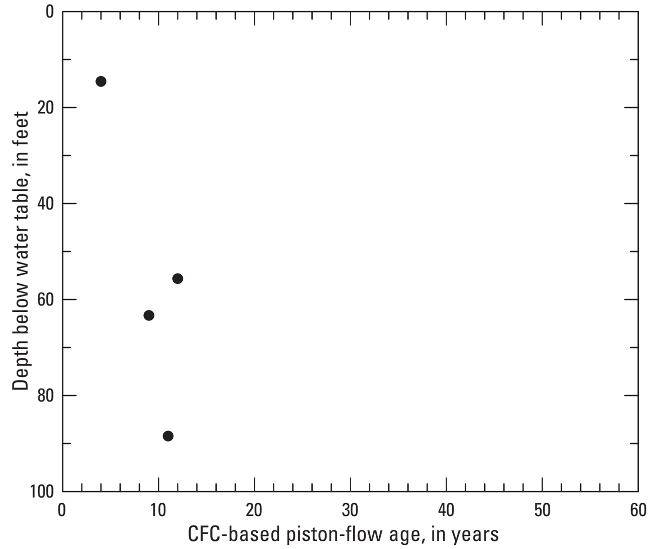

Figure G33. Age gradient for dated sites from the LUSOR1 network in the SANJ Study Unit.

SANT LUSCR1

Samples from 29 sites in the SANT Study Unit were collected during 1997 for CFCs (network and, in parentheses, number of sites):

LUSCR1 (29)
See table G24.

The aquifer is composed of sediments.

Major dissolved-gas data were collected at 10 sites. Two of the three oxic sites had major dissolved-gas data that implied negative excess air; these samples require negative excess N_2 (negative denitrification) or require adding 5,000 to 9,000 feet to the recharge elevation just to bring excess air to 0.00 cc(STP)/Kg. Additional problems with the major dissolved-gas data were the presence of highly variable concentrations among replicate samples. For example, differences in inferred recharge temperatures for replicate samples (assuming no denitrification) = 1.9 °C (median), and differ by as much as 11.5 °C. Because there were these problems with the major dissolved-gas data, and because the major dissolved-gas data were incomplete (available for only 10 of the 29 sites), the major dissolved-gas data were not used. Instead, it was assumed that recharge elevation was equal to the elevation of the water table, that recharge temperature was equal to the mean annual air temperature + 1°C, and that excess air concentrations were 2 cc(STP)/Kg.

Well construction data from the DWH for one site required re-interpretation. Taking DWH data at face value, the static water level (SWL) for 332355080410401 (ORG-395) lies below the bottom of the screen. However, DWH data indicate that the bottom of the screened interval for this well lies 6 feet above the bottom of the well. The other 28 LUSCR1 wells that were age-dated are listed in the DWH as having the bottom of the screened interval equal to the bottom of the well. It would appear that the DWH data for ORG-395 are incorrect. Larry G. Harrelson, hydrologist, USGS, South Carolina, written commun., March 9, 2009, confirmed the error, and indicates that depth to top of screen = 6.94 ft, to bottom of screen = 16.94 ft, and well depth = 16.94 ft. These updated well construction data were used in lieu of DWH data.

Advantages associated with these samples:

Short open intervals (median saturated open interval 5.00 feet).

Monitoring wells, therefore low pumping stress.

Median penetration below water table: 4.10 feet, thus sampling near the water table and thus minimizing mixing.

Median field O_2 = 5.70 mg/L.

Disadvantages associated with these samples:

No tracers other than CFCs.

Major dissolved-gas data were not useful.

The SWL data retrieved from the DWH on 12-16-08 and 02-05-09 were used in this analysis. These SWL data do not agree exactly with SWL data on the USGS NWIS-WEB website as of 03-05-09. Study Unit hydrologists are investigating, but this analysis proceeded with the currently available DWH data.

Depth to water (can affect tracer transport to water table):
Median: 10.80 feet
Mean: 11.23 feet
Minimum: 5.20 feet
Maximum: 22.30 feet

Brief analysis:
The age gradient for these sites is shown in figure G34. The center of the screened interval was less than 10 feet below the water table for each of these wells, yielding a small range of depths for evaluating the local age gradient. However, the generally young tracer-based piston-flow ages are consistent with the location of samples near the water table in recharge areas.

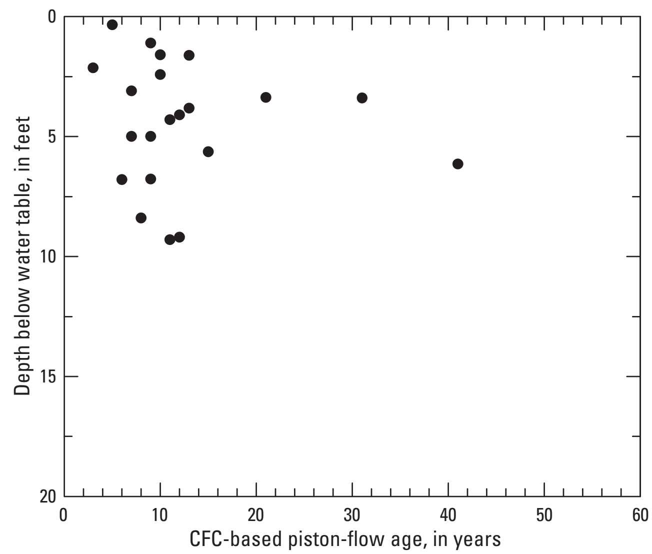

Figure G34. Age gradient for dated sites from the LUSCR1 network in the SANT Study Unit.

SANT SUS3

Samples from 29 sites in the SANT Study Unit were collected during 1998 for CFCs (network and, in parentheses, number of sites):

SUS3 (29)
See table G25.

The aquifer is composed of fractured rock.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites. Major dissolved-gas data were not available for 8 sites, so the median recharge temperature and median excess air estimates from the oxic sites were used at these 8 sites.

Advantages associated with these samples:

Major dissolved-gas data were available for 21 of the 29 sites.

Primarily oxic. Median field O_2 = 6.90 mg/L.

Disadvantages associated with these samples:

No tracers other than CFCs.

Long saturated open intervals (median 120 feet) (however, not unusual for fractured rock aquifers).

Depth to water (can affect tracer transport to water table):
Median: 26.00 feet
Mean: 29.23 feet
Minimum: 9.00 feet
Maximum: 134.50 feet

Brief analysis:

The age gradient is shown in figure G35. Scatter in these data reflect, in part, the generally greater hydrologic heterogeneity that is found in fractured rocks than is found in sediments.

Analysis of age gradients can provide useful information about a hydrologic system if the tracer-based piston-flow ages are considered reliable, or alternatively, can provide a tool for screening tracer-based piston-flow ages where hydrologic systems are well characterized. In the case of fractured rock aquifers, hydrodynamics are seldom well characterized and age gradients often exhibit substantial scatter. An alternative tool for screening tracer-based piston-flow ages can be comparing tracer-based piston-flow age to geochemical evolution. One such simple application is to compare tracer-based piston-flow age to pH because there is a tendency of pH to increase with increasing ground-water age in response to (kinetically limited) hydrolysis reactions (for example, Rademacher and others, 2001). Tracer-based piston-flow age was plotted against pH (fig. G36). The pattern of generally increasing pH with increasing residence time as represented by tracer-based piston-flow age provides some support for the age-dating interpretations.

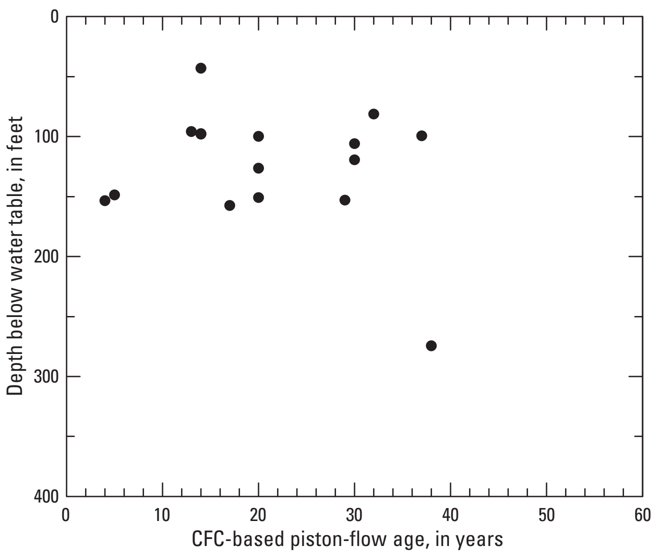

Figure G35. Age gradient for dated sites from the SUS3 network in the SANT Study Unit.

