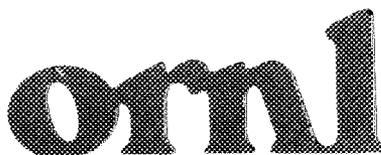




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# Transport of Contaminants During Storms in the White Oak Creek and Melton Branch Watersheds

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Environmental Sciences Division  
Publication No. 3395

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ENVIRONMENTAL SCIENCES DIVISION

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Date Published--January 1991

Prepared for the  
Environmental Restoration Program  
(Budget Activity No. ADS 322 GF72101)

Prepared by the  
OAK RIDGE NATIONAL LABORATORY  
Oak Ridge, Tennessee 37831-6285  
managed by  
MARTIN MARIETTA ENERGY SYSTEMS, INC.  
for the  
U.S. DEPARTMENT OF ENERGY  
under contract DE-AC05-84OR21400





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## ACKNOWLEDGMENTS

The authors wish to thank the following individuals for their contributions to this report. Dennis Borders, for hourly stream flow data for the water year 1988; Jerry Jones, for rainfall data for the 1988 water year; and Curtis Olsen and Ron Haese for their help in collecting stream samples in the pouring rain.

We also wish to thank Ed Davis and Glenn Wilson, for reviewing the manuscripts.



## EXECUTIVE SUMMARY

This report documents the transport of contaminants from Solid Waste Storage Area (SWSA) 5 along two principle pathways: the saturated groundwater system and the intermittently saturated storm flow system.

The results of the storm flow sampling show a  $^{90}\text{Sr}$  anomaly in SWSA 5 that is suggested by the similar mobility of  $^3\text{H}$  and  $^{90}\text{Sr}$ , in spite of the reactive nature of  $^{90}\text{Sr}$ . An empirical relationship between concentration and discharge was established for  $^3\text{H}$  and  $^{90}\text{Sr}$  in the Melton Branch Watershed. The relationship is of the form  $C = AD^b$ , where C is concentration of either  $^3\text{H}$  or  $^{90}\text{Sr}$ , D is discharge at MBS, and A and b are empirical constants. A model was developed and a computer program written to separate the discharge into quick-flow and base flow components. The results of the modeling, using data collected during storm flow, showed that 44% of the annual stream discharge occurred as quick flow, whereas only 16% of the  $^3\text{H}$  and 27% of the  $^{90}\text{Sr}$  occurred as quick flow. The data show that for SWSA 5 the saturated groundwater pathway is quite important in dry years, such as the 1988 water year. Data from other areas, such as SWSA 6 suggest that the storm flow pathway may be more important in wet years.

This study has several important implications for remedial actions and site monitoring.

1. Any remedial actions must be directed toward both the groundwater and storm flow systems.
2. The short-term effectiveness of remedial actions aimed at reducing the contaminant source depends critically on the mass of contaminants that are currently stored within the porous media. If the mass stored is low, source-level remedial actions such as grouting, compaction, in-situ vitrification, etc., would result in reduced releases to streams within the first 1 or 2 years after remediation. If the mass of contaminants stored in the porous media is high, then only remedial actions that reduce the water flux will effectively reduce the release of contaminants to streams on a time scale of 1 or 2 years.

3. If the mass of contaminants stored in the porous media is small, the source term can be evaluated by measuring the release into streams during the coming years. If the source term declines over time, more-passive forms of remediation, such as French drains and simple caps, may be viable options.
4. The highly discrete nature of contaminant transport in the groundwater system suggests that repeated (i.e., quarterly) sampling of groundwater monitoring wells is a futile exercise unless well locations are very carefully selected. Even then, knowledge of the transport in adjacent surface water systems is essential in interpreting sampling results.

## 1. INTRODUCTION

### 1.1 BACKGROUND

Traditionally, the saturated groundwater system has been viewed as the major pathway for contaminant transport to streams. During FY 1987, several exploratory studies were conducted to examine the manner in which subsurface contaminants are transported to streams. These studies suggest that during storm events laterally moving water, above the water table is responsible for a large fraction (>50%) of the total contaminant load of streams.

To quantify the fraction of water moving laterally above the water table during storms, a time series of stream samples were collected during storm events. Because the mass flow of a given contaminant is the product of the stream discharge and the concentration of that contaminant in the stream water, these time-series samples were collected near stream discharge monitoring stations. The collected samples were analyzed for a variety of radionuclides and trace metals. The radionuclides included tritium,  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$ . To reduce analytical costs, only a select number of samples were analyzed for all constituents. The procedure used for selecting samples is outlined in the methods section of this report.

The analytical results obtained from these samples were combined with stream discharge data to produce rating curves, which relate contaminant concentrations to stream discharge. These rating curves can then be used to estimate total contaminant releases on an annual basis using stream discharge data only.

The rate at which contaminants are released from waste trenches into hydrologic systems is known as the source term. Although an accurate estimate of the source term is critical for making remedial action decisions, this parameter remains virtually undefined throughout the Oak Ridge Reservation (Solomon et al. 1988). One approach to defining the source term is to accurately monitor contaminant releases in streams over an extended period of time and extrapolate both backward

and forward in time. Although such an approach cannot estimate the portion of the source term that is bypassing local surface systems (i.e., deep groundwater recharge), previous work with water balance studies (Moore 1988) has suggested that only a small fraction of this total would be missed. This approach has the advantage of integrating the source term over a large area but requires that very accurate measurements be made of contaminant fluxes in streams.

Accurate measurement of contaminant fluxes in streams is also important in evaluating the effectiveness of remedial actions. Significant time and effort will undoubtedly be spent on remediating contaminant problems on the Oak Ridge Reservation, and a proper assessment of the effectiveness of each project can only be performed if contaminant fluxes are quantified. It is especially important that these fluxes be measured for a statistically significant period of time before remedial action begins.

## 1.2 OBJECTIVES

The objective of this study is to quantify the release of subsurface contaminants to streams in and around Oak Ridge National Laboratory (ORNL) waste management areas. Specific objectives include

1. To develop, using rating curves, methods to accurately measure the total contaminant discharge in streams.
2. To quantify the ratio of the amount of contaminants released relatively slow to the amount of contaminants released rapidly during storm events.

## 2. METHODS

### 2.1 SELECTION OF ANALYTES

Because it was not feasible to analyze for every possible contaminant, a list of analytes thought to include the major

contaminants present as well as span a variety of geochemical properties that affect transport in hydrologic systems was developed. The list of analytes includes (1) tritium, (2)  $^{90}\text{Sr}$ , (3) gamma-emitting radionuclides (principally  $^{137}\text{Cs}$  and  $^{60}\text{Co}$ ), and stable (nonradioactive) trace metals.

Tritium was selected because its chemical form (HTO) results in near-conservative (nonreactive) geochemical behavior. Tritium is also a major contaminant of concern, especially in Solid Waste Storage Area (SWSA) 5. Strontium-90 is a divalent cation that can be sorbed by clay minerals by the process of cation exchange. As a result, the movement of  $^{90}\text{Sr}$  through hydrologic systems is attenuated and, in general,  $^{90}\text{Sr}$  will travel at a rate less than the average water velocity. Because significant quantities of  $^{90}\text{Sr}$  have been released into the environs of ORNL and especially because the regulatory limit for  $^{90}\text{Sr}$  concentrations in drinking water is extremely low (8 pCi/L, EPA 1980)  $^{90}\text{Sr}$  represents a contaminant of major concern. Significant quantities of  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  have also been introduced into the terrestrial environment. Cesium-137 and  $^{60}\text{Co}$  are strongly, and irreversibly sorbed by aquifer materials and thus are only slightly mobile in the dissolved state; however, significant transport of cesium- and cobalt-burdened sediments may be occurring.

Tritium,  $^{90}\text{Sr}$ ,  $^{60}\text{Co}$ , and  $^{137}\text{Cs}$  analysis were done on each sample collected. These analytes represent a wide range of contaminant mobility in hydrologic systems, and significant sources for each is known to exist. In addition, inductively coupled plasma (ICP) spectroscopy has been used to analyze a selected number of samples for trace metals.

## 2.2 SAMPLE COLLECTION

Samples were collected from three separate sites: (1) White Oak Creek (WOC) near monitoring station 3, (2) Melton Branch (MB) near monitoring station 4, and (3) a tributary of MB near monitoring station 4B. At WOC and MB, the samples were collected upstream of the pool created by the monitoring weirs. Because a pool did not exist at

the MB tributary site, the samples were collected immediately downstream of the weir. The monitoring station locations are illustrated in Fig. 1.

The stream samples were collected with an ISCO (model 2700) automatic sampler. This sampler is equipped with a peristaltic pump and is capable of collecting up to twenty-four 1-L samples at a user-defined sampling interval. The sampler intake lines were installed in the stream by driving a 2.2 cm diameter PVC pipe about 25 cm into the stream bed and attaching the intake line (0.95 cm flexible tygon tubing with and closed off) to the pipe with electricians tape. Several small notches were made in the tygon tubing to act as strainers to prevent entry of large debris. In addition, the intake notches were positioned just below the water surface during periods of base flow and at least 10 cm above the stream bottom to inhibit streambed particles from entering the tubing. All samplers were new when installed. The sample bottles were washed with a dilute (10%) HCl solution and rinsed several times with distilled water before sample collection.

The autosamplers were not slaved to any stream discharge or precipitation monitoring devices, and thus it was necessary to operate the samplers at all times to ensure that samples were collected just prior to the onset of storm flow. Samples were collected at 2 and 3 hour intervals, which represents a compromise between resolution of contaminant releases and logistical considerations.

Not all of the samples collected by the autosampler were actually processed for radionuclide and contaminant analysis. Real time hydrologic data from the Environmental Monitoring and Compliance (EMC) Department's data collection system was used to cost effectively select specific samples for analysis. In general, an attempt was made to collect samples at critical points in the stream hydrograph, such as just before storm flow, at peak flow, and after the stream had returned to base flow conditions. Additional samples were also collected at intermediate times between these critical points on the stream hydrograph. Samples not selected for analysis were not treated in any way and were returned to the stream. Suspended sediment was removed from all the selected samples by pressure filtration through in-line

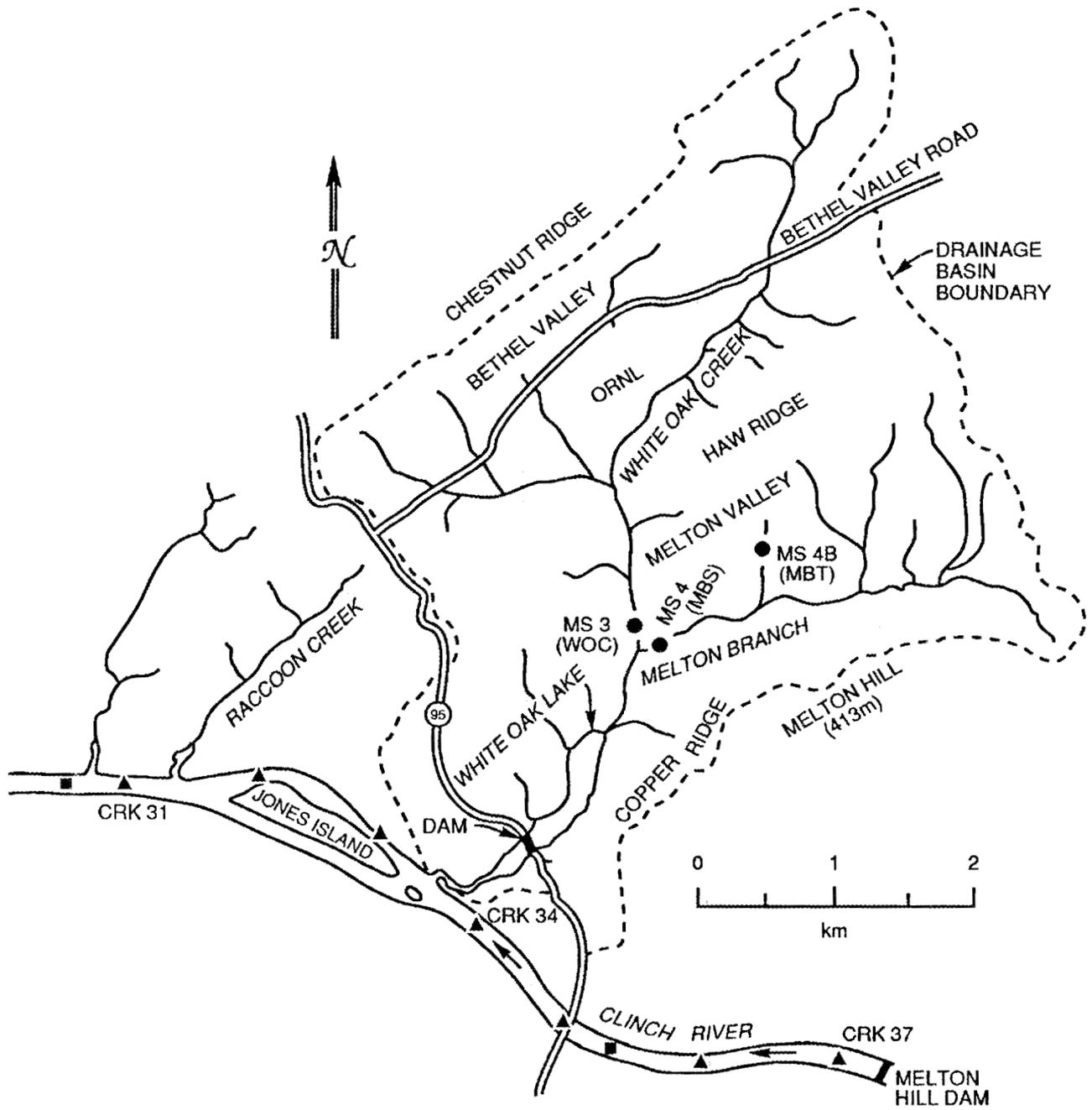


Fig. 1. Map of the Melton Branch and White Oak Creek drainage basins.

0.45  $\mu\text{m}$  polycarbonate filters using a peristaltic pump and tygon tubing. All the filters and retained suspended particulate matter samples were saved for gamma counting. Samples collected from each monitoring station were processed together chronologically, beginning with the first sample collected. The tygon tubing around the pump head was replaced whenever a group of samples from a different monitoring station was filtered. Samples were generally filtered within about 6 h from the time of collection. Although filters were not prewashed, approximately 50-mL of water was filtered before sampling began.

Each filtered 1-L stream-water sample was divided into three separate aliquots to facilitate the various analytical procedures. A 750-mL aliquot was placed in a Marinelli beaker and acidified to a  $\text{pH} < 2$  using HCl. This aliquot sample was gamma-counted for  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  and then analyzed for  $^{90}\text{Sr}$  by Cerenkov radiation counting. A second 50-mL aliquot was stored in a high-density polyethylene bottle for subsequent analysis of metals. (These bottles were purchased precleaned, having been subjected to a dilute acid wash followed by thorough rinsing with distilled water.) These samples were also acidified to a  $\text{pH} < 2$  with HCl. A third 150-mL aliquot was collected for tritium and anion analyses. Except for filtration, these 150-mL samples remained untreated.

## 2.3 SAMPLE ANALYSIS

### 2.3.1 Gamma-emitting Radionuclides

Cesium-137 and  $^{60}\text{Co}$  were measured in the 750-mL water sample and on the filtered suspended matter by gamma spectrometry. An Intrinsic Germanium (IG) coaxial detector was used with a relative efficiency of 25%. The detector was coupled to a Nuclear Data 6600 microprocessor programmed to acquire gamma spectra in 4096 channels. Counting times for the water samples were typically 4000 seconds but a few samples were counted for 60,000 seconds or longer. Spectral data reduction was accomplished using Nuclear Data software programs that include peak area determinations, background subtraction, nuclide

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Corporate: Oak Ridge National Lab., TN, Environmental Sciences Div.  
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Reservation: summary of groundwater modeling  
Conference:  
Publisher:  
Year: 1992

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	1992	ES/REPORTS	3445603682352	SHELF
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Author(s): SOLOMON, D. K.;MARSH, J. D.;LARSEN, I. L.;WICKLIFF, D.  
S.;CLAPP, R. B.  
Corporate: Oak Ridge National Lab., TN, Environmental Sciences Div.  
Title: TRANSPORT OF CONTAMINANTS DURING STORMS IN THE WHITE OAK  
CREEK AND MELTON BRANCH WATERSHEDS  
Conference:  
Publisher:  
Year: 1991

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identification, and quantification of total radioactivity present as of the sampling date.

Calibration of the IG detector for the 750-mL water samples was performed using an Amersham certified mixed-gamma standard and following the procedures described in Larsen and Cutshall (1981). Cross-check solutions supplied by the Environmental Protection Agency (EPA) were routinely analyzed for quality control/quality assurance. The minimum detectable concentrations, defined as the concentration necessary to report a number greater than zero 95% of the time (Pasternack and Harley 1971), were approximately 5 to 6 pCi/L for both  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  for a 6000 second counting interval and 2 to 3 pCi/L for a 60,000 second counting interval. These values should not be considered absolute but may vary by several factors, depending on sample matrix composition, sample size, counting time, detector efficiency, and background contributions. Typically, samples having concentrations near these levels have a relative uncertainty of 40 to 60%.

The filters containing suspended, particulate matter were not removed from the in-line filter holders prior to counting. Instead, one of the in-line connectors was cut off to allow the filter holder to be placed securely and level on the detector. Counting times and data reduction procedures were similar to those described for water samples. Calibration of the detector for this filter holder arrangement was accomplished by cutting a filter holder in half and adding a known concentration of the Amersham certified mixed gamma standard to the filter. The filter holder was resealed with silicon calk and counted in the same geometric configuration as the samples. During counting, the filter standard was rotated on top of the detector periodically to average out any nonuniformity in application of the standard solution. The data are expressed in units of picocuries per liter of water because approximately 1 L of water was filtered. The data have been decay corrected to the time of collection. The minimum detectable activity for filter samples for both  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  was ~1.5 pCi/filter for a 6000 second count.

### 2.3.2 Strontium-90

After gamma-counting, two duplicate 20-mL aliquots of each filtered water sample were analyzed for  $^{90}\text{Sr}$  via Cerenkov radiation counting (Ross 1969). This technique utilizes the highly energetic beta particle emitted during the decay of  $^{90}\text{Y}$ , which is the daughter of  $^{90}\text{Sr}$ . The duplicate 20-mL aliquots were placed directly into plastic scintillation vials and analyzed in a liquid scintillation counter for 3600 seconds (Larsen 1981). The  $^{90}\text{Sr}$  activity in each sample was calculated by comparing the net count rate of the sample to that of a  $^{90}\text{Sr}$ - $^{90}\text{Y}$  (Amersham) standard after correcting for background blanks, which were about 5 cpm. The  $^{90}\text{Sr}$  activities reported for each sample are the average of two duplicates and counting errors are  $1 \sigma$ .

Because of the highly energetic maximum decay energy of the  $^{90}\text{Y}$  beta particle (2.28 MeV), an appropriate electronic window setting on the liquid scintillation counter is used to discriminate against radiation interference from other less energetic beta particles. Compton electrons produced by energetic gamma rays in the sample may also cause interference and produce a false-positive signal (Larsen 1981). In the presence of equal activities of  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{90}\text{Sr}$ - $^{90}\text{Y}$ , the false signal contribution of  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  is about 3 and 10%, respectively, of the total  $^{90}\text{Sr}$ - $^{90}\text{Y}$  activity (Larsen 1981). Although measurements of  $^{90}\text{Sr}$  by Cerenkov radiation counting may be influenced by the presence of other radionuclides in the sample, the ease and simplicity of this method allows for rapid cost-effective estimations of  $^{90}\text{Sr}$ - $^{90}\text{Y}$  concentrations. For a given system, the relative values should be useful for reflecting overall trends. The minimum detectable concentration for  $^{90}\text{Sr}$  via Cerenkov radiation counting for 3600 seconds is approximately 40 pCi/L. Values reported near this concentration will typically have relatively high counting uncertainties.

An EPA quality assurance/quality control sample (6 May 1988) containing  $^{90}\text{Sr}$  was analyzed directly by Cerenkov radiation counting. Triplicate samples indicated values of 18.7, 23.1, and 19.6 pCi/kg, averaging  $20.5 \pm 2.3$  pCi/kg. This is in agreement with the expected

value of  $20.0 \pm 1.5$  and within the acceptable range of 17.4 to 22.6 pCi/kg.

### 2.3.3 Tritium

The tritium procedure for the Storm Surveillance Project was adapted from EPA Method 906.0 for tritium analyses in drinking water (EPA 1980). After filtration, the 150-mL aliquot stream-water samples were distilled in an alkaline permanganate solution. Aliquots of 8 mL of the distillate were added to a liquid scintillation cocktail and counted for 100 min on a Packard 4640 liquid scintillation counter. Calibration of the liquid scintillation counter consisted of counting Packard low-energy tritium standards with varying amounts of quenching material. This gives a quench-corrected efficiency curve, which can be used to automatically correct for quench in the samples. A series of three EPA standards of known activity and a blank were then distilled and counted using this quench-corrected efficiency curve. The ratio of the blank corrected average of the known activities and the activities calculated from the efficiency curve served as a calibration factor for relating the instrument efficiency curve and the distillation procedure. This ratio had a value of 0.8862.

Approximately 8 to 16 stream water samples were processed and analyzed as a set. With each set, one blank and one standard of known activity were also analyzed. Quality control charts were kept for both the blank and the standard to monitor the performance of each run to ensure good quality control. Most standards were within 10% of the known value, the highest error being 12.8%. An EPA cross-check was also run during the period of sample analysis and was within the  $2 \sigma$  control limits.

The detection limit is a function of the blank, which includes quenching, chemical composition, sample size, detector efficiency, counting time, and the background of the instrument. The tritium blank had an average of  $15.5 \pm 0.4$  cpm. For a 100-min count, this gives a lower limit of detection (LLD), as defined in HASL-300 (Harley 1972) of 360 pCi/L. This is an a priori value based on an average blank. Actual

LLDs will vary from analysis to analysis, depending on the actual conditions of measurement. To put this LLD in perspective, the maximum permissible concentration for drinking water is 20,000 pCi/L (EPA 1980). Because tritium concentrations in some of the stream water samples were as high as  $1.5 \times 10^6$  pCi/L, all glassware was soaked in an acid bath and then rinsed with distilled water before use to ensure that the blank count did not increase with time.

#### 2.3.4 Metals

Although a 50-mL aliquot of each filtered water sample was saved for metal analysis, only samples that were critical for defining the relationship between metal concentration and discharge were analyzed. These samples were screened and selected on the basis of the tritium,  $^{90}\text{Sr}$ , and gamma-emitting radionuclide data. The metal analyses were conducted by the Analytical Chemistry Division of ORNL using ICP spectroscopy.

#### 2.4 HYDROLOGIC DATA

Hydrologic data collected by the EMC automatic Data Acquisition System (DAS) is being utilized in this study. The system is described in detail by Environmental Monitoring and Services, Inc. (1987). Although 10-min discharge data were available for the MB (MS 4) and WOC (MS 3) sites, the MB tributary (MS 4B) site had only a flow totalizer, which was of limited use for this study. In addition, both the MB and WOC monitoring stations were equipped with low- and high-flow measuring devices. The high-flow device at both sites was a broad-crested weir. Recently, the reliability of the high-flow device at the MB site has been questioned because downstream obstructions in the stream channel below the weir may have resulted in submergence of the weir in excess of design capabilities, therefore affecting the discharge rating for which the high-flow instrumentation was calibrated. Therefore, all discharge data at the Melton Branch site exceeding 60,000 L/min was simulated

using the Streamflow Synthesis and Reservoir Regulation (SSARR) model (USAE 1975).

### 3. RESULTS

#### 3.1 STORMS SAMPLED

Three separate storm periods have been sampled to date. These storms represent a range of stream-discharge conditions that commonly occur on the Oak Ridge Reservation. For example, the peak discharge at Monitoring Station 3 on WOC for the three events was about 850,000, 200,000, and 26,000 L/min.

A total of 49 stream samples were collected between the 16th and 20th of January 1988. Stream discharge at Monitoring Station 4 (MS 4) on MB and from Monitoring Station 3 (MS 3) on WOC is shown in Figs. 2 and 3, respectively.\*

Four major peaks of the stream hydrography were recorded at MS 4 at discharges of about 5000, 18,000, 40,000, and 900,000 L/min. As discussed in Sect. 2.4, discharges above 60,000 L/min were corrected using the SSARR model.

Four major hydrograph peaks were also recorded at MS 3 at discharges of about 30,000, 44,000, 125,000, and 850,000 L/min. All of the discharge data from MS 3 is considered to be valid.

Several sampling problems were encountered during the January 16 to 20 storm, and thus, only a limited number of samples were collected. Air temperatures were below freezing, causing the intake lines of the autosamplers to become plugged with ice. This was a problem especially at the MB tributary site. During peak discharge on WOC, the floodplain on which the autosampler was located was inundated by water approximately 1 meter deep. This caused the sampler to overturn, spilling all previously collected samples. A nylon tether line

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\*Julian days for all hydrographs (Figs. 2 through 7) are for 24:00 hours on that day. For example, Julian day 19 begins at Julian day 18 (24:00) and is completed at Julian day 19 (24:00).

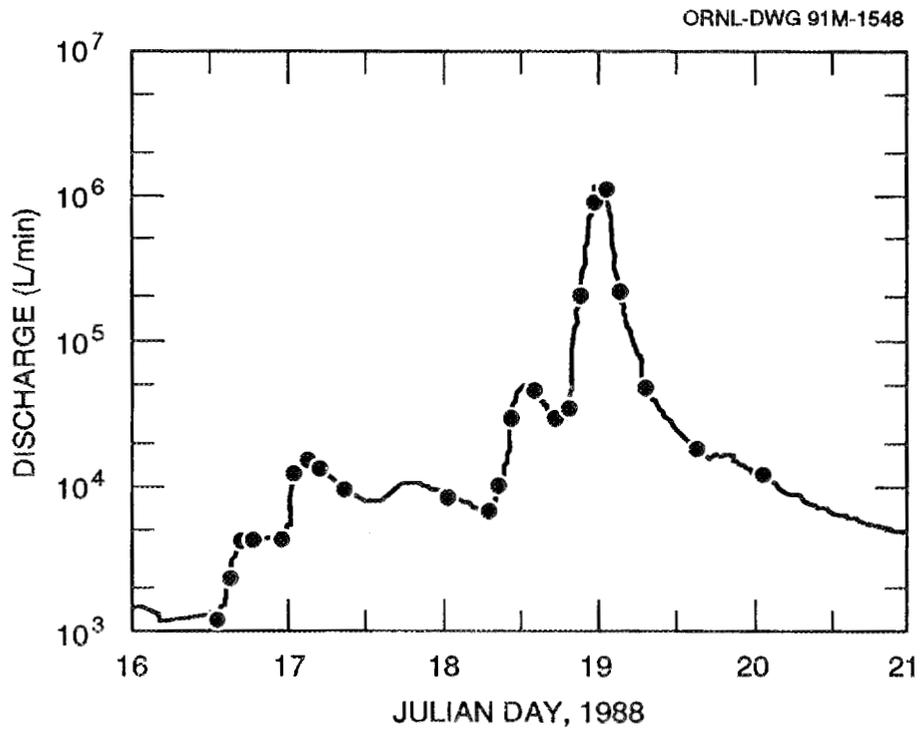


Fig. 2. Melton Branch (MS-4) hydrograph for the 17-21 January 1988 storm event. Dots represent sample collection points. (See footnote in text for explanation of Julian day.)

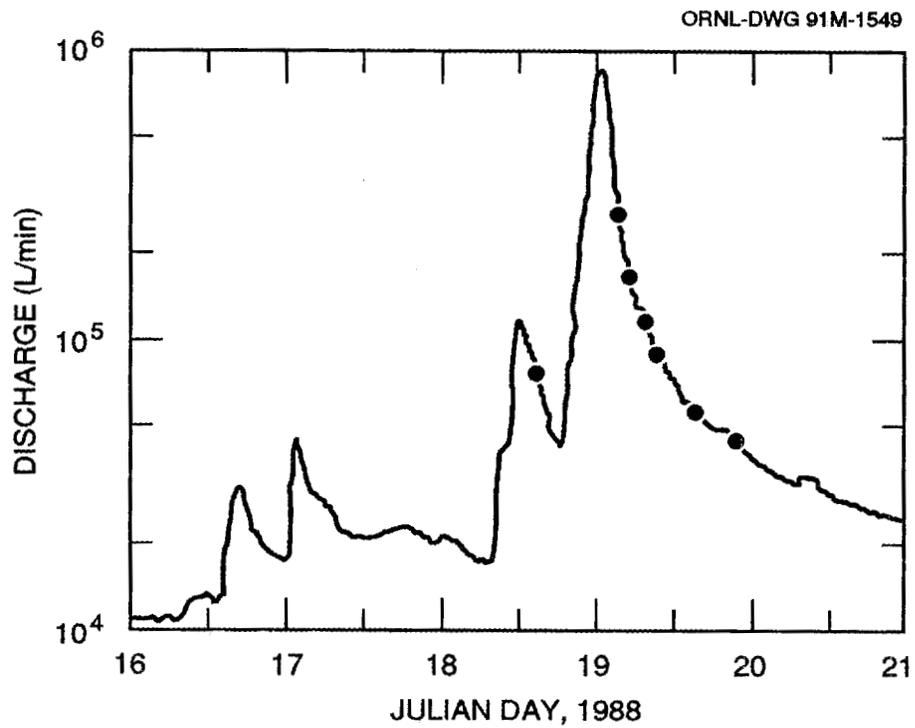


Fig. 3. White Oak Creek (MS-3) hydrograph for the 17-21 January 1988 storm event. Dots represent sample collection points. (See footnote in text for explanation of Julian day.)

prevented the sampler from floating downstream, however, and the sampler was placed back into service just prior to 0100 hours on January 20.

A second series of samples was collected between February 2 and 4 from all of the monitoring stations. A total of 30 samples was kept and processed for analysis during this period. Stream discharge data from MS 4 and MS 3 are shown in Figs. 4 and 5.

One major peak in the stream hydrograph was recorded at MS 4 at a discharge of about 90,000 L/min. One major peak in the hydrograph was also recorded at MS 3 at a discharge of about 200,000 L/min. Discharge values for MS 3 and MS 4 are considered valid for the February storm, including those values at MS 4 exceeding 60,000 L/min because the problem during the January storm was corrected. No particular sampling problems were encountered during the February storm period.

A final series of samples was collected between May 3 and 5, 1988. Only MB and WOC were sampled. A total of 21 samples were collected. Stream hydrographs for MS 4 and MS 3 are shown in Figs. 6 and 7. A variety of peaks were recorded at both stations. Peak discharge was about 3600 L/min at MS 4 and 26,000 L/min at MS 3.

### 3.2 CONTAMINANT CONCENTRATIONS VS STREAM DISCHARGE

The concentrations of tritium,  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$  as functions of stream discharge at MB (MS 4) and WOC (MS 3) are shown in Figs. 8 through 14. Each figure shows concentrations of a single contaminant at a given monitoring station for all of the samples analyzed for the three storms.

