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Tritium Concentrations in Environmental Samples and Transpiration Rates from the Vicinity of Mary's Branch Creek and Background Areas, Barnwell, South Carolina, 2007–2009

Scientific Investigations Report 2009–5245

U.S. Department of the Interior
U.S. Geological Survey

Cover. **Mary's Branch Creek near tree T16 looking southwest, Barnwell, South Carolina, June 29, 2009** *(photograph by Don A. Vroblesky, U.S. Geological Survey).*

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (mt^2)
square foot (ft^2)	0.09290	square meter (mt^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Pressure	
kilopascal (kPa)	20.88	pound per square foot (lb/ft^2)
	Density	
kilogram per cubic meter (kg/m^3)	0.06242	pound per cubic foot (lb/ft^3)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Abbreviations used in this report

AH	absolute humidity
AVP	absolute vapor pressure
BLS	below land surface
C_A	concentration of tritium in air
C_W	concentration of tritium in water
DPM	disintegrations per minute
DPM/tree	disintegrations per minute per tree core
pCi/L	picocuries per liter
RH	relative humidity
SVP	saturation vapor pressure
USGS	U.S. Geological Survey

Tritium Concentrations in Environmental Samples and Transpiration Rates from the Vicinity of Mary's Branch Creek and Background Areas, Barnwell, South Carolina, 2007–2009

By Don A. Vroblesky[1], Judy L. Canova[2], Paul M. Bradley[1], and James E. Landmeyer[1]

Abstract

Tritium in groundwater from a low-level radioactive waste disposal facility near Barnwell, South Carolina, is discharging to Mary's Branch Creek. The U.S. Geological Survey conducted an investigation from 2007 to 2009 to examine the tritium concentration in trees and air samples near the creek and in background areas, in groundwater near the creek, and in surface water from the creek. Tritium was found in trees near the creek, but not in trees from background areas or from sites unlikely to be in direct root contact with tritium-contaminated groundwater. Tritium was found in groundwater near the creek and in the surface water of the creek. Analysis of tree material has the potential to be a useful tool in locating shallow tritium-contaminated groundwater. A tritium concentration of 1.4 million picocuries per liter was measured in shallow groundwater collected near a tulip poplar located in an area of tritium-contaminated groundwater discharge. Evapotranspiration rates from the tree and tritium concentrations in water extracted from tree cores indicate that during the summer, this tulip poplar may remove more than 17.1 million picocuries of tritium per day from the groundwater that otherwise would discharge to Mary's Branch Creek. Analysis of air samples near the tree showed no evidence that the transpirative release of tritium to the air created a vapor hazard in the forest.

Introduction

The Barnwell Disposal Facility is near Barnwell, South Carolina, and has been accepting low-level radioactive waste for burial since 1971. The facility is about 5 miles west of Barnwell, South Carolina, and includes approximately 235 acres (fig. 1). Tritium contamination from the facility is present in groundwater in a plume that extends from the facility southwestward to Mary's Branch Creek (fig. 1; Energy Solutions, 2007). Overland flow and most precipitation that enters the groundwater system at the disposal facility drains to Mary's Branch Creek, approximately 3,000 feet (ft) south of the disposal facility (Cahill, 1982). Mary's Branch Creek is predominantly a groundwater-supplied water body, originating as seeps, some of which are in the discharge area for groundwater affected by the Barnwell Disposal Facility. The presence of tritium in surface water at Mary's Branch Creek in the area of investigation (175,000 to 515,000 picocuries per liter [pCi/L]) and in groundwater beneath and near the creek (1,100,000 pCi/L) indicates that tritium-contaminated groundwater discharges to Mary's Branch Creek (Energy Solutions, 2007). The area of probable tritium-contaminated groundwater discharge to Mary's Branch Creek is the study area for this investigation (figs. 1 and 2).

The area around Mary's Branch Creek is a forest (fig. 3), consisting primarily of tulip poplar (*Liriodendron tulipifera*), oak (*Quercus* sp.), sweet gum (*Liquidambar* sp.), and holly (*Ilex* sp.). Less common species include loblolly pine (*Pinus taeda*) and sweet bay (*Laurus nobilis*). Utilization of soil water by the trees and evaporation reduces the amount of groundwater discharging to the creek. The reduction of groundwater discharge by trees and evaporation is confirmed by the observation that although the highest rainfall occurs during the summer months, the highest streamflow occurs during the winter months (Cahill, 1982). Mary's Branch Creek discharges into Lower Three Runs about 2.5 miles downstream from the disposal facility (fig. 1).

The U.S. Geological Survey (USGS) initiated an investigation in 2007 to evaluate the potential for tritium uptake by riparian trees in the vicinity of Mary's Branch Creek, thereby decreasing the amount of tritium discharging to the creek. Groundwater, surface water, water extracted from tree cores, whole tree cores, and water condensed from air were analyzed for tritium concentration. The purpose of this report is to present and discuss tritium data from these environmental samples and transpiration data from trees near Mary's Branch Creek, Barnwell, South Carolina.