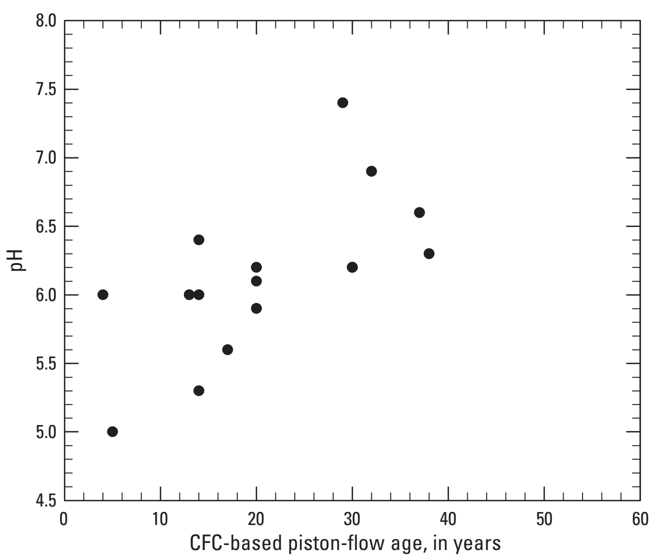

Figure G36. Relation between tracer-based piston-flow age and pH for dated sites from the SUS3 network in the SANT Study Unit.

SANT LUSRC1

Samples from 14 sites in the SANT Study Unit were collected during 1996 and 1999 for CFCs (network and, in parentheses, number of sites):

LUSRC1 (14)
See table G26.

The aquifer is composed of sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites. Major dissolved-gas data were not available for 6 sites, so the median recharge temperature and median excess air estimates from the oxic sites were used at these 6 sites.

Advantages associated with these samples:

Major dissolved-gas data were available for 8 of the 14 sites.

Primarily oxic. Median field O_2 = 4.55 mg/L.

These were monitoring wells, thus subject to low pumping stress.

The wells were screened near the water table (median penetration into the water table: 3.15 feet).

Disadvantages associated with these samples:

No tracers other than CFCs.

Extensive CFC contamination, possibly associated with the urban land use in this urban LUS.

Depth to water (can affect tracer transport to water table):

Median: 11.95 feet
Mean: 16.81 feet
Minimum: 3.20 feet
Maximum: 48.90 feet

Brief analysis:

None of the sites were considered datable.

SCTX LUSRC1 (CFCs)

Samples from 30 sites in the SCTX Study Unit were collected during 1998 for CFCs (network and, in parentheses, number of sites):

LUSRC1 (30)
See table G27.

The aquifer is a karst aquifer (the Edwards aquifer).

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites.

Advantages associated with these samples:

Major dissolved-gas data were available for all 30 sites that had CFC analyses.

The wells were monitoring wells, thus subject to low pumping stress.

These sites were generally oxic (minimum field O_2 = 4.85 mg/L and no detectable CH_4 in any of the 30 samples; however, some samples were mixtures of oxic and reduced components).

Disadvantages associated with these samples:

Long saturated open intervals (median saturated open interval 70.00 feet).

Median penetration of the center of the open interval into water table was 41.17 feet (possibly more mixing at these depths).

Karst aquifers present challenges, including the potential for complex mixtures, and flow that can alternate between saturated and unsaturated conditions (such as flow from saturated conduits to partially flooded caverns and back to saturated conduits).

The mode of introduction of CFCs into Edwards aquifer water includes introduction of CFCs in stream water where streams recharge the aquifer. According to Bush and others (2000): "As the major streams flow across the faulted and fractured carbonate rocks of the Edwards aquifer outcrop (recharge zone), they lose substantial amounts of flow directly into the highly permeable aquifer." Concentrations of CFCs in stream water may be low due to upstream discharge of low-CFC ground water, or may be elevated due to contamination associated with urban or other land uses.

Depth to water (can affect tracer transport to water table):

Median: 179.59 feet
Mean: 176.53 feet
Minimum: 104.51 feet
Maximum: 255.47 feet

Brief analysis:

The age gradient for these sites is shown in figure G37. No structure is evident in this figure, probably reflecting heterogeneity of groundwater flow in this karst aquifer.

At 29 of the sites, ^3H data were available. Of these 29 sites, 21 were datable with CFCs. The reconstructed ^3H plot is shown in figure G38.

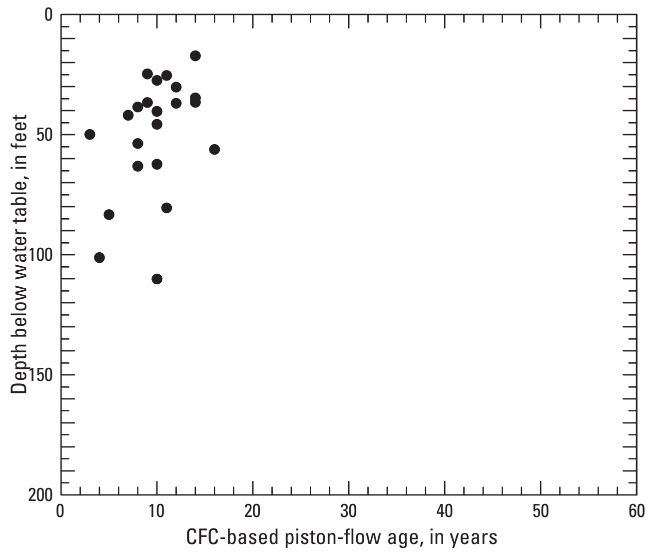

Figure G37. CFC-based age gradient for dated sites from the LUSRC1 network in the SCTX Study Unit.

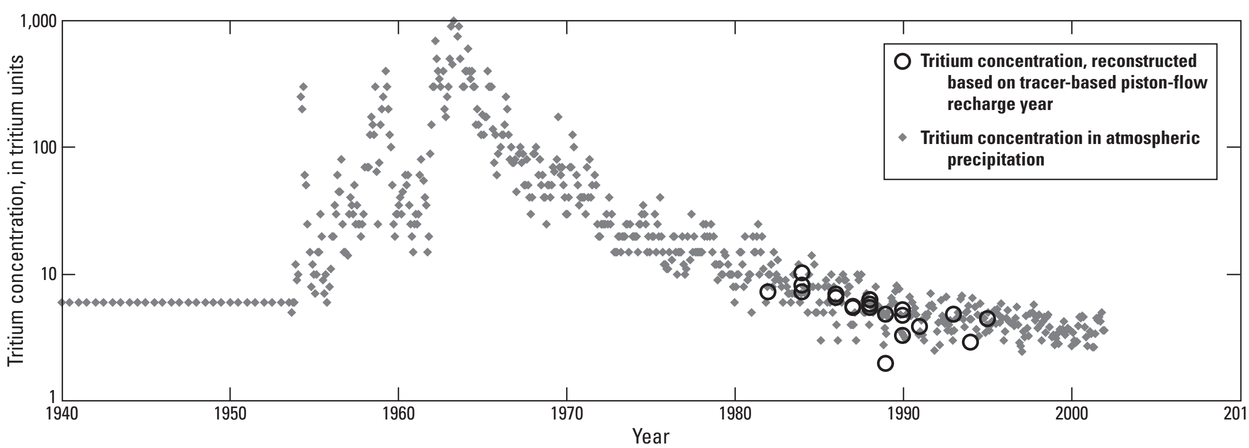

Figure G38. Reconstructed tritium concentrations (reconstruction based on CFCs) and tritium in atmospheric precipitation for the LUSRC1 network, SCTX Study Unit.

The reconstructed ^{3}H analysis could be consistent with the bulk of these samples being relatively unmixed and approximating piston-flow transport.

Five of these sites were sampled for $^{3}H/^{3}He$ in addition to CFCs. At 3 sites, sampling for $^{3}H/^{3}He$ and CFCs occurred on the same date. At 2 sites, sampling for $^{3}H/^{3}He$ and CFCs occurred on different dates. A comparison between the CFC results and the $^{3}H/^{3}He$ results is presented with the SCTX $^{3}H/^{3}He$ results (below).

For the three sites where both $^{3}H/^{3}He$ and CFC samples were collected on the same date, the tracer-based piston-flow ages derived from these two methods agree well, although at one of these sites, the $^{3}H/^{3}He$-based piston-flow age was censored (<45 years). In general, a $^{3}H/^{3}He$-based piston-flow age is considered more reliable than a CFC-based piston-flow age, and this generalization is thought to apply here with the exception of the one site with a censored $^{3}H/^{3}He$-based piston-flow age (site 293404098382001), where the CFC-based piston-flow age is more useful. For the other two sites, if one sample is to be used to characterize the sites, the $^{3}H/^{3}He$-based piston-flow age is likely to be more reliable than the CFC-based piston-flow age.

SCTX LUSRC1 and REFRE1 ($^{3}H/^{3}He$)

Samples from six sites in the SCTX Study Unit were collected during 1998, 1999, and 2000 for $^{3}H/^{3}He$ (networks and, in parentheses, number of sites):

LUSRC1 (5)
REFRE1 (1)
See table G28.