An exponential relationship between concentration and discharge is apparent for both  $^3\text{H}$  and  $^{90}\text{Sr}$  at both MS 4 and MS 3. At low discharge values, when stream flow is made up primarily of groundwater discharge, significant dilution occurs as less-contaminated water enters the stream; however, at a critical discharge value, further dilution no longer occurs and concentrations remain relatively constant with increasing discharge. As a result, the actual mass of both  $^3\text{H}$  and  $^{90}\text{Sr}$  being transported rises dramatically during periods of high flow. The concentration vs discharge relationship for  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  is a function

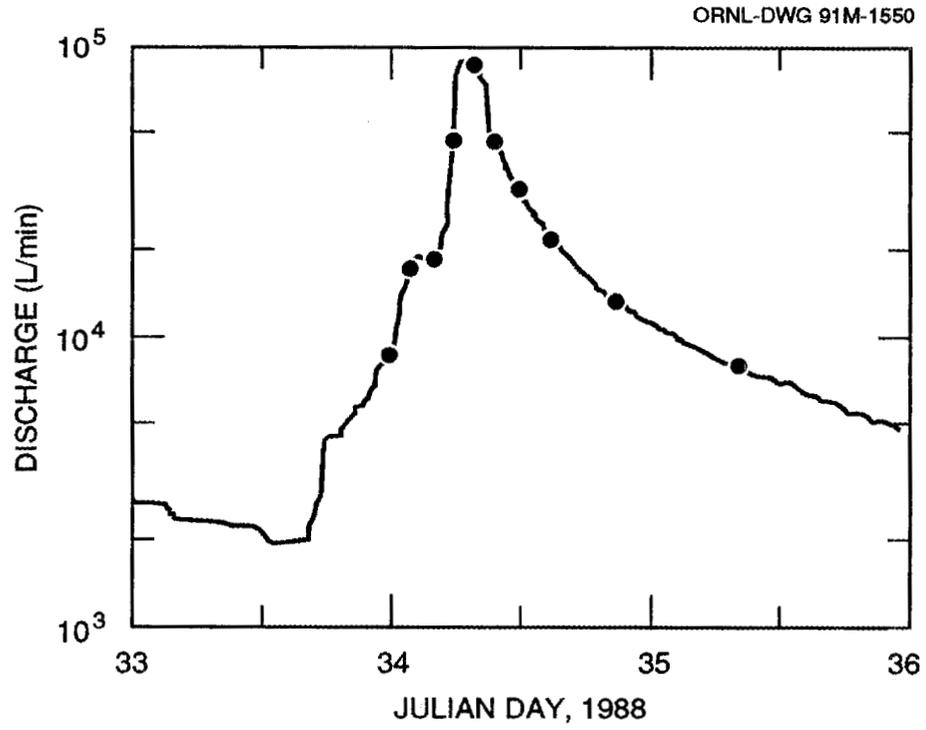


Fig. 4. Melton Branch (MS-4) hydrograph for the 3-5 February 1988 storm event. Dots represent sample collection points. (See footnote in text for explanation of Julian day.)

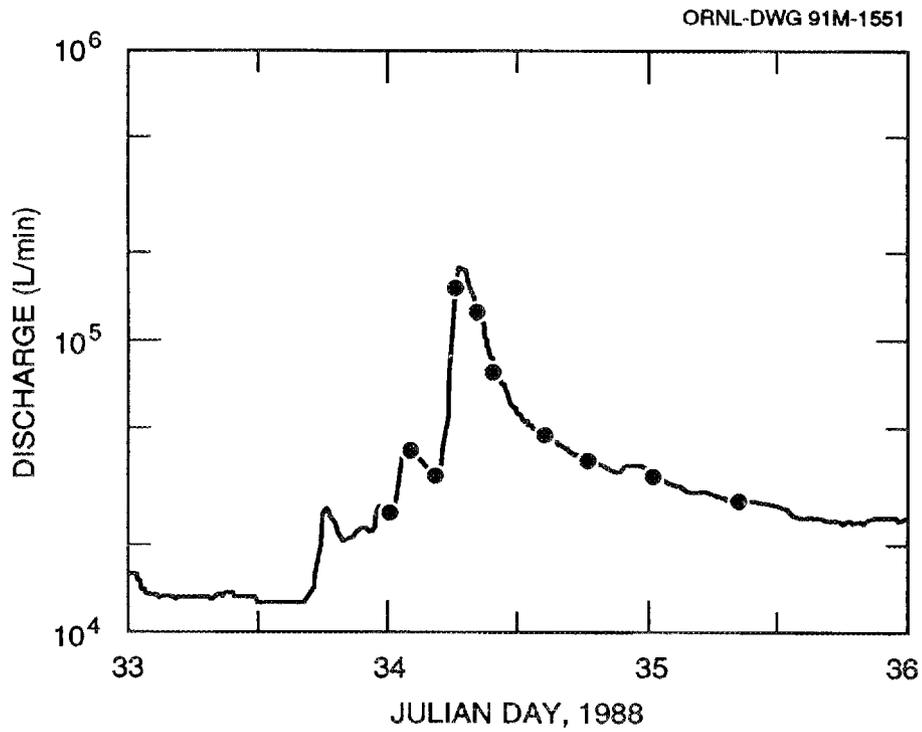


Fig. 5. White Oak Creek (MS-3) hydrograph for the 3-5 February 1988 storm event. Dots represent sample collection points. (See footnote in text for explanation of Julian day.)

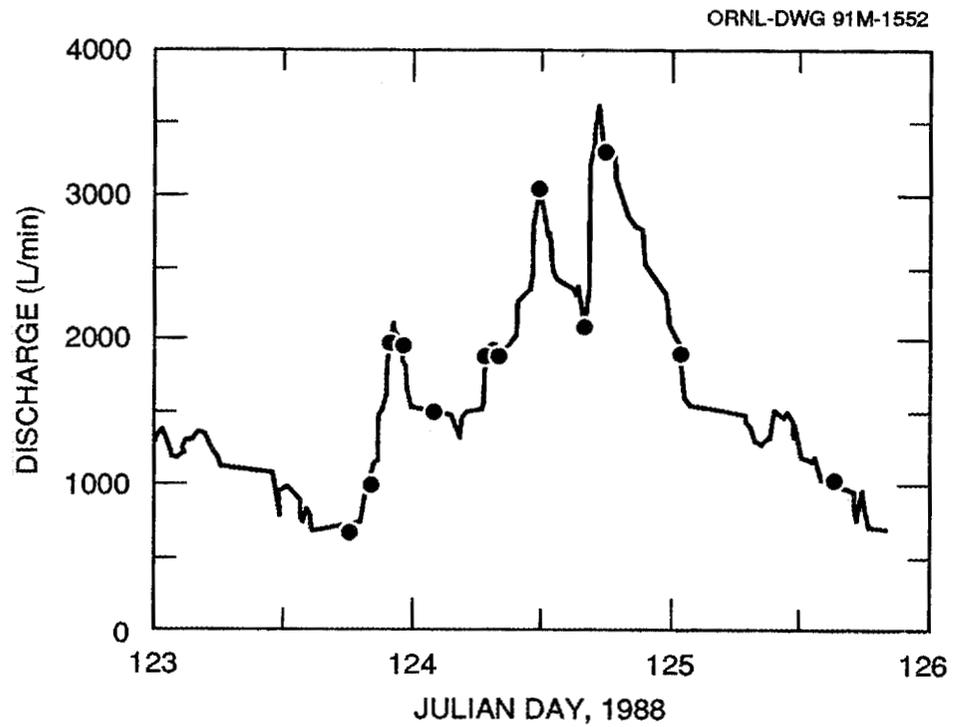


Fig. 6. Melton Branch (MS-4) hydrograph for the 3-5 May 1988 storm event. Dots represent sample collection points. (See footnote in text for explanation of Julian day.)

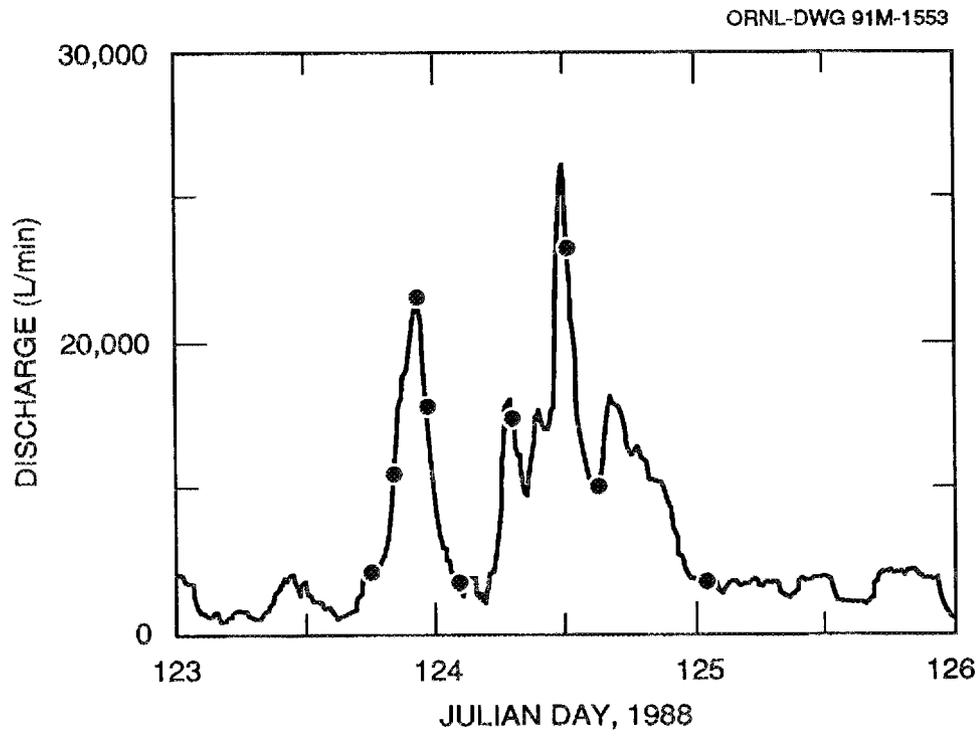


Fig. 7. White Oak Creek (MS-3) hydrograph for the 3-5 May 1988 storm event. Dots represent sample collection points. (See footnote in text for explanation of Julian day.)

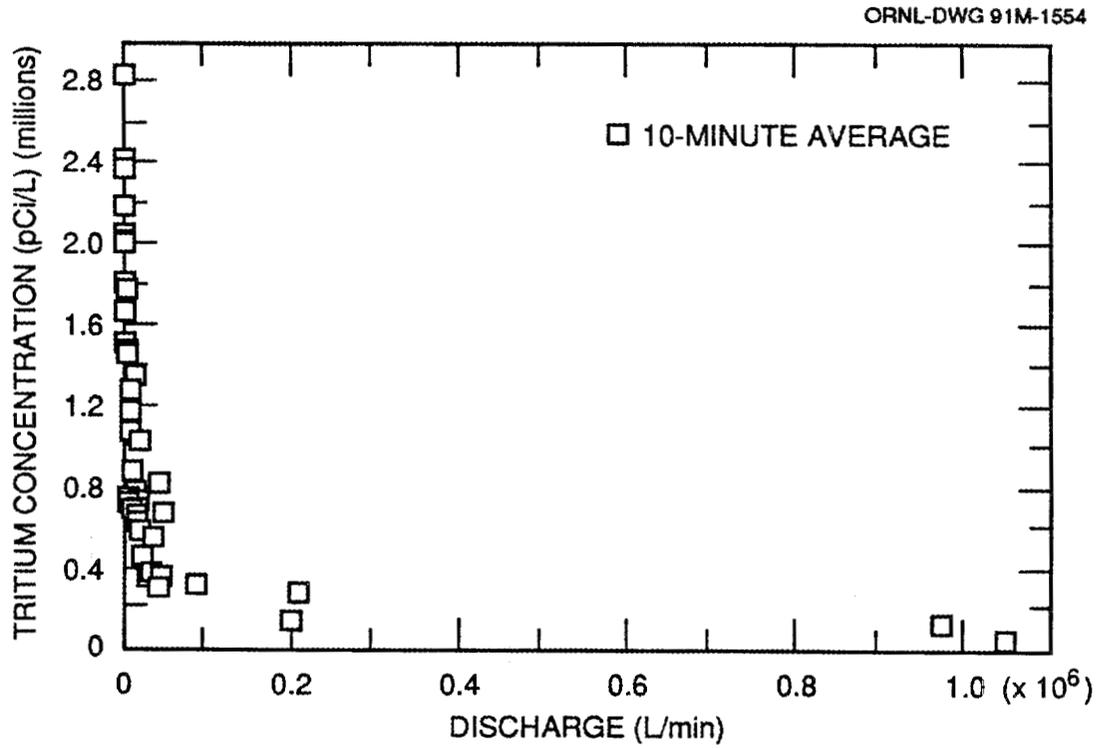


Fig. 8. Melton Branch (MS-4) tritium concentration vs discharge for the January, February, and May 1988 storms.

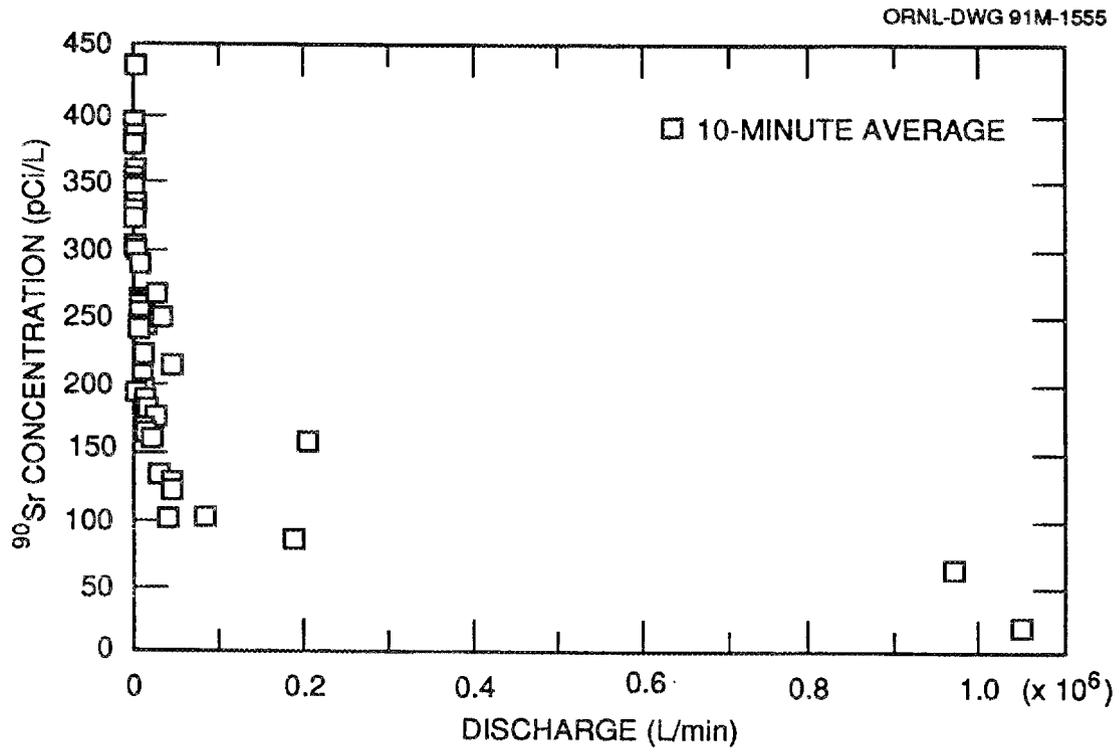


Fig. 9. Melton Branch (MS-4)  $^{90}\text{Sr}$  concentration vs discharge for the January, February, and May 1988 storms.

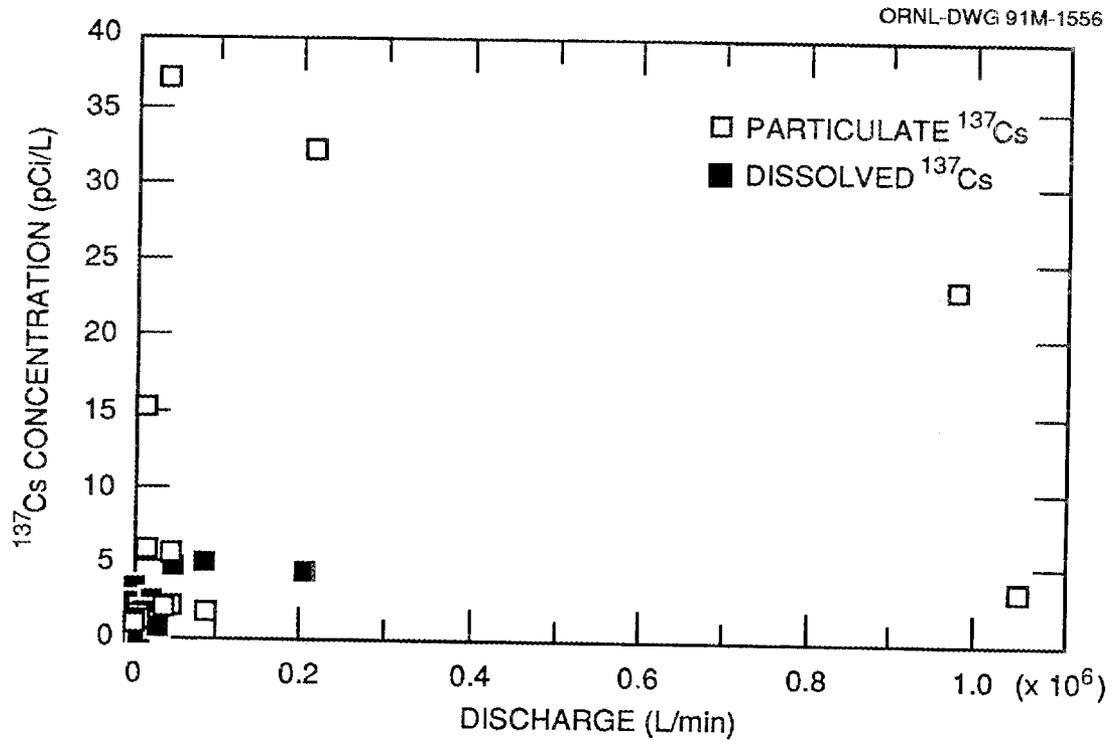


Fig. 10. Melton Branch (MS-4)  $^{137}\text{Cs}$  concentration vs discharge for the January, February, and May 1988 storms.

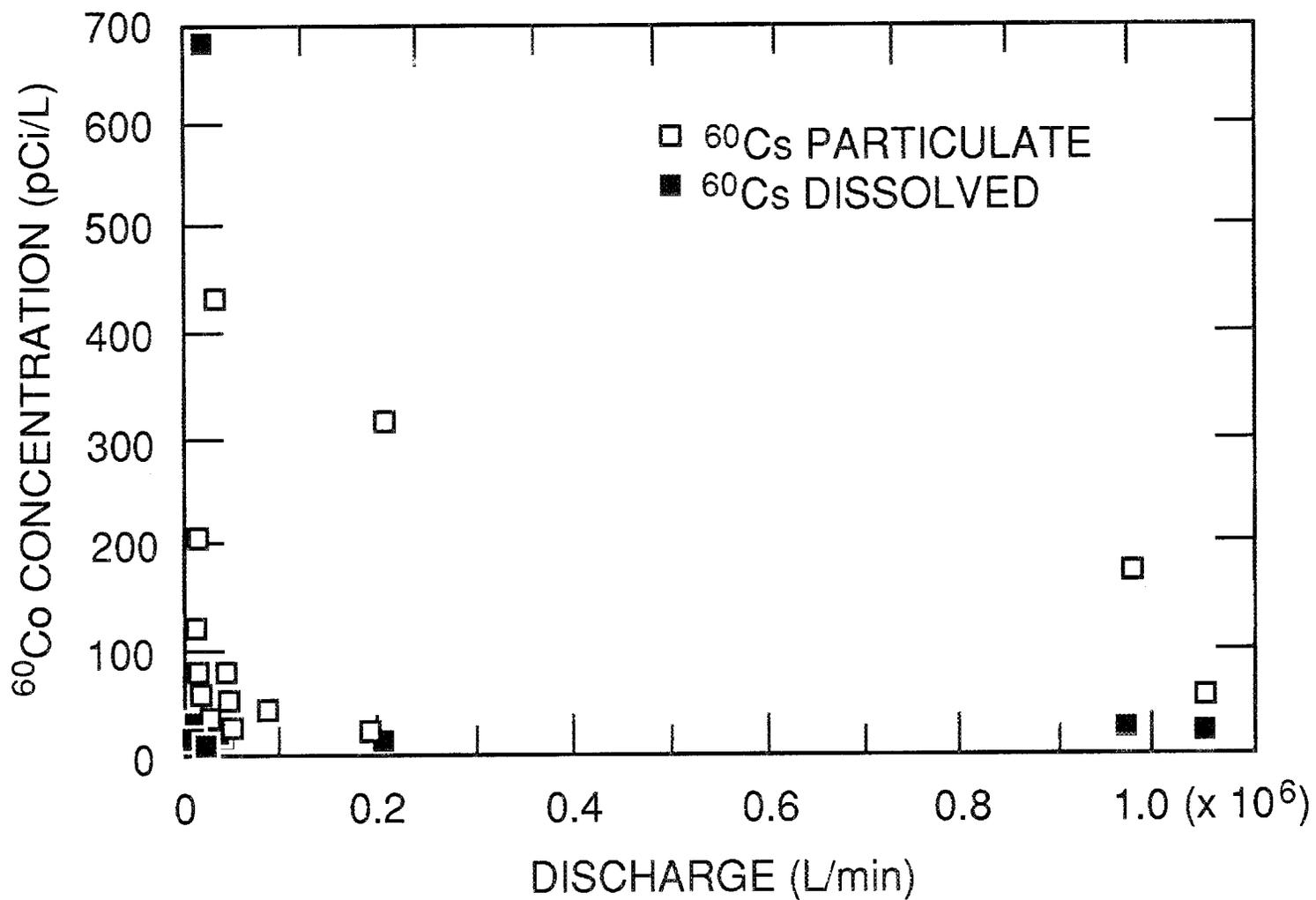


Fig. 11. Melton Branch (MS-4) <sup>60</sup>Co concentration vs discharge for the January and February 1988 storms.

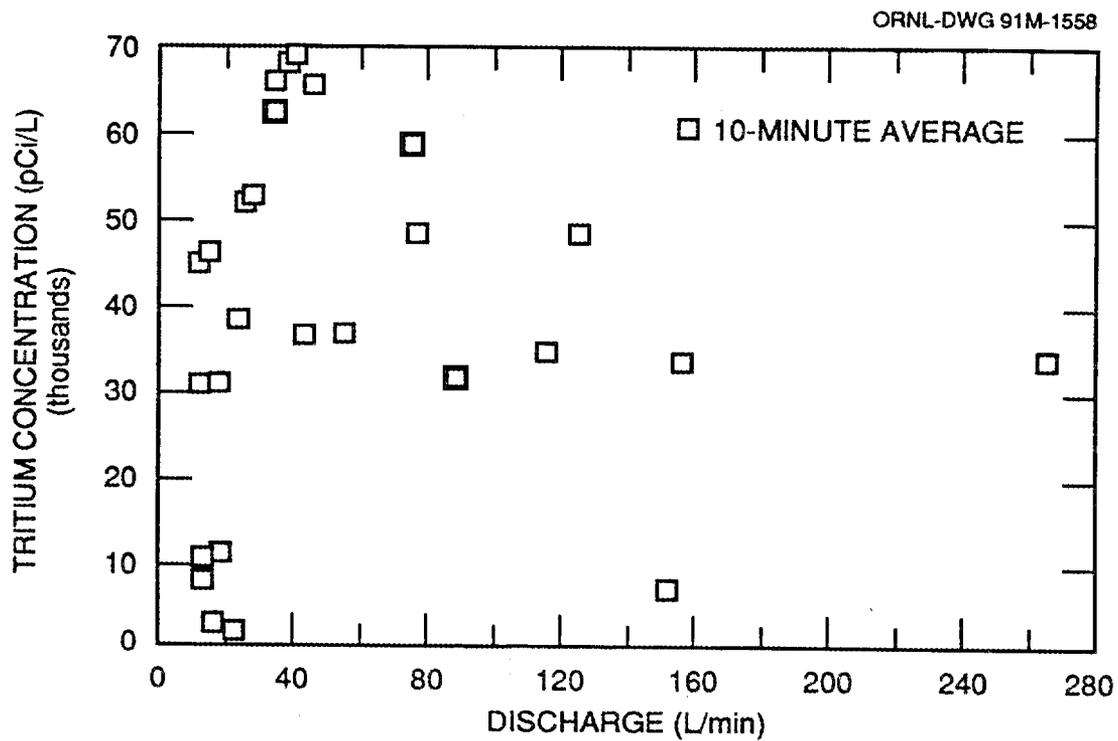


Fig. 12. White Oak Creek (MS-3) tritium concentration vs discharge for the January, February, and May 1988 storms.

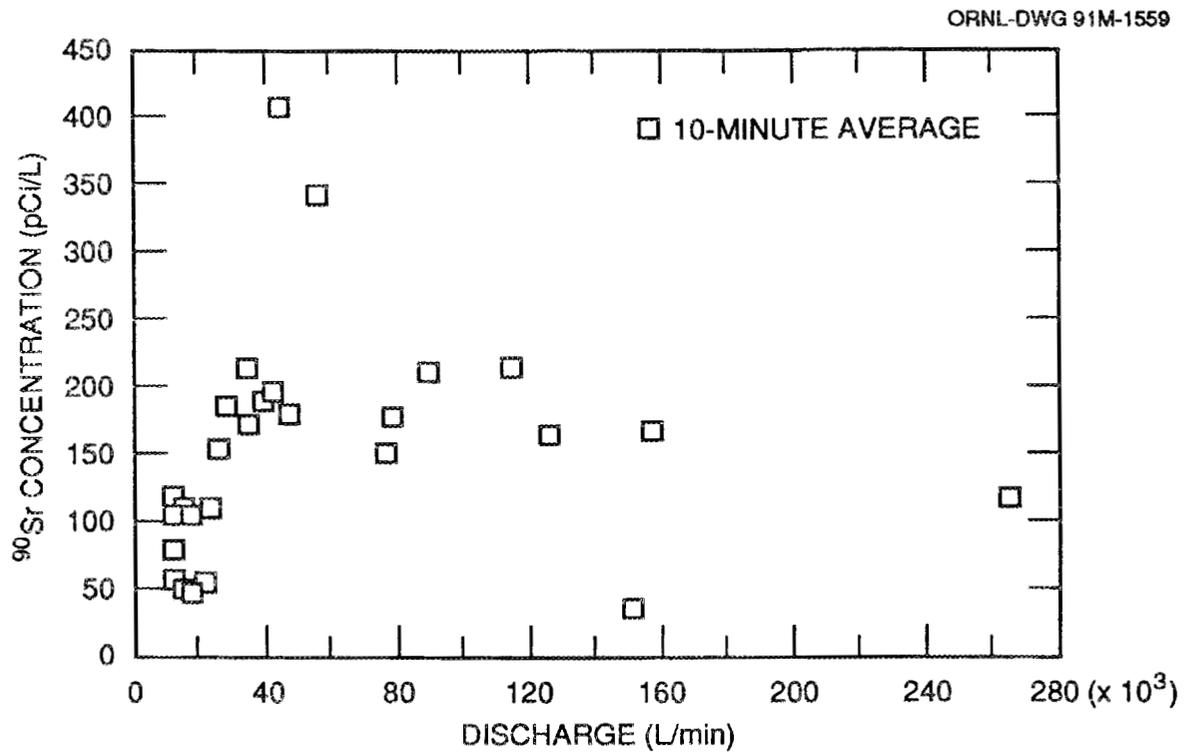


Fig. 13. White Oak Creek (MS-3) <sup>90</sup>Sr concentration vs discharge for the January, February, and May 1988 storms.

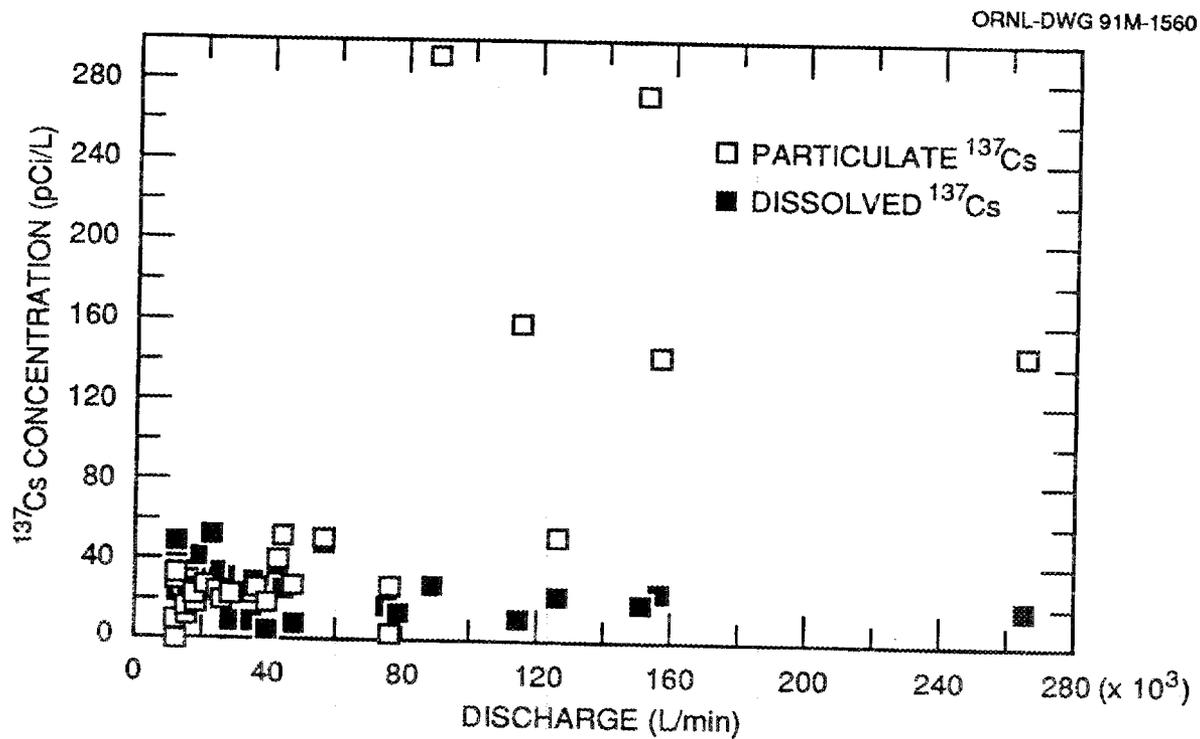


Fig. 14. White Oak Creek (MS-3)  $^{137}\text{Cs}$  concentration vs discharge for the January, February, and May 1988 storms.

of suspended sediment transport and thus does not parallel the  $^3\text{H}$  and  $^{90}\text{Sr}$  results.