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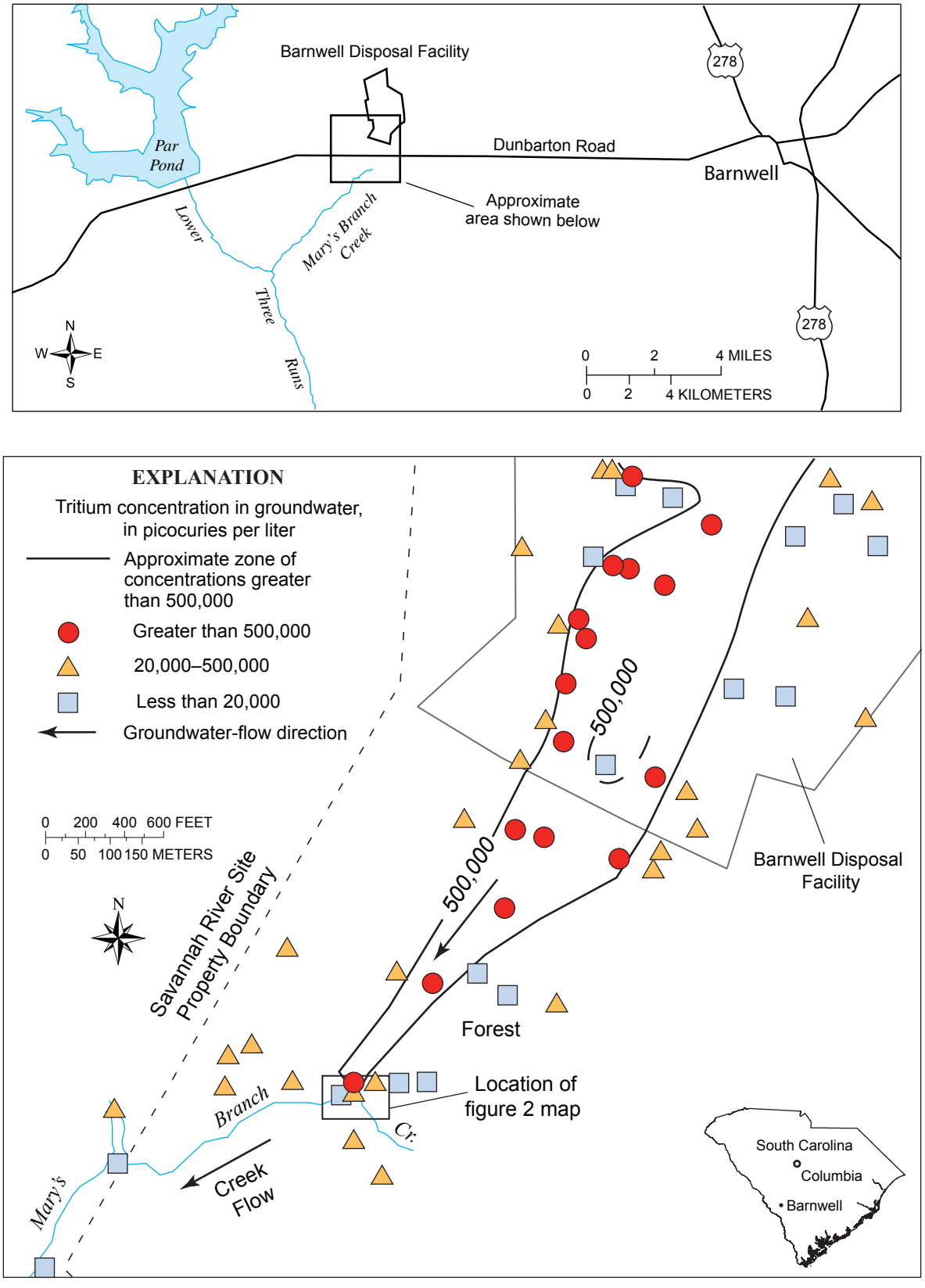

Figure 1. Location of Barnwell Disposal Facility and concentrations of tritium in groundwater (modified from Energy Solutions, 2007), Barnwell, South Carolina.