The aquifer is a karst aquifer (the Edwards aquifer).

The standard procedure for $^{3}H/^{3}He$ dating that was documented in the body of the report was used for these sites.

Advantages associated with these samples:

The wells were monitoring wells with low pumping stress.

Major dissolved-gas data available for 5 of the 6 sites.

Disadvantages associated with these samples:

Long saturated open intervals (median saturated open interval: 70.00 feet).

Median penetration of the center of the open interval into the water table was 37.76 feet (possibly more mixing at these depths).

Karst aquifers present challenges, including the potential for complex mixtures, and flow that can alternate between saturated and unsaturated conditions (such as flow from saturated conduits to partially flooded caverns and back to saturated conduits).

Brief analysis:

The age gradient for these networks is shown in figure G39. Age gradients in karst aquifers are not expected to be strong, and this age gradient is limited by the small number of data points.

The reconstructed ^{3}H plot is shown in figure G40. The ^{3}H analysis could be consistent with the bulk of these samples being relatively unmixed and approximating piston-flow transport.

Five sites were sampled for both $^{3}H/^{3}He$ and CFCs. At three sites, sampling for $^{3}H/^{3}He$ and CFCs occurred on the same date. At two sites, sampling for CFCs occurred in 1998, whereas sampling for $^{3}H/^{3}He$ occurred during 2000. The CFC data were interpreted separately (above). Three sites with multiple tracers collected on the same date (the year-1998 samples) were not evaluated for possible mixing scenarios because the number of multi-tracer samples was insufficient for such analysis. A comparison between the $^{3}H/^{3}He$-based piston-flow ages and the CFC-based piston-flow ages is shown below.

Site identifier	Local identifier	Sample date	$^{3}H/^{3}He$-based piston-flow recharge year	$^{3}H/^{3}He$-based piston-flow age	Sample date	CFC-based piston-flow recharge year	CFC-based piston-flow age
293340098344701	AY-68-28-516	12-08-98	1994	4	12-08-98	1995	3
293404098382001	AY-68-27-612	12-10-98	>1953	<45	12-10-98	1986	12
293456098280201	AY-68-29-418	12-09-98	1988	10	12-09-98	1990	8
293436098343001	AY-68-28-517	06-28-00	1983	17	12-08-98	1990	8
293643098264001	AY-68-29-216	06-29-00	1995	5	11-09-98	>1945	<53

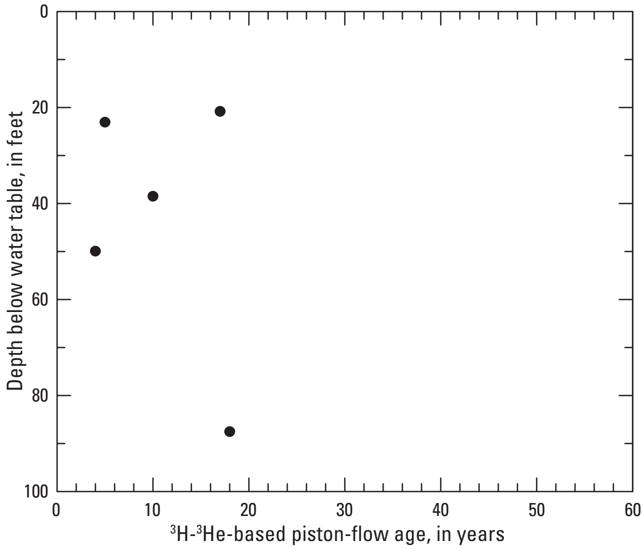

Figure G39. $^3H/^3He$-based age gradient for dated sites from the LUSRC1 and REFRE1 networks in the SCTX Study Unit.

For the 3 sites where both $^3H/^3He$ and CFC samples were collected on the same date, the tracer-based piston-flow ages derived from these two methods agree well, although at one of these sites, the $^3H/^3He$-based piston-flow age was censored (<45 years). In general, a $^3H/^3He$-based piston-flow age is considered more reliable than a CFC-based piston-flow age, and this generalization is thought to apply here with the exception of the one site with a censored $^3H/^3He$-based piston-flow age (site 293404098382001), where the CFC-based piston-flow age is more useful.

For the 2 sites where the $^3H/^3He$ and CFC samples were collected on different dates, the fact that the $^3H/^3He$ and CFC samples were collected on different dates prevents rigorous comparisons, in part because the nature of flow in karstic systems is particularly variable in time. If one sample is to be used to characterize each of these two sites, the $^3H/^3He$-based piston-flow age is likely to be more reliable.

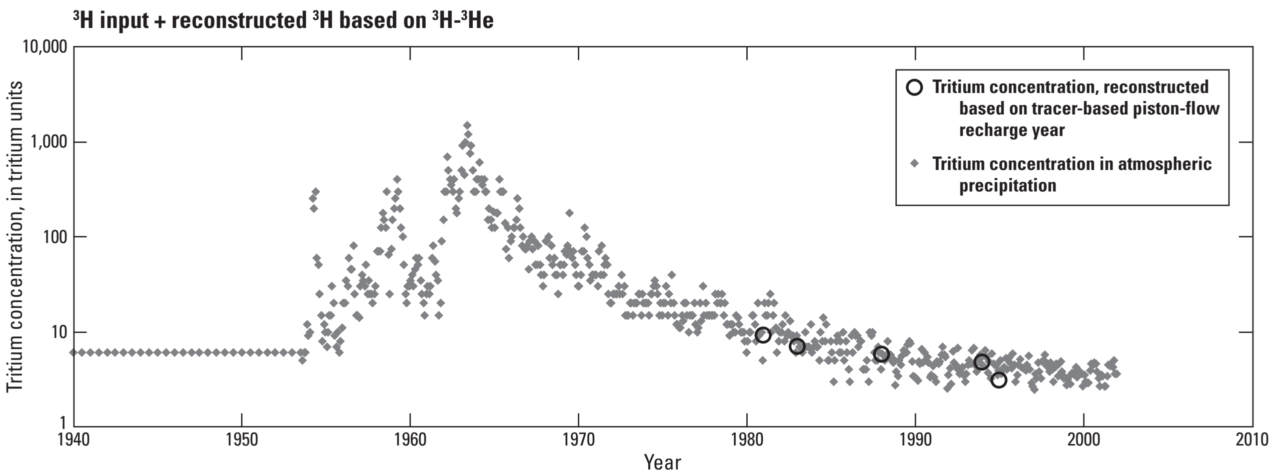

Figure G40. Reconstructed tritium concentrations (reconstruction based on $^3H/^3He$) and tritium in atmospheric precipitation for the LUSRC1 and REFRE1 networks, SCTX Study Unit.

TENN SUS1

Samples from 10 sites in the TENN Study Unit were collected during 1999 for CFCs (network and, in parentheses, number of sites):

SUS1 (10)
See table G29.

The aquifer is a karst aquifer.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at the 9 oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at 1 suboxic site using median excess air at oxic sites.

Advantages associated with these samples:

Major dissolved-gas data were available for all 10 sites.

Redox conditions were generally oxidizing: all field $O_2 \geq 2.7$ mg/L, all Mn < 4 µg/L, and all Fe <30 µg/L. Two sites did have detectable CH4, but at concentrations of 1.7 and <1.0 µg/L, which might be of little significance given the otherwise oxidizing conditions.

Disadvantages associated with these samples:

No tracers other than CFCs.

Karst aquifer (piston flow conditions unlikely)

Supply wells with long saturated open intervals (median = 28.50 feet, for the 8 sites with well construction data).

Depth to water (can affect tracer transport to water table) (9 sites had static water level data):

Median: 37.97 feet
Mean: 32.78 feet
Minimum: 1.00 feet
Maximum: 62.30 feet

Brief analysis:

The age gradient is composed of only 2 data points (3 sites were dated, but well construction data were not available for 1 of the 3 dated sites). Nevertheless, to be consistent with the approach taken with other networks, the age gradient is shown (figure G41).

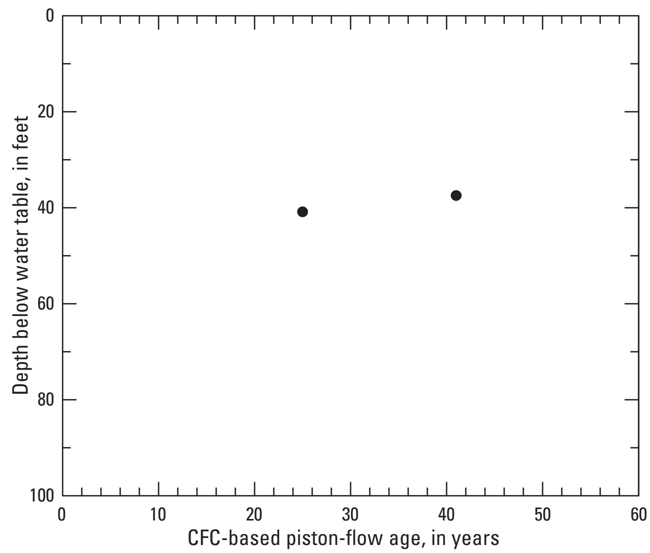

Figure G41. Age gradient for dated sites from the SUS1 network in the TENN Study Unit.