### 3.3 CONTAMINANT CONCENTRATIONS VS TIME

The concentrations of  $^3\text{H}$ ,  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$  throughout the January, February, and May storm periods at MB (MS 4) and WOC (MS 3) are shown in Figs. 15 through 35. Melton Branch tributary (MS 4B) radionuclide concentrations vs time are shown for the January and February storms only. Because of the unavailability of discharge data at MS 4B, this site was not sampled during the May storm.

## 4. ANALYSIS

The sampling completed in FY 1988 was primarily designed to examine the release of contaminants from SWSA 5. The total area of SWSA 5 is about 30.9 ha, of which about 42.8% drains into MB, and the remaining 57.2% drains into WOC. Perhaps the most important question to answer concerning the release of contaminants from SWSA 5 relates to the magnitude and timing of the maximum annual releases from the site. If the maximum release period has already occurred, remedial action scenarios can be designed and evaluated on the basis of being able to meet a given release objective. If, however, maximum releases have not yet occurred, it is impossible to design remedial actions unless the source term is known. Even removal of the residual waste could not ensure that cleanup objectives would be met because significant portions of the contaminant mass may have already migrated from the source and be contained within the porous media. Defining the source term has proven to be very difficult, if not impossible, at most waste disposal sites. Because it is possible to design remedial actions without a knowledge of the source term if the maximum off-site release has already occurred, it is critical that long-term temporal trends in contaminant releases be evaluated.

Identifying contaminant pathways is also essential for designing remedial actions. Releases ranging from  $2.0 \times 10^3$  pCi/L to  $2.8 \times 10^6$

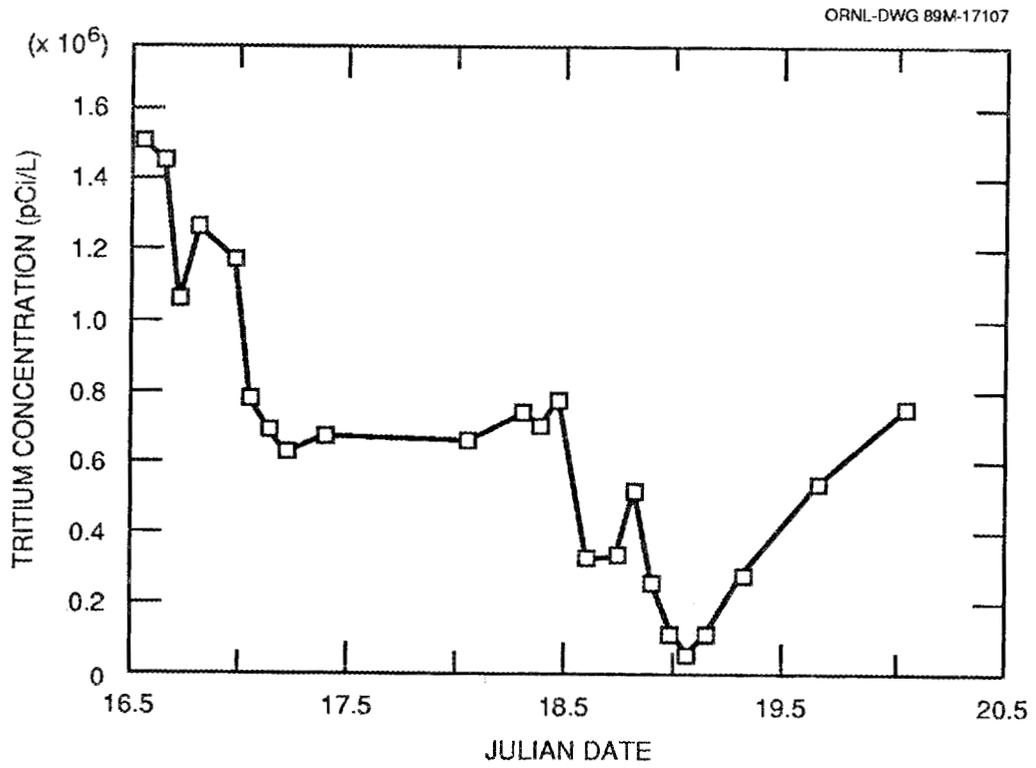


Fig. 15. Melton Branch Stream (MS-4) tritium concentration vs time for the 17-21 January 1988 storm event

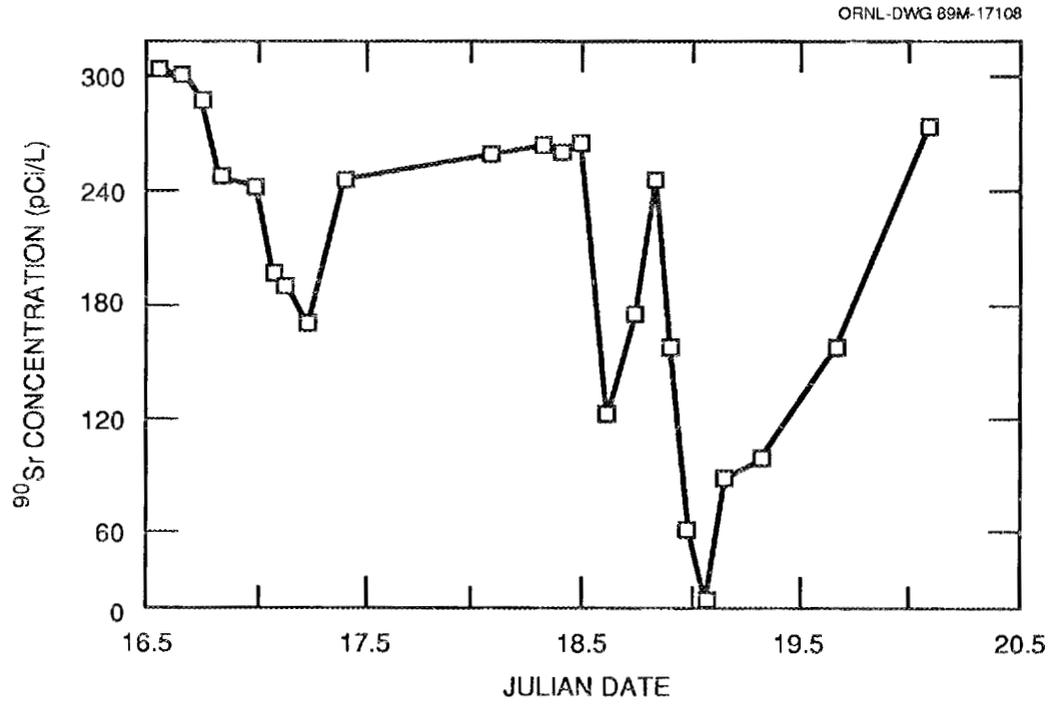


Fig. 16. Melton Branch stream (MS-4)  $^{90}\text{Sr}$  concentration vs time for the 17-21 January 1988 storm event

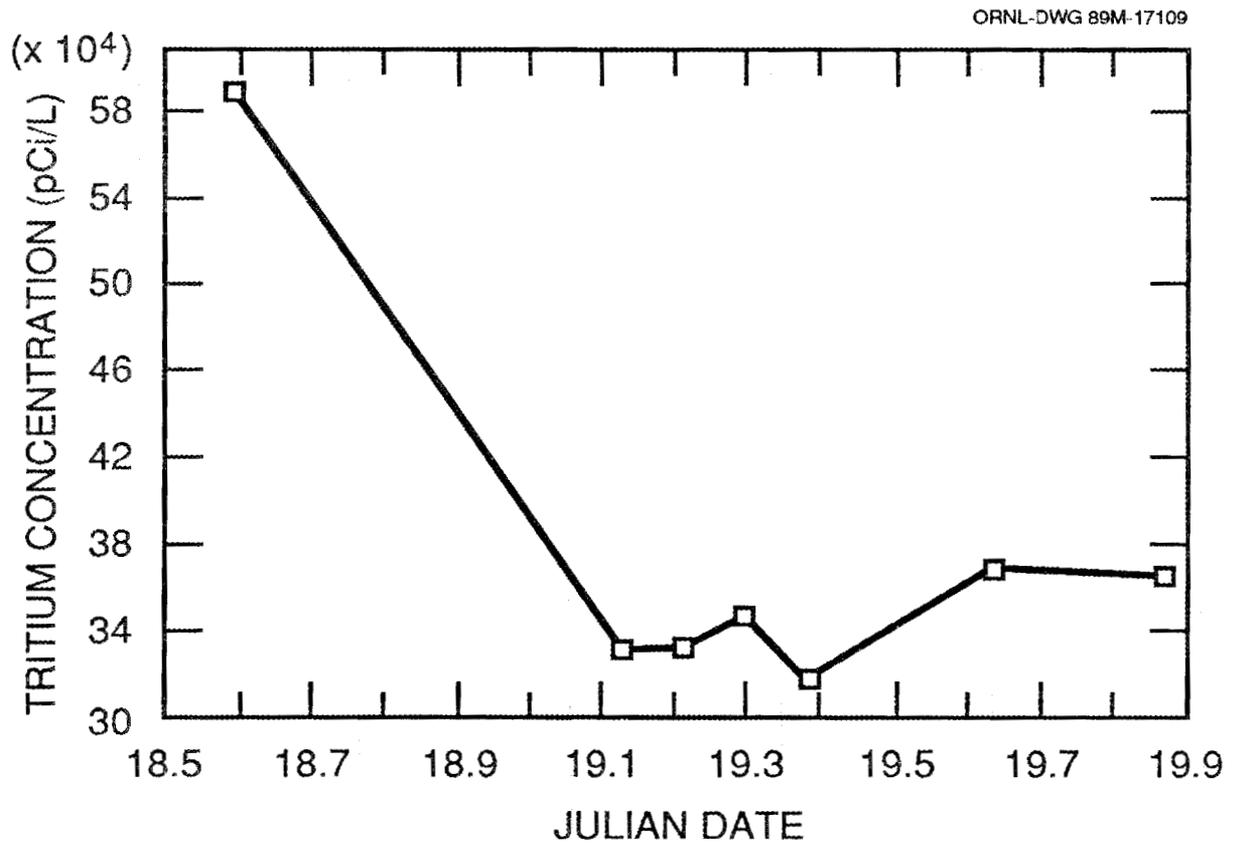


Fig. 17. White Oak Creek (MS-3) tritium concentration vs time for the 19-21 January 1988 storm event

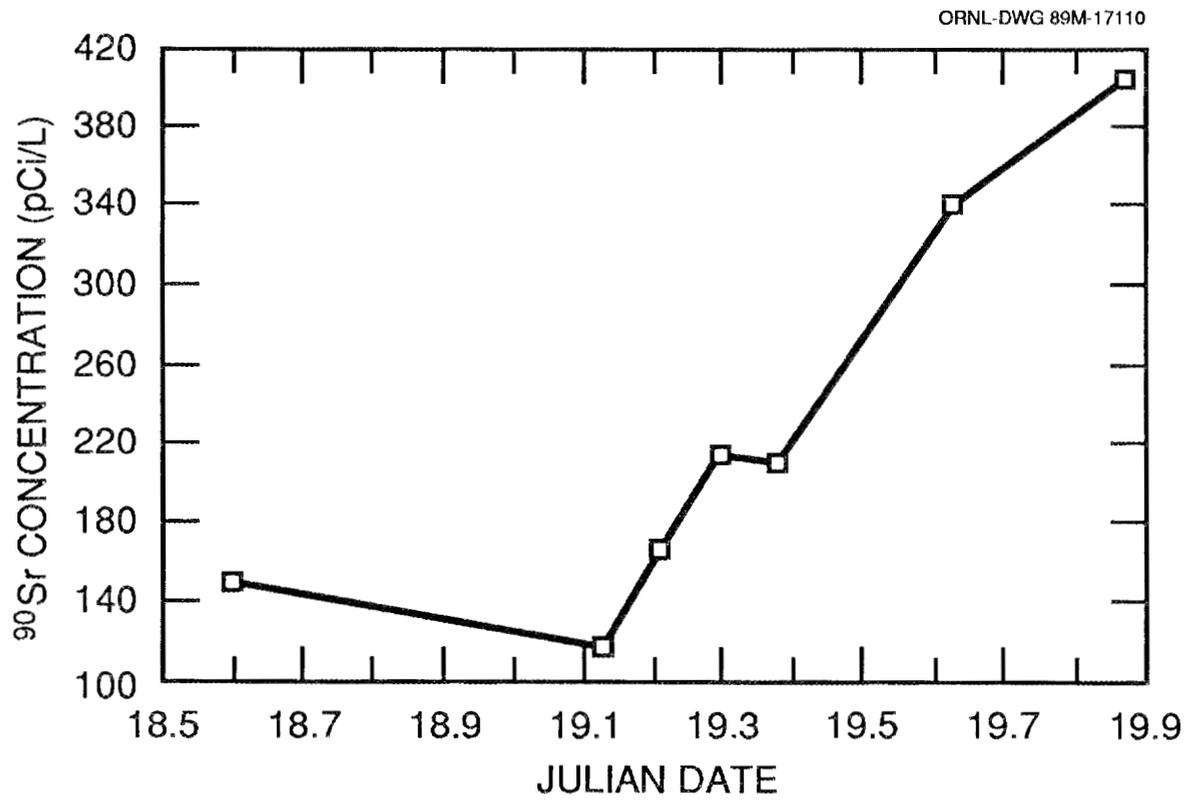


Fig. 18. White Oak Creek (MS-3)  $^{90}\text{Sr}$  concentration vs time for the 19-21 January 1988 storm event

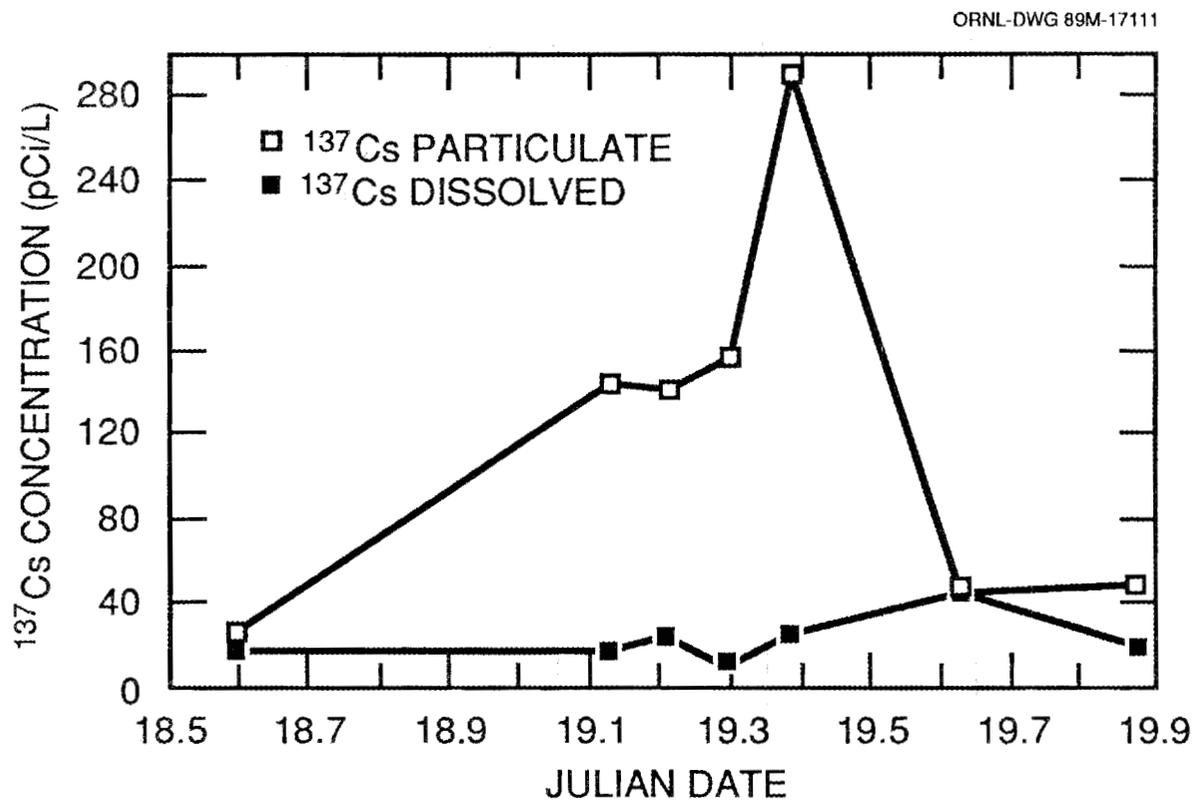


Fig. 19. White Oak Creek (MS-3)  $^{137}\text{Cs}$  concentration vs time for the 19-21 January 1988 storm event

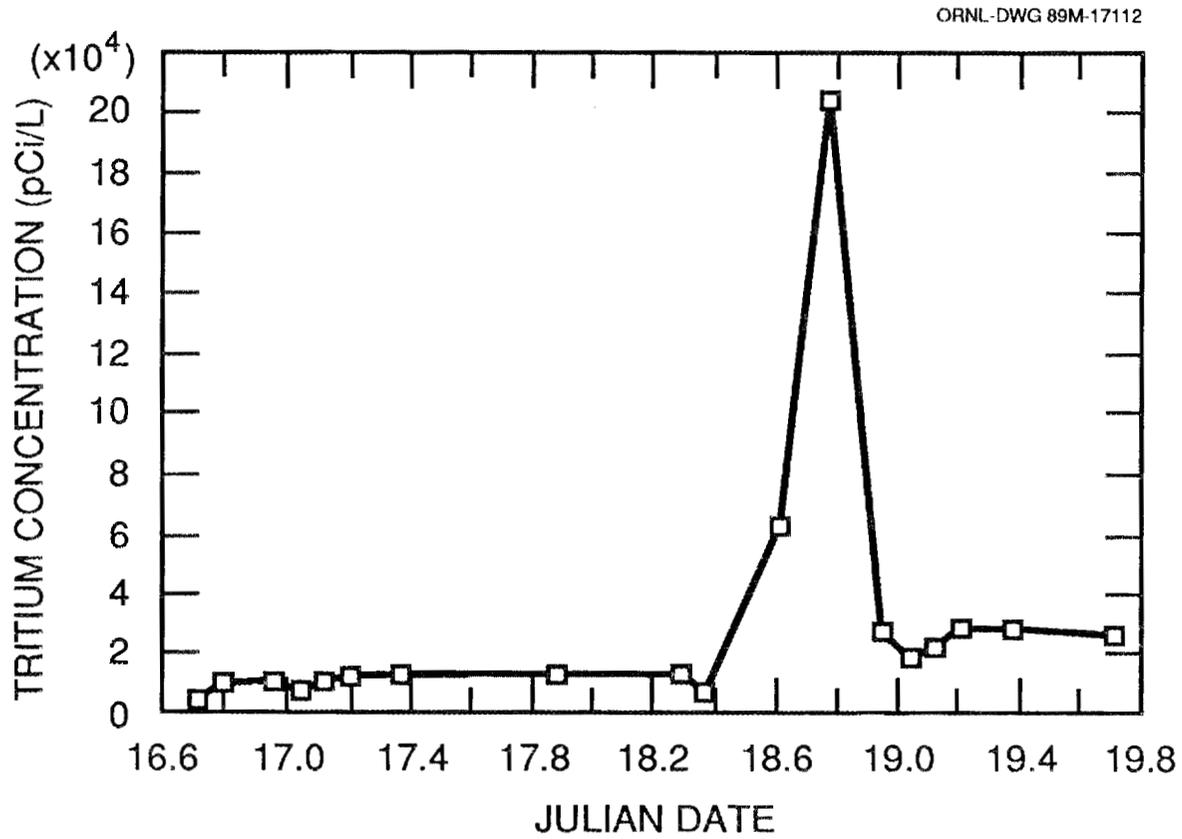


Fig. 20. Melton Branch Tributary (MS-4B) tritium concentration vs time for the 17-20 January 1988 storm event

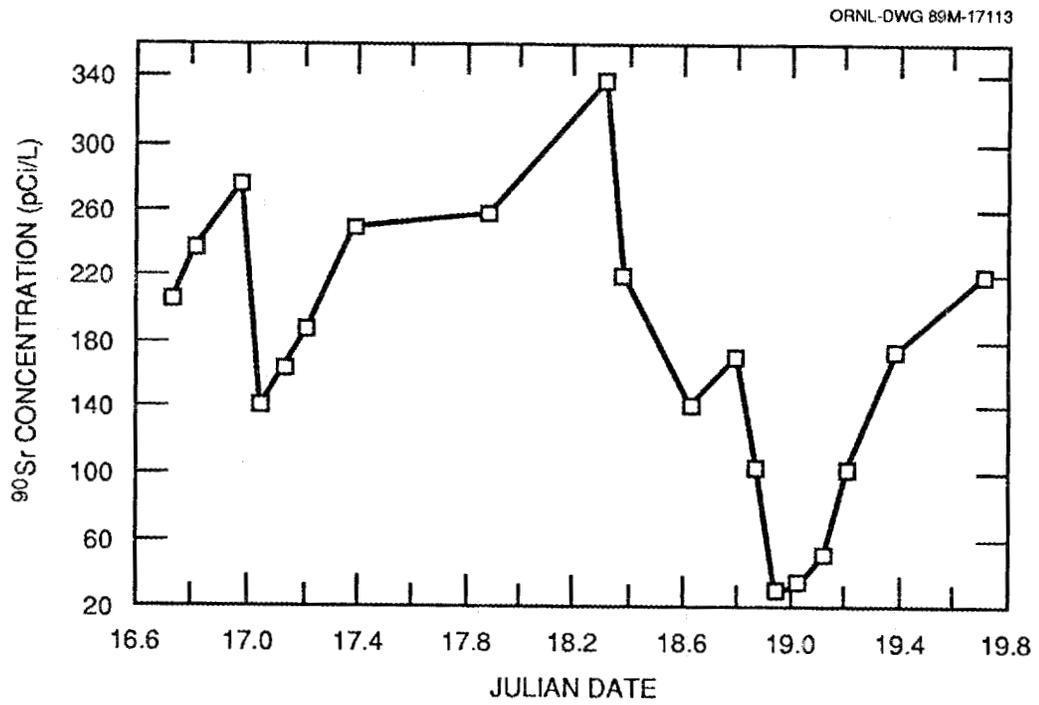


Fig. 21. Melton Branch Tributary (MS-4B)  $^{90}\text{Sr}$  concentration vs time for the 17-20 January 1988 storm event

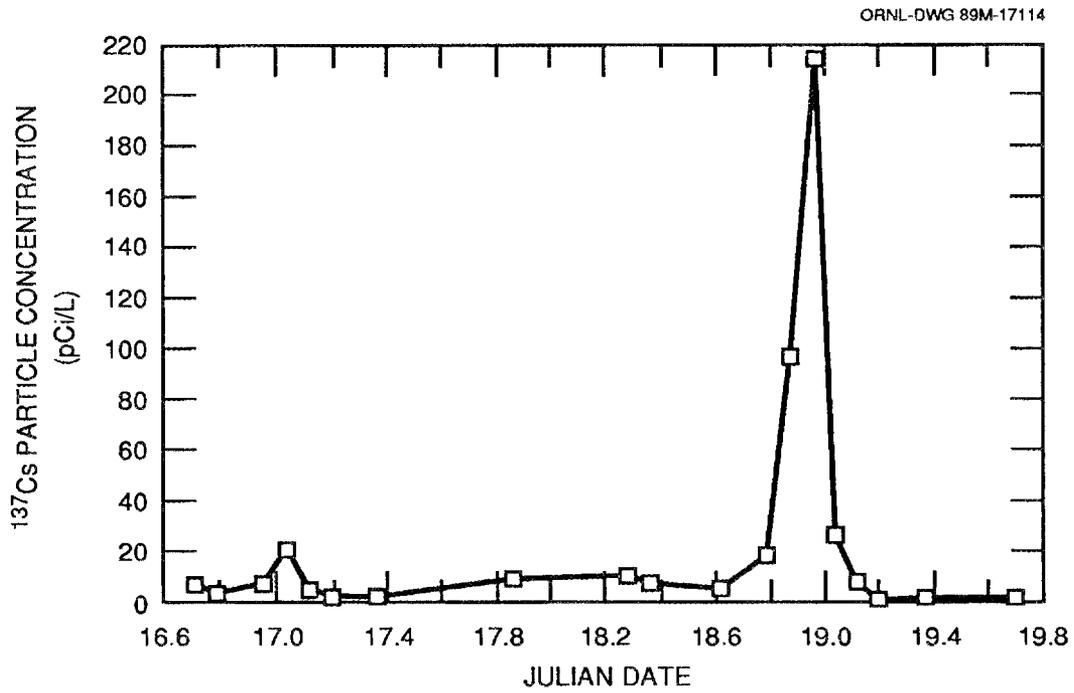


Fig. 22. Melton Branch tributary (MS-4B)  $^{137}\text{Cs}$  particulate concentration vs time for the 17-20 January 1988 storm event.

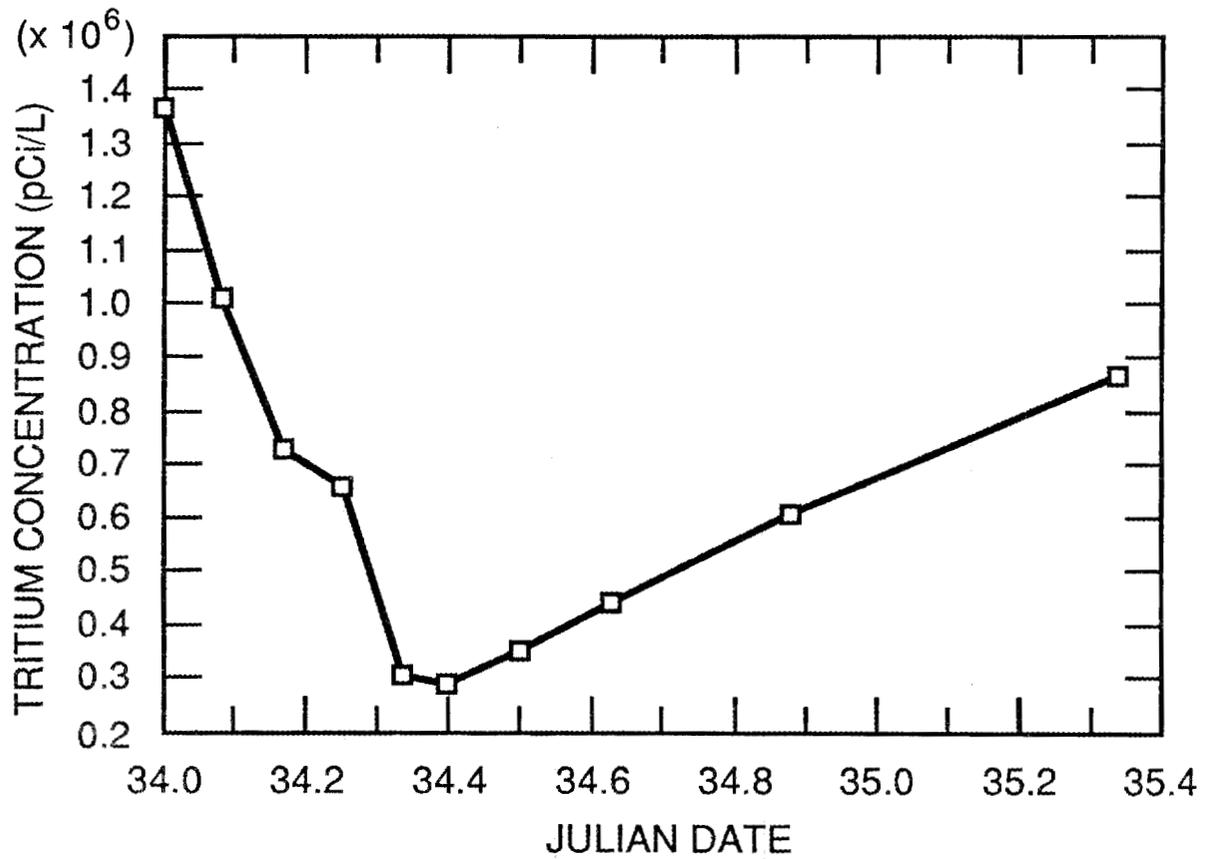


Fig. 23. Melton Branch stream (MS-4) tritium concentration vs time for the 3-5 February 1988 storm event

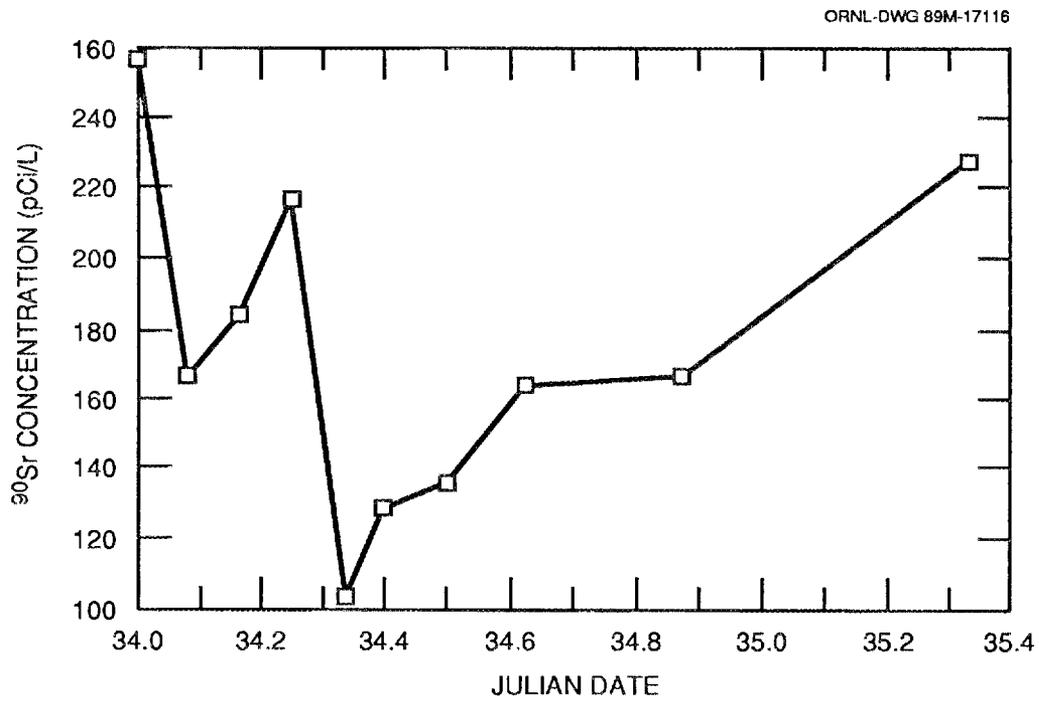


Fig. 24. Melton Branch stream (MS-4)  $^{90}\text{Sr}$  concentration vs time for the 3-5 February 1988 storm event.