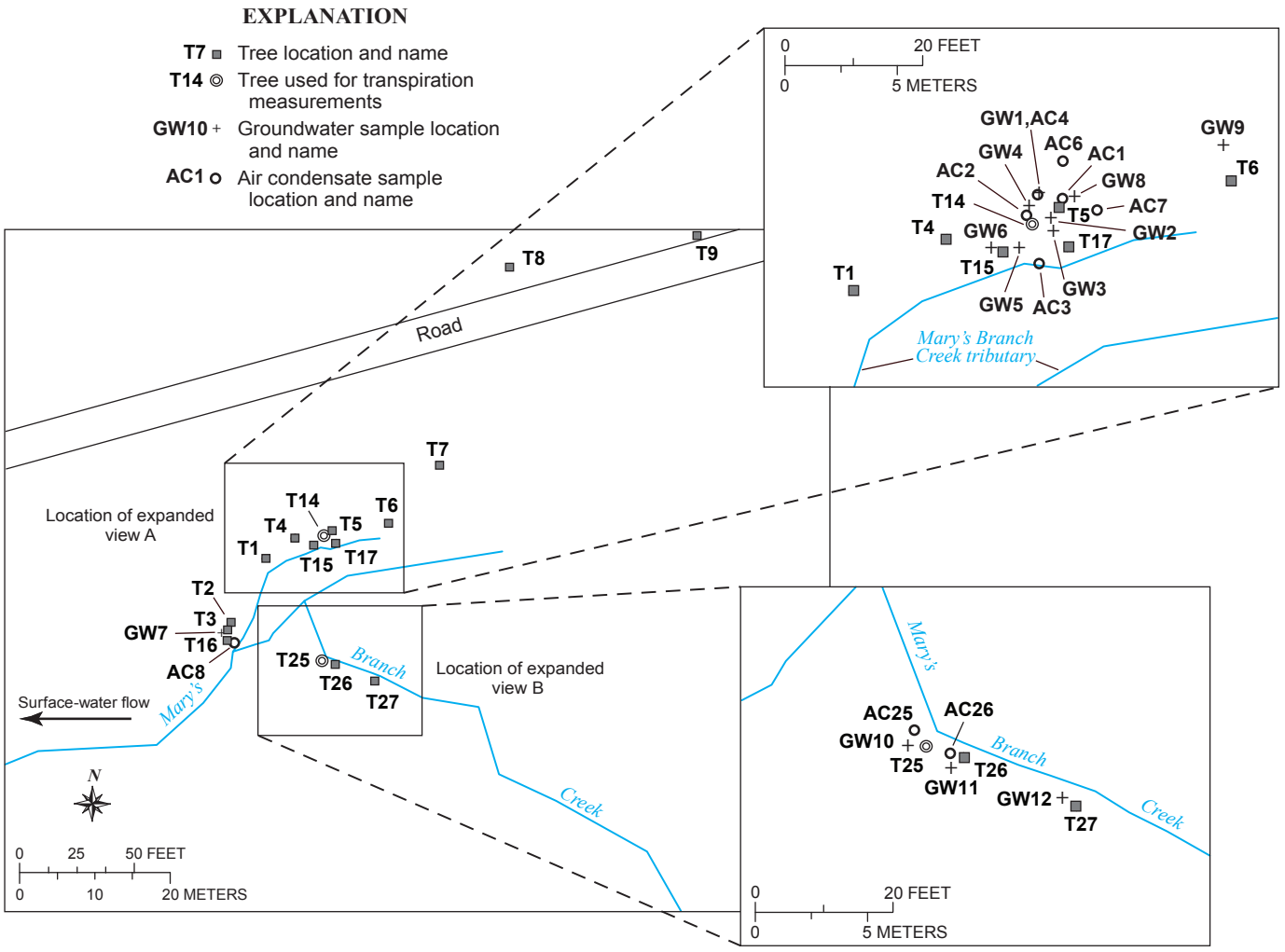

Figure 2. Sampling locations near Mary's Branch Creek, Barnwell, South Carolina, 2007–2009.

Figure 3. Mary's Branch Creek showing tree T27 (tied with pink ribbon), looking northwest, Barnwell, South Carolina, June 29, 2009.

Methods

During this investigation, tritium concentrations were obtained from a variety of environmental samples. The samples included shallow groundwater, surface water, water extracted from tree cores, whole tree cores, and water condensed from air.

For this investigation, 27 trees of varying species were examined for tritium concentration (table 1). Water was extracted and analyzed for tritium content from 47 tree cores, representing 16 total trees, 9 of which were adjacent to Mary's Branch Creek. Forty-two whole tree cores were analyzed for tritium, representing 19 trees, 13 of which were near Mary's Branch Creek. Eighteen samples of groundwater and 24 samples of water condensed from air were analyzed for tritium. Transpiration data were collected from tree T14 in 2008 and from tree T25 in 2009 (fig. 2).

Background sample locations are beyond the area shown in figure 2. Background trees T10–T13 were located within the Mary's Branch Creek drainage basin, but several hundred feet on the opposite side of Mary's Branch Creek from the disposal facility. Background trees T18 and T19 were located about 1,000 ft upstream from the area of known tritium-contaminated groundwater discharge to Mary's Branch Creek. Background trees T29, T32, and T33 were located within the city limis of Barnwell, several miles from the disposal facility. Background trees T30–T31 were located within the city limits of Columbia, South Carolina, approximately 70 miles northeast of the disposal facility.

Table 1. Trees sampled near Mary's Branch Creek and in background areas, Barnwell, South Carolina, 2007–2009.

[*, background tree not shown in figure 2; >, greater than]

Tree name (see figure 2 for location)	Species	Diameter, in inches, at about 4 feet above ground
T1	Tulip poplar (*Liriodendron tulipifera*)	19
T2	Willow oak (*Quercus phellos*)	31
T3	Holly (*Ilex* sp.)	11
T4	Oak(*Quercus* sp.)	17
T5	Tulip poplar (*Liriodendron tulipifera*)	13
T6	Maple (*Acer* sp.)	20
T7	Sweet gum (*Liquidambar* sp.)	9.9
T8	Post oak (*Quercus stellata*)	13
T9	Loblolly pine (*Pinus taeda*)	21
T10*	Willow oak (*Quercus phellos*)	11
T11*	Sweet gum (*Liquidambar* sp.)	10
T12*	Post oak (*Quercus stellata*)	4.8
T13*	Loblolly pine (*Pinus taeda*)	10
T14	Sweet gum (*Liquidambar* sp.)	15
T15	Sweet bay (*Laurus nobilis*)	6.7
T16	Holly (*Ilex* sp.)	6.2
T17	Holly (*Ilex* sp.)	5.6
T18*	Holly (*Ilex* sp.)	Not measured
T19*	Tulip poplar (*Liriodendron tulipifera*)	Not measured
T25	Tulip poplar (*Liriodendron tulipifera*)	8.9
T26	Red maple (*Acer rubrum*)	10
T27	Tulip poplar (*Liriodendron tulipifera*)	14
T29*	Tulip poplar (*Liriodendron tulipifera*)	>20
T30*	Red maple (*Acer rubrum*)	12
T31*	Sweet gum (*Liquidambar* sp.)	5.8
T32*	Tulip poplar (*Liriodendron tulipifera*)	20
T33*	Red maple (*Acer rubrum*)	8.1

Tritium concentrations were determined by using low-level liquid scintillation spectroscopy (Tri-Carb Liquid Scintillation Analyzer Model 1600TR™, PerkinElmer, Inc.). In brief, aqueous and bulk tissue samples were added without distillation or digestion, respectively, to no more than 10 milliliters (mL) of low-level scintillation cocktail (Ultima Gold™, PerkinElmer, Inc.) in 20 mL plastic counting vials and capped. The sample disintegrations per minute (DPM) were analyzed using the Direct DPM option of the Model 1600TR™ (Cook and others, 1992). Samples were analyzed at either the USGS laboratory in Columbia, SC, or GEL Laboratories LLC in Charleston, SC. Quality control included collection of duplicate samples. In some cases, both the original and duplicate were analyzed at the USGS laboratory. In other cases, the original was analyzed at the USGS laboratory, and the duplicate was analyzed at GEL Laboratories LLC. Data analyzed by the USGS laboratory in 2007–2009 used a 10-minute counting time. Data analyzed by the USGS laboratory in 2009 used a 1-minute counting time, with the exception of the surface-water sample, groundwater sample G12, and tree core-water samples T25-East, T26-West, and T27-West, which were analyzed using a 10-minute counting time. Samples analyzed by GEL Laboratories LLC used a 15-minute count time. In general, increased counting times produce decreased measurement error.

Groundwater samples were obtained by inserting a push-point sampler 1.5 ft or less into the soil and using a peristaltic pump to collect groundwater. Samples were collected in 40-mL volatile organic analysis vials. Duplicate samples were collected and analyzed in October 2008 and both the original and duplicate contained undetectable tritium at a sample-specific reporting limit of 500 pCi/L.