TRIN LUSRC1 and REFOT1

Samples from eight sites in the TRIN Study Unit were collected during 2003 for CFCs (networks and, in parentheses, number of sites):

LUSRC1 (7)
REFOT1 (1)
See table G30.

The aquifer is composed of sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites. At one site, 301008095302901 (MW13), low Ar concentrations (<0.47 mg/L) suggest the possibility of degassing, and the inferred recharge temperature (32.7 °C) appears unusually warm, so the median major-dissolved-gas-inferred recharge temperature and median major-dissolved-gas-inferred excess air from the oxic sites was used for this site.

Advantages associated with these samples:

Major dissolved-gas data available for all 8 sites.

Open intervals were short (saturated open intervals ≤ 10 feet).

The wells were monitoring wells, therefore associated with low pumping stress.

Disadvantages associated with these samples:

Although both CFC and SF_6 samples were collected, the SF_6 samples were at contaminant levels. Thus, only one tracer was available for age-dating purposes.

Half of the samples had field O_2 less than 0.5 mg/L.

Depth to water (can affect tracer transport to water table):

Median: 20.74 feet
Mean: 34.55 feet
Minimum: 7.26 feet
Maximum: 103.14 feet

Brief analysis:
The age gradient is composed of only 2 data points (fig. G42). Nevertheless, to be consistent with the approach taken with other networks, the age gradient is shown.

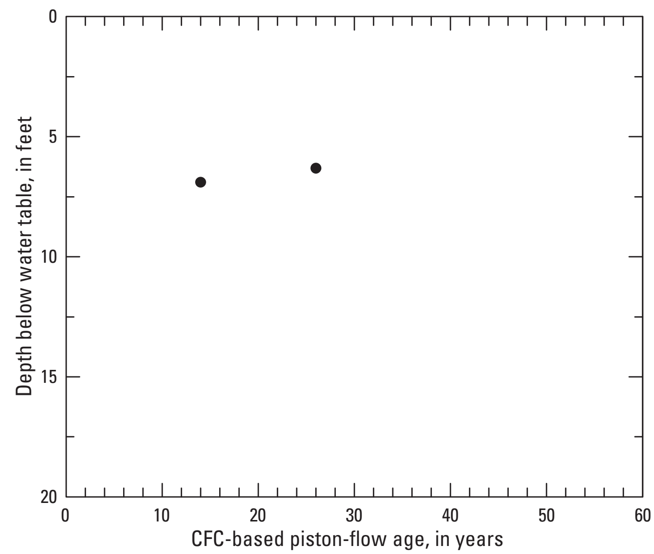

Figure G42. Age gradient for dated sites from the LUSRC1 and REFOT1 networks in the TRIN Study Unit.

UIRB LUSRC1 (3H/3He)

Samples from 13 sites in the UIRB Study Unit were collected during 2000 for $^3H/^3He$ (network and, in parentheses, number of sites):

LUSRC1 (13)
See table G31.

The aquifer is composed of glacial sediments.

The standard procedure for $^3H/^3He$ dating that was documented in the body of the report was used for these sites. A total of 15 sites were sampled, but samples from 2 sites appeared to have been mislabeled or misidentified and were not usable, leaving 13 sites with $^3H/^3He$ data. Of these 13 sites, 10 were datable (2 sites did not require a correction for terrigenic He; 8 sites did require a correction for terrigenic He). The remaining 3 sites were not datable because 2 exhibited evidence of gas fractionation and 1 was beyond the dating range.

Advantages associated with these samples:
Major dissolved-gas data were available for all sites.

- Short open intervals (all saturated open intervals were ≤5 feet).
- The wells were monitoring wells with low pumping stress.
- The wells exhibited few problems with fractionation, low ^3H samples beyond dating range, or high He concentrations that would typically escape during measurement.

Disadvantages associated with these samples:

- No notable disadvantages.

Brief analysis:
The age gradient for this network is shown in figure G43. The roughly linear age gradient provides support for the interpretations.

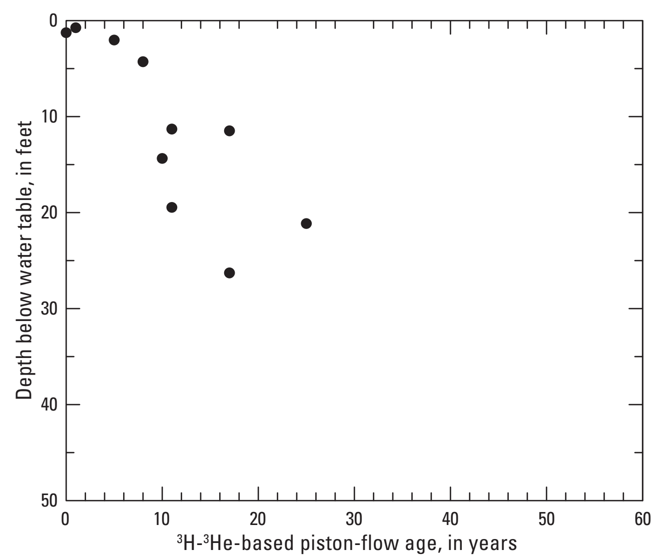

Figure G43. $^3H/^3He$-based age gradient for dated sites from the LUSRC1 network in the UIRB Study Unit.

The reconstructed ^3H plot is shown in figure G44. The ^3H analysis could be consistent with the bulk of these samples being relatively unmixed and approximating piston-flow transport. The one sample with a $^3H/^3He$-based piston-flow recharge date of 1975 is not consistent with piston flow conditions, indicating that the sample may have been affected by dispersion and (or) mixing.

These sites also were sampled for CFCs; those results are discussed separately. In general, the CFC results were less reliable than the $^3H/^3He$ results. However, two of the sites (424052088180101 and 430239088164001) that had inconclusive $^3H/^3He$ results were better represented by the CFC results.

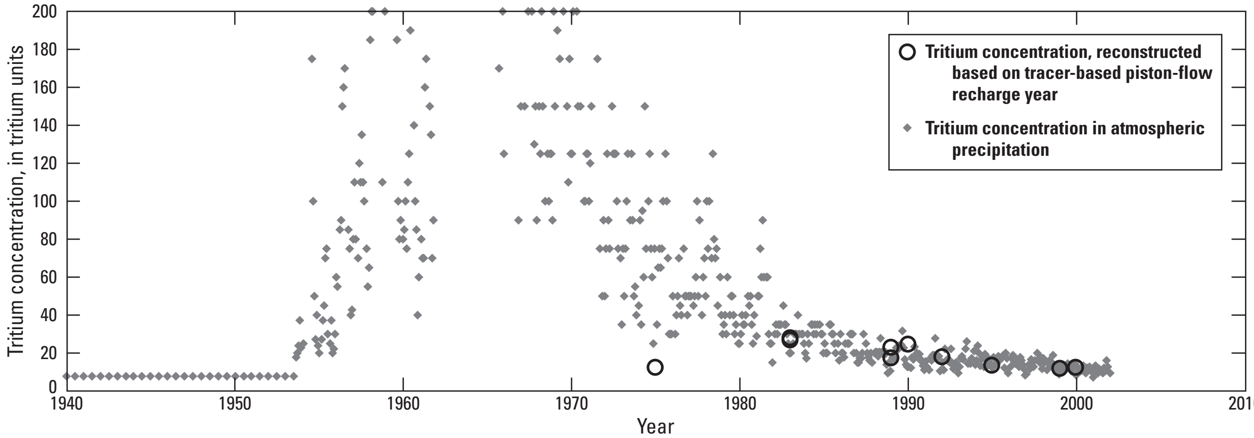

Figure G44. Reconstructed tritium concentrations (reconstruction based on $^3H/^3He$) and tritium in atmospheric precipitation for the LUSRC1 network, UIRB Study Unit.

UIRB LUSRC1 (CFCs)

Samples from 20 sites in the UIRB Study Unit were collected during 2000 for CFCs (network and, in parentheses, number of sites):

LUSRC1 (20)
See table G32.

The aquifer is composed of glacial sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using Ne data (for those sites with Ne data) or the median excess air from the oxic sites. Results from the oxic sites were used for the one site that did not have major dissolved-gas data.