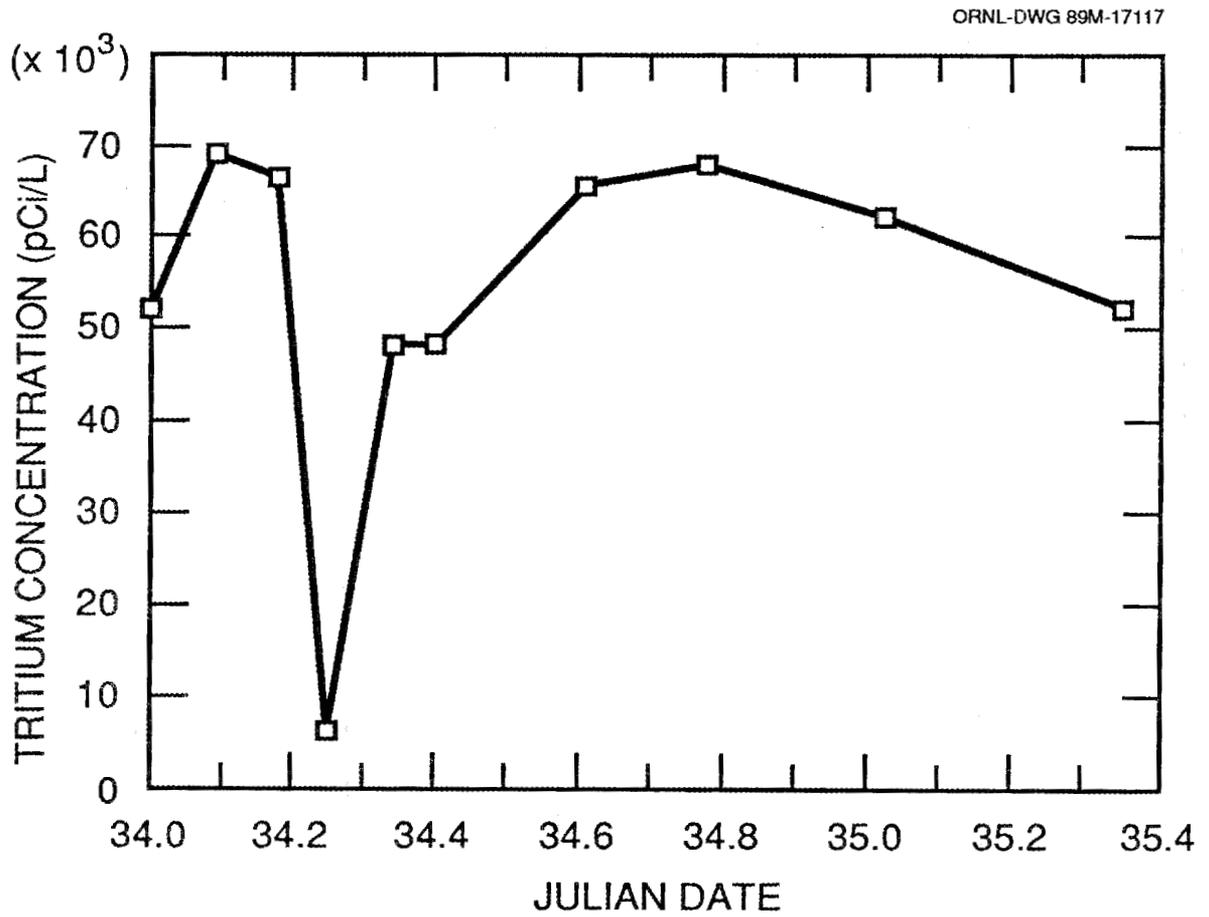


Fig. 25. White Oak Creek (MS-3) tritium concentration vs time for the 3-5 February 1988 storm event

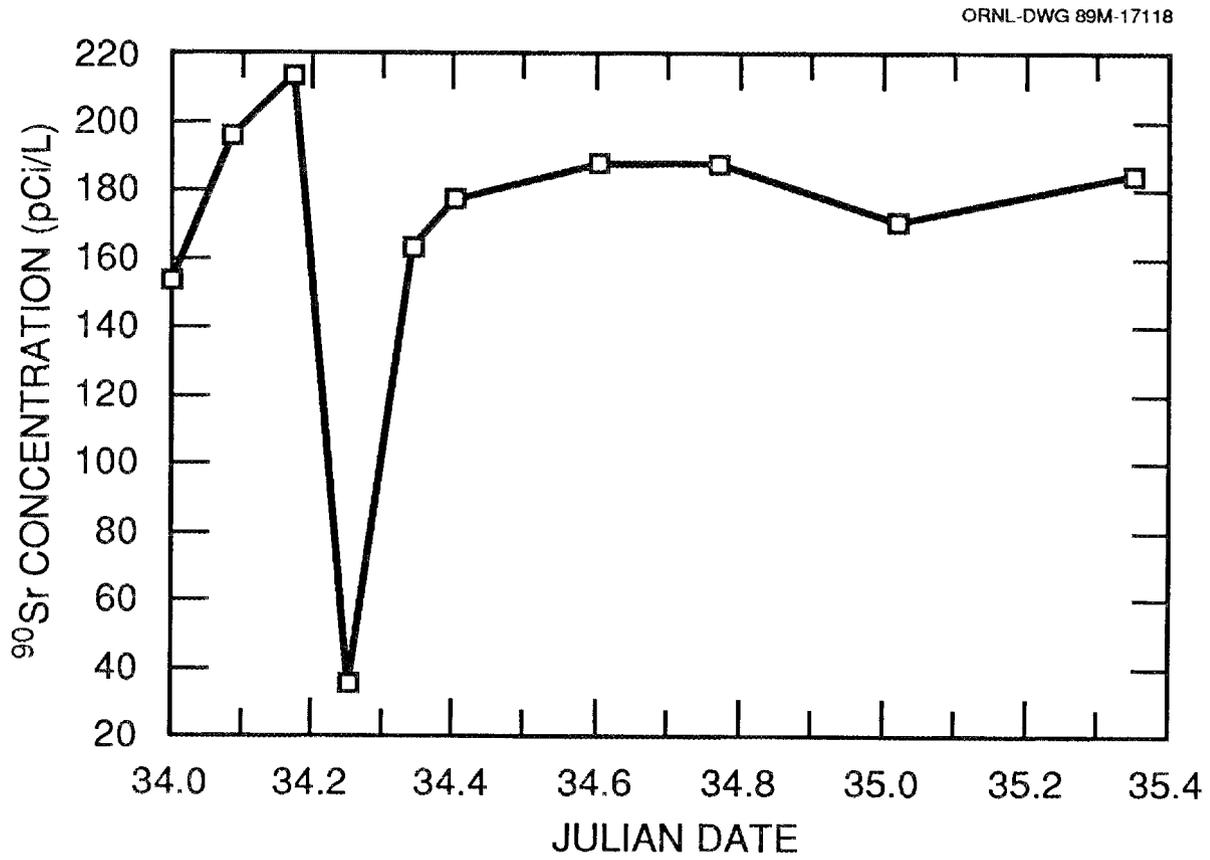


Fig. 26. White Oak Creek (MS-3)  $^{90}\text{Sr}$  concentration vs time for the 3-5 February 1988 storm event

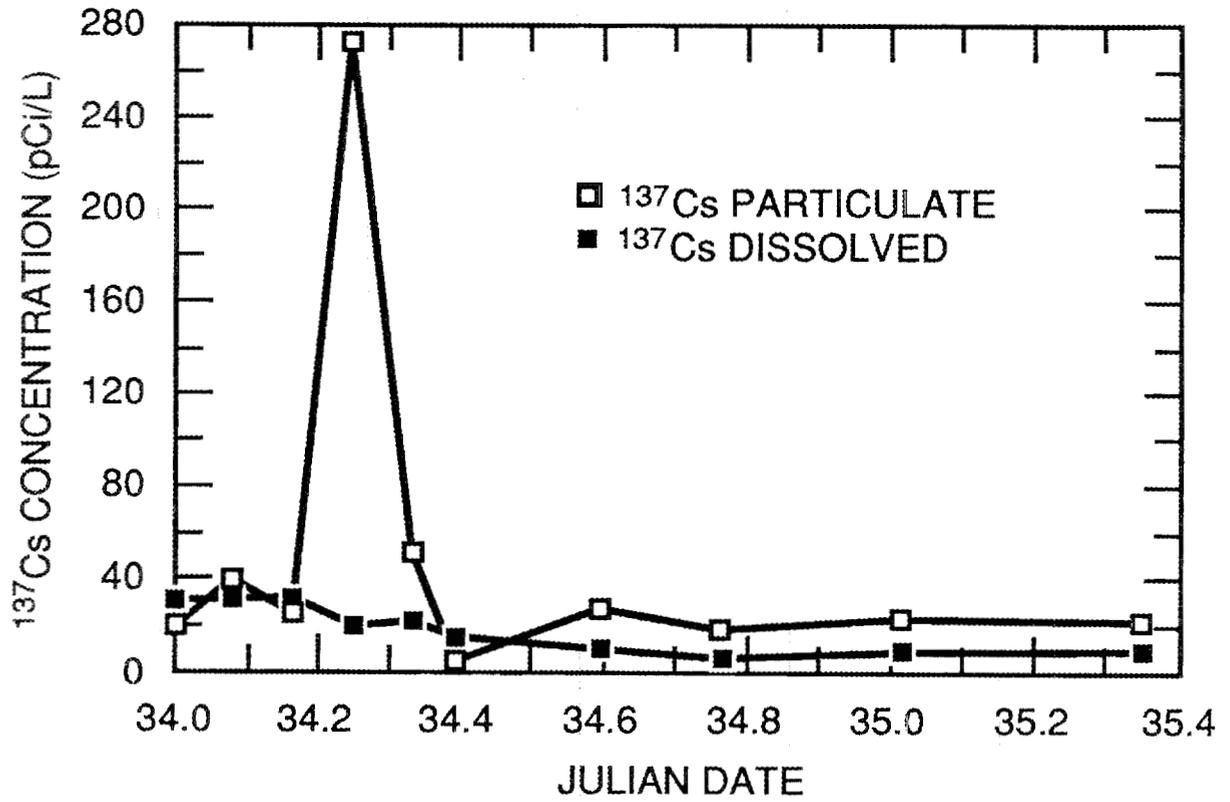


Fig. 27. White Oak Creek (MS-3)  $^{137}\text{Cs}$  concentration vs time for the 3-5 February 1988 storm event

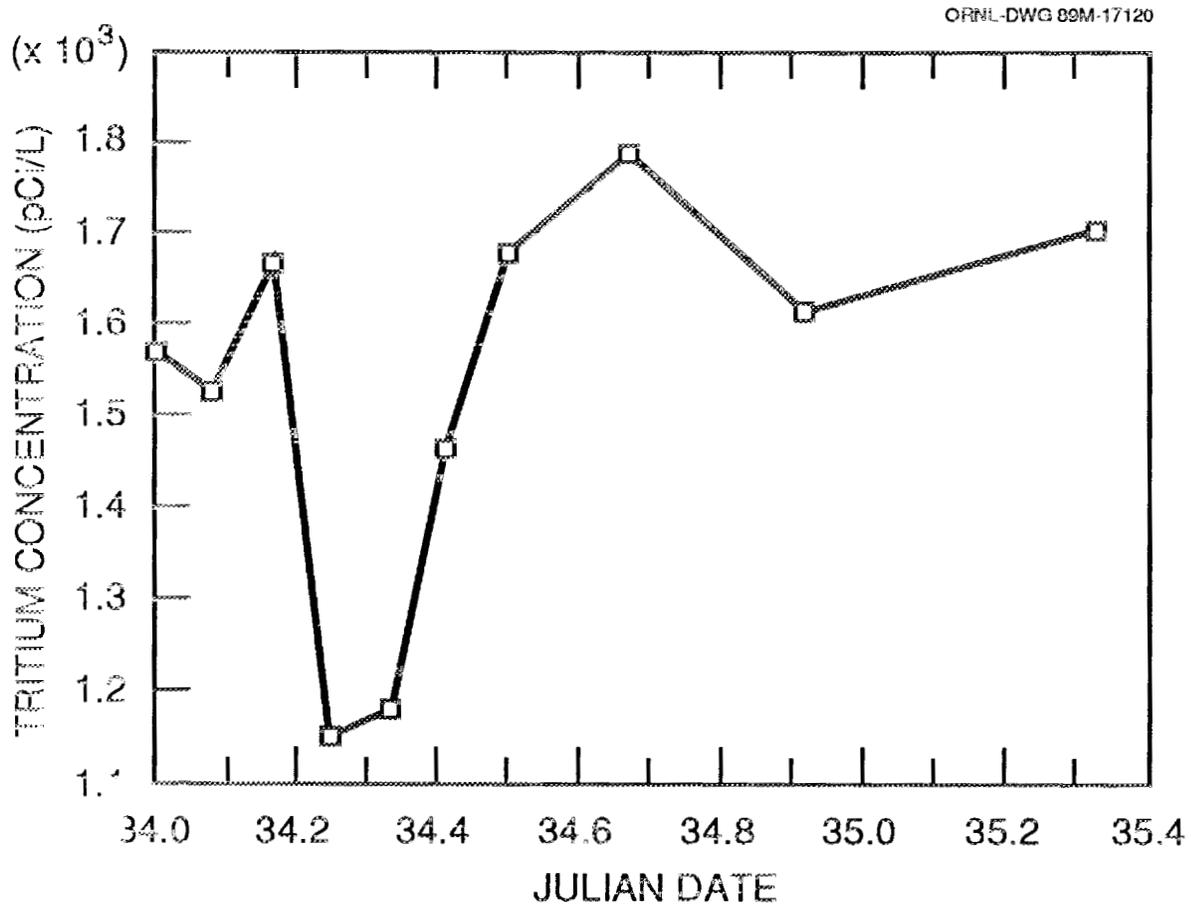


Fig. 28. Melton Branch tributary (MS-4B) tritium concentration vs time for the 3-5 February 1988 storm event

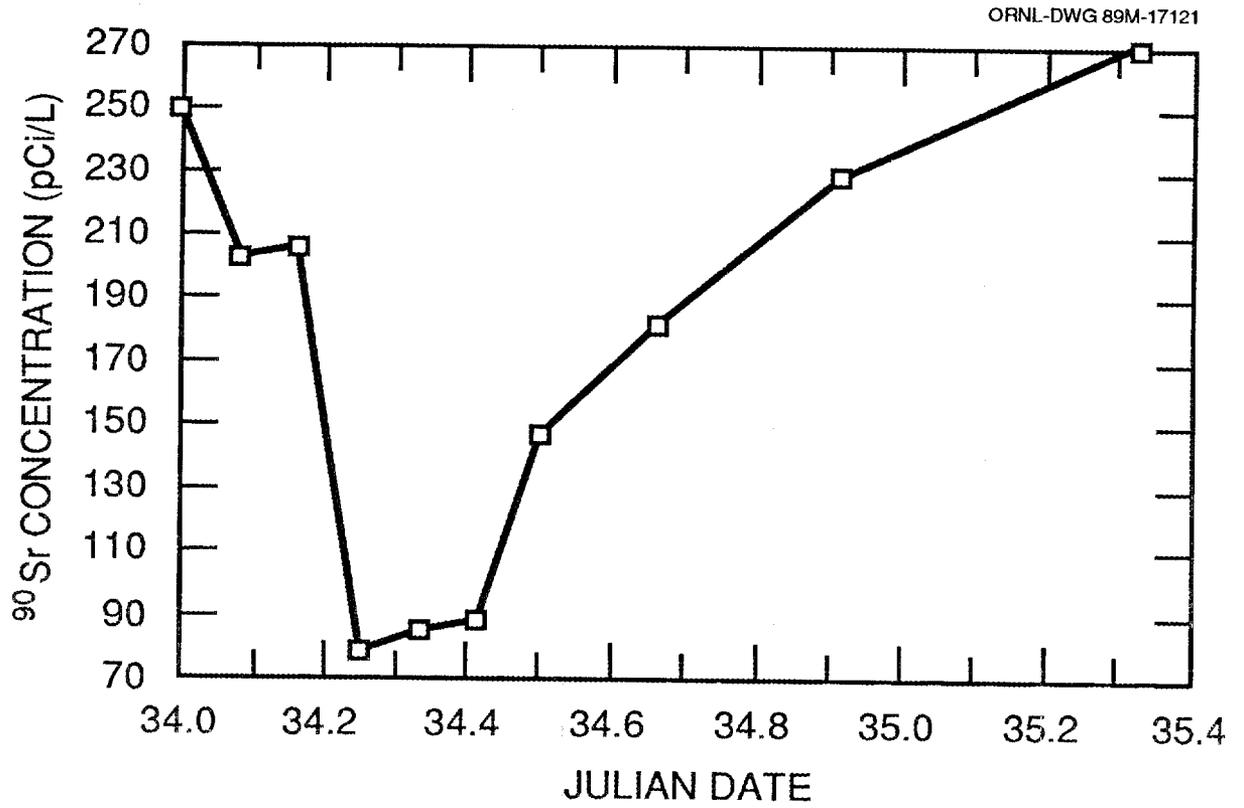


Fig. 29. Melton Branch tributary (MS-4B)  $^{90}\text{Sr}$  concentration vs time for the 3-5 February 1988 storm event

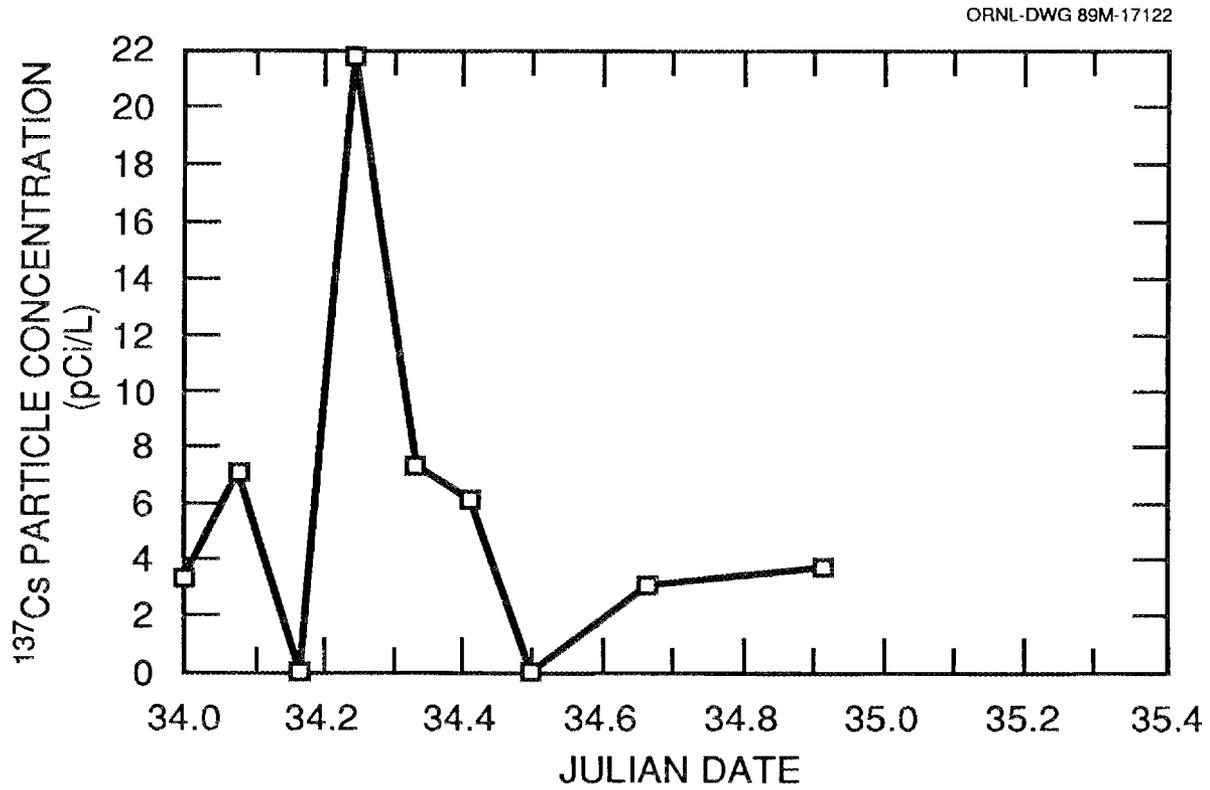


Fig. 30. Melton Branch tributary (MS-4B)  $^{137}\text{Cs}$  particulate concentration vs time for the 3-5 February 1988 storm event

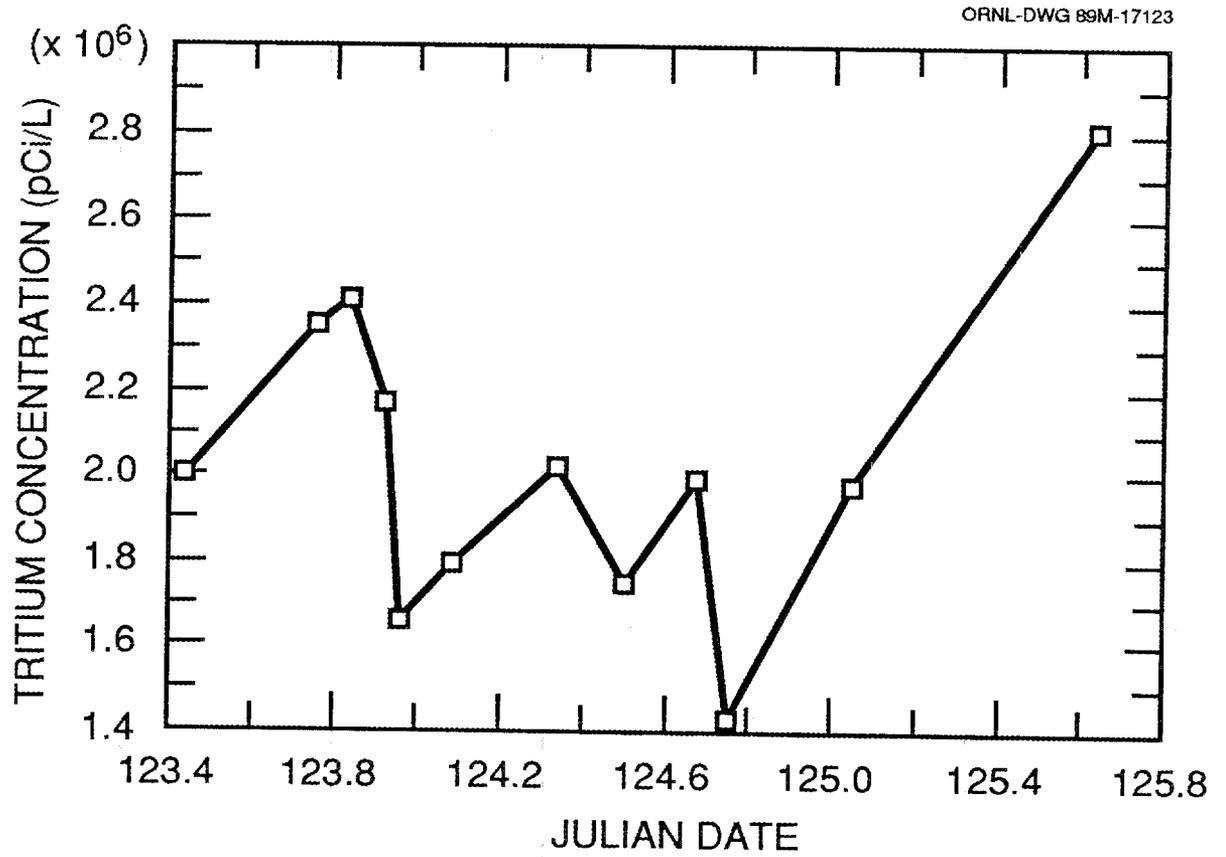


Fig. 31. Melton Branch (MS-4) tritium concentration vs time for the 3-5 May 1988 storm event

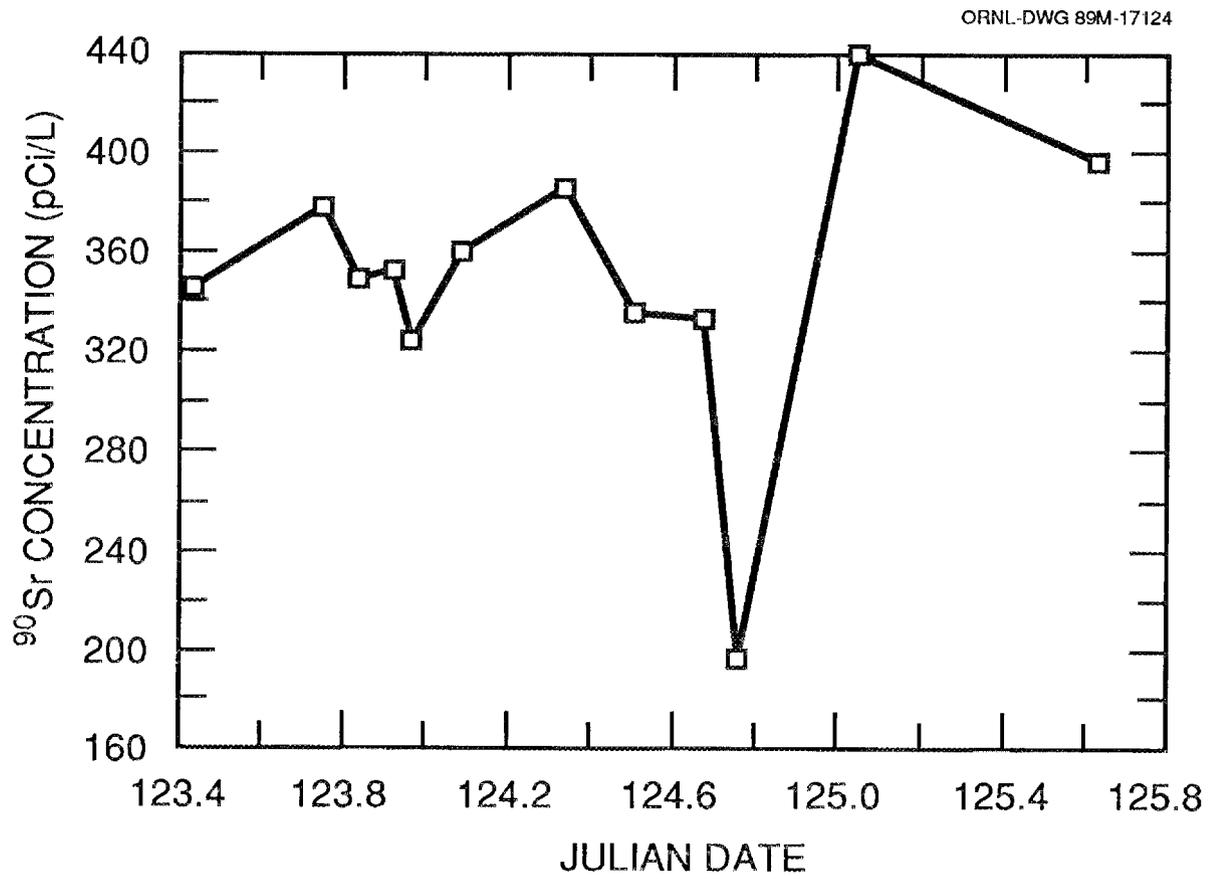


Fig. 32. Melton Branch (MS-4)  $^{90}\text{Sr}$  concentration vs time for the 3-5 May 1988 storm event

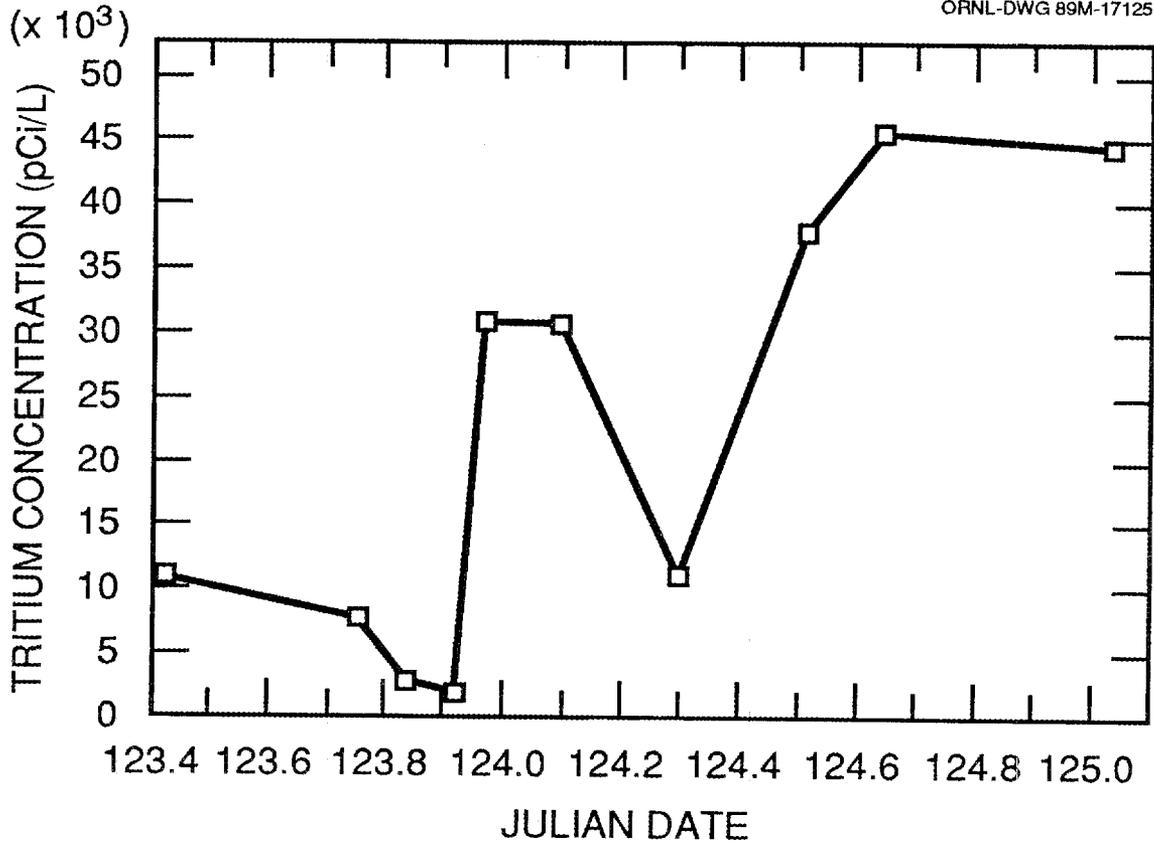


Fig. 33. White Oak Creek (MS-3) tritium concentration vs time for the 3-5 May 1988 storm event