The single surface-water sample collected from Mary's Branch Creek was obtained by pumping from beneath the water surface by means of tubing attached to a peristaltic pump. The sample was collected at 12:23 p.m. on September 9, 2009, from Mary's Branch Creek adjacent to tree T25, which is adjacent to the creek (fig. 2).

Tree-core samples were obtained by use of a 0.2-inch-diameter increment borer. In most cases, cores were collected from multiple sides of the trees because of the potential for differences in contaminant concentrations on different sides of the tree (Vroblesky, 2008). Water was extracted from the tree cores by placing the tree cores in 40-mL vials and microwaving them for 90 seconds (fig. 4). The vials were then allowed to cool and condense the extracted water vapor on the sides and bottom of the vial. Approximately 0.3 mL of water typically was obtained per 3-inch-long tree core by using this method. A similar approach was used by Kalisz and others (1988) in which water was extracted from foliage by using a microwave oven, and the condensate was analyzed for tritium content. The July 2008 values cited in this report for tree-core water are listed as approximate concentrations because a uniform value of 0.33 mL was used to represent the sample volume for the data collected on July 16, 2008. The uniform value was used because of uncertainties in the measurements of July 2008 sample volumes. This uniform value (0.33 mL) is based on the measurement of the water volume extracted from tree T5 in October 2008 as well as from several trees in the study area and background areas sampled in 2009. The volume of water collected from tree core T5 in October 2008 was 0.3 mL. The average volumes of water collected from 7 tree cores on June 9, 2009, 2 tree cores on June 10, 2009, and 13 tree cores on June 29, 2009, was 0.33 mL, with a standard deviation of 0.14. Based on the range of water volumes extracted from tree cores in October 2008 and June 2009, the average error in tritium calculations associated with using a uniform value to represent sample volume for the July 2008 data is probably about ±35 percent. Analysis of tritium in water extracted from tree cores resulted in a relatively high quantitation limit (16,000 pCi/L), primarily because of the result of large dilution factors and small sample volumes.

Analysis of whole tree-core samples for tritium involved placing each core in a scintillation cocktail and analyzing the whole core. With this approach, the only tritium detections are those on the outer surface of the tree core. This value, therefore, does not represent the entire mass of the tree core. Because the resulting value does not reflect picocuries per liter or picocuries per gram of wood, data from the analysis of whole tree cores are herein reported as disintegrations per minute per tree core (DPM/tree core). In 2007, tree cores were analyzed without prior drying. In 2008, the tree cores were

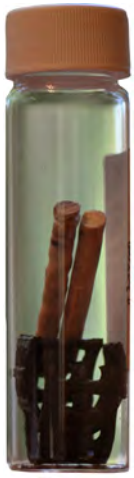

Figure 4. Vial (40-milliliter volume) containing tree core and plastic screen to isolate wood from extracted water.

analyzed after removing most of the water by using a microwave oven in order to analyze the water separately. Removal of the water likely resulted in lower whole tree-core tritium concentrations than would have been present if the sample had been analyzed without removal of the water, but no specific comparisons were done to make that determination.

To obtain tritium concentrations in the air, water was condensed from the air and analyzed for tritium content. The water was condensed from the air by use of frozen water bottles suspended in the air with a funnel attached to the bottom of the bottle and a 40-mL vial attached to the bottom of the funnel (fig. 5). To obtain samples from various heights up the trees, condensing samplers were attached to a 37-ft expandable pole. Typically, about 15–20 mL of water was condensed from the air over a few hours by this method. Previous investigations have used condensed water from the air to examine tritium concentrations in soil water vapor by passing soil vapor through a freeze trap (Andraski and others, 2003; 2005). Background samples AC10, AC11, and AC28 were obtained in Columbia, SC. Background sample AC9 was obtained from a location approximately 200 ft west of the map area shown in figure 2 and probably is west of the groundwater contamination plume.

Figure 5. Frozen water bottle, funnel, and 40-milliliter vial in the process of condensing water from forest air near Mary's Branch Creek, Barnwell, South Carolina, June 8, 2009.

Adjustment of the tritium concentration in water condensed from the air, in picocuries per liter of water (C_W), to concentrations of tritium in picocuries per liter of air (C_A) was done by using the following equation:

$$C_A = AH \times \frac{C_W}{1{,}000}, \tag{1}$$

Where AH is the absolute humidity, in liters (or kilograms), of water contained in a cubic meter of air. Equations used to calculate the AH are as follows (provided by Dr. Greg Carbone, Climatology Professor, Department of Geography, University of South Carolina, written commun., 2008):

$$AH = 1{,}000 \times \frac{AVP}{461 \times T}, \tag{2}$$

Where T is the temperature in degrees Kelvin, and AVP is the absolute vapor pressure, in kilograms per cubic meter, as defined by the following equation:

$$AVP = SVP \times \frac{RH}{100}, \tag{3}$$

Where RH is the percent relative humidity, and SVP is the saturation vapor pressure, in kilopascals, as defined by the following equation:

$$SVP = 0.611 \times e^{\left(5{,}423 \times \frac{1}{273} - \frac{1}{T}\right)}. \tag{4}$$

The temperature and relative humidity were measured near Mary's Branch Creek by use of a digital sling psychrometer held at approximately chest height. The temperature and relative humidity measured during sampling events ranged from 83 to 89 degrees Celsius and 46 to 65 percent, respectively. There was little or no air circulation at chest height during the sampling events.

Sap-flow velocity was measured on October 1 and 2, 2008, and June 5, 2009, on representative trees using a modified method of Granier (1987) by attaching two, 1.18-inch-long thermal dissipation probes (TDP™, Dynamax, Inc.) into the tree stemwood. Sap-flow measurements concentrate on the outer part of the trunk because it is the zone of greatest water flow during transpiration. In ring-porous trees, over 90 percent of water transported through the xylem is in the outermost growth ring (Ellmore and Ewers, 1986). The transpiration rate was calculated by multiplying the measured sap-flow velocity by the stemwood area as determined from tree cores. The transpiration rate for June 5, 2009, should be considered a minimum probable value because no data were collected prior to noon that day.