The one exception to this approach was site 422314088140001 (URBLUS20). At this site, the field O_2 was 1.83 mg/L, Mn was less than 2.2 µg/L, Fe was less than 10 µg/L, and CH_4 was 0.0000 mg/L, thus this site would usually be considered oxic. However, if the site is treated as oxic (no denitrification), the major-dissolved-gas-inferred recharge temperature is 21.5 °C and excess air is 9.8 cc(STP)/Kg. The other oxic sites in this network have median major-dissolved-gas-inferred recharge temperatures of 10.2 °C and median excess air of 2.1 cc(STP)/Kg. The difference (11.3°C) in inferred recharge temperatures between URBLUS20 and the other oxic sites, and the large inferred excess air (9.8 cc(STP)/Kg) at URBLUS20, suggest that URBLUS20 may need different treatment. Although this sample meets the conditions for classification as oxic, the field O_2 is sufficiently low that the sample could have consisted oxic ground water with a large component of suboxic ground water. If denitrification is allowed, the major-dissolved-gas-inferred recharge temperature = 9.4 °C, similar to the 10.2 °C from the oxic sites. The more reasonable value of inferred recharge temperature lead to the decision to treat URBLUS20 as suboxic.

Advantages associated with these samples:

Major dissolved-gas data were available for 19 of the 20 sites.

Short open intervals (saturated open interval ≤5 feet).

Monitoring wells, therefore low pumping stress.

Median penetration below water table: 11.41 feet, sampling near water table and thus minimizing mixing.

Disadvantages associated with these samples:

Although most sites were oxic, O_2 was not abundant (median field O_2 = 2.4 mg/L, of 17 sites with field-measured O_2), and 5 sites (out of 20) had Fe concentrations greater than 1 mg/L. CH_4 was commonly detected (8 detections, between 0.0007 and 0.3252 mg/L, with median of the 8 = 0.0130 mg/L).

Depth to water (can affect tracer transport to water table):

Median: 12.64 feet
Mean: 17.13 feet
Minimum: 0.00 feet
Maximum: 47.58 feet

Brief analysis:
The age gradient is composed of only 4 data points (fig. G45). Nevertheless, to be consistent with the approach taken with other networks, the age gradient is shown.

Samples were analyzed for ^3H at 13 sites. Of these 13 sites, 1 was considered datable with CFCs. The reconstructed ^3H plot is shown in figure G46. This one sample could be consistent with the ^3H data.

Thirteen of these sites also were sampled for $^3H/^3He$; those results are discussed separately. In general, the $^3H/^3He$ results were more reliable than the CFC results. However, two of the sites (424052088180101 and 430239088164001) had inconclusive $^3H/^3He$ results and the CFC results were selected to represent these two sites.

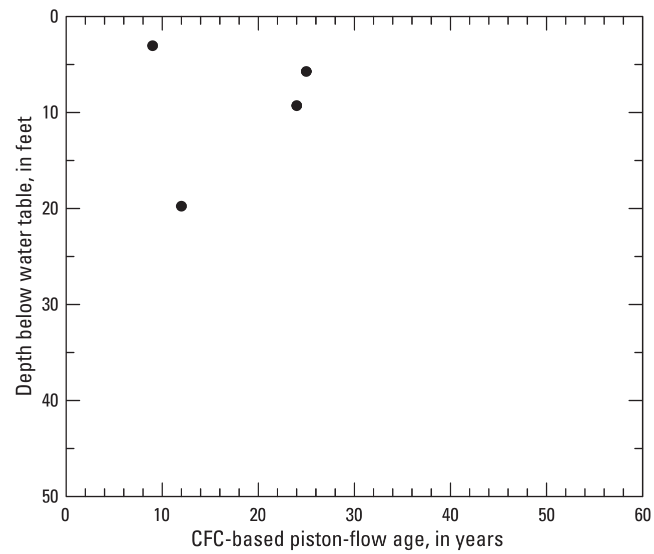

Figure G45. CFC-based age gradient for dated sites from the LUSRC1 network in the UIRB Study Unit.

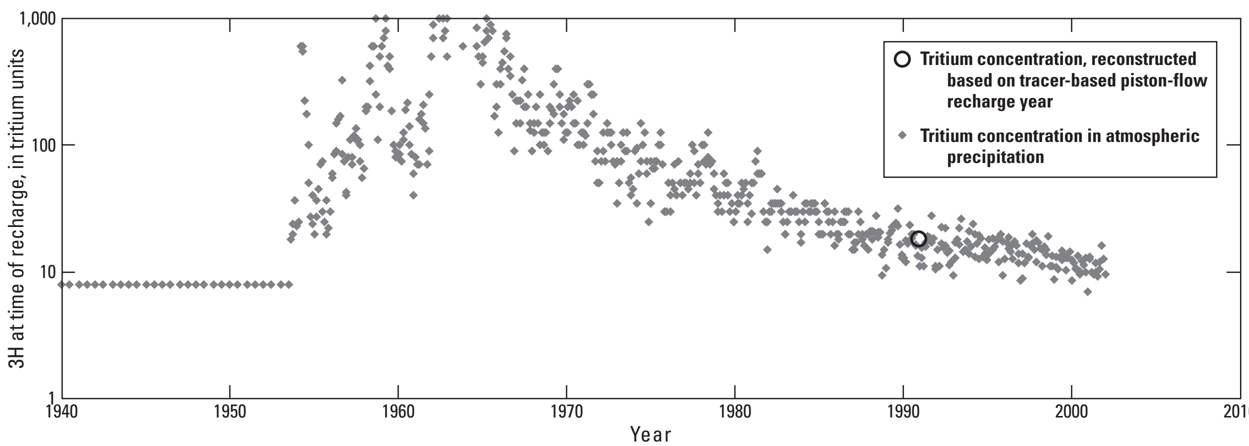

Figure G46. Reconstructed tritium concentrations (reconstruction based on CFCs) and tritium in atmospheric precipitation for the LUSRC1 network, UIRB Study Unit.

UIRB SUS1

Samples from 27 sites in the UIRB Study Unit were collected during 2001 for CFCs (network and, in parentheses, number of sites):

SUS1 (27)
See table G33.

The aquifer is composed of glacial sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites. One site did not have major dissolved-gas data, so the median recharge temperature and median excess air estimates from the oxic sites were used.

Advantages associated with these samples:

Major dissolved-gas data were available for 26 of the 27 sites.

Disadvantages associated with these samples:

No tracers other than CFCs.

Extensive occurrence of strongly reducing conditions. For example, of the 26 sites with major dissolved-gas data, 19 contained ≥1 µg/L of methane.

There appears to be CFC contamination in many samples.

Depth to water (can affect tracer transport to water table):
Median: 29.04 feet
Mean: 22.00 feet
Minimum: 0.00 feet
Maximum: 81.00 feet

Brief analysis:
The age gradient is composed of only 2 data points (fig. G47). Nevertheless, to be consistent with the approach taken with other networks, the age gradient is shown, below.

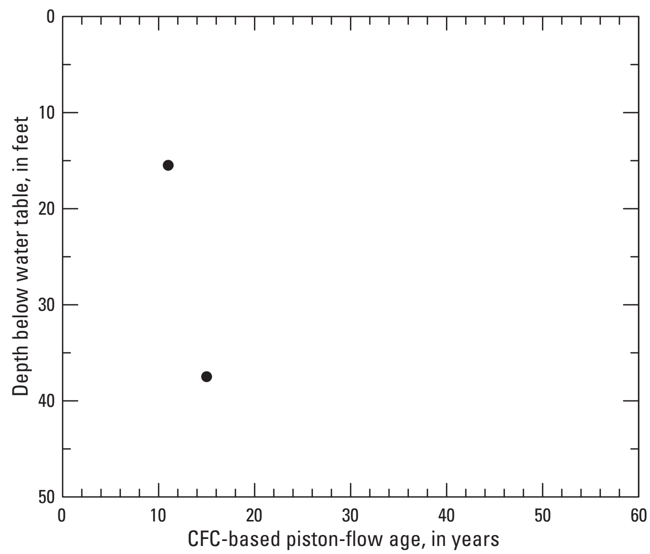

Figure G47. Age gradient for dated sites from the SUS1 network in the UIRB Study Unit.

UIRB SUS2

Samples from 23 sites in the UIRB Study Unit were collected during 2000 for CFCs (network and, in parentheses, number of sites):

SUS2 (23)
See table G34.

The aquifer is composed of glacial sediments.

The major dissolved-gas data were affected at most sites by denitrification, and at one site by degassing. Using standard procedures, the median excess air from the 4 oxic sites was used as a constraint for the suboxic sites. (Four sites is a small number of sites, but the major-dissolved-gas-inferred excess air concentrations exhibited little variation.) With excess air constrained, the major dissolved-gas data were used to calculate recharge temperature for the suboxic sites. However, due to the highly variable recharge temperatures, major-dissolved-gas-inferred recharge temperatures were not relied upon for the CFC age-dating in this network, and the mean annual air temperature + 1 °C was used as a proxy for recharge temperatures.