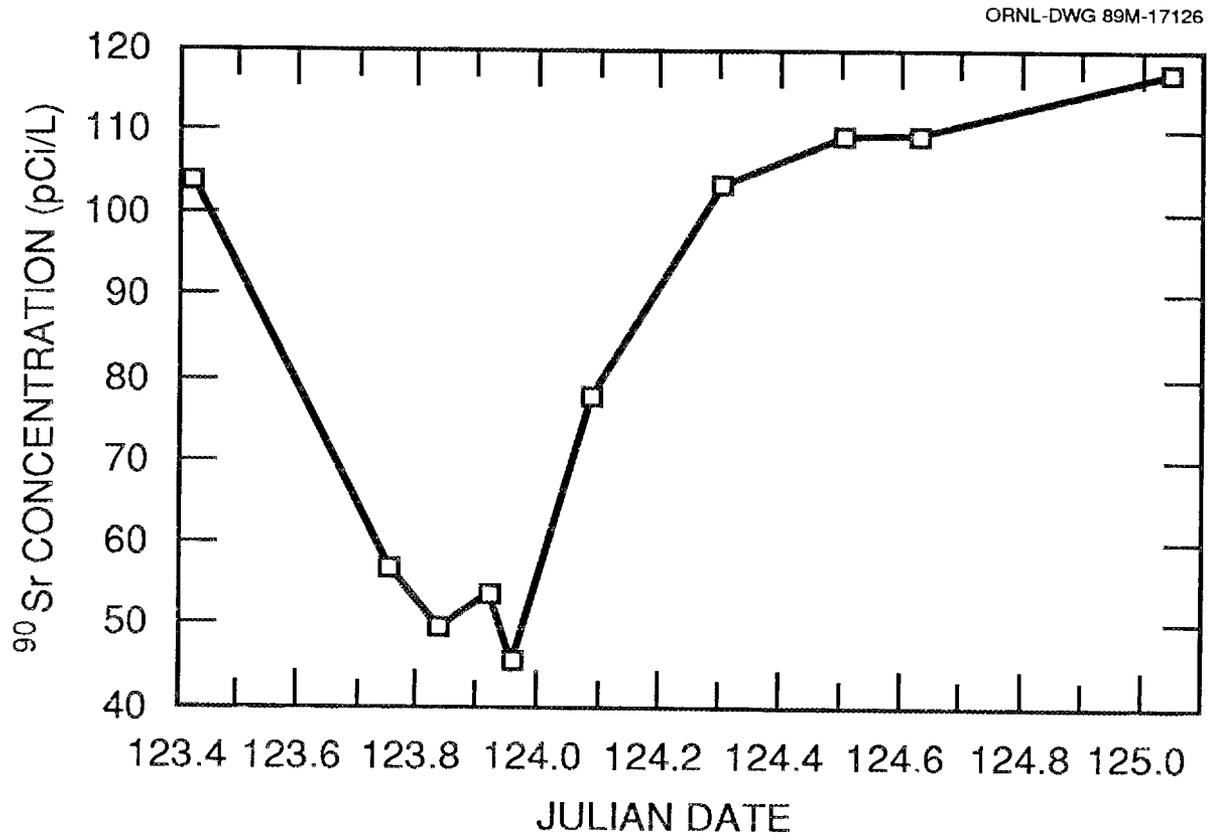


Fig. 34. White Oak Creek (MS-3)  $^{90}\text{Sr}$  concentration vs time for the 3-5 May 1988 storm event

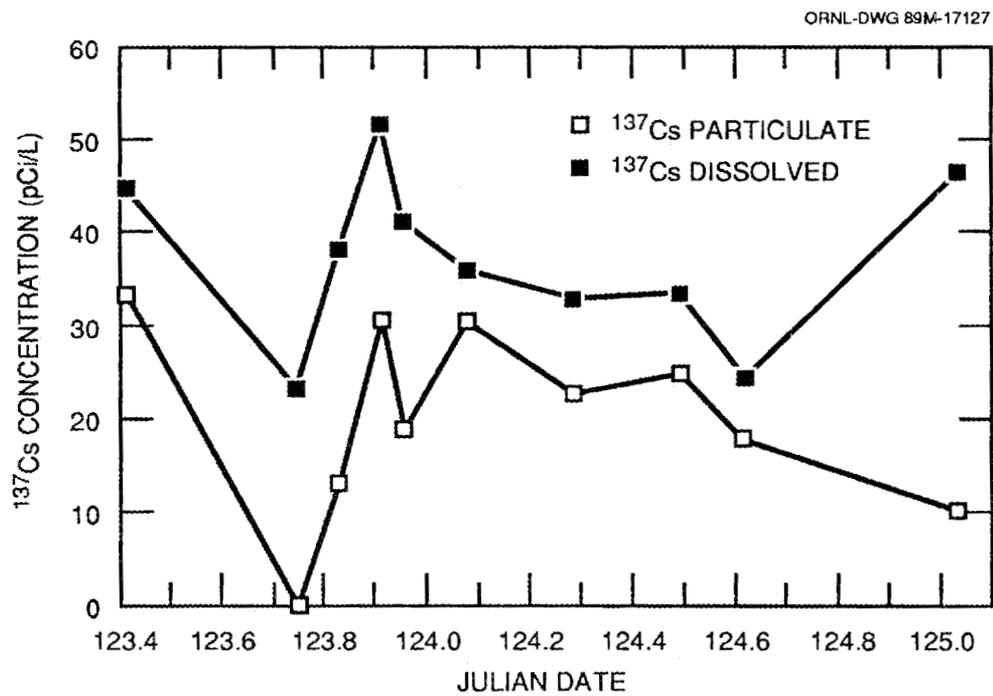


Fig. 35. White Oak Creek (MS-3) dissolved and particulate  $^{137}\text{Cs}$  concentration vs time for the 3-5 May 1988 storm event.

pCi/L of  $^3\text{H}$  and 36 to 438 pCi/L of  $^{90}\text{Sr}$  have been observed in this study. Characterizing the movement of these contaminants through the subsurface is extremely difficult because of (1) extreme heterogeneities in the site geology, (2) lack of data concerning actual contaminant sources, and (3) complex geochemical processes that can control contaminant migration. As a result, an evaluation of active contaminant pathways must be rather general. One possible conceptualization is to divide subsurface contaminant releases into two general categories: transport through the saturated groundwater system below the permanent water table and transport through the vadose zone above the permanent water table. Below the water table, the hydraulic gradient (which is the driving force for fluid flow) results primarily in lateral flow toward discharge areas such as streams. The vadose zone above the water table is generally unsaturated, with a predominantly vertical hydraulic gradient and vertical flow. However, saturated regions perched above the water table can form during storms as a result of discrete, large permeability-contrast zones that exist between the root zone and the C-soil-horizon (Moore 1988). Within these transient saturated zones, significant horizontal hydraulic gradients can develop, resulting in horizontal flow above the water table during storms. Because remediation techniques could be substantially different for each of these conceptual pathways, it is very important that the relative mass of contaminants transported along each pathway be evaluated.

#### 4.1 TOTAL CONTAMINANT RELEASES

The instantaneous release of a contaminant from the subsurface to streams can be computed by multiplying contaminant concentrations in streams by the stream discharge. We will refer to this release as the contaminant mass flow. Figures 36 through 38 show the mass flow for  $^3\text{H}$  and  $^{90}\text{Sr}$  in MB for the January, February, and May storms, and Figs. 39 and 40 show the  $^3\text{H}$  and  $^{90}\text{Sr}$  mass flow in WOC for the February and May storms. As noted in Sect. 3.1, problems occurred with the sampler on WOC during the January storm, and thus a complete set of stream samples was not obtained. These curves were computed by the program MASSFLO,

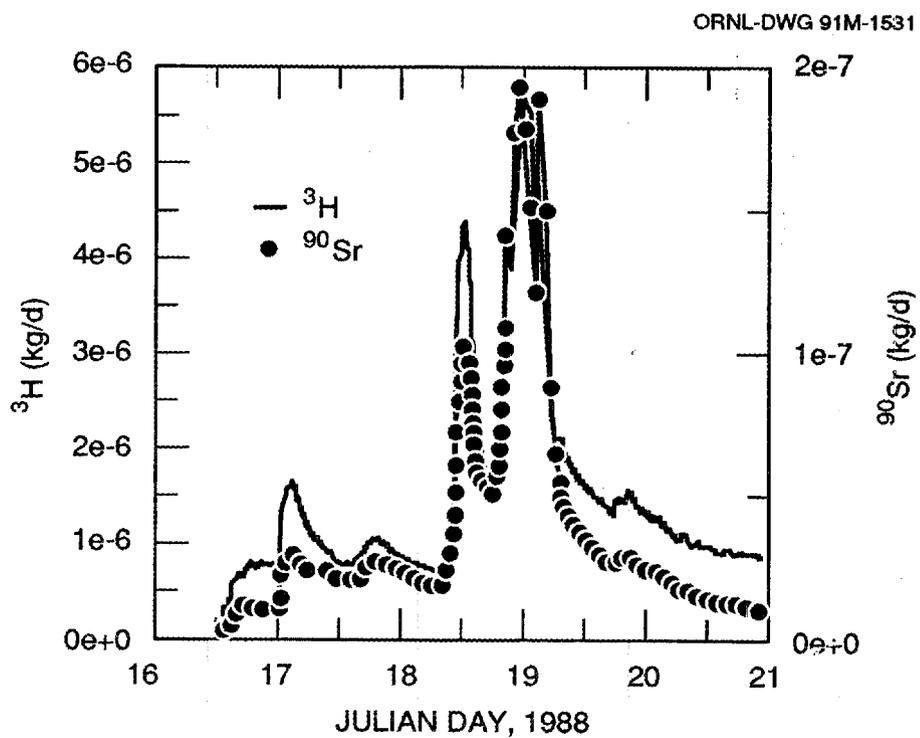


Fig. 36. Mass flow of  $^3\text{H}$  and  $^{90}\text{Sr}$  in Melton Branch at MS 4 during January storm ( $1 \text{ kg } ^3\text{H} = 9.7201 \times 10^6 \text{ Ci}$ ,  $1 \text{ kg } ^{90}\text{Sr} = 1.3890 \times 10^5 \text{ Ci}$ ).

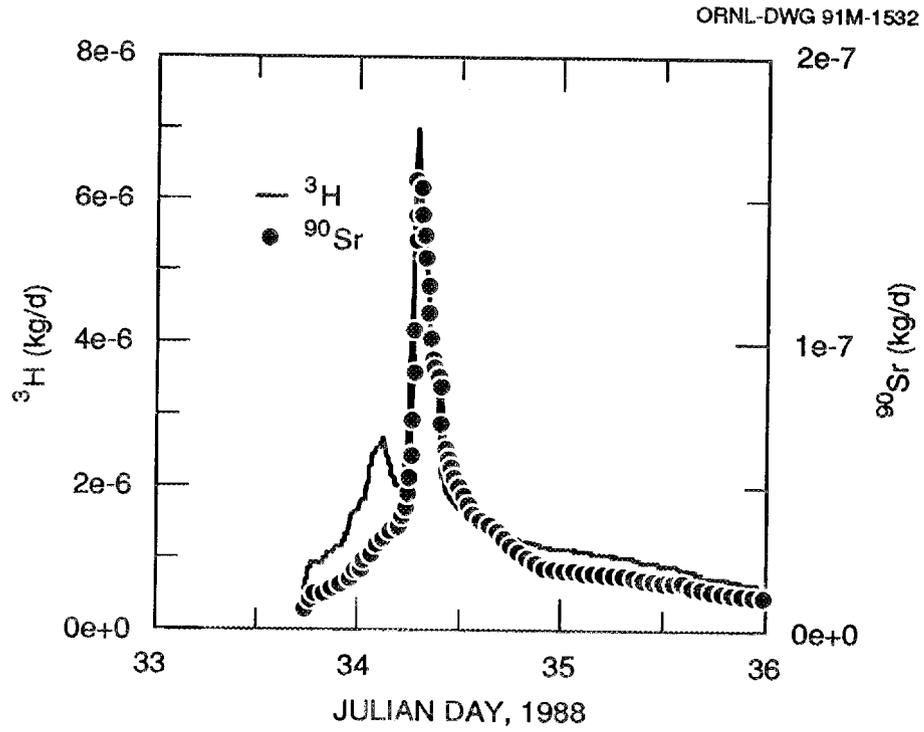


Fig. 37. Mass flow of  $^3\text{H}$  and  $^{90}\text{Sr}$  in Melton Branch at MS 4 during February storm ( $1 \text{ kg } ^3\text{H} = 9.7201 \times 10^6 \text{ Ci}$ ,  $1 \text{ kg } ^{90}\text{Sr} = 1.3890 \times 10^5 \text{ Ci}$ ).

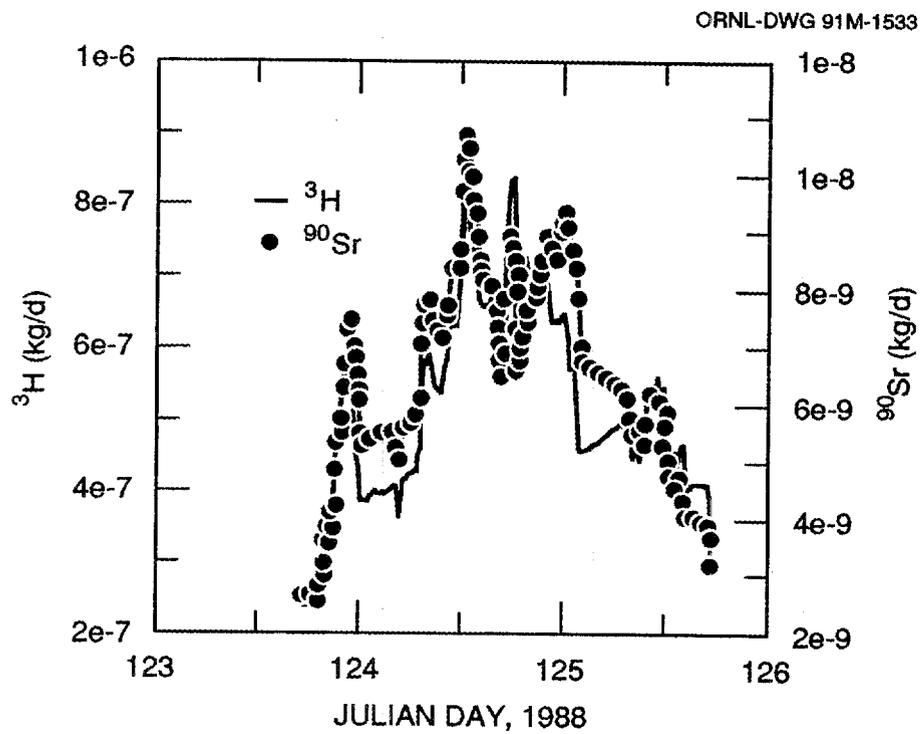


Fig. 38. Mass flow of  $^3\text{H}$  and  $^{90}\text{Sr}$  in Melton Branch at MS 4 during May storm ( $1 \text{ kg } ^3\text{H} = 9.7201 \times 10^6 \text{ Ci}$ ,  $1 \text{ kg } ^{90}\text{Sr} = 1.3890 \times 10^5 \text{ Ci}$ ).

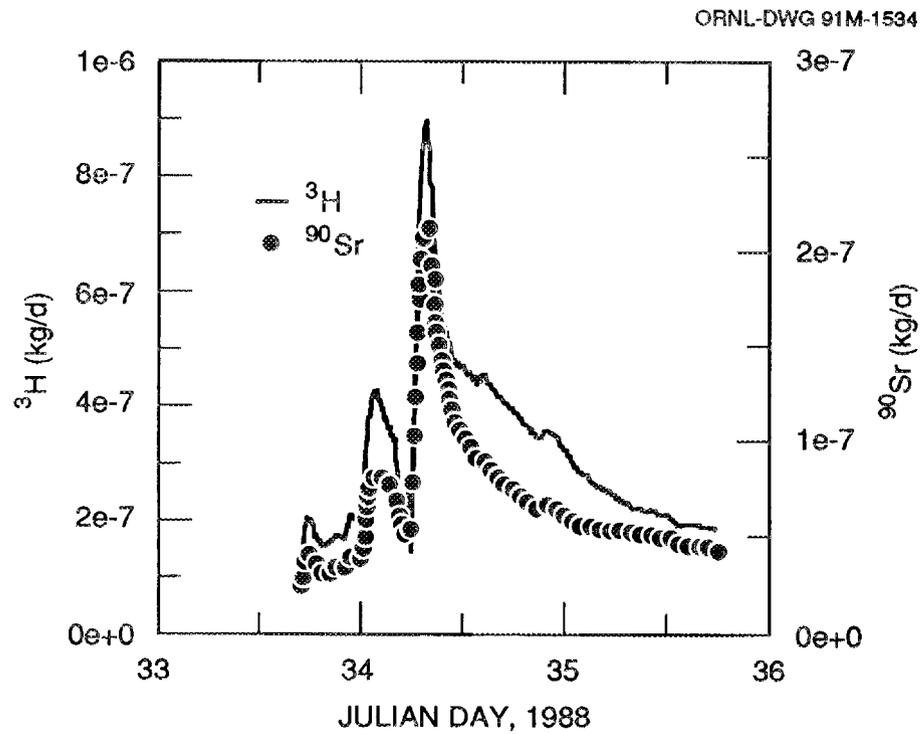


Fig. 39. Mass flow of  $^3\text{H}$  and  $^{90}\text{Sr}$  in White Oak Creek at MS 3 during February storm ( $1\text{ kg } ^3\text{H} = 9.7201 \times 10^6\text{ Ci}$ ,  $1\text{ kg } ^{90}\text{Sr} = 1.3890 \times 10^5\text{ Ci}$ ).

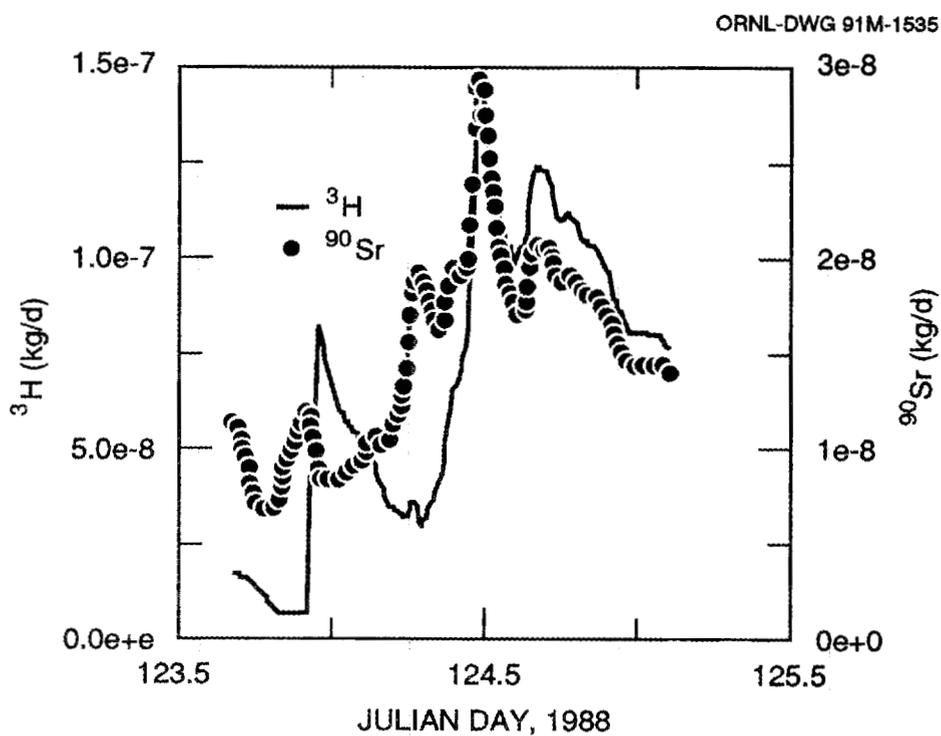


Fig. 40. Mass flow of  $^3\text{H}$  and  $^{90}\text{Sr}$  in White Oak Creek at MS 3 during May storm ( $1\text{ kg } ^3\text{H} = 9.7201 \times 10^6\text{ Ci}$ ,  $1\text{ kg } ^{90}\text{Sr} = 1.3890 \times 10^5\text{ Ci}$ ).

which is described in more detail in the following sections. The most significant feature of Figs. 36 through 40 is the increase in mass flow that occurs during storm periods. For example, the  $^3\text{H}$  mass flow in MB during the January storm changes from 7.2 to 42 Ci/d in less than 5 hours. The primary source of this  $^3\text{H}$  is SWSA 5, which represents only about 7.91% of the MB watershed above the sampling point. Thus, the  $^3\text{H}$  mass flow from SWSA 5 increased by about a factor of six during the January storm, assuming that all of the  $^3\text{H}$  in Melton Branch originated in SWSA 5. The maximum  $^3\text{H}$  mass flow during the January storm in MB was 55 Ci/d and was concurrent with peak discharge. Similar patterns of  $^3\text{H}$  mass flow were observed during the February and May storms. In general, the  $^3\text{H}$  mass flow increases as discharge increases. Thus, the maximum mass flow during the May storm was substantially less than the January and February storms.

As can be seen in Figs. 36 through 40, the  $^{90}\text{Sr}$  mass flow also increases during storms. Although the absolute magnitude of the  $^{90}\text{Sr}$  release is much lower than  $^3\text{H}$ , peak mass flow values for both  $^3\text{H}$  and  $^{90}\text{Sr}$  occur at the same time. For example, the  $^{90}\text{Sr}$  mass flow increased from 2.6 to 15 mCi/d in less than 5 hours during the January storm. The maximum  $^{90}\text{Sr}$  mass flow was 26 mCi/d and, as with  $^3\text{H}$ , occurred at peak discharge of the January storm. The temporal pattern of  $^{90}\text{Sr}$  mass flow was similar during the February and May storms.

In addition to  $^3\text{H}$  and  $^{90}\text{Sr}$ , the measured concentrations of  $^{137}\text{Cs}$ , along with a variety of metals, were used to compute the total mass released during a storm. Data on the total releases of  $^3\text{H}$ ,  $^{90}\text{Sr}$ , Ca, Na,  $\text{SiO}_2$ , and  $^{137}\text{Cs}$  (both dissolved and sorbed to suspended particulate matter) are shown in Table 1. Total values were computed by the program MASSFLO by integrating the instantaneous mass flow values over the duration of the storm. Also shown in Table 1 is the total stream discharge for the storms monitored. Discharge in WOC is between 2 and 6 times greater than the discharge in MB, partly because of differences in the areas of the two catchments, 3.91 km<sup>2</sup> for MB and 9.35 km<sup>2</sup> for WOC. Although stream discharge is greater, the total  $^3\text{H}$  release in WOC is 2 to 10 times less than MB. This reflects the substantial release of  $^3\text{H}$  from SWSA 5 into MB. Unlike  $^3\text{H}$ , the total  $^{90}\text{Sr}$  release is greater in

Table 1. Total release of contaminants and major ions in Melton Branch and White Oak Creek during storms

Stream	Storm	Discharge (m <sup>3</sup> )	<sup>3</sup> H (Ci)	<sup>90</sup> Sr (Ci)	Ca (Kg)	Na (Kg)	SiO <sub>2</sub> (Kg)	<sup>137</sup> Cs-p (mCi)	<sup>137</sup> Cs-d (mCi)
Melton Branch	Jan.	196,000	59.9	0.0228	3470	664	1090	ID	ID
	Feb.	52,600	30.6	0.0088	1230	194	348	ID	ID
	May	3,610	6.52	0.0011	NA	NA	NA	ID	ID
White Oak Creek	Feb.	138,000	7.12	0.0226	5330	1490	639	7.01	2.10
	May	27,200	0.752	0.0025	NA	NA	NA	ID	ID

<sup>a</sup>ID = Insufficient data for reliable estimate.

<sup>b</sup>NA = No analysis.

White Oak Creek by about a factor of 2. A significant portion of this  $^{90}\text{Sr}$  is probably discharging from SWSA 4 and from the main plant area via First Creek. Analyses for major ions were not performed on all samples, and thus comparisons between WOC and MB are only possible for the February storm. The total Ca release was about 4 times larger in WOC than Melton Branch during the February storm, whereas the total Na release was about 6 times larger. The total release of dissolved silica was greater in MB than in WOC during the February storm. This difference is most likely related to the geology of the two watersheds. Several members of the Conasauga Shale, including the Maryville and Nolichucky members, underlie the MB watershed. Although some members of the Conasauga Shale are referred to as limestone (e.g., Maryville Limestone) the shale content is high. Because hydrous aluminum silicates are the primary minerals in shale, it is not surprising that MB streamflow is enriched in  $\text{SiO}_2$  relative to WOC. Much of the WOC watershed is underlain by the Chickamauga Group, consisting of limestone and shales, and the Knox group, consisting primarily of dolostone, which has a substantially lower silica content. This difference in silica release represents an important difference in the two watersheds. The cation exchange capacity of clay minerals (hydrous aluminum silicates) is very large relative to carbonate minerals that dominate the mineralogy of the Chickamauga and Knox groups. The mobility of many contaminants is significantly reduced by the process of ion exchange. Thus, the mobility of exchangeable contaminants in MB watershed is expected to be reduced relative to WOC watershed. Although it was possible to detect  $^{137}\text{Cs}$  in some of the samples from MB, sufficient results for an entire storm period could not be obtained and, thus, a meaningful total release could not be calculated. During the February storm, 7.01 mCi of particulate-sorbed  $^{137}\text{Cs}$  and 2.10 mCi of dissolved  $^{137}\text{Cs}$  were computed to be released in WOC. During the May storm, which had much less total stream discharge, the computed  $^{137}\text{Cs}$  release was 0.602 mCi particulate-sorbed and 1.17 mCi dissolved. As expected, the release of particulate sorbed  $^{137}\text{Cs}$  is a strong function of stream discharge because the stream velocity must be sufficient to suspend the particulate matter. The release of dissolved  $^{137}\text{Cs}$  is also a function

of stream discharge but much less so than the particulate-sorbed fraction. The distinction between particulate-sorbed and dissolved  $^{137}\text{Cs}$  is rather arbitrary and is based on passage through a  $0.45\text{-}\mu\text{m}$  filter. As a result, it is difficult to make further conclusions regarding the release of particulate-sorbed vs dissolved  $^{137}\text{Cs}$  in this study.

#### 4.2 CONTAMINANT PATHWAYS

From the  $^3\text{H}$  and  $^{90}\text{Sr}$  base flow concentrations, there is no doubt that contaminants are being transported through the saturated groundwater system. As discussed in Sect. 4.1, the mass flow of contaminants such as  $^3\text{H}$  and  $^{90}\text{Sr}$  increases during storm periods. If the saturated groundwater system were the only source of contaminants to streams, the discharge of contaminated groundwater would have to increase proportionally to the increase in the contaminant mass flow. Although the saturated groundwater system is highly fractured, it is reasonable to assume that groundwater movement is governed by Darcy's law:  $q = KI$ , where  $q$  is the specific discharge,  $K$  is the effective hydraulic conductivity for the fractured system, and  $I$  is the hydraulic gradient. In a saturated system, the hydraulic conductivity  $K$  is constant and, thus, a change in the specific discharge  $q$  results from a change in the hydraulic gradient. Although hydraulic head measurements were not a part of this study, continuous monitoring of piezometers near streams in SWSA 6 during storms suggest that only small changes in the hydraulic gradient are likely to occur. Thus, the increased mass flow during storms cannot be explained by an increase in contaminated groundwater discharge.

An alternative pathway for the transport of contaminants during storms is the region above the water table that can become temporarily saturated during storms. Because the saturated groundwater system below the water table would still be delivering contaminants to the streams, the lateral transport of contaminants above the water table would represent an additional source and, thus, cause the mass flow to increase. The majority of wastes in SWSA 5 were disposed of above or

near the water table in unlined trenches. Several studies of trenches in SWSA 4 and SWSA 5 have shown that during storms bathtubbing occurs, which could then result in rapid lateral transport.

The dynamics of stream flow generation is such that rapid movement of shallow storm flow is required if the increase in groundwater discharge is small. For example, streamflow in MB during the January storm increased from 9700 to 71,500 m<sup>3</sup>/d in less than 6 h. Examination of the storm hydrographs (Figs. 2 through 7) shows that the rapid increase in stream discharge is followed by a more gradual decline. In fact, streamflow near the end of a storm period, as the slope of the hydrograph approaches 0, is generally greater than the streamflow before the storm. This has lead to the concept of quick flow and delayed flow, used for many years in surface-water hydrology. Stream discharge is viewed as resulting from two components: quick flow accounts for the rapid increase in discharge near the peak of the hydrograph, and delayed flow accounts for the increased discharge near the end of the storm period.

A number of techniques have been used to separate quick flow from delayed flow. Perhaps the simplest and easiest to implement is the technique described by Hewlett and Hibbert (1967). This approach was applied to the Walker Branch watershed on the Oak Ridge Reservation by Huff and Begovich (1976). The technique is illustrated in Fig. 41. Quick flow is separated from delayed flow by a straight line of constant slope. The volume of quick flow is represented by the area of the hydrograph above the separation line. This streamflow separation technique was extended by Huff et al. (1978) to consider the concentration of species associated with the delayed and quick-flow components. The concentration of species in delayed flow was assumed to vary linearly from the start to the end of the storm. The concentration in quick flow was then calculated as the difference between measured concentrations of total flow and the estimated concentration in delayed flow.

Strictly speaking, quick flow and delayed flow computed using this hydrograph separation method represent regions of the stream hydrograph and cannot be rigorously linked to physical transport pathways.

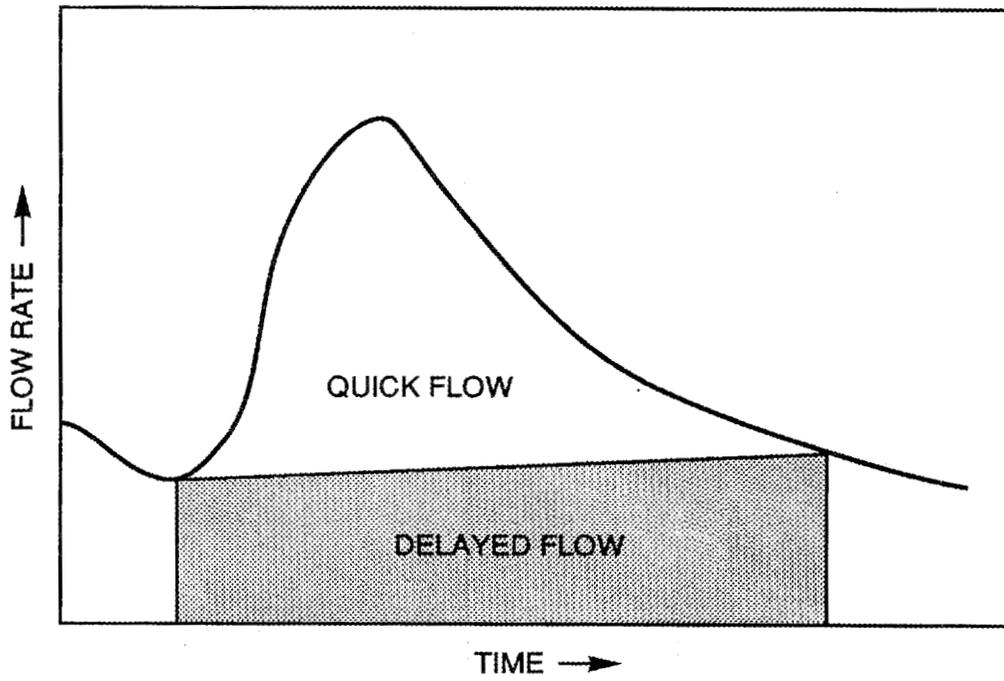


Fig. 41. Method of hydrograph separation.

However, Huff et al. (1978) found that the concentration of certain species are more strongly related to one of the stream flow components than the other. Thus, it seems reasonable to associate delayed flow with groundwater discharge from below the water table and quick flow with subsurface storm flow above the water table.