Tritium Concentrations in Environmental Samples

Groundwater samples collected from the vicinity of Mary's Branch Creek show a broad range of tritium concentrations (less than 500 to 1,490,000 pCi/L; table 2). Such variation is not surprising because of the shallow depth of the samples (0.7 to 1.5 ft below land surface [BLS]). The tritium-contaminated groundwater near the creek may be overlain by a zone of uncontaminated groundwater that discharges to the creek; therefore, parts of the shallow groundwater beneath the creek may represent discharging uncontaminated groundwater, tritium-contaminated groundwater, local infiltration of rainwater, or a mixture. The single surface-water sample collected from Mary's Branch Creek contained 107,000 pCi/L of tritium (table 2).

Water extracted from at least one of the cores from each of the nine trees sampled in the study area near Mary's Branch Creek contained detectable tritium above background concentration (table 3). The tritium concentrations were variable with location, with the side of the tree that was cored, and, in some cases, with the same tree over different dates. Collection of duplicate cores (within a few centimeters of each other) from the south side of tree T5 on July 16, 2008, showed little difference in tritium concentration in the water extracted from the two cores (51,800 and 54,600 pCi/L; table 3), indicating that the variation probably is not due to collection technique. Concentration variations from the same side of the tree may be related to the source of water to the tree. For example, on June 9, 2009, the west sides of trees T26 and T27 contained core-water tritium concentrations greater than 300,000 pCi/L, yet the east sides contained concentrations less than 16,000 pCi/L (table 3). The southwestern sides of those trees faced away from Mary's Branch Creek, and the northeastern sides of the trees were within a foot of Mary's Branch Creek. The proximity to different water sources may indicate a difference in concentration uptake as an influence on tritium concentrations from different sides of the trees.

Differences in tritium concentrations in water extracted from the tree cores also were seen in cores taken from the same side of the tree over time (table 3). Tritium concentrations in water extracted from cores taken at the west sides of trees T26 and T27 declined from greater than 300,000 pCi/L to less than 16,000 pCi/L from June 9 to June 29, 2009 (table 3). The reason for the decline is not clear. Little or no

Table 2 . Concentrations of tritium in groundwater near Mary's Branch Creek and in surface water from Mary's Branch Creek, Barnwell, South Carolina, 2008–2009.

[GW, groundwater sample; †, data analyzed at GEL Laboratories LLC. All other data were analyzed at the U.S. Geological Survey laboratory in Columbia, South Carolina; <, less than]

Sample location (see figure 2 for location)	Collection date	Depth of sample, in feet below land surface	Tritium concentration, in picocuries per liter
GW1	7/16/2008	1.5	3,720; 5,510†
GW2	7/16/2008	1.5	2,940
GW2	9/11/2008	1	1,840
GW3	7/16/2008	1	1,840
GW4	7/16/2008	2	1,670
GW5	7/16/2008	1	591; 584†
GW6	7/16/2008	1	176,000; 204,000†
GW7	7/16/2008	1	<500
GW8	7/16/2008	1	2,830
GW8	10/3/2008	1	<500; <500
GW9	7/16/2008	1	2,070
GW10	6/9/2009	.7	1,370,000; 1,410,000†
GW10	6/9/2009	1	1,490,000
GW10	6/29/2009	1	89,100†
GW11	6/9/2009	.7	1,240,000
GW11	6/29/2009	1	438,000; 406,000†
GW12	6/9/2009	.7	161,000
GW12	6/29/2009	1	169,000; 179,000†
Surface water[1]	6/9/2009	not applicable	107,000

[1]The surface-water sample was located adjacent to tree T25.

Table 3. Concentrations of tritium in water extracted from tree cores near Mary's Branch Creek, Barnwell, South Carolina, and from background areas, 2008–2009.

[€, values are approximate because a uniform value of 0.33 milliliters was used as a representative sample volume; <, less than; *, background sample; azimuth direction indicates the side of the tree that was cored]

Sample location (see figure 2 for location)	Collection date	Tritium, in picocuries per liter
T2-South	7/16/2008	62,700 €
T3-East	7/16/2008	53,700 €
T3-North	7/16/2008	17,400 €
T3-South	7/16/2008	45,100 €
T3-West	7/16/2008	<16,000 €
T5-East	7/16/2008	33,000 €
T5-North	7/16/2008	25,300 €
T5-South	7/16/2008	51,800 €
T5-South	7/16/2008	54,600 €
T5-West	7/16/2008	63,700 €
T5-West	10/3/2008	<16,000
T14-East	7/16/2008	41,100 €
T14-North	7/16/2008	<16,000 €
T14-South	7/16/2008	53,000 €
T14-West	7/16/2008	<16,000 €
T14-West	6/9/2009	<16,000
T16-East	7/16/2008	49,400 €
T16-North	7/16/2008	48,300 €
T16-West	7/16/2008	38,000 €
T17-East	7/16/2008	<16,000 €
T17-North	7/16/2008	54,500 €
T17-South	7/16/2008	<16,000 €
T17-West	7/16/2008	22,900 €
T18-North*	7/16/2008	<16,000 €
T18-South*	7/16/2008	<16,000 €
T19-North*	7/16/2008	<16,000 €
T25-East	6/29/2009	655,000
T25-North	6/29/2009	372,000
T25-South	6/29/2009	650,000
T25-West	6/9/2009	693,000
T26-East	6/9/2009	<16,000
T26-East	6/29/2009	<16,000
T26-West	6/9/2009	327,000
T26-West	6/29/2009	<16,000
T26-South	6/29/2009	<16,000
T26-North	6/29/2009	<16,000
T27-East	6/9/2009	<16,000
T27-East	6/29/2009	<16,000
T27-West	6/9/2009	819,000
T27-West	6/29/2009	<16,000
T27-South	6/29/2009	<16,000
T27-North	6/29/2009	<16,000
T29-West*	6/9/2009	<16,000
T30-South*	6/10/2009	<16,000
T31-West*	6/10/2009	<16,000
T32-North*	6/29/2009	<16,000
T33-North*	6/29/2009	<16,000

rainfall took place in Barnwell during the 10 days prior to the June 29 sampling, so rainfall dilution of the tritium was not a factor. Although a substantial decrease in groundwater tritium concentration was seen adjacent to tree T26 from June 9 to June 29 (site G11), no substantial change in groundwater tritium concentrations was seen adjacent to tree T27 (site G12; table 2). One possible explanation is that in the heterogeneous environment near Mary's Branch Creek, the limited number of samples collected during this investigation were too few to fully characterize the spatial and temporal influences on tritium concentrations in groundwater and tree samples, although the differences may be due to other environmental factors not yet identified.