Advantages associated with these samples:

Thin open intervals; all saturated open intervals, except for one, were ≤5.00 feet.

Disadvantages associated with these samples:

No tracers other than CFCs.

Redox conditions were generally reducing. For example, the median field O_2 concentration was 0.33 mg/L, and CH4 was detected at 20 of the 23 sites.

CFC degradation as well as CFC contamination present.

Depth to water (can affect tracer transport to water table):
Median: 10.00 feet
Mean: 11.52 feet
Minimum: 5.00 feet
Maximum: 40.00 feet

Brief analysis:
Only 1 site from this network was considered datable. As such, no age gradient is shown for this network.

UIRB LUSCR1

Samples from 25 sites in the UIRB Study Unit were collected during 1999 for CFCs (network and, in parentheses, number of sites):

LUSCR1 (25)
See table G35.

The aquifer is composed of glacial sediments.

Major dissolved-gas data were available for 19 of the 25 sites. The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites. At one of the sites that had major dissolved-gas data (411329087121201), the major dissolved gases had been partially lost and the major dissolved-gas data were not used; for this site, as well as the 6 sites without major dissolved-gas data, the median recharge temperature and median excess air from oxic sites were used.

Advantages associated with these samples:

Major dissolved-gas data available for 19 of the 25 sites.

Monitoring wells, so generally low pumping stress and short well screens.

Disadvantages associated with these samples:

No tracers other than CFCs.

Many sites yielded reducing groundwater. Median field O_2 = 0.85 mg/L. Median CH_4=0.0007 mg/L (n=18; major dissolved-gas data from 1 of the 19 sites had been degassed and was not included in this calculation).

Depth to water (can affect tracer transport to water table):

Median: 5.83 feet

Mean: 7.15 feet
Minimum: 2.43 feet
Maximum: 14.35 feet

Brief analysis:
The age gradient for these sites is shown in figure G48. The small number of datable samples and the narrow range of depths represented by these wells restrict analysis of the age gradient. However, the overall pattern of relatively young groundwater from sampling points near the water table in recharge areas is consistent with the network design.

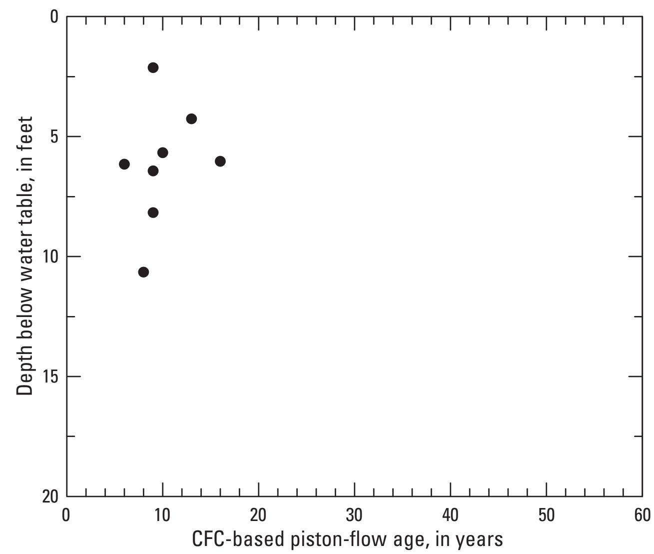

Figure G48. Age gradient for dated sites from the LUSCR1 network in the UIRB Study Unit.

WHMI LUSCR1 LUSCR1a LUSCR3a and SUS1

Samples from 69 sites in the WHMI Study Unit were collected during 1999 and 2000 for $^3H/^3He$ (networks and, in parentheses, number of sites):

LUSCR1 (26)
LUSCR1a (8)
LUSCR3a (5)
SUS1 (30)
See table G36.

The aquifer is composed of glacial sediments.

The standard procedure for $^3H/^3He$ dating that was documented in the body of the report was used for these sites. Of the 69 sites, 52 were considered datable (23 sites did not require a correction for terrigenic He; 29 sites did require a correction for terrigenic He). Of the remaining 17 sites, 10 exhibited evidence of gas fractionation, 3 were beyond the dating range, and at 4 sites the samples were lost during analysis.

Advantages associated with these samples:

The 39 LUS sites are monitoring wells with short open intervals (saturated open intervals all ≤5.00 feet). The 30 SUS sites are supply wells with relatively short saturated open intervals (median 3.00 feet and maximum 11.00 feet).

There were few problems with fractionation, low ^3H concentrations, or high He concentrations.

Disadvantages associated with these samples:

The only substantial limitations specific to these sites are discussed below.

Brief analysis:

The age gradient for these sites is shown in figure G49.

The age gradient for these networks, although weak, does indicate increasing $^3H/^3He$-based piston-flow age with increasing depth below the water table. There is a general pattern, too, in which the LUS wells tend to be shallower and younger, and the MAS wells tend to be deeper and older, consistent with the NAWQA design for LUS and MAS networks. Although tracers are subject to uncertainties, the scatter in the age gradient plot may be dominated by the actual geologic heterogeneity inherent in glacial sediments.

The deepest MAS well, with a $^3H/^3He$-based piston-flow age of 0 years, was the only well in these networks that was not a domestic well; it was a county park well (Donna Runkle, written commun., June 8, 2009). There is a “large reservoir tank” before the sampling point (Donna Runkle, written commun., June 8, 2009); this might have affected the samples. Additionally, the well construction data in the DWH may be incorrect (Mary Ann Thomas, written commun., June 10, 2009). This sample is suspect.

The reconstructed ^3H plot is shown in figure G50. Most samples with $^3H/^3He$-based piston-flow recharge dates in the period from about the mid-1970s to the present are consistent with the ^3H input function for this area. The sample with the $^3H/^3He$-based piston-flow date in the 1940s and a reconstructed $^3H + ^3He$ value of about 10 TU is consistent with pre-bomb ^3H inputs in precipitation for this location (but the flat pre-bomb input function does not provide discrimination of age, just identification as being composed primarily of pre-bomb water). The four samples with $^3H/^3He$-based piston-flow dates in the 1960s and early 1970s plot below the ^3H input function, indicating that mixing and dispersion are operating on at least these samples.

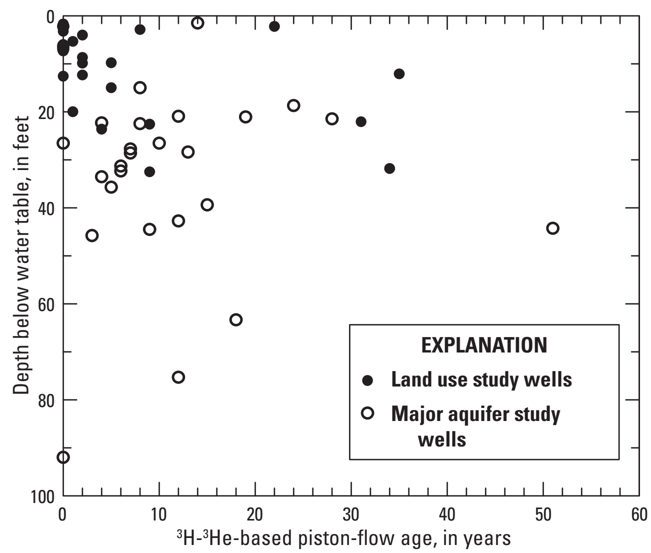

Figure G49. Age gradient for dated sites from the LUSCR1, LUSCR1a, LUSCR3a and SUS1 networks in the WHMI Study Unit.

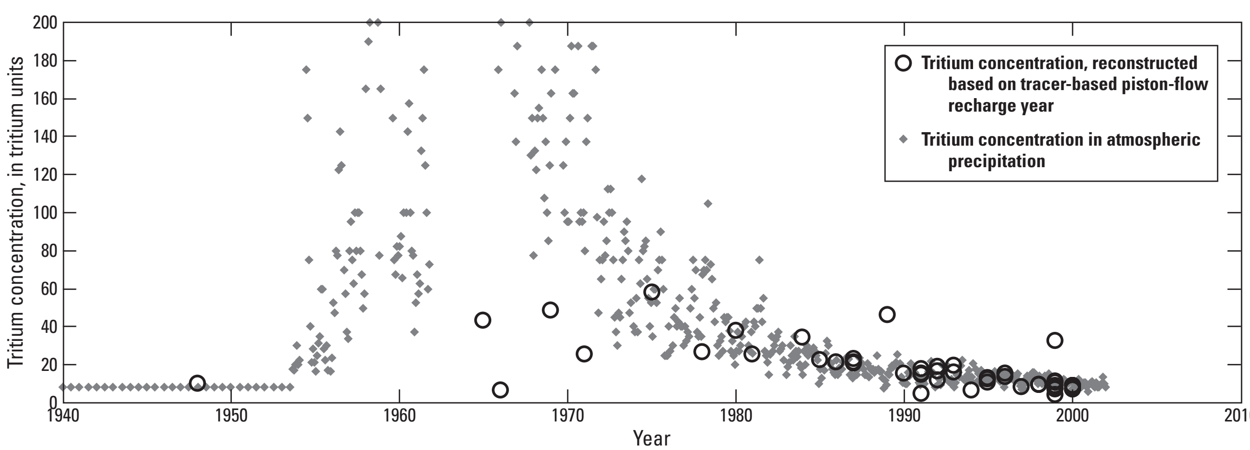

Figure G50. Reconstructed tritium concentrations and tritium in atmospheric precipitation for the LUSCR1, LUSCR1a, LUSCR3a and SUS1 networks, WHMI Study Unit.