The concept of streamflow separation was used to examine the release of contaminants in MB and WOC during storms. A computer program called MASSFLO was written to perform hydrograph separation and calculate the mass flow of species in quick flow. The program was patterned after the one used by Huff et al. (1978). Input to the program includes streamflow measurements, concentration measurements, the starting and ending times of the storm, and the starting and ending streamflows and concentrations. The total mass flow at any given time is computed as the product of stream discharge and concentration. Total mass flow is computed at every point in time in which a streamflow measurement was made. Because the frequency of streamflow measurements was much greater than concentration measurements, linear interpolation is used to estimate concentrations between actual measurements. The mass flow associated with delayed flow is computed as the product of the estimated delayed flow (from the streamflow separation line) and the estimated delayed flow concentration. As previously indicated, the delayed flow concentration was assumed to vary linearly from the start to the end of the storm. The mass flow associated with quick flow is then computed as the difference between the total and the delayed mass flows. The total release of a given species is simply the integral of the total mass flow, evaluated between the beginning and ending of the storm. Total release values were thus computed by numerically integrating the mass flow values over time using the trapezoid rule. Because delayed flow and the concentration of delayed flow are linear functions of time, the release associated with delayed flow was computed by analytically integrating the mass flow data over time. The contaminant release associated with quick flow was then computed as the difference between the total and delayed flow values. A listing of the source code can be found in Appendix B.

The program was checked by computing a hypothetical synthetic hydrograph where streamflow was given by

$$\text{discharge} = 50\sin[2\pi(\text{time} - 0.25)] + 51 ,$$

and the concentration of some ion was given by:

$$\text{concentration} = \sin[2\pi(\text{time} - 1)] .$$

Time ranged from 0 to 1, and the total release computed from MASSFLO was then compared with the value obtained using existing numerical integration software (Hewlett-Packard 1982). The relative error was less than 0.01%, and thus the program was deemed to be functioning correctly.

The program MASSFLO was used to estimate the relative fractions of quick and delayed flow for the January, February, and May storms in MB and the February and May storms in WOC. The slope of the hydrograph separation lines were  $2230 \text{ m}^3 \text{ d}^{-2}$  for MB and  $5330 \text{ m}^3 \text{ d}^{-2}$  for WOC. These slopes are smaller by about a factor of 2 than the suggested value (Huff et. al 1978) and were chosen to prevent negative computed concentrations in quick flow, which occurred when the recommended value was used. A sensitivity analysis showed that the relative fractions of quick and delayed flow were not extremely sensitive to the hydrograph separation slope. The results are shown in Figs. 42 through 46. Approximately 60% of the  $^3\text{H}$  release during the January and February storms and 25% during the May storm resulted from quick flow in MB. In WOC about 51% during February and 10% during May of the  $^3\text{H}$  release resulted from quick flow. In MB the fraction of  $^{90}\text{Sr}$  resulting from quick flow was always greater than that for  $^3\text{H}$ . Approximately 75%, 67%, and 27% of the  $^{90}\text{Sr}$  release resulted from quick flow during the January, February, and May storms respectively in MB. In WOC however, the fraction of quick flow responsible for  $^{90}\text{Sr}$  release was less than the quick flow release of  $^3\text{H}$ , with about 50% and 1% resulting from quick flow during the February and May storms, respectively. One possible

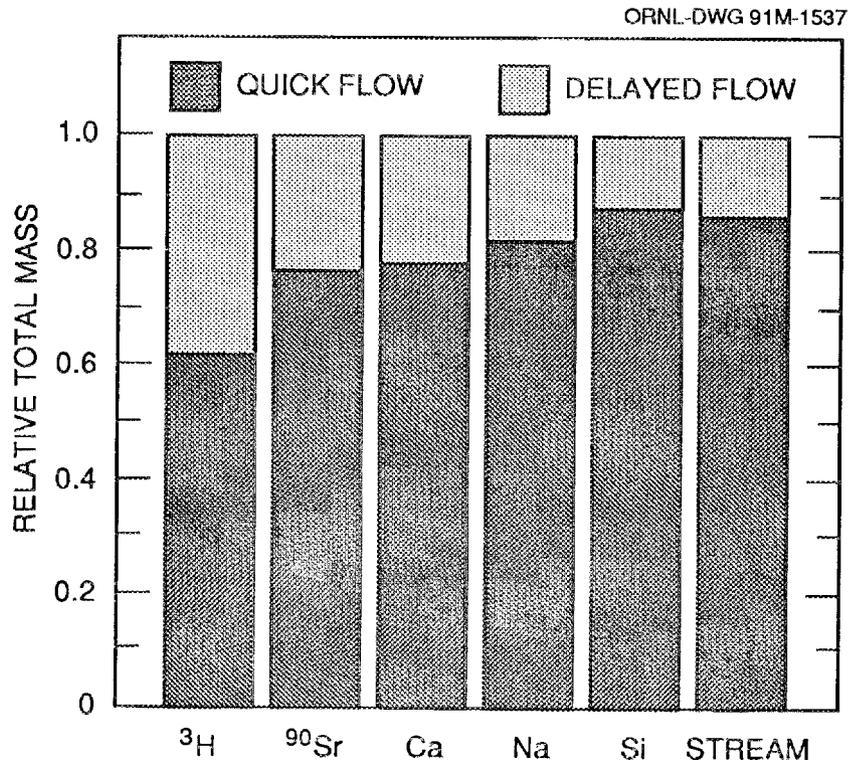


Fig. 42. Relative total release occurring as quick flow and delayed flow in Melton Branch during January storm.

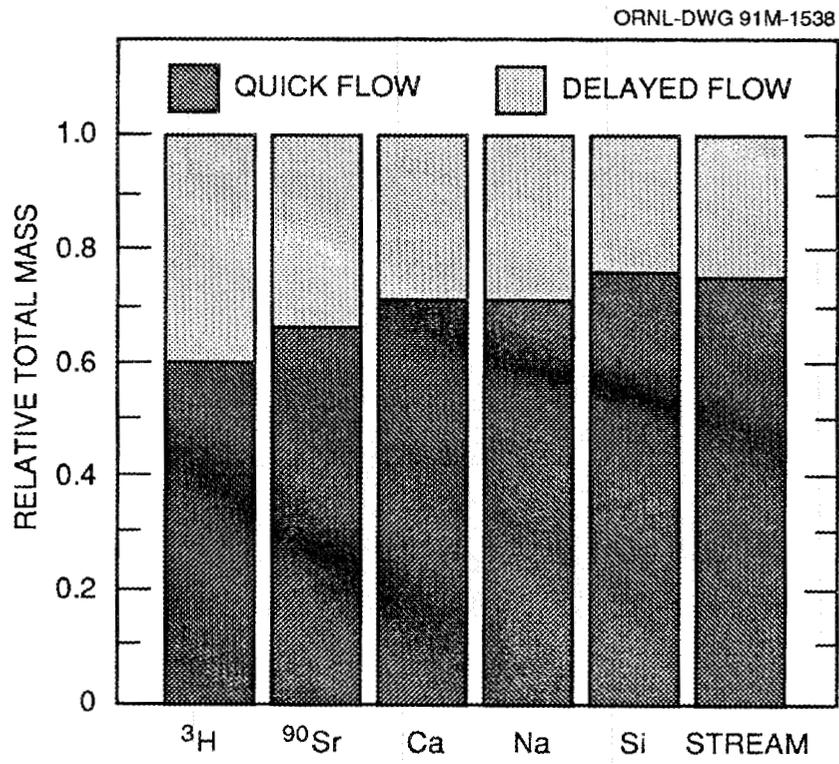


Fig. 43. Relative total release occurring as quick flow and delayed flow in Melton Branch during February storm.

ORNL-DWG 91M-1539

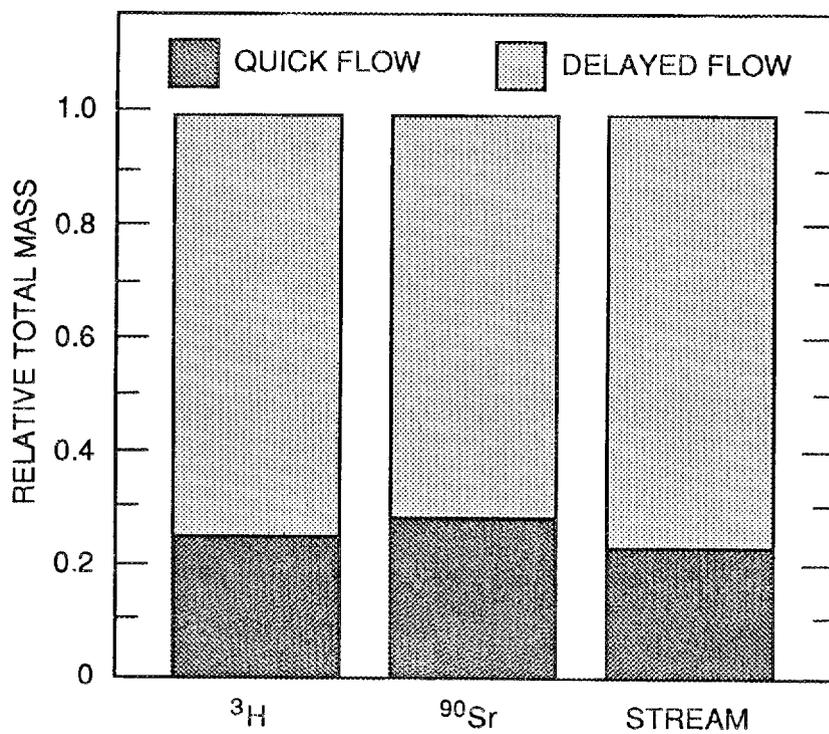


Fig. 44. Relative total release occurring as quick flow and delayed flow in Melton Branch during May storm.

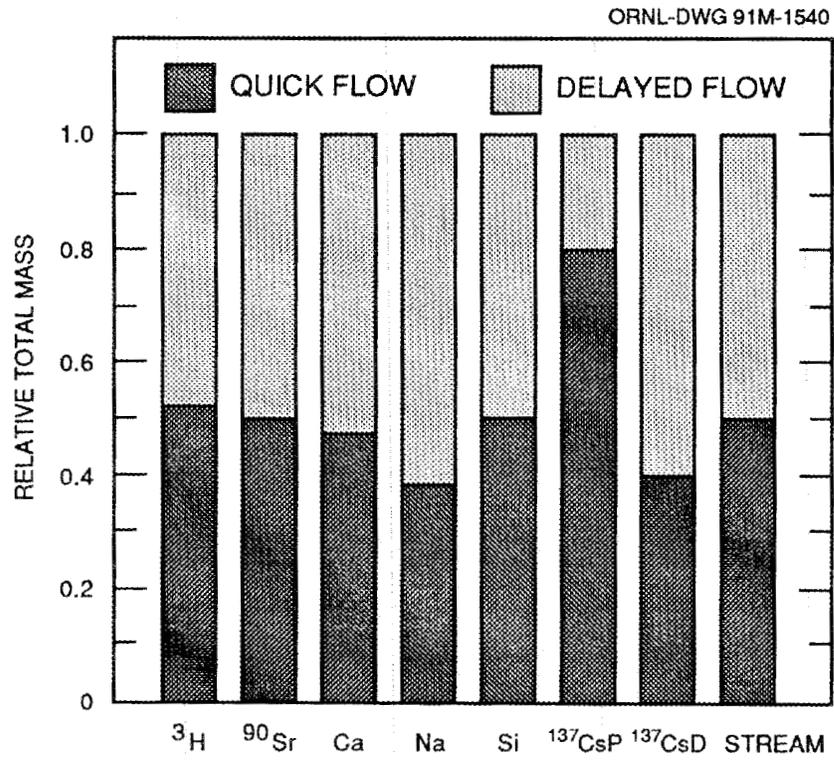


Fig. 45. Relative total release occurring as quick flow and delayed flow in White Oak Creek during February storm.

ORNL-DWG 91M-1541

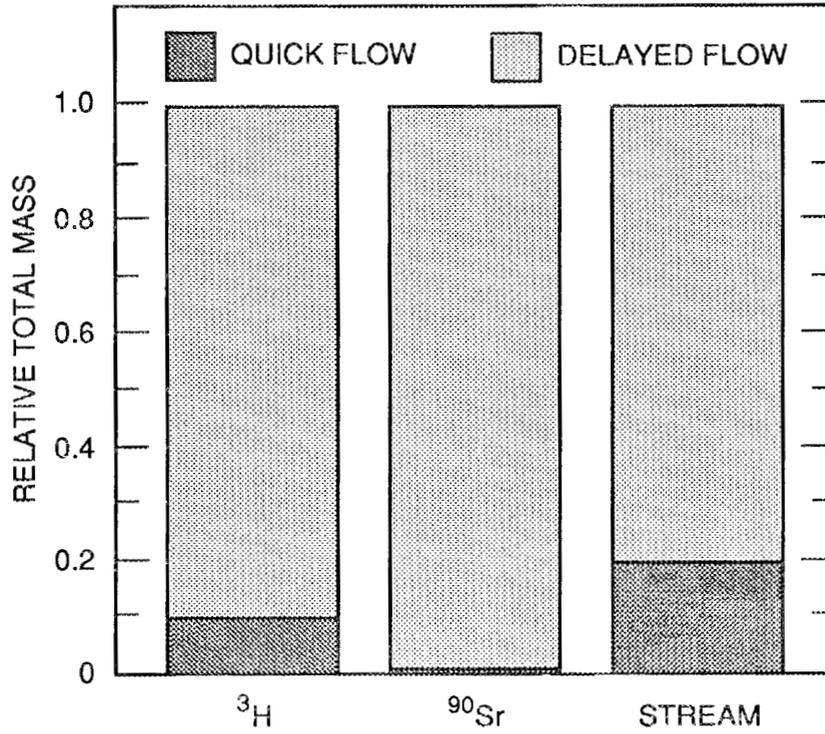


Fig. 46. Relative total release occurring as quick flow and delayed flow in White Oak Creek during May storm.

explanation for this difference is the release of  $^{90}\text{Sr}$  from sources within the main plant area and releases from SWSA 4.

The release of  $^{137}\text{Cs}$  in quick flow was computed for the February storm in WOC. About 80% of the particulate-sorbed  $^{137}\text{Cs}$  occurred as quick flow. About 41% of the dissolved  $^{137}\text{Cs}$  resulted from quick flow during the February storm in WOC.

In addition to radionuclides, the release of several major ions in quick flow, including Ca, Na, and Si, were computed by using MASSFLO. In both MB and WOC, Si release associated with quick flow was slightly higher than that for Ca and Na. Although this is consistent with soil studies conducted in SWSA 6 (Davis et al. 1984) that indicate that very little, if any, calcium carbonate and other soluble minerals exists in the weathered zone, considerable Ca and Na may exist as exchangeable cations in this region. As a result of mineralogical differences between the upper weathered zone and the saturated groundwater region, the average Ca concentration (computed by dividing the total mass released by the volume of water discharged) is a function of total discharge. For example, the average Ca concentration in MB was 18 mg/L for the January storm (total discharge of 196,000 m<sup>3</sup>) and was 24 mg/L for the February storm (52,600 m<sup>3</sup>). The average concentration of dissolved silica (expressed as SiO<sub>2</sub>) was less variable, ranging from 5.6 to 6.6 mg/L during the January and February storms, respectively, in MB.

The validity of associating groundwater discharge (a physically based quantity) with delayed flow (a conceptual quantity based only on the stream hydrograph) can be made by comparing the average computed concentration of major ions in delayed flow with the average concentration of ions observed in groundwater monitoring wells. Moore (1988) computed the geometric mean Ca concentration for wells finished in the shallow aquifer below the water table in the Conasauga Shale to be 64 mg/L. The average concentration of delayed flow computed by MASSFLO during the January and February storms was 36 and 29 mg/L, respectively. Although these values differ by about a factor of 2, the conceptual model implemented by MASSFLO is considered adequate for the following reasons. First, the geometric mean Ca concentration for 187 wells in both the Conasauga and Chickamauga formations was reported

by Moore (1988) to be 91 mg/L, with the mean minus one geometric standard deviation being 38 mg/L. The geometric standard deviation for wells in the Conasauga Group alone was not reported by Moore (1988); however, it is reasonable to assume that the range in concentrations is similar. Thus, the delayed flow values computed by MASSFLO would probably be within one geometric standard deviation of the geometric mean. Second, groundwater samples from wells are seldom collected during storms and thus may not adequately represent dynamic concentrations resulting from dilution during storms. Moore (1988) monitored specific conductance monthly in several wells in SWSA 6 and found that changes of more than 50% occurred in shallow wells. Although these measurements were not necessarily made during or immediately after storms, the results illustrate the nonstatic nature of ion concentrations in the shallow groundwater system.

#### 4.3 MODE OF CONTAMINANT RELEASE

An increase in mass flow of all measured species occurred during each of the monitored storms. The streamflow separation analysis suggest that as much as 80% of the total mass release occurs as quick flow during storm periods. Although there are some conceptual difficulties with assigning quick flow to a physical pathway, it seems clear that the saturated groundwater system is not capable of supplying this increase in mass during storms. For example, if the Ca concentration of groundwater from below the water table is assigned an average value of 64 mg/L (Moore 1988) and it remained constant during the January storm, a total groundwater discharge of 54,000 m<sup>3</sup> would be required to account for the Ca release if the saturated groundwater system were the only pathway transporting Ca. Because the storm lasted for 3.83 days, the average groundwater discharge would have to have been 14,100 m<sup>3</sup>/d. Before the storm, the base flow in MB was 1700 m<sup>3</sup>/d and even at the end of the storm base flow was only at 10,400 m<sup>3</sup>/d. Thus, even using a groundwater concentration of 64 mg/L, which as discussed earlier is probably too high, it is very difficult to account for major ion releases such as Ca through the saturated groundwater system alone.

Figures 47 and 48 show the cumulative release of  $^3\text{H}$  and  $^{90}\text{Sr}$  in quick flow for the February storm in MB and WOC. Only the release computed to occur in quick flow was included in this analysis. The  $^3\text{H}$  release precedes  $^{90}\text{Sr}$  during the early portion of the storms; however, the two curves are nearly concurrent during the majority of the storm period.

The mobility of a species in a porous media is often defined in terms of a retardation factor. Mathematically the retardation factor for a granular porous media is

$$R = 1 + \text{Pb Kd}/n ,$$

where

Pb = dry bulk density of solids in the porous media,

Kd = distribution coefficient,

n = porosity of the porous media.

For transport along a fracture with parallel walls, the retardation factor becomes

$$R = 1 + \text{Kf}/b ,$$

where

Kf = distribution coefficient per unit surface area,

b = half of the fracture spacing.

Contaminants such as  $^3\text{H}$  have generally been considered to be geochemically conservative with Kd and Kf values near 0. Although various studies have proposed that some exchange between tritiated water and hydroxyl groups on clay minerals occurs (Nkedi-Kizza et al. 1982; Seyfried and Rao 1987), retardation factors ranging from 1.15 to 1.05 have been reported, and thus, for the purpose of this study,  $^3\text{H}$  is considered to be geochemically conservative. The Kd for  $^{90}\text{Sr}$  has been determined using a variety of laboratory and in situ field experiments. Cerling and Spalding (1981) estimated an in situ Kd for  $^{90}\text{Sr}$  on stream sediments from the MB and WOC watersheds and reported average values of 82 and 20 mL/g, respectively. The  $^{90}\text{Sr}$  retardation factor depends on

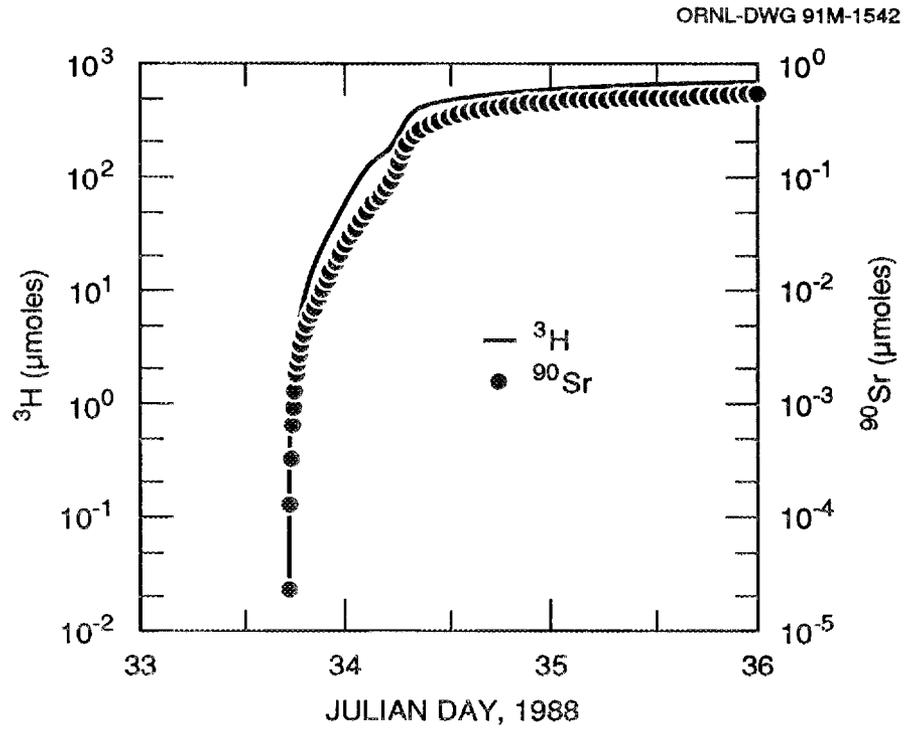


Fig. 47. Cumulative release of  $^3\text{H}$  and  $^{90}\text{Sr}$  in quick flow in Melton Branch during February storm (1  $\mu\text{mole } ^3\text{H} = 29.16 \text{ mCi}$ , 1  $\mu\text{mole } ^{90}\text{Sr} = 12.50 \text{ mCi}$ ).

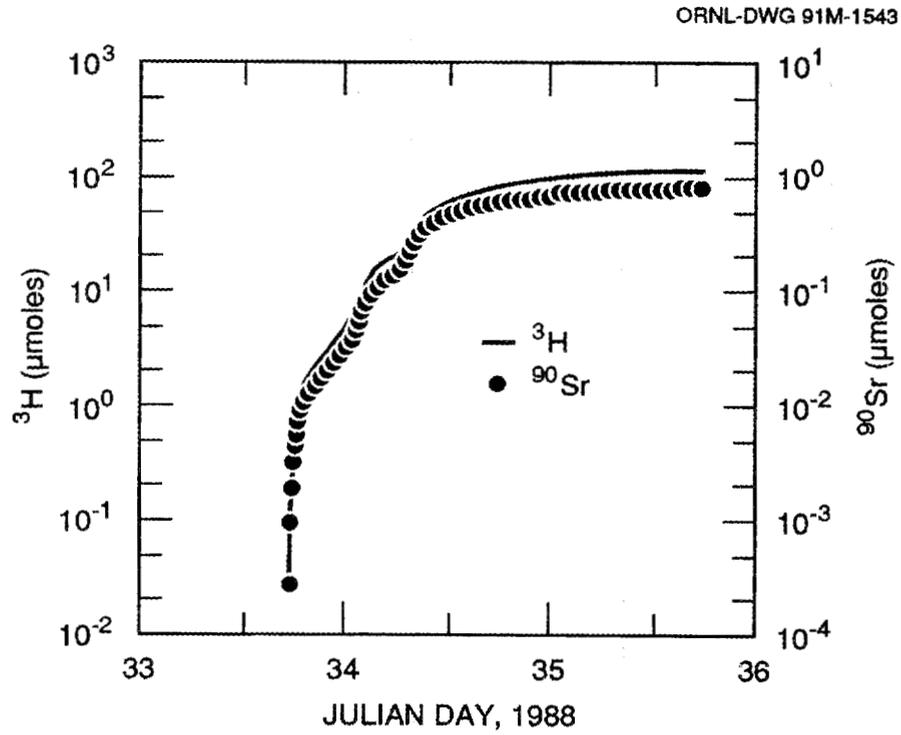


Fig. 48. Cumulative release of  $^3\text{H}$  and  $^{90}\text{Sr}$  in quick flow in White Oak Creek during February storm ( $1 \mu\text{mole } ^3\text{H} = 29.16 \text{ mCi}$ ,  $1 \mu\text{mole } ^{90}\text{Sr} = 12.50 \text{ mCi}$ ).

the nature of the flow system: granular or fractured. Dreier et al. (1987) observed linear fracture densities approaching 200 fractures per meter in test trenches in SWSA 6. Thus, a retardation factor based on  $K_f$  rather than  $K_d$  would seem more appropriate; however, measurements of  $K_f$  have not been made, and it is difficult to determine by observation whether or not a fracture is hydraulically active. As a result, the effective fracture spacing is unknown. Thus, it is only possible to place bounds on the  $^{90}\text{Sr}$  retardation factor. We can estimate an upper bound by assuming that the subsurface is a granular porous media. Using a bulk density of 1.7 g/cc and a porosity of 0.35, we would estimate retardation factors of about 400 and 100 for MB and WOC, respectively. Because only estimates of  $K_f$  and  $b$  are available, it can only be conclusively stated that the lower bound of the retardation factor is  $>1$ . The  $K_d$  values determined by Cerling and Spalding (1981) were obtained using stream gravels having a size distribution ranging from 2 to 3.3 mm. If the gravels are assumed to resemble spheres, it is possible to compute the mass of sorbed  $^{90}\text{Sr}$  per unit surface area, and thus it is possible to estimate  $K_f$ . Performing the calculation we find that  $K_f$  equals 10.8 cm for MB and 2.54 cm for WOC. The retardation factor then becomes

$$R = 1 + 10.8 \text{ (cm)}/b \text{ for MB ,}$$

and

$$R = 1 + 2.54 \text{ (cm)}/b \text{ for WOC .}$$

Thus, the retardation factor for  $^{90}\text{Sr}$  in a fracture porous media is near unity for half fracture spacings on the order of 100 cm; however, it is much larger for smaller fracture spacings.

The retardation factor, computed using either  $K_d$  for  $K_f$ , is a mathematical concept for describing reversible geochemical sorption reactions. Chemically reactive species will move more slowly through a porous media relative to conservative species as a result of mass being stored within the porous media itself. In a fractured media most of the water mass moves through fractures that generally constitute only a small portion of the bulk porosity. Although the porous matrix

surrounding fractures contributes little to bulk water movement, significant water can be stored within the matrix. As ions are transported through fractures, a concentration gradient exists between fractures and the surrounding matrix, resulting in the diffusion of ions into or, sometimes, out of the surrounding matrix. This process, known as matrix diffusion, results in mass being stored within the porous medium and thus, like geochemical sorption, causes ions to move more slowly. Although matrix diffusion is a process very different from chemical sorption, the net effect in terms of transport rates is similar. In general, it is very difficult to distinguish, on the basis of transport rates alone, between the processes of chemical sorption and matrix diffusion when a highly fractured system is modeled as an equivalent porous medium. In this report, the term effective retardation will be used to account for both the effects of matrix diffusion and geochemical sorption.

The results of the streamflow separation analysis suggest that significant transport of contaminants including  $^3\text{H}$  and  $^{90}\text{Sr}$  occurs in subsurface storm flow. Predictions concerning future releases in storm flow depend on (1) the contaminant source term, (2) the average linear velocity of storm flow, and (3) the effective retardation factor of a given contaminant. The source term is a mathematical statement that describes the generation of dissolved contaminants from the bulk waste as a function of time and space. As previously indicated, the source term is completely unknown at waste facilities at ORNL. One of the long-term objectives of this study is to quantify the source term by measuring future storm flow releases; however, such an evaluation can only be made if accurate estimates of the average linear velocity of storm flow and effective retardation factors for all contaminants of concern are available.

The physical occurrence of subsurface storm flow was summarized by Moore (1988). A large permeability contrast exists between the B- and C-horizons as a result of root holes, biochanneling, cracks, etc. The mean saturated hydraulic conductivity of the storm flow zone is about 9 m/d, whereas the mean hydraulic conductivity of the underlying regolith is about 0.003 m/d. During storms, this permeability contrast can

result in saturation of the storm flow zone, followed by the horizontal flow of water toward streams. The average linear velocity of storm flow can be estimated using Darcy's law

$$V = KI/n_e ,$$

where  $K$  is the saturated hydraulic conductivity,  $I$  is the hydraulic gradient, and  $n_e$  is the effective porosity. The maximum horizontal hydraulic gradient can be no greater than the surface slope, which is  $<0.1$  for the majority of Oak Ridge National Laboratory (ORNL) waste management areas. Although the total porosity of the storm flow zone is about 0.4, the effective hydraulic porosity is much less because most of the flow occurs through only a small portion of the total pores. Estimates of the effective porosity of the storm flow zone range from 0.1 (Moore 1989) to 0.002 (Watson and Luxmoore 1986). The uncertainty in the average linear velocity is directly proportional to the uncertainty in effective porosity. For example, using a hydraulic gradient of 0.1 and a saturated hydraulic conductivity of 9 m/d, estimates of the average linear velocity range from 9 to 450 m/d. The average travel distance for contaminants in SWSA 5 is on the order of 100 meters. Thus, the residence time of mobile water in storm flow could range from about 5 hours to more than 11 days. Because storm flow is only active within a day or so after a storm, the total residence time associated with an effective porosity of 0.1 is around 60 days, assuming that storm flow is active for 2 out of every 10 days. Thus, even if no contaminant retardation were occurring, the mass flux of contaminants entering the stream would lag the mass flux at the source by as much as 60 days or as little as 5 hours.

As previously discussed, the process of matrix diffusion probably results in some retardation of even  $^3\text{H}$ , and  $^{90}\text{Sr}$  would be further retarded, depending on the effective fracture spacing. The average linear velocity of retarded species is related to the average linear velocity of water by the following:

$$V_c = V/R_e ,$$

where  $V_c$  is the average linear velocity of a retarded species,  $V$  is the average linear velocity of water, and  $R_e$  is the effective retardation factor. The maximum value of  $R_e$  for  $^{90}\text{Sr}$  is about 400. Thus, the maximum lag time between  $^{90}\text{Sr}$  release at the source and entry into streams ranges from 1.1 to 60 years, depending on the value used for effective porosity. A minimum lag time cannot be estimated because retardation resulting from matrix diffusion is unquantified.

The previous discussion illustrates the importance of quantifying the effective porosity and retardation factors. Because the  $^{90}\text{Sr}$  mass flow increases significantly during storms, it would seem that the effective retardation factor is well below 400, and/or the effective porosity is substantially less than 0.1. However, another possibility exists for explaining the increase in  $^{90}\text{Sr}$  mass flow during storms.