Analysis of tree cores showed that the cores from most of the trees near Mary's Branch Creek contained tritium at concentrations greater than those found in background trees (table 4). The highest concentrations in cores collected on July 16, 2008, were in trees T5 and T14, which are located adjacent to each other (table 4; fig. 2). Cores from some trees in the study area contained no detectable tritium, such as trees T6 and T7, which are thought to be east of the groundwater tritium plume, and trees T8 and T9, which are up a steep embankment with probably little direct root contact with tritium-contaminated groundwater (table 4). For unknown reasons, the single core from tree T4 contained no detectable tritium despite the fact that it was near other trees that did contain tritium.

The presence of tritium in tree cores and in water extracted from tree cores in areas where the roots come into contact with tritium-contaminated groundwater indicates that groundwater contaminated by tritium is being taken up by the trees during transpiration. These data also indicate that collection and analysis of tree cores and water extracted from tree cores have the potential to be used as a tool for location of shallow tritium-contaminated groundwater; phytoremediation may be a viable tool to assist in remediation of tritium contamination in this groundwater discharge area.

Air condensate samples collected from near Mary's Branch Creek showed higher-than-background tritium concentrations. Tritium concentrations in water condensed from air near the creek contained 1,300 to 67,000 pCi/L, while concentrations in water condensed from air in background areas was less than 800 pCi/L (table 5). The maximum concentrations, when converted to concentrations in air, were less than 15 pCi/L of air. In most cases, the tritium concentrations in air were less than 5 pCi/L of air. The maximum allowable effluent concentration of tritium in air is 100 pCi/L (South Carolina Department of Health and Environmental Control, 2007). Therefore, the detected tritium concentrations in air were substantially lower than concentrations considered to be hazardous to human health.

In July and October 2008, concentrations of tritium in water condensed from the air were generally greater near the ground than in the tree canopy at heights greater than 12 ft. This finding may be a function of a larger amount of tritium evaporation near the ground than in the tree canopy, or it

Table 4. Concentrations of tritium in whole tree cores near Mary's Branch Creek, Barnwell, South Carolina, and from background areas, 2007–2008.

[<, less than; *, background tree; azimuth direction, where noted, indicates the side of the tree from which the sample was obtained]

Sample location (see figure 2 for location)	Collection date	Tritium, in disintegrations per minute per tree core
T1-North	10/2/2007	59
T1-South	10/2/2007	56
T2-North	10/2/2007	<30
T2-North	10/2/2007	<30
T2-South	7/16/2008	110
T3-North	10/2/2007	<30
T3-South	10/2/2007	<30
T3-East	7/16/2008	73
T3-North	7/16/2008	<30
T3-South	7/16/2008	<30
T3-West	7/16/2008	<30
T4-North	10/2/2007	<10
T5-North	10/2/2007	32
T5-East	7/16/2008	88
T5-North	7/16/2008	57
T5-South	7/16/2008	191
T5-South	7/16/2008	170
T5-West	7/16/2008	186
T5-West	10/3/2008	36
T6-North	10/2/2007	<30
T7-North	10/2/2007	<30
T8-North	10/2/2007	<30
T9-North	10/2/2007	<30
T10*	10/2/2007	<30
T11*	10/2/2007	<30
T12*	10/2/2007	<30
T13*	10/2/2007	<30
T14-East	7/16/2008	110
T14-North	7/16/2008	47
T14-South	7/16/2008	220
T14-West	7/16/2008	97
T15-West	9/11/2008	36
T16-North	7/16/2008	56
T16-West	7/16/2008	75
T17-East	7/16/2008	42
T17-North	7/16/2008	63
T17-South	7/16/2008	33
T17-West	7/16/2008	40
T18-North*	7/16/2008	<30
T18-South*	7/16/2008	<30
T19-North*	7/16/2008	<30
T19-South*	7/16/2008	<30

may be a function of potentially greater air circulation with uncontaminated air at greater heights above the forest floor. In June 2009, samples of water condensed from air showed comparatively little variability with height.

Transpiration data showed that in early October 2008, tree T14 transpired about 10–12 liters of water per day (table 6; fig. 6). On June 5, 2009, tree T25 transpired at least 24.4 liters of water, a value that does not include transpiration before noon. On June 9, 2009, the tritium concentration in groundwater on the western side of tree T25 was 1,370,000 to 1,490,000 pCi/L (sample GW10; table 2). Assuming an average groundwater tritium concentration of 1,430,000 pCi/L (average of the two samples analyzed by the USGS) at tree T25, then the potential amount of tritium transpired by tree T25 on the afternoon of June 5, 2009, may have been more than 34.9 million picocuries. Because the tritium concentration in water extracted from a tree T25 tree core (693,000 pCi/L) was approximately half of that in the groundwater on June 9, 2009, however, the tree may derive approximately half of its water from less contaminated sources. Therefore, if we assume that the average tritium concentration in water taken up by tree T25 on June 9, 2009, was about 700,000 pCi/L, then it is reasonable to estimate that tree T25 was transpiring at least 17.1 million pCi/day in early June 2009. This value is likely to be an underestimate because the June 2009 transpiration data do not include pre-noon transpiration. A visual approximation of the potential percentage of unaccounted transpiration can be seen by comparing the pre-noon to post-noon sap-flow data for tree T14 in October 2008 (fig. 6).