WHMI LUSRC1 and REFOT1

Samples from 27 sites in the WHMI Study Unit were collected during 2001 for SF_6 (networks and, in parentheses, number of sites):

LUSRC1 (25)
REFOT1 (2)
See table G37.

The aquifer is composed of glacial sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table. For sites with major dissolved-gas data, the procedure was to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at the 1 suboxic site using median excess air from the 9 oxic sites. For sites without major dissolved-gas data, the median recharge temperature and median excess air estimates from the oxic sites were used.

SF_6 data were collected at 392008084335501 and 392008084343801 on two occasions, in July of 2001 and again in November of 2001. The November SF_6 data were compiled here because they were similar to the July SF_6 data yet had the advantage of being accompanied by a full suite of chemistry and water-level data.

Advantages associated with these samples:

- Major dissolved-gas data available for 10 of the 27 sites.
- Saturated open intervals were short: all were ≤5.00 feet.
- These were monitoring wells, therefore low pumping stress.
- These wells were installed close to the water table; median depth of center of open interval below water table: 10.99 feet.

Disadvantages associated with these samples:

- Extensive SF_6 contamination.

Depth to water (can affect tracer transport to water table):

- Median: 20.07 feet
- Mean: 22.46 feet
- Minimum: 2.87 feet
- Maximum: 42.99 feet

Brief analysis:

Of the 27 sites, 23 were contaminated and only 4 were datable. Given the extensive SF_6 contamination, it is possible that the 4 samples that were in the range of the SF_6 dating method also contained some SF_6 that was not from background atmospheric sources (that is, was from natural sources in sediments or was from atmospheric sources at above-background concentrations), and the tracer-based piston-flow ages may represent minimum ages.

The age gradient for these sites is shown in figure G51. There are few data in this figure for analysis. The essentially vertical age gradient could be consistent with these samples having been affected by natural SF_6 from aquifer sediments.

The reconstructed ^3H plot is shown in figure G52 for the 4 datable samples.

Three of the 4 samples plot within the ^3H input function. However, this analysis does not exclude the distinct possibility that these 4 samples might have been affected by SF_6 contamination. Earlier recharge would yield greater ^3H concentrations that also could plot within the ^3H input function.

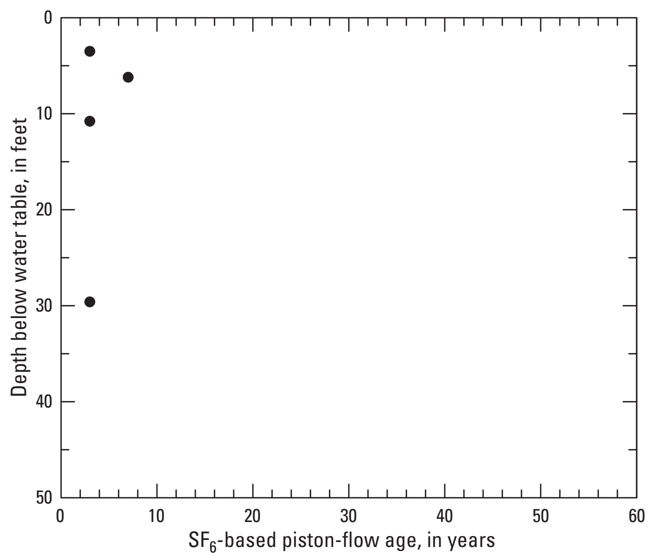

Figure G51 Age gradient for dated sites from the LUSRC1 and REFOT1 networks in the WHMI Study Unit.

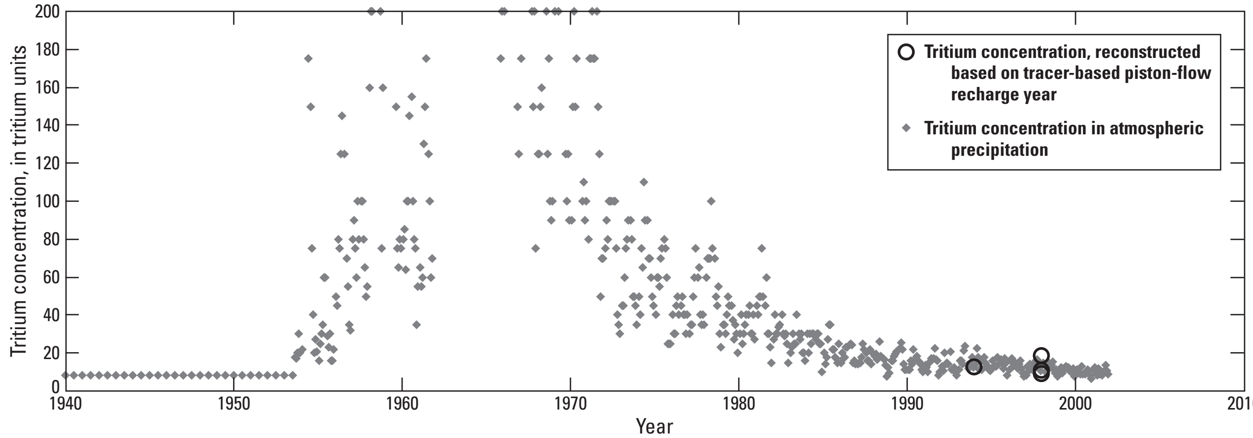

Figure G52. Reconstructed tritium concentrations and tritium in atmospheric precipitation for the LUSRC1 and REFOT1 networks, WHMI Study Unit.

WHMI LUSCR1 and REFOT1

Samples from 6 sites in the WHMI Study Unit were collected during 2007 for SF_6 (networks and, in parentheses, number of sites):

LUSCR1 (5)
REFOT1 (1)
See table G38.

The aquifer is composed of glacial sediments.

Only 1 of the 6 sites was oxic, and that one site had negative excess air (that is, the major dissolved-gas samples exhibited evidence of degassing), so the standard approach of using major dissolved-gas data from oxic sites to estimate typical excess air for the networks could not be used. For the one site with negative excess air, the procedure was to assume that recharge elevation was equal to the elevation of the water table, that recharge temperature was equal to the mean annual air temperature + 1 °C, and that the excess air concentration was 2 cc(STP)/Kg. For the other 5 sites, the procedure was to assume that recharge elevation was equal to the elevation of the water table, and to use 2 cc(STP)/Kg along with major dissolved-gas data to infer recharge temperatures.

Advantages associated with these samples:

Major dissolved-gas data were available for all 6 sites.

Short open intervals: median saturated open interval 5.00 feet.

Median penetration of center of the open interval into the water table was 13.72 feet (sampling close to the water table, potentially minimizing mixing).

These were monitoring wells, thus generally subject to low pumping stress.

Disadvantages associated with these samples:

No tracers other than SF_6.

Depth to water (can affect tracer transport to water table):

Median: 10.04 feet
Mean: 12.59 feet
Minimum: 8.09 feet
Maximum: 26.38 feet

Brief analysis:
The age gradient for these sites is shown in figure G53. The age gradient is composed of only 3 points, but they do suggest the presence of an approximately linear age gradient in the shallow portion of this aquifer.

WILL LUSAG3 and REFFO1

Samples from 18 sites in the WILL Study Unit were collected during 2002 for CFCs (networks and, in parentheses, number of sites):

LUSAG3 (16)
REFFO1 (2)
See table G39.

The aquifer is composed of sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites.