Figure 49 shows that the concentration of  $^{90}\text{Sr}$  and stable Sr for all measurements in MB are highly correlated. Stable Sr results from natural weathering processes and is unrelated to the disposal of  $^{90}\text{Sr}$ . This high correlation suggests that desorption processes are controlling the concentration and, hence, release of  $^{90}\text{Sr}$ . Cerling and Spalding (1981) have shown that significant sorption of  $^{90}\text{Sr}$  by stream sediments occurs in MB and WOC. The concentration of  $^{90}\text{Sr}$  in MB at the beginning of the January and February storms was greater than at the end of these storms. Furthermore,  $^{90}\text{Sr}$  concentrations dropped significantly during these storms. As a result, desorption of  $^{90}\text{Sr}$  from stream sediments would occur until a new equilibrium is established. We can make a crude estimate of the importance of this mechanism by comparing the total quick flow release of  $^{90}\text{Sr}$  during the February storm with the mass of  $^{90}\text{Sr}$  that could be desorbed from stream sediments. The  $^{90}\text{Sr}$  concentration at the beginning and the end of the February storm in MB was 257 and 227 pCi/L, respectively. If we assume that the mass of sediments interacting with the stream is  $6.36 \times 10^8$  grams (computed using a stream reach of 1000 meters, sediment thickness of 0.2 meter, a sediment width of 1.5 meters, a porosity of 20%, and a mineral density of 2.65 g/cc) with a  $K_d$  of 82 mL/g, we estimate that

$$6.36 \times 10^8 \text{ g } (257-227) \text{ pCi/L } 82 \text{ mL/g } 0.001 \text{ L/mL} = 1.6 \text{ mCi}$$

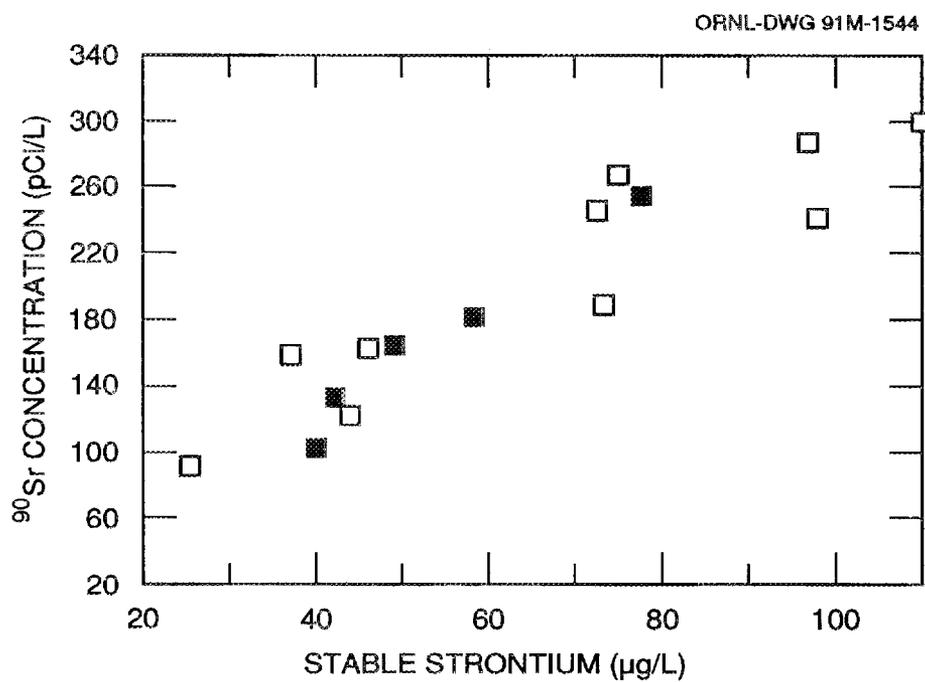


Fig. 49. Melton Branch (MS-4) <sup>90</sup>Sr vs stable strontium concentrations for the January, February, and May 1988 storm events.

of  $^{90}\text{Sr}$  could be released as a result of desorption from stream sediments. The release of  $^{90}\text{Sr}$  associated with quick flow during the February storm was 5.9 mCi. Thus, desorption of  $^{90}\text{Sr}$  from stream sediments during storms, followed by sorption during periods of base flow, could be an important mechanism. Conclusive statements however, will require a more accurate estimate of the mass of sediment that interacts with the stream during storms. Because this mechanism requires that  $^{90}\text{Sr}$  be transported through the groundwater system, which is likely to be a longer flow path than storm flow, it would appear that the effective  $^{90}\text{Sr}$  retardation factor and/or the effective porosity are less than the postulated maximum values.

It is not possible to predict future contaminant releases until the source term and contaminant residence time are known. Long-term monitoring of contaminant release into streams can define the source term only if the effective porosity and retardation factors are known. If rapid transport through a fractured porous media in which a relatively small surface area available for sorption is occurring, and matrix diffusion is an insignificant process, the mass of reactive contaminants stored in the storm flow portion of the porous media would be small. As a result, the  $^{90}\text{Sr}$  release in quick flow determined in this study would be a measure of the actual  $^{90}\text{Sr}$  source term in waste trenches. This would not represent the entire source term value because migration through the saturated groundwater system is certainly occurring. Furthermore, if the amount of stored mass is low, remedial actions that can reduce the source flux of  $^{90}\text{Sr}$  (and presumably other contaminants) are likely to result in a fairly rapid decrease in the  $^{90}\text{Sr}$  mass flow occurring along the storm flow pathway. If however, the contaminant mass stored within the system as a result of either matrix diffusion or chemical sorption is large and the flux of water through the system remains unchanged, significant contaminant release in stormflow could continue long after the source flux is eliminated. Thus, remedial actions are intimately linked to the mass of contaminants stored in the porous media. Remedial actions designed to reduce the source term (i.e., grouting, in situ vitrification, compaction, removal, etc.) could be effective if the mass storage is low; however, only

remedial actions that reduce the water flux would be effective if significant contaminant mass is stored in the porous media. This statement is also true for contaminant migration along the saturated groundwater pathway. Thus, determining the amount of mass stored in the porous media is extremely critical for assessing the long-term remediation of the site.

#### 4.4 BASELINE VALUES OF CONTAMINANT RELEASE

As previously indicated, the source term for contaminant releases from waste trenches in SWSA 5 is unknown. Migration from the source to streams appears to occur along two pathways: subsurface storm flow and migration through the saturated groundwater system. It is not known if the release along these pathways is increasing or decreasing and it is only possible to make such a determination if changes in the contaminant release are measured over time. An important objective of this study is to establish a baseline value of contaminant release so that future studies can evaluate changes.

Figure 50 shows the total release of both  $^3\text{H}$  and  $^{90}\text{Sr}$  as a function of total stream discharge in MB watershed. Because the contaminant release is a strong function of discharge, it is apparent from Fig. 50 that a meaningful evaluation of changes in release based only on measurements of the total release for a given time period (i.e., 1 year) can only be made if rainfall conditions were very similar for the periods being evaluated. Because it is highly unlikely that rainfall conditions will remain constant during the evaluation of waste storage areas at ORNL, it is important that methods for evaluating changes in contaminant release be developed that compensate for fluctuations in rainfall.

The release of ions such as stable Sr result from natural weathering processes and thus, like the release of contaminants, are a function of rainfall. The ratio of the total release of  $^{90}\text{Sr}$  to the total release of stable Sr for both the January and February storms in MB is shown in Table 2. The ratio of  $^3\text{H}$  to stable Sr is also shown in Table 2. Measurements of stable Sr in WOC were only available for the

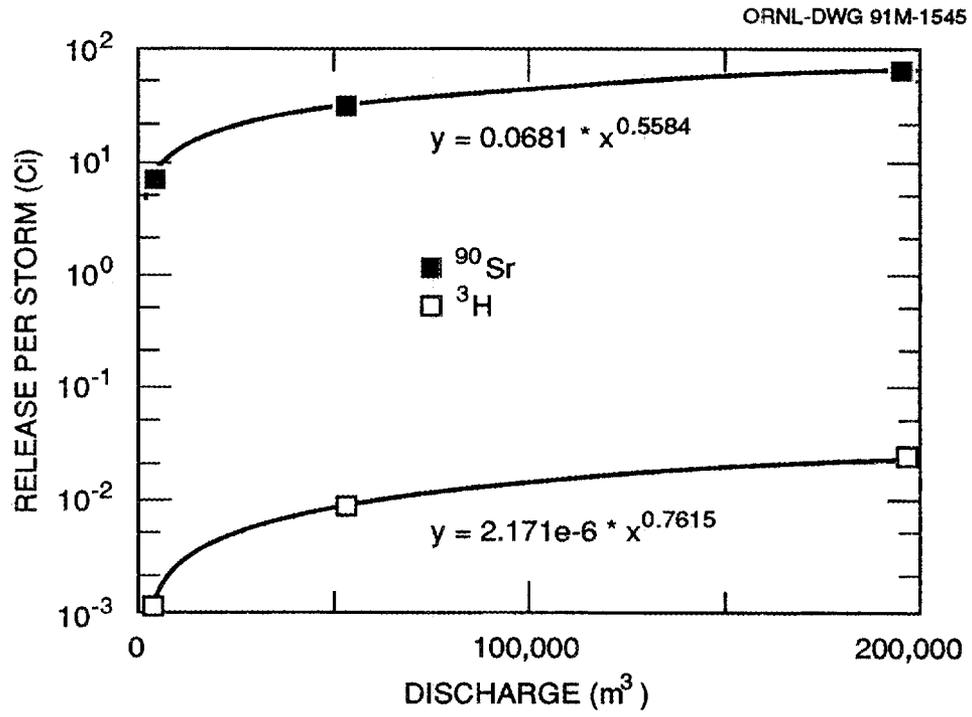


Fig. 50. Relationship between <sup>3</sup>H and <sup>90</sup>Sr releases and stream discharge in Melton Branch.

Table 2. Molar ratios of  $^3\text{H}$  and  $^{90}\text{Sr}$  to stable Sr in Melton Branch and White Oak Creek watersheds

Stream	Storm	$^3\text{H}/\text{Sr}$ total flow	$^3\text{H}/\text{Sr}$ quick flow	$^{90}\text{Sr}/\text{Sr}$ total flow	$^{90}\text{Sr}/\text{Sr}$ quick flow
MB	Jan.	2.74E-5	1.99E-5	2.33E-8	2.20E-8
MB	Feb.	3.79E-5	3.18E-5	2.54E-8	2.41E-8
WOC	Feb.	2.07E-6	2.42E-6	1.52E-8	1.72E-8

February storm, and the ratios of  $^{90}\text{Sr}$  and  $^3\text{H}$  to stable Sr are included in Table 2. The ratio of  $^{90}\text{Sr}$  to stable Sr is quite constant in MB. Thus, normalizing the total release of  $^{90}\text{Sr}$  by the total release of stable Sr will effectively compensate for variations in rainfall, providing a very good measure of  $^{90}\text{Sr}$  release. Although the ratio of  $^3\text{H}$  to  $^{90}\text{Sr}$  is more variable, variations appear to be sufficiently small that the stable Sr normalization will also provide an adequate index for annual  $^3\text{H}$  releases.

The ratio of  $^{90}\text{Sr}$  to stable Sr (known as the specific activity of  $^{90}\text{Sr}$ ) has an additional interesting application. If all of the  $^{90}\text{Sr}$  being released is the result of desorption from exchange sites, the rate of change of  $^{90}\text{Sr}$  to stable Sr ratio should follow a first-order decay curve with a decay constant equal to that of  $^{90}\text{Sr}$ . If however, additional  $^{90}\text{Sr}$  is being supplied from trenches (i.e., a nonzero source term) the rate of change of the specific activity will be different by an amount that results from the source term. Thus, in addition to simply defining the change in total  $^{90}\text{Sr}$  release, it may be possible to evaluate the source term by measuring the specific activity of  $^{90}\text{Sr}$  in streamflow in the future.

#### 4.5 ANNUAL RELEASE OF $^3\text{H}$ AND $^{90}\text{Sr}$ IN MELTON BRANCH

The relationship between concentration and discharge for  $^3\text{H}$  and  $^{90}\text{Sr}$  in MB is shown in Figs. 51 and 52. Because a good correlation exists between concentration and discharge, it is possible to create an empirical model that describes the concentration as a function of discharge for MB. The relationship between concentration and discharge for WOC is much more random than in MB because of the randomness of releases from the main plant area. Thus, it was not possible to create a model describing concentration as a function of discharge for WOC.

The relationship between concentration and discharge for MB is of the form

$$\text{concentration} = A \text{ discharge}^B ,$$

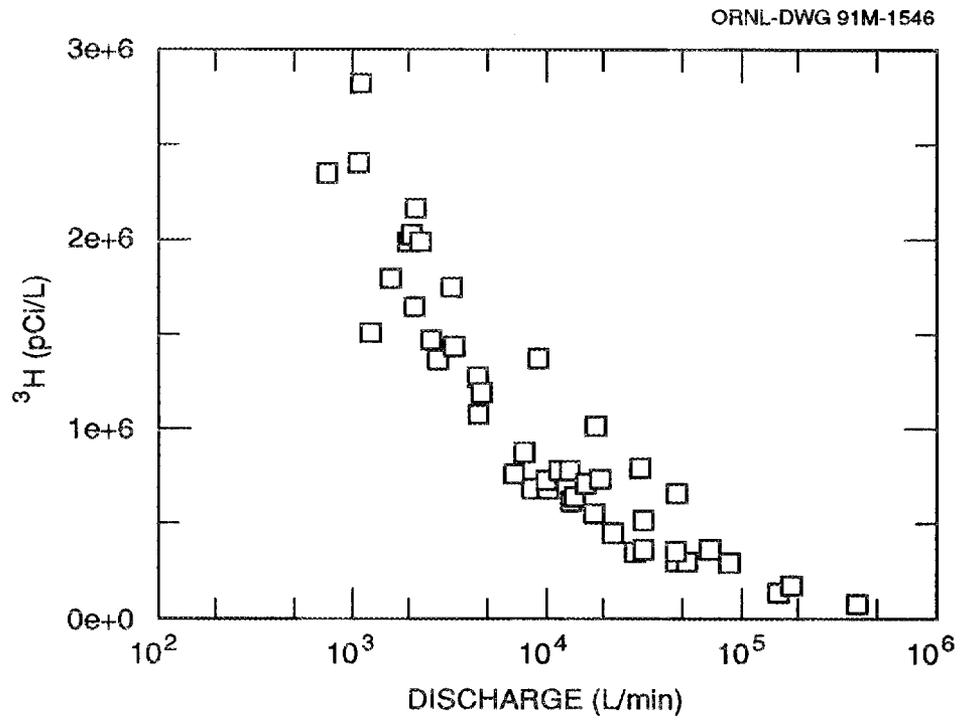


Fig. 51. Relationship between  $^3\text{H}$  concentration and streamflow in Melton Branch.

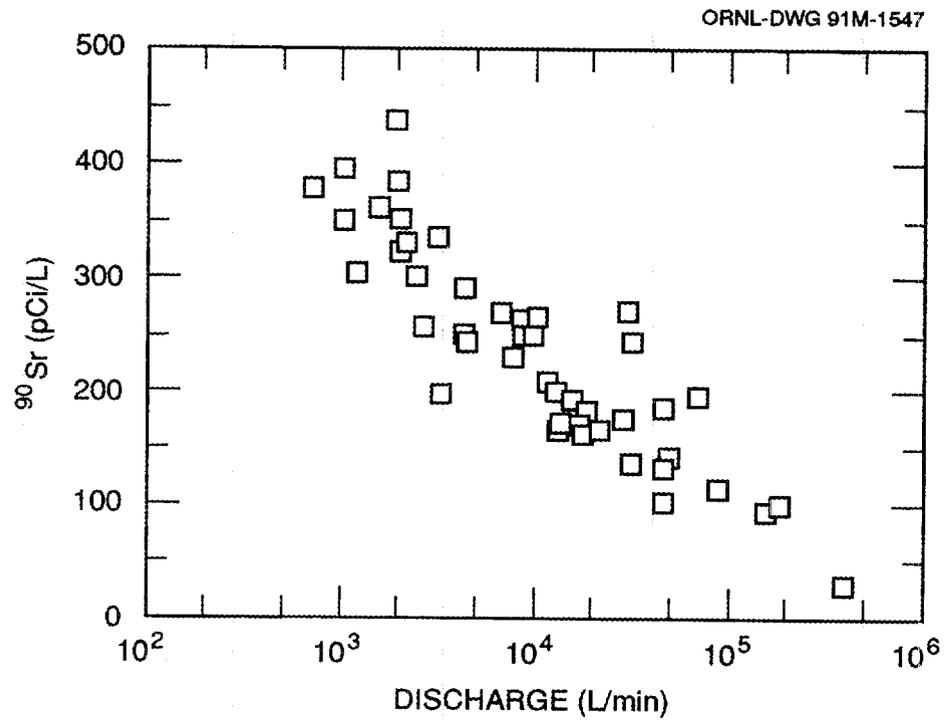


Fig. 52. Relationship between  $^{90}\text{Sr}$  concentration and streamflow in Melton Branch.

where A and B are fitting parameters. This empirical model was combined with hourly streamflow data for the 1988 water year to estimate the annual releases of  $^3\text{H}$  and  $^{90}\text{Sr}$  in MB. Hourly streamflow data were obtained from a combination of the EMC VAX Data Acquisition System (DAS), data collected by the Environmental Sciences Division (ESD), and simulations with a hydrologic forecasting model (SSARR-8). Flow data from October 1987 to April 1988 were retrieved from the EMC DAS system. As previously indicated, high flow measurements made by the EMC DAS system were found to be inaccurate. A hydrologic forecasting model, SSARR-8, calibrated for the MB and WOC watersheds, was used to estimate flows in which the measured values were deemed to be inaccurate. This model was also used to estimate flows for periods in which the EMC DAS was not functioning.

A computer program, SEPARATE, was written to estimate the total annual release of  $^3\text{H}$  and  $^{90}\text{Sr}$ , along with the annual release separated according to quick flow and delayed flow. This program performs hydrograph separation similar to the program MASSFLO described previously in this report. Unlike MASSFLO, however, SEPARATE estimates the concentration of a dissolved species at any point in time from an empirical mathematical model describing the concentration as a function of discharge. Two relationships are required: one for the concentration of total streamflow and one for the concentration of delayed flow. Because total streamflow is equal to delayed flow when a storm is not in progress, it is important that these relationships yield similar concentrations when the total stream discharge is low. SEPARATE identifies the start of a storm by comparing the slope of the measured hydrograph with the slope of a user-specified hydrograph separation line. Before a storm, all discharge is considered to be delayed flow and the mass release is considered to be delayed mass flow. During a storm, both the streamflow and mass flow are separated into quick flow and delayed flow. The end of a given storm is identified as the point at which delayed flow, computed according to the hydrograph separation line, is equal to total flow. If the total stream discharge for a given storm is less than a user-specified amount, the storm is disregarded and

the streamflow and mass flow are added to the delayed flow category. A listing of the source code for the program can be found in Appendix B. The program SEPARATE was used to estimate the annual release of  $^3\text{H}$  and  $^{90}\text{Sr}$  in MB. The following parameters were used for the concentration vs discharge relationship which was of the form

$$\text{concentration} = A \text{ discharge}^B;$$

for  $^3\text{H}$

$$A = 8.116\text{E}7, B = -0.5036 \text{ for total streamflow}$$

$$A = 3.580\text{E}7, B = -0.4141 \text{ for delayed flow,}$$

for  $^{90}\text{Sr}$

$$A = 2896.5219, B = -0.2837 \text{ for total streamflow,}$$

$$A = 2045.0947, B = -0.2571 \text{ for delayed flow,}$$

where concentration is in pCi/L and discharge is in L/min.

The parameters for total release were estimated by using the measured concentration and discharge values. The parameters for delayed flow were estimated using values computed by the program MASSFLO as part of the individual storm analyses presented in the report. Total storm discharges less than 500 m<sup>3</sup> were considered to be delayed flow. A total of 68 storms were identified for the 1988 water year. Total stream discharge was 9.795 X 10<sup>5</sup> m<sup>3</sup>, and the total  $^3\text{H}$  and  $^{90}\text{Sr}$  releases were 1210 Ci and 0.242 Ci, respectively. About 44% of the stream discharge occurred as quick flow, whereas only 16% of the  $^3\text{H}$  and 27% of the  $^{90}\text{Sr}$  release occurred as quick flow. Mean annual rainfall on the Oak Ridge Reservation is about 133 cm, while the rainfall during the 1988 water year was 110 cm (Wilson et al. 1989). It is likely that the fraction of quick flow will increase during periods of average or above average rainfall.

#### 4.6 RECOMMENDATIONS FOR FUTURE WORK

Evaluating the source term at SWSA 5 and other waste disposal areas should be a top priority. The most promising method for evaluating the source term appears to be through stream monitoring, which can only provide a meaningful average estimate at such hydrologically complex sites. The results of this study provide baseline values of groundwater and storm flow releases into MB for future comparisons. This study should be repeated within 3 to 5 years in order to evaluate the SWSA 5 source term. As pointed out in this report, the success of this effort depends on the average time required for contaminants to travel from diffuse and multiple discrete sources to discharge points in MB. It is important that travel time estimates be made for both the groundwater and storm flow systems.

The use of  $^3\text{H}/^3\text{He}$  dating, recently demonstrated at ORNL (Poreda et al. 1988), could provide estimates of the travel time of conservative species in the groundwater system. Samples for  $^3\text{H}/^3\text{He}$  dating should be collected near the observed  $^3\text{H}$  discharge points. The travel time for reactive species in groundwater can be estimated if realistic values for retardation can be made. Large-scale tracer tests using both conservative and reactive species (i.e.,  $^{82}\text{Br}$  and  $^{90}\text{Sr}$ ) should be conducted below the water table. Several existing ponds in Melton Valley could be used for these tests. Results of storm flow tracer experiments, currently being conducted by ESD in MB and Walker Branch watersheds, should be reviewed when available, to help estimate effective porosity and retardation factors for the storm flow zone. The possibility that the increase in  $^{90}\text{Sr}$  mass flow during storms results from desorption of stream sediments should be evaluated by conducting a field survey to determine the mass of existing stream sediments. In addition, a time series of stream sediments should be collected throughout a large storm and analyzed for exchangeable  $^{90}\text{Sr}$ . Cores collected in areas of known  $^3\text{H}$  migration should be sectioned and pore waters analyzed for  $^3\text{H}$  to provide a detailed profile of  $^3\text{H}$  concentrations in fractures and the surrounding matrix. This work will aid in evaluating the process of matrix diffusion.

## 5. SUMMARY

The transport of contaminants from SWSA 5 occurs along two principle pathways: the saturated groundwater system and the intermittently saturated storm flow system.

A large permeability contrast exists between the B and C soil horizons. As a result, a temporary perched water table develops during storms, resulting in significant horizontal flow towards streams. Subsurface flow through waste disposal areas results in a significant flux of dissolved contaminants rapidly transported to streams. The mass flow of contaminants in streams increases during storms as a result of this subsurface transport. For example, the  $^3\text{H}$  mass flow in MB during the January storm increased by about a factor of 6 at peak discharge. The relative fraction of contaminants transported in quick flow vs delayed flow was examined by performing a hydrograph separation of MB and WOC streamflows. The fraction of storm flow release varied for each contaminant; however, it is generally greater than 50% during major storms such as the January and February storms evaluated in this study.

Contaminants such as  $^3\text{H}$  are considered geochemically conservative in that they do not react with the porous media as transport occurs; however, they may diffuse from fractures into the surrounding matrix, effectively resulting in retardation. Contaminants such as  $^{90}\text{Sr}$  may react with the porous media. As a result, the mobility of reactive contaminants is less than conservative contaminants. The results of this study suggest that both  $^3\text{H}$  and  $^{90}\text{Sr}$  are mobile in SWSA 5 in spite of the reactivity of  $^{90}\text{Sr}$ . Hypotheses for explaining this mobility include, little interaction between  $^{90}\text{Sr}$  and the porous media as a result of transport along fractures and/or desorption of  $^{90}\text{Sr}$  from stream sediments during storms.

An empirical relationship between concentration and discharge was established for  $^3\text{H}$  and  $^{90}\text{Sr}$  in MB. This relationship was combined with hourly streamflow data for the 1988 water year to estimate the annual release of these contaminants. The total  $^3\text{H}$  release in MB for the 1988 water year was 1210 Ci, whereas the total  $^{90}\text{Sr}$  release was 0.242 Ci. Approximately 44% of the annual stream discharge occurred as quick flow,

and about 16% of the  $^3\text{H}$  release and 27% of  $^{90}\text{Sr}$  release occurred as quick flow. The fraction of quick flow is likely to be larger during years having average or above-average rainfall.

The long-term performance of SWSA 5 cannot be predicted because of two major unknowns: the contaminant source term and the lag time between the release of reactive contaminants at the source and the release into streams. If the hypothesis that little interaction between reactive contaminants and the porous media occurs because of transport along a fractured porous media is correct, the lag time will be small and it will thus be possible to evaluate the source term by measuring the release of contaminants into streams. Even if the lag time is large, the first step in evaluating the source term is to accurately quantify releases to streams along both the saturated groundwater and storm flow pathways. In addition to a dependence on the source term and lag time, the release of contaminants to streams along the storm flow pathway is a strong function of rainfall. Although the groundwater release will also depend on rainfall, the dependence will be on a longer time scale than will the storm flow release. Thus, the total annual release of contaminants depends on the annual rainfall as a result of the significant fraction of contaminants transported along the storm flow pathway. Therefore, simply measuring the total annual contaminant release into streams will only permit an evaluation of the source term if comparisons are made between years having very similar rainfalls. The separation of groundwater transport from storm flow transport and the analysis of the  $^{90}\text{Sr}$  specific activity performed in this study will allow comparisons between years that are climatologically dissimilar.

This study has several important implications for remedial actions and site monitoring.

1. Any remedial actions must be directed toward both the groundwater and the storm flow systems.
2. The short term effectiveness of remedial actions aimed at reducing the contaminant source depends critically on the mass of contaminants currently stored within the porous media. If the

mass stored is low, source-level remedial actions such as grouting, compaction, in situ vitrification, etc., would result in reduced releases to streams within the first 1 or 2 years after remediation. If the mass of contaminants stored in the porous media is high, then only remedial actions that reduce the water flux will effectively reduce the release of contaminants to streams on a time scale of 1 or 2 years.

3. If the mass of contaminants stored in the porous media is small, the source term can be evaluated by measuring the release into streams during the coming years. If this source term is declining, more passive forms of remediation such as French drains and simple caps may be viable options.



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APPENDIX A - STORM SURVEILLANCE DATA



Appendix A - Storm Surveillance Data  
 Melton Branch Stream (MBS) (Monitoring Station, MS-4)

Date	Time	Julian Date	Discharge (l/min) (10-min Ave)	Tritium Concentration (pCi/l)	%Error (1 Sigma)	Water Cs-137 (pCi/l)	1 Sigma Counting Error	Particles Cs-137 (pCi/l)	1 Sigma Counting Error	Water Co-60 (pCi/l)	1 Sigma Counting Error	Particles Co-60 (pCi/l)	1 Sigma Counting Error	Sr-90 Water (pCi/l) (Cerenkov)	1 Sigma Counting Error
01/17/88	13:00	16.542	1199	1503836	0.23	0.2	1.1	0.9	1.3	6.0	0.7	8.0	2.0	305	36
01/17/88	15:00	16.625	2377	1457257	0.24	ND	ND	1.3	1.0	7.7	2.5	ND	ND	302	36
01/17/88	17:00	16.708	4296	1055408	0.28	ND	ND	1.2	0.5	9.2	4.5	5.1	0.7	290	36
01/17/88	19:00	16.792	4327	1268293	0.26	ND	ND	ND	ND	ND	ND	ND	ND	248	35
01/17/88	23:00	16.958	4406	1179010	0.27	0.3	1.4	ND	ND	1.6	2.0	ND	ND	244	35
01/18/88	01:00	17.042	12465	780804	0.32	1.4	1.3	15.2	4.0	33.7	1.7	207.0	10.5	198	34
01/18/88	03:00	17.125	15641	697439	0.34	2.5	2.5	ND	ND	29.1	4.9	77.0	5.4	191	33
01/18/88	05:00	17.208	13548	627945	0.36	ND	ND	ND	ND	1.6	1.3	56.0	4.6	170	33
01/18/88	09:00	17.375	9782	681215	0.35	ND	ND	ND	ND	ND	ND	ND	ND	248	34
01/19/88	01:00	18.042	8521	672677	0.35	ND	ND	ND	ND	ND	ND	ND	ND	262	35
01/19/88	07:00	18.292	6757	751835	0.33	ND	ND	ND	ND	ND	ND	ND	ND	269	35
01/19/88	09:00	18.375	10107	715495	0.34	ND	ND	ND	ND	ND	ND	16.2	2.3	266	35
01/19/88	11:00	18.458	29712	793884	0.32	0.8	0.9	37.1	3.3	6.7	1.7	434.0	14.0	270	35
01/19/88	14:30	18.596	45539	336771	0.49	ND	ND	5.5	1.6	ND	ND	51.4	4.1	124	32
01/19/88	17:45	18.727	27673	346540	0.25	ND	ND	ND	ND	10.0	6.0	29.0	3.7	178	34
01/19/88	19:45	18.810	35696	539553	0.20	ND	ND	ND	ND	6.6	1.0	27.0	4.0	252	35
01/19/88	21:45	18.894	204545	275380	0.28	4.4	1.8	32.4	4.9	14.5	3.9	319.0	14.0	160	33
01/19/88	23:45	18.977	968308	141238	0.40	ND	ND	24	4.0	11.5	4.0	176.0	11.0	64	31
01/20/88	01:45	19.060	1048938	67707	0.59	ND	ND	4.0	0.6	11.0	9.0	35.8	3.3	22	30
01/20/88	03:45	19.144	197069	131448	0.41	ND	ND	ND	ND	ND	ND	22.7	4.0	92	32
01/20/88	07:45	19.310	44195	297145	0.28	ND	ND	2.0	1.9	ND	ND	31.0	3.3	102	31
01/20/88	15:45	19.644	17252	559791	0.20	ND	ND	ND	ND	ND	ND	ND	ND	163	33
01/21/88	01:45	20.060	11190	774519	0.17	ND	ND	ND	ND	687.0	32.0	120.0	8.0	208	60
02/03/88	24:00	34.000	8805	1365443	0.13	ND	ND	ND	ND	11.1	2.6	21.0	0.9	257	35
02/04/88	02:00	34.083	17155	1008774	0.14	ND	ND	5.8	2.1	ND	ND	55.0	6.0	166	33
02/04/88	04:00	34.167	18454	728943	0.17	ND	ND	ND	ND	ND	ND	28.0	3.5	184	33
02/04/88	06:00	34.250	46409	660280	0.18	4.7	4.6	ND	ND	11.4	6.1	79.0	8.0	216	34
02/04/88	08:00	34.333	86837	307983	0.27	5.0	3.7	1.8	0.6	ND	ND	42.0	2.0	103	32
02/04/88	09:50	34.396	45690	290443	0.28	ND	ND	ND	ND	ND	ND	20.0	2.0	128	32
02/04/88	12:00	34.500	31476	353512	0.25	ND	ND	1.9	0.4	ND	ND	7.7	0.6	135	33
02/04/88	15:00	34.625	21622	441308	0.22	ND	ND	ND	ND	4.9	1.9	9.0	2.0	163	33
02/04/88	21:00	34.875	13037	609474	0.19	ND	ND	ND	ND	ND	ND	ND	ND	166	33

Appendix A - Storm Surveillance Data  
 Melton Branch Stream (MBS) (Monitoring Station, MS-4)