Because this calculation represents only a single tree, and because contaminant concentrations vary across the study area, the calculated tritium transpiration value should not be uniformly applied across the site. Lower groundwater tritium concentrations were found on the north side of Mary's Branch Creek than near tree T25, so tritium transpiration rates probably are lower along the north side of Mary's Branch Creek than near tree T25. In addition, tritium removal rates by transpiration would be expected to decline during the fall to winter, as demonstrated by the comparatively lower transpiration rates at tree T14 in October 2008 than in tree T25 in June 2009 (table 6). The tritium transpired by the trees represents tritium removed from the groundwater that otherwise would have discharged to Mary's Branch Creek.

The broad range of tritium concentrations in environmental samples collected near Mary's Branch Creek may reflect the heterogeneity of the source water. Although little rainfall took place prior to field activities for this investigation, it is likely that trees near the creek typically derive water from localized uncontaminated rainwater infiltration, from uncontaminated groundwater, from tritium-contaminated groundwater, and possibly from tritium-contaminated surface water in Mary's Branch Creek (fig. 7). Spatial and temporal variations in contribution from these sources may produce spatial and temporal variations in the tritium content of environmental samples.

Table 5. Concentrations of tritium in water condensed from air and concentrations of tritium in air near Mary's Branch Creek, Barnwell, South Carolina, and from background areas, 2008–2009.

[*, background sample; <, less than; †, data analyzed at GEL Laboratories LLC. All other data were analyzed at the U.S.Geological Survey laboratory in Columbia, SC]

Sample location (see figure 2 for location)	Sample height above ground, in feet	Collection date	Tritium concentration in water condensed from air, in picocuries per liter of water	Calculated tritium concentration in air, in picocuries per liter of air
AC1	0.5	7/16/2008	21,100; 32,400†	4.2; 6.5
AC1	5	7/16/2008	13,000	2.6
AC1	12.5	7/16/2008	4,200	0.8
AC1	.5	10/3/2008	23,400	4.7
AC1	6	10/3/2008	10,700	2.1
AC1	24	10/3/2008	3,610	0.7
AC1	38	10/3/2008	2,420	0.5
AC2	4.5	7/16/2008	19,000; 22,000	3.8; 4.4
AC3	1	7/16/2008	37,400; 67,000†	7.5, 13.5
AC4	0	7/16/2008	19,700	4.0
AC5	.5	7/16/2008	15,200	3.1
AC6	.5	7/16/2008	1,300	1.5
AC7	6	7/16/2008	9,620	1.9
AC8	6	7/16/2008	8,360	1.7
AC9*	.5	7/16/2008	<800	<0.2
AC10*	.5	7/25/2008	<800	<0.2
AC10*	.5	10/4/2008	<800	<0.2
AC25	34	6/9/2009	9,740†	2.5
AC25	3	6/9/2009	7,190†	2.2
AC28*	.5	6/10/2009	<154†	<0.2
AC26	37	6/29/2009	6,940†	1.9
AC26	24	6/29/2009	4,900†	1.0
AC26	19	6/29/2009	4,070†	0.9

Table 6. Transpiration rates measured in trees at Mary's Branch Creek, Barnwell, South Carolina, 2008–2009.

Tree name (see figure 2 for location)	Date	Transpired water, in liters per day
T14	10/1/2008	9.9
T14	10/2/2008	12.4
T25	6/5/2009	At least 24.4[1]

[1]The actual value is probably higher than shown because pre-noon data were not collected.

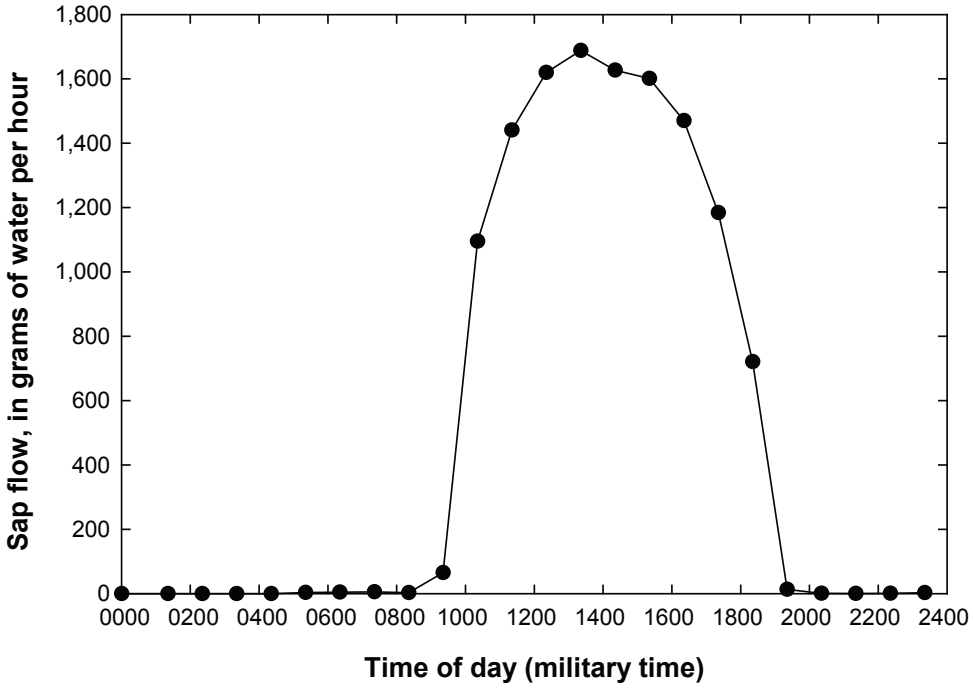

Figure 6. Sap-flow measurements from tree T14, October 2, 2008, near Mary's Branch Creek, Barnwell, South Carolina.