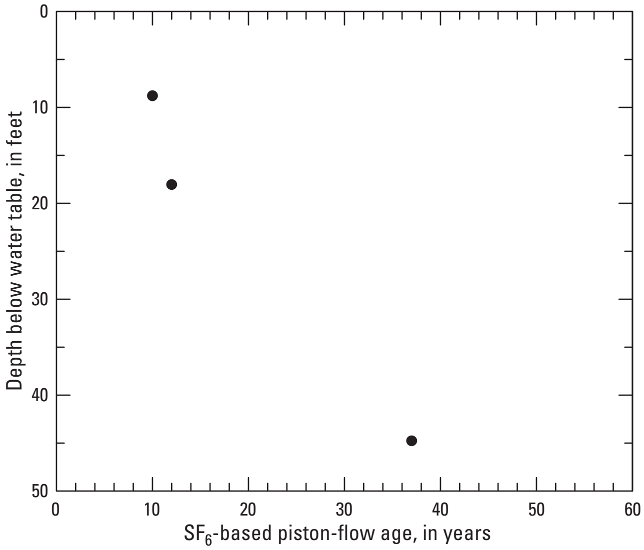

Figure G53. Age gradient for dated sites from the LUSCR1 and REFOT1 networks in the WHMI Study Unit.

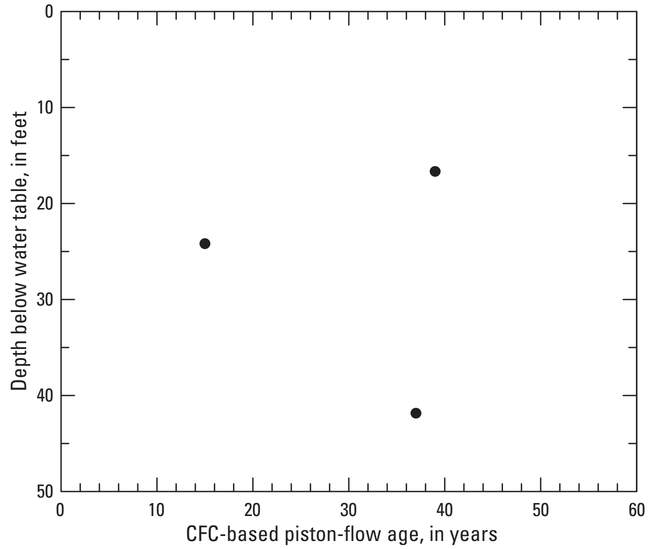

Figure G54. Age gradient for dated sites from the LUSAG3 and REFFO1 networks in the WILL Study Unit.

Advantages associated with these samples:

Major dissolved-gas data were available for all 18 sites.

Although these were supply wells, the open intervals were moderately short (median saturated open interval = 10 feet).

Disadvantages associated with these samples:

No tracers other than CFCs.

Reducing conditions were common. The median field O_2 was 0.3 mg/L, and CH_4 was commonly detected (8 detections, between 0.0010 and 0.1458 mg/L, with median of the 8 = 0.0114 mg/L).

Depth to water (can affect tracer transport to water table):
Median: 16.05 feet
Mean: 20.47 feet
Minimum: 3.30 feet
Maximum: 60.33 feet

Brief analysis:
The age gradient is composed of only 3 data points (fig. G54). Nevertheless, to be consistent with the approach taken with other networks, the age gradient is shown.

YELL LUSOT1

Samples from 28 sites in the YELL Study Unit were collected during 2001 for CFCs (network and, in parentheses, number of sites):

LUSOT1 (28) (low-density residential land use)
See table G40.

The aquifer is composed of sediments.

The procedure was to assume that recharge elevation was equal to the elevation of the water table, to estimate recharge temperature and excess air at oxic sites based upon major dissolved-gas data, and to constrain recharge temperature and excess air at suboxic sites using median excess air at oxic sites. (At one site in this network, major dissolved-gas data were available but tracer data were not available; interpretation of the major dissolved-gas data for this site was included in this appendix.)

Advantages associated with these samples:

Major dissolved-gas data were available for all sites that had CFC analyses.

These monitoring wells had short saturated open intervals (all saturated open intervals ≤ 10 feet).

The median penetration of the center of the open interval into the water table was 4.66 feet (for the 28 wells sampled for CFCs) (sampling close to the water table, potentially minimizing mixing).

Monitoring wells, therefore low pumping stress.

Mostly oxic (median field O_2 = 3.0 mg/L, for the 28 wells sampled for CFCs); only one sample contained detectable CH_4 (at 0.0011 mg/L).

Disadvantages associated with these samples:

Four of the datable sites also had ^3H data, but multiple tracers were otherwise lacking.

Depth to water (can affect tracer transport to water table) (calculated for the 28 sites with CFC data):
Median: 6.48 feet
Mean: 12.42 feet
Minimum: 0.93 feet
Maximum: 48.20 feet

Brief analysis:
The age gradient for this network (fig. G55) shows little structure, in part because these wells represent only the uppermost 9 feet of the aquifer. However, the overall pattern of relatively young groundwater from sampling points near the water table in recharge areas is consistent with the network design.

Four of the datable sites had ^3H data. The reconstructed ^3H plot is shown in figure G56. The ^3H data could be consistent with these four samples being relatively unmixed and approximating piston-flow transport.

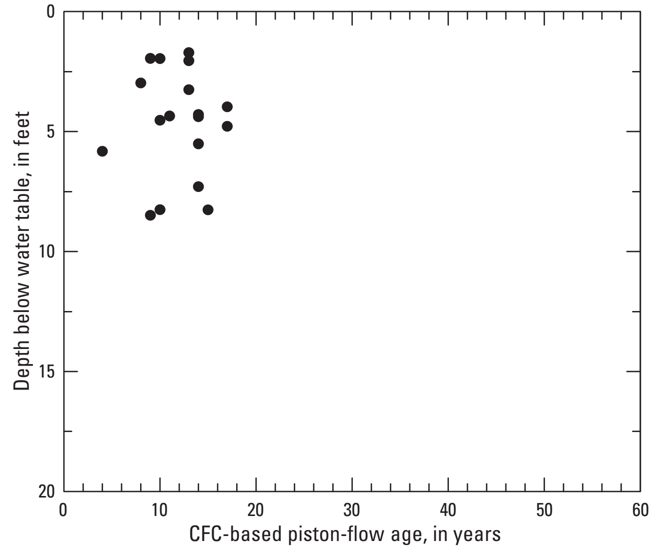

Figure G55. Age gradient for dated sites from the LUSOT1 network in the YELL Study Unit.

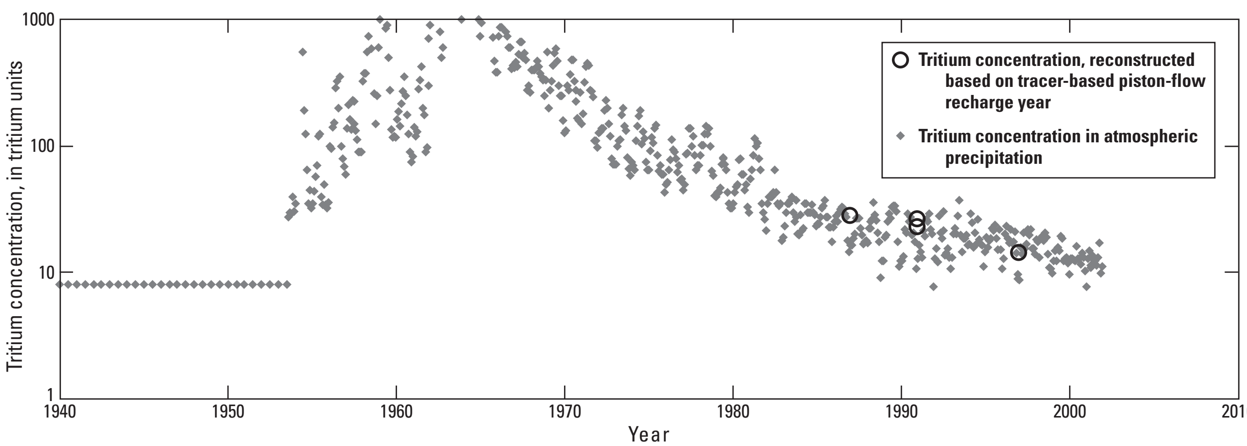

Figure G56. Reconstructed tritium concentrations and tritium in atmospheric precipitation for the LUSOT1 network, YELL Study Unit.

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Description of Data Files in Appendix G

These data files are organized by Study Unit (see figure 1 in the body of the report, and table A1 in appendix A) and Network (see table A1 in appendix A).

Each file contains a “Summary” table that includes USGS site identification numbers, dates of sample collection, tracer-based piston-flow ages and tracer-based piston-flow recharge dates, selected environmental tracer data, and ancillary data such as well-construction data and basic geochemical data. The sources of these data and interpretations were described in the body of the report.

Each file also contains a “Raw Tracer Data” table. This table contains detailed information on environmental tracer concentrations. The sources of these data were described in the body of the report.

For Networks where major dissolved-gas data were collected, a “Major Dissolved Gases” table is included. This table contains detailed information on major dissolved-gas concentrations. The source of these data was described in the body of the report.

Appendix G tables can be accessed and downloaded at URL http://pubs.usgs.gov/sir/2010/5229/data/sir20105229_apps.zip.