Date	Time	Al (ug/l)	Ba (ug/l)	Be (ug/l)	Ca (ug/l)	Fe (ug/l)	K (ug/l)	Mg (ug/l)	Mn (ug/l)	Na (ug/l)	SiO2 (ug/l)	Sr (ug/l)	V (ug/l)	Zn (ug/l)	Cl (ug/l)	NO3 (ug/l)	PO4 (ug/l)	SO4 (ug/l)
05/03/88	10:20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/03/88	18:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8560	NA	310	25300
05/03/88	20:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/03/88	22:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/03/88	23:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8520	70	360	25100
05/04/88	02:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/04/88	08:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8720	NA	320	23900
05/04/88	12:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7330	NA	240	23200
05/04/88	16:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/04/88	18:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6770	NA	290	23000
05/05/88	01:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/05/88	15:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8230	NA	270	25000

NA - Not Analyzed

Appendix A - Storm Surveillance Data  
 Melton Branch Stream (MBS) (Monitoring Station, MS-4)

Date	Time	Julian Date	Discharge (l/min) (10-min Ave)	Tritium Concentration (pCi/l)	%Error (1 Sigma)	Water Cs-137 (pCi/l)	1 Sigma Counting Error	Particles Cs-137 (pCi/l)	1 Sigma Counting Error	Water Co-60 (pCi/l)	1 Sigma Counting Error	Particles Co-60 (pCi/l)	1 Sigma Counting Error	Sr-90 Water (pCi/l) (Cerenkov)	1 Sigma Counting Error
02/05/88	08:00	35.333	7677	867239	0.16	ND	ND	ND	ND	ND	ND	ND	ND	227	34
05/03/88	10:20	123.431	1129	2002872	0.10	ND	ND	ND	ND	ND	ND	ND	ND	346	36
05/03/88	18:00	123.750	686	2353576	0.09	ND	ND	ND	ND	ND	ND	ND	ND	378	36
05/03/88	20:00	123.833	996	2414085	0.09	ND	ND	ND	ND	ND	ND	ND	ND	349	36
05/03/88	22:00	123.917	1981	2172320	0.10	ND	ND	ND	ND	ND	ND	ND	ND	352	36
05/03/88	23:00	123.958	1968	1657586	0.11	2.2	1.0	ND	ND	69.0	1.5	ND	ND	324	35
05/04/88	02:00	124.083	1498	1797615	0.10	ND	ND	ND	ND	ND	ND	ND	ND	360	36
05/04/88	08:00	124.333	1893	2027533	0.10	ND	ND	ND	ND	ND	ND	ND	ND	385	37
05/04/88	12:00	124.500	3046	1754814	0.11	3.3	3.7	ND	ND	ND	ND	ND	ND	335	35
05/04/88	16:00	124.667	2080	1999137	0.10	ND	ND	ND	ND	ND	ND	ND	ND	332	35
05/04/88	18:00	124.750	3291	1433617	0.12	ND	ND	ND	ND	ND	ND	ND	ND	196	33
05/05/88	01:00	125.042	1859	1989734	0.10	ND	ND	ND	ND	1226.0	35.0	82.100	6.0	438	38
05/05/88	15:00	125.625	997	2824749	0.09	ND	ND	ND	ND	40.0	22.0	4.700	1.2	395	37

ND - Not Detected

Appendix A - Storm Surveillance Data  
 Melton Branch Stream (MBS) (Monitoring Station, MS-4)

Date	Time	Al (ug/l)	Ba (ug/l)	Be (ug/l)	Ca (ug/l)	Fe (ug/l)	K (ug/l)	Mg (ug/l)	Mn (ug/l)	Na (ug/l)	SiO2 (ug/l)	Sr (ug/l)	V (ug/l)	Zn (ug/l)	Cl (ug/l)	NO3 (ug/l)	PO4 (ug/l)	SO4 (ug/l)
01/17/88	13:00	250	43	1.8	46000	<20	1800	9400	50	12000	4065	110	9.3	<7	NA	NA	NA	NA
01/17/88	15:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/17/88	17:00	260	43	1.9	43000	20	NA	8200	53	18000	3637	96	8.2	<7	NA	NA	NA	NA
01/17/88	19:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/17/88	23:00	250	43	1.7	44000	23	NA	7400	66	14000	4921	97	6.9	<7	NA	NA	NA	NA
01/18/88	01:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/18/88	03:00	520	40	1.6	35000	320	NA	5700	96	12000	5134	73	5.6	10	NA	NA	NA	NA
01/18/88	05:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/18/88	09:00	230	36	1.5	34000	47	NA	5400	56	9300	5134	72	5.7	<7	NA	NA	NA	NA
01/19/88	01:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/19/88	07:00	250	37	1.5	35000	45	NA	5200	42	7000	5348	74	5.1	<7	NA	NA	NA	NA
01/19/88	09:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/19/88	11:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/19/88	14:30	200	26	0.6	21000	93	NA	3200	100	5100	4707	44	<4.0	<7	NA	NA	NA	NA
01/19/88	17:45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/19/88	19:45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/19/88	21:45	1200	36	0.4	18000	990	NA	2700	190	3200	6632	37	4.8	20	NA	NA	NA	NA
01/19/88	23:45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/20/88	01:45	1000	27	<0.3	9700	810	2100	1800	95	1400	5776	20	4.3	9	NA	NA	NA	NA
01/20/88	03:45	360	21	<0.3	12000	230	NA	2000	64	1800	4921	26	<4.0	<7	NA	NA	NA	NA
01/20/88	07:45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/20/88	15:45	190	28	0.7	23000	34	NA	3500	66	3400	5562	46	<4.0	<7	NA	NA	NA	NA
01/21/88	01:45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/03/88	24:00	240	38	1.6	36000	28	1700	5500	20	6500	5348	77	5.2	<7	NA	NA	NA	NA
02/04/88	02:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	04:00	220	31	1.0	29000	47	NA	4200	14	5000	5562	58	4.4	<7	NA	NA	NA	NA
02/04/88	06:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	08:00	1200	38	0.5	19000	94	1700	3000	67	3100	7702	40	4.6	<7	NA	NA	NA	NA
02/04/88	09:50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	12:00	170	24	0.5	20000	46	NA	3000	22	3000	5562	42	<4.0	<7	NA	NA	NA	NA
02/04/88	15:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	21:00	640	33	0.9	25000	400	NA	3800	34	3500	7060	49	<4.0	<7	NA	NA	NA	NA
02/05/88	08:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Appendix A - Storm Surveillance Data  
 White Oak Creek (WOC) (Monitoring Station, MS-3)

Date	Time	Julian Date	Discharge Q (l/min) (10 min Average)	Tritium Concentration (pCi/l)	%Error (1 Sigma)	Dissolved Cs-137 (pCi/l)	1 Sigma Counting Error	Particle Cs-137 (pCi/l)	1 Sigma Counting Error	Water Co-60 (pCi/l)	1 Sigma Counting Error	Particle Co-60 (pCi/l)	1 Sigma Counting Error	Sr-90 Water (pCi/l) (Cerenkov)	1 Sigma Counting Error
01/19/88	14:30	18.596	75708	59055	1.16	16.8	3.9	26.4	1.3	ND	ND	ND	ND	150	27
01/20/88	03:06	19.128	265130	33258	1.51	19.6	8.5	146.0	9.6	ND	ND	ND	ND	118	26
01/20/88	05:06	19.211	156224	33351	1.51	25.4	6.0	143.0	6.6	ND	ND	3.0	3.2	167	27
01/20/88	07:06	19.294	113979	34791	1.48	11.8	4.0	159.0	5.5	ND	ND	ND	ND	214	28
01/20/88	09:06	19.378	88427	31929	1.55	27.8	7.0	292.0	9.4	ND	ND	ND	ND	210	28
01/20/88	15:06	19.628	55002	37086	1.45	48.3	5.9	48.5	3.7	ND	ND	ND	ND	342	30
01/20/88	21:06	19.878	43419	36845	1.47	25.0	5.1	52.6	3.2	ND	ND	ND	ND	406	32
02/03/88	24:00	34.000	25336	52232	1.25	30.9	4.0	19.2	0.9	ND	ND	ND	ND	154	26
02/04/88	02:00	34.083	41564	69331	1.10	31.5	5.1	39.8	1.5	ND	ND	ND	ND	196	28
02/04/88	04:00	34.167	34720	66540	1.12	29.9	6.0	24.5	1.0	ND	ND	ND	ND	214	28
02/04/88	06:00	34.250	150924	6581	2.98	19.5	5.7	273.0	6.0	ND	ND	3.9	2.0	36	24
02/04/88	08:00	34.333	125297	48561	1.31	22.2	1.7	51.8	3.6	ND	ND	ND	ND	164	27
02/04/88	09:45	34.394	77658	48777	1.31	14.3	1.7	4.4	0.9	ND	ND	ND	ND	178	27
02/04/88	14:30	34.596	46485	65922	1.12	9.1	4.3	27.4	2.5	ND	ND	ND	ND	180	29
02/04/88	18:30	34.763	38687	68551	1.10	5.6	4.0	18.4	2.3	ND	ND	ND	ND	189	27
02/05/88	00:30	35.013	34311	62832	1.15	9.2	1.8	23.0	2.5	ND	ND	ND	ND	172	27
02/05/88	08:30	35.346	27819	53080	1.24	9.4	1.3	22.5	0.9	1.3	1.5	ND	ND	186	27
02/04/88	BLANK	-----	-----	112	5.03	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
05/03/88	10:00	123.417	11947	10865	1.64	44.7	6.8	33.1	3.2	ND	ND	ND	ND	104	32
05/03/88	18:00	123.750	12174	8010	2.01	22.9	6.8	0.0	0.0	ND	ND	ND	ND	57	31
05/03/88	20:00	123.833	15448	3003	4.11	37.9	6.6	12.7	2.3	ND	ND	ND	ND	50	31
05/03/88	22:00	123.917	21596	2154	5.39	51.7	3.8	30.4	3.5	ND	ND	ND	ND	54	31
05/03/88	23:00	123.958	17818	31303	0.88	41.0	6.4	18.5	2.6	ND	ND	ND	ND	46	31
05/04/88	02:00	124.083	11788	31107	0.88	35.6	6.9	30.1	2.0	ND	ND	ND	ND	78	32
05/04/88	07:00	124.292	17489	11511	1.63	32.4	5.2	22.1	4.0	ND	ND	ND	ND	104	32
05/04/88	12:00	124.500	23326	38640	0.8	33.0	6.4	24.2	2.9	ND	ND	ND	ND	110	32
05/04/88	15:00	124.625	15119	46474	0.72	23.7	5.4	17.2	2.1	ND	ND	ND	ND	110	32
05/05/88	01:00	125.042	11928	45481	0.73	46.0	5.7	9.6	1.9	ND	ND	ND	ND	118	32
12/07/87	14:30A	340.596	-----	1647	4.11	39.4	1.8	16.7	0.6	3.5	3.1	ND	ND	46	24
12/07/87	14:35B	340.598	-----	1487	4.18	29.2	2.5	128.0	1.7	ND	ND	ND	ND	54	24

ND - Not Detected

Appendix A - Storm Surveillance Data  
 White Oak Creek (WOC) (Monitoring Station, MS-3)

Date	Time	Al (ug/l)	Ba (ug/l)	Be (ug/l)	Ca (ug/l)	Fe (ug/l)	K (ug/l)	Mg (ug/l)	Mn (ug/l)	Na (ug/l)	SiO2 (ug/l)	Sr (ug/l)	V (ug/l)	Zn (ug/l)	C (ug/l)	NO3 (ug/l)	PO4 (ug/l)	SO4 (ug/l)
01/19/88	14:30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/20/88	03:06	510	30	0.8	24000	310	2400	4100	21	4800	4707	44	5.4	17	NA	NA	NA	NA
01/20/88	05:06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/20/88	07:06	180	30	1.0	29000	23	NA	5400	<5	5500	4707	53	4.8	<7	NA	NA	NA	NA
01/20/88	09:06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/20/88	15:06	210	34	1.6	35000	29	NA	6700	<5	7800	5134	69	6.6	<7	NA	NA	NA	NA
01/20/88	21:06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/03/88	24:00	250	36	1.8	41000	29	2300	8100	28	15000	4065	96	7.5	26	NA	NA	NA	NA
02/04/88	02:00	230	32	1.6	36000	23	NA	6600	23	12000	3851	82	6.3	19	NA	NA	NA	NA
02/04/88	04:00	290	39	1.9	49000	32	NA	8100	29	17000	4707	100	8.1	23	NA	NA	NA	NA
02/04/88	06:00	170	18	0.9	25000	27	1900	3600	13	5800	3209	47	<4.0	<7	NA	NA	NA	NA
02/04/88	08:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	09:45	260	31	1.7	36000	54	NA	5800	14	7700	4921	70	5.5	<7	NA	NA	NA	NA
02/04/88	14:30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	18:30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/05/88	00:30	260	37	1.8	44000	26	NA	8400	25	13000	5134	88	7.3	17	NA	NA	NA	NA
02/05/88	08:30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	BLANK	<60	<2	<0.3	<200	<20	<100	<10	<5	<200	<428	<5	<4.0	<7	NA	NA	NA	NA
05/03/88	10:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/03/88	18:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	14200	210	500	32100
05/03/88	20:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/03/88	22:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10400	90	NA	28900
05/03/88	23:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10000	NA	NA	27100
05/04/88	02:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/04/88	07:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	17900	230	540	55900
05/04/88	12:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	9740	NA	230	27200
05/04/88	15:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/05/88	01:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	19200	2370	670	48800
12/07/87	14:30A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/07/87	14:35B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA - Not Analyzed

Appendix A - Storm Surveillance Data  
 Melton Branch Tributary (MBT) (Monitoring Station, MS-4B)

Date	Time	Julian Date	Tritium Concentration (pCi/l)	%Error (1 Sigma)	Water Cs-137 (pCi/l)	1 Sigma Counting Error	Particles Cs-137 (pCi/l)	1 Sigma Counting Error	Water Co-60 (pCi/l)	1 Sigma Counting Error	Particles Co-60 (pCi/l)	1 Sigma Counting Error	Sr-90 Water (pCi/l) (Cerenkov)	1 Sigma Counting Error
01/17/88	17:00	16.708	458	4.74	ND	ND	7.0	1.5	ND	ND	ND	ND	206	30
01/17/88	19:00	16.792	1029	4.40	ND	ND	3.1	0.8	ND	ND	ND	ND	238	31
01/17/88	23:00	16.958	1012	4.42	ND	ND	7.4	0.6	ND	ND	ND	ND	277	31
01/18/88	01:00	17.042	741	4.56	ND	ND	21.3	1.9	ND	ND	ND	ND	142	29
01/18/88	03:00	17.125	1052	4.39	ND	ND	5.3	2.3	ND	ND	ND	ND	166	29
01/18/88	05:00	17.208	1196	4.32	ND	ND	2.3	1.1	ND	ND	ND	ND	190	30
01/18/88	09:00	17.375	1250	4.29	ND	ND	2.8	0.6	ND	ND	ND	ND	252	31
01/18/88	21:00	17.875	1285	4.28	ND	ND	8.6	1.9	ND	ND	ND	ND	262	31
01/19/88	07:00	18.292	1259	4.29	ND	ND	11.0	1.7	ND	ND	ND	ND	344	33
01/19/88	09:00	18.375	648	4.62	ND	ND	8.1	1.2	ND	ND	ND	ND	225	31
01/19/88	15:00	18.625	6189	2.95	ND	ND	4.1	1.7	ND	ND	ND	ND	146	29
01/19/88	19:00	18.792	20455	1.86	ND	ND	17.8	1.5	ND	ND	ND	ND	177	29
01/19/88	21:00	18.875	11947	2.43	ND	ND	96.2	5.6	ND	ND	ND	ND	110	28
01/19/88	23:00	18.958	2632	3.86	ND	ND	215.0	9.0	ND	ND	ND	ND	28	26
01/20/88	01:00	19.042	1792	4.18	10.5	3.9	28.3	1.0	ND	ND	ND	ND	36	26
01/20/88	03:00	19.125	2137	4.03	ND	ND	8.3	2.1	ND	ND	ND	ND	56	27
01/20/88	05:00	19.208	2783	3.80	ND	ND	0.0	0.0	ND	ND	ND	ND	110	28
01/20/88	09:00	19.375	2788	3.78	ND	ND	2.5	1.7	ND	ND	ND	ND	181	29
01/20/88	17:00	19.708	2442	3.90	ND	ND	2.5	1.0	0.8	0.6	ND	ND	223	31
02/03/88	24:00	34.000	1567	4.24	2.2	1.7	3.3	1.8	ND	ND	ND	ND	250	32
02/04/88	02:00	34.083	1525	4.26	ND	ND	7.1	0.7	ND	ND	ND	ND	202	30
02/04/88	04:00	34.167	1665	4.20	0.4	1.2	0.0	0.0	ND	ND	ND	ND	206	30
02/04/88	06:00	34.250	1150	4.45	ND	ND	21.8	0.7	ND	ND	ND	ND	78	27
02/04/88	08:00	34.333	1180	4.43	ND	ND	7.3	0.7	ND	ND	ND	ND	85	27
02/04/88	09:55	34.415	1462	4.29	ND	ND	6.1	1.1	ND	ND	ND	ND	88	27
02/04/88	12:00	34.500	1677	4.20	1.4	1.5	0.0	0.0	ND	ND	ND	ND	146	29
02/04/88	16:00	34.667	1786	4.15	ND	ND	3.1	0.5	5.3	5.1	ND	ND	181	29
02/04/88	22:00	34.917	1614	4.22	ND	ND	3.7	0.6	ND	ND	ND	ND	227	31
02/05/88	08:00	35.333	1704	4.24	ND	ND	ND	ND	ND	ND	ND	ND	270	31
02/04/88	BLANK	-----	240	5.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
05/03/88	09:45	ND	884	12.36	ND	ND	ND	ND	ND	ND	ND	ND	396	37

ND - Not Detected

Appendix A - Storm Surveillance Data  
 Melton Branch Tributary (MBT) (Monitoring Station, MS-4B)

Date	Time	Al (ug/l)	Ba (ug/l)	Be (ug/l)	Ca (ug/l)	Fe (ug/l)	K (ug/l)	Mg (ug/l)	Mn (ug/l)	Na (ug/l)	SiO2 (ug/l)	Sr (ug/l)	V (ug/l)
01/17/88	17:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/17/88	19:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/17/88	23:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/18/88	01:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/18/88	03:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/18/88	05:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/18/88	09:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/18/88	21:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/19/88	07:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/19/88	09:00	210	48	1.5	34000	32	1800	7000	59	15000	3851	74	6.3
01/19/88	15:00	480	45	0.9	25000	430	NA	5400	100	6900	5348	51	6.0
01/19/88	19:00	180	40	0.9	27000	42	NA	5600	52	7900	4279	54	6.0
01/19/88	21:00	140	36	0.6	19000	52	1900	3800	260	4800	3637	40	4.1
01/19/88	23:00	450	33	<0.3	13000	490	NA	2700	180	2600	3637	31	<4.0
01/20/88	01:00	120	26	<0.3	11000	57	NA	2700	84	2100	3423	26	<4.0
01/20/88	03:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/20/88	05:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/20/88	09:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/20/88	17:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/03/88	24:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	02:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	04:00	190	46	1.0	29000	36	1700	6300	47	6300	4921	62	6.5
02/04/88	06:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	08:00	140	34	0.5	19000	40	NA	4100	40	3800	4921	41	4.2
02/04/88	09:55	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	12:00	150	37	0.5	21000	41	NA	4700	36	3900	5348	45	4.2
02/04/88	16:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	22:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/05/88	08:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	BLANK	<60.0	<2.0	<0.3	<200	<20	<100	<10	<5	<200	<427	<5	<4.0
05/03/88	09:45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA - Not Analyzed

APPENDIX B  
LISTING OF COMPUTER PROGRAMS MASSFLO AND SEPARATE



CC

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\* M A S S F L O \*

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C

THIS PROGRAM ESTIMATES THE TOTAL MASS OF A DISSOLVED SPECIES  
IN STREAM WATER THAT IS TRANSPORTED PAST A MONITORING STATION  
DURING A STORM. IN ADDITION IT ESTIMATES THAT FRACTION OF BOTH  
STREAM FLOW AND DISSOLVED MASS THAT OCCUR AS QUICKFLOW BY  
PERFORMING SIMPLE HYDROGRAPH SEPARATION. THE HYDROGRAPH SEPARATION  
IS BASED ON THE CONCEPT DESCRIBED BY HEWLETT AND HIBBERT, 1967  
("FACTORS AFFECTING THE RESPONSE OF SMALL WATERSHEDS TO  
PRECIPITATION IN HUMID AREA", PP. 275-290 IN: W.E. SOPPER AND  
H.W. LULL (eds.). INTERNATIONAL SYMPOSIUM ON FOREST HYDROLOGY,  
PERGAMON PRESS, OXFORD.) A DETAILED DESCRIPTION OF THE SEPRATION  
CONCEPT IS ALSO GIVEN BY HUFF AND BEGOVICH, 1976 (AN EVALUATION  
OF TWO HYDROGRAPH SEPARATION METHODS OF POTENTIAL USE IN REGIONAL  
WATER QUALITY ASSEMSSMENT.

C

SELECTED PROGRAM VARIABLES

C

TMC(I) JULIAN TIME OF WHEN ITH CONCENTRATION WAS MEASURED

C

MC(I) MEASURED CONCENTRATION

C

FLOCON CONVERSION FACTOR FOR INPUT FLOW VALUES, ALL FLOW  
VALUES SHOULD BE CONVERTED TO M<sup>3</sup>/DAY

C

CONCON CONVERSION FACTOR FOR CONCENTRATION, ALL  
CONCENTRATIONS SHOULD BE CONVERTED TO KG/M<sup>3</sup>

C

ETC ESTIMATED (BY LINEAR INTERP.) TOTAL CONCENTRATION

C

BC BASEFLOW CONCENTRATION

C

NCON NUMBER OF MEASURED CONCENTRATION VALUES

C

MAXCON MAXIMUM ALLOWED MEASURED CONCENTRATION VALUES

C

SYR STARTING YEAR, USED TO HANDLE JULIAN TIME

C

IF STORMS OCCURS DURING TWO CALENDAR YEARS

C

BETA SLOPE OF HYDROGRAPH SEPARATION LINE

C

GAMMA SLOPE OF CHEMICAL SEPARATION LINE

C

BB INTERCEPT OF HYDROGRAPH SEPARATION LINE

C

BG INTERCEPT OF CHEMICAL SEPARATION LINE

C

SPACE TIME INTERVAL BETWEEN FLOW MEASUREMENTS, USED FOR  
WARNING ABOUT MISSING DATA POINTS

C

NCOUNT COUNTER TO KEEP TRACK OF NUMBER OF FLOW RECORDS  
PROCESSED

C

TITLE CHARACTER VARIALBE TO DESCRIBE DATA

C

TDIS TOTAL DISCHARGE FOR A STORM PERIOD

C

TMAS TOTAL MASS RELEASED DURING A STORM PERIOD

C

C

C

C

C

C

C

C

C

C

INPUT PARAMETERS: NOTE THAT 2 INPUT FILES ARE REQUIRED. THE  
CONCENTRATION FILE CONTAINS CONTROL PARAMETERS, THE FLOW FILE  
CONTAINS STREAMFLOW MEASUREMENTS. THE USERS IS PROMPTED FOR THE  
NAMES OF THESE FILES

C  
 C CONCENTRATION FILE  
 C CARD 1 (I2,A80)  
 C ISKIP NUMBER OF INTERVALS TO SKIP FOR OUTPUT FILE. IF  
 C =-1 OUTPUT DATA FOR PLOTTING WILL BE WRITTEN EACH  
 C TIME A FLOW INPUT DATA POINT IS READ, IF=2  
 C OUTPUT DATA WILL BE WRITTEN WHEN EVERY OTHER FLOW  
 C INPUT DATA IS READ ETC. IE THIS PARAMETERS  
 C ALLOWS THE OUTPUT FILE, WHICH IS GENERATED FOR  
 C PLOTTING PURPOSES, TO BE CONDENSED IF HIGHEST  
 C RESOLUTION IS NOT REQUIRED.  
 C TITLE DESCRIPTION OF DATA SET, 80 CHAR. MAX  
 C CARD 2 (F10.2,5X,F10.2)  
 C FLOCON CONVERSION FACTOR FOR CONVERTING FLOW TO M<sup>3</sup>/DAY  
 C CONCON CONVERSION FACTOR FOR CONVERTING CONCENTRATION  
 C TO KG/M<sup>3</sup>  
 C CARD 3 (I4,1X,5(I2,1X),5X,F10.2,5X,F10.2)  
 C TSTART STARTING TIME OF HYDROGRAPH SEPARATION, IE THE  
 C TIME AT WHICH BASEFLOW EQUALS TOTAL FLOW JUST PRIOR  
 C TO THE RISE OF THE STORM HYDROGRAPH, INPUT TIME AS  
 C YYYY/MM/DD:HH:MM:SS CCSTARTCONCENTRATION OF BASEFLOW  
 C AT TIME TSTART  
 C FSTART FLOW OF BASEFLOW AT TIME TSTART  
 C CARD 4 (I4,1X,5(I2,1X),5X,F10.2,5X,F10.2)  
 C TEND ENDING TIME OF HYDROGRAPH SEPARATION, IE THE  
 C TIME AT WHICH BASEFLOW EQUALS TOTAL FLOW JUST AFTER  
 C THE END OF THE STORM, INPUT TIME AS  
 C YYYY/MM/DD:HH:MM:SS CCENDCONCENTRATION OF BASEFLOW  
 C AT TIME TEND  
 C FEND FLOW OF BASEFLOW AT TIME TEND  
 C CARDS 5-NUMBER OF MEASURED CONCENTRATIONS VALUES  
 C (I4,1X,5(I2,1X),5X,F10.2)  
 C TMC(I) TIME OF MEASURED CONCENTRATION VALUE, ENTERED AS  
 C YYYY/MM/DD:HH:MM:SS  
 C MC(I) MEASURED CONCENTRATION--NOTE: MEASURED CONCENTRATION  
 C VALUES MUST BE ENTERED IN CHRONOLOGICAL ORDER  
 C  
 C FLOW FILE  
 C CARDS 1-NUMBER OF FLOW MEASUREMENTS  
 C (I4,1X,I2,1X,I2,8X,I2,1X,I2,10X,E10.4)  
 C JTIME TIME OF FLOW MEASUREMENTS, ENTERED AS  
 C YYYY/MM/DD:HH:MM:SS CTFLODISCHARGE AT TIME JTIME  
 C  
 C INTEGER ISKIP  
 C INTEGER YR, MON, DAY, HR, MIN, SEC, MAXCON, SYR  
 C REAL TSTART, CSTART, FSTART, TEND, CEND, FEND  
 C REAL TMC(100), MC(100), ETC, BC, QC, JTIME, JTIME2, TFLO, BFLO, QFLO  
 C REAL TFLX, BFLX, QFLX  
 C REAL TDIS, BDIS, QDIS, TMAS, BMAS, QMAS  
 C CHARACTER\*80 TITLE  
 C CHARACTER\*32 CONIN, FLOIN, PLTOUT, OUTFILE  
 C CHARACTER\*1 HT

```

HT=CHAR(9)
C
C
DIMENSION HINTS
C DATA MAXCON /100/
C
C INITIALIZE VARIABLES
C TDIS=0.
C TMAS=0.
C YR=0
C MON=0
C DAY=0
C HR=0
C MIN=0
C SEC=0
C
C GET FILE NAMES
C
C PRINT 1
1 FORMAT('Enter the concentration filename:')
  READ(*,2) CONIN
  2 FORMAT(A32)
  PRINT 3
  3 FORMAT('Enter the flow filename:')
  READ(*,2) FLOIN
  PRINT 4
  4 FORMAT('Enter the plotting filename:')
  READ(*,2) PLTOUT
  PRINT 6
  6 FORMAT('Enter the output filename:')
  READ(*,2) OUTFILE
C
C READ CONTROL PARAMETERS AND CONCENTRATION DATA FROM UNIT 8
C
OPEN(UNIT=8, FILE=CONIN, STATUS='OLD')
OPEN(UNIT=10, FILE=FLOIN, STATUS='UNKNOWN')
OPEN(UNIT=12, FILE=PLTOUT, STATUS='UNKNONW')
READ(8,5) ISKIP, TITLE
5 FORMAT(I2, A80)
  READ(8,7) FLOCON, CONCON
7 FORMAT(F10.2, 5X, F10.2)
  READ(8,10) YR, MON, DAY, HR, MIN, SEC, CSTART, FSTART
10 FORMAT(I4, 1X, 5(I2, 1X), 5X, F10.2, 5X, F10.2)
  SYR=YR
  TSTART=TCON(YR, MON, DAY, HR, MIN, SEC, SYR)
  CSTART=CSTART*CONCON
  FSTART=FSTART*FLOCON
  READ(8,10) YR, MON, DAY, HR, MIN, SEC, CEND, FEND
  TEND=TCON(YR, MON, DAY, HR, MIN, SEC, SYR)
  IF(TEND.LE.TSTART) THEN
    PRINT 20
20 FORMAT('FATAL ERROR, ENDTIME LESS THAN START TIME')

```

```

        PRINT 300
        READ(*,*) ANYKEY
        STOP
    END IF
    CEND=CEND*CONCON
    FEND=FEND*FLOCON
C
C        READ CONCENTRATION DATA
C
C
C        ASSIGN STARTING CONCENTRATION TO ARRAY
C    TMC(1)=TSTART
    MC(1)=CSTART
C
C        LOOP OVER CONCENTRATION DATA
C    I=2
    25 READ(8,30,END=50) YR,MON,DAY,HR,MIN,SEC,MC(I)
    30 FORMAT(I4,1X,5(I2,1X),5X,F10.2)
        MC(I)=MC(I)*CONCON
        TMC(I)=TCON(YR,MON,DAY,HR,MIN,SEC,SYR)
        IF(TMC(I).LE.TMC(I-1)) THEN
            PRINT 35,YR,MON,DAY,HR,MIN,SEC
    35     FORMAT('FATAL ERROR AT TIME ',I4,'/',I2,'/',3(I2,':'),I2,/'
    $     ', 'INPUT DATA MUST BE IN CHRONOLOGICAL ORDER')
            PRINT 300
            READ(*,*) ANYKEY
            STOP
        END IF
        I=I+1
        GO TO 25
    50 NCON=I
        CLOSE(8)
C
C        ASSIGN ENDING TIME AND CONCENTRATION TO ARRAYS
C    TMC(NCON)=TEND
    MC(NCON)=CEND
C
C        CHECK FOR SUFFICIENT ARRAY SIZE
C
    IF(NCON.GT.MAXCON) THEN
        PRINT 55
    55     FORMAT('FATAL ERROR, NUMBER OF MEASURED CONCENTRATION VALUES
    $     EXCEEDS PROGRAM DIMENSION')
        PRINT 300
        READ(*,*) ANYKEY
        STOP
    END IF
C
C        READ FLOW DATA UNTIL TSTART IS REACHED, CHECK THAT A FLOW
C        MEASUREMENT WAS MADE AT TSTART
C    70 READ(10,60,END=150) YR,MON,