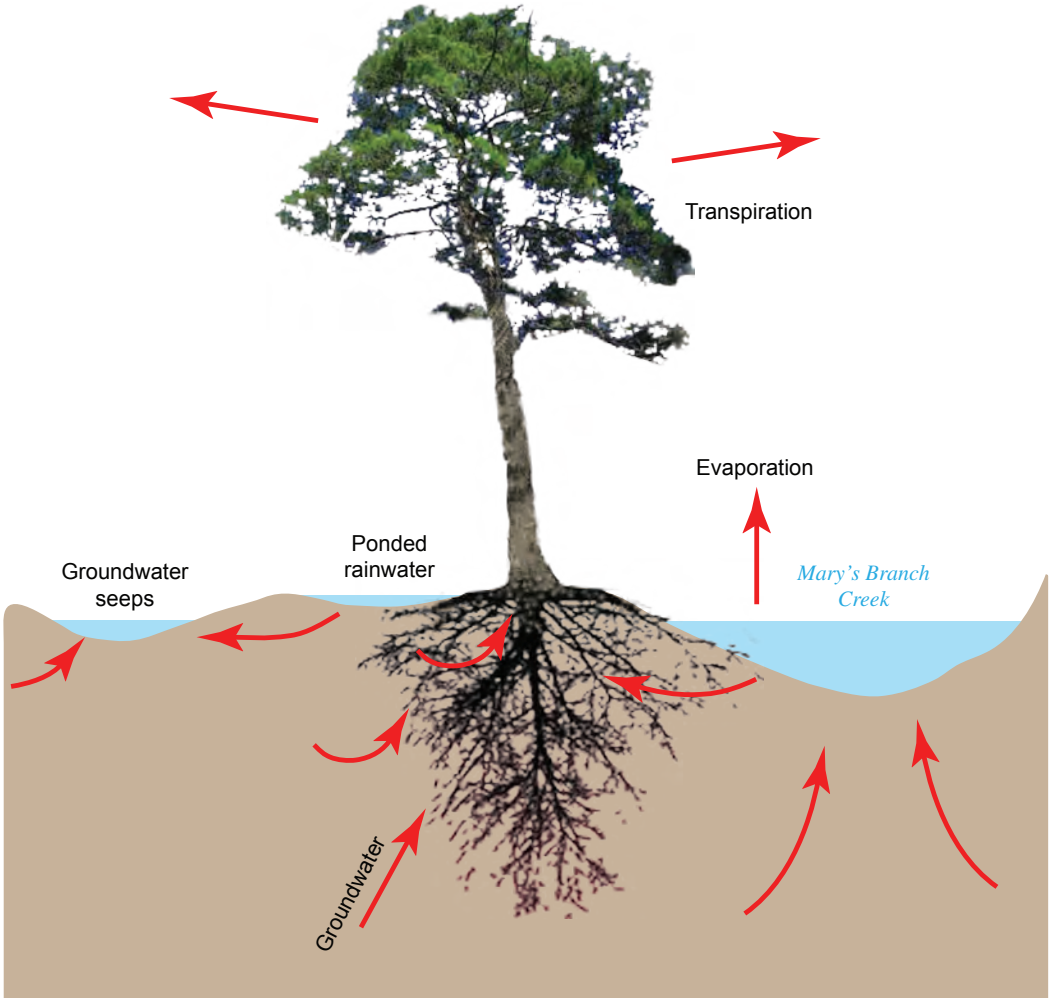

Figure 7. Conceptualization of water movement in the forest near Mary's Branch Creek, Barnwell, South Carolina.

The presence of tritium in the forest air probably is a result of evaporation from soil and surface water and uptake of tritium-contaminated groundwater by the trees and transpiration of the tritium into the air from the leaves. The low concentrations of tritium detected in air indicate that although tritium-contaminated groundwater is removed from the shallow subsurface and released to the atmosphere by these processes, there is no evidence that the attenuation resulted in a vapor hazard in the forest.

Summary

Tritium from a low-level radioactive waste disposal facility is present in groundwater near Barnwell, South Carolina. The tritium-contaminated groundwater discharges to Mary's Branch Creek, approximately 3,000 ft south of the disposal facility. This investigation examined the potential for tritium uptake by riparian trees in the vicinity of Mary's Branch Creek to reduce the amount of tritium discharging to the creek. Groundwater, surface water, water extracted from tree cores, whole tree cores in the riparian zone, and water condensed from air were analyzed for tritium content. Water extracted from one or more of the cores from each of nine trees sampled in the study area near Mary's Branch Creek contained detectable tritium above background concentration. Tritium was not found in water extracted from tree cores from background trees, from trees on a hill where it was unlikely that the roots were in contact with contaminated groundwater, or from trees considered to be to the east of the groundwater contamination. Tritium was present at greater-than-background concentrations in water extracted from air in the vicinity of Mary's Branch Creek, but the concentrations were lower than concentrations considered by the State of South Carolina to be hazardous to human health. The presence of tritium in the trees indicates that the trees are taking up tritium-contaminated groundwater during transpiration. Therefore, analysis of tree material has the potential to be a useful tool in identifying shallow tritium-contaminated groundwater. Based on the transpiration rate of tree T25 on June 5, 2009, and the presence of 1,410,000 pCi/L in groundwater adjacent to tree T25 on June 9, 2009, it is likely that tree T25 probably transpires more than 17.1 million pCi/day in the summer, with lower concentrations during the winter. Because this calculation represents only a single tree, and because contaminant concentrations vary across the study area, the calculated tritium transpiration value should not be uniformly applied across the site. Lower groundwater tritium concentrations were found on the north side of Mary's Branch Creek than near tree T25, so tritium transpiration rates probably are lower along the north side of Mary's Branch Creek than near tree T25. The data show that the trees remove a portion of the tritium-contaminated groundwater, thus reducing the amount of tritium discharge to Mary's Branch Creek. No evidence was found that removal of tritium-contaminated groundwater by soil evaporation, root uptake and discharge of tritium by transpiration at the leaves created a vapor hazard in the forest.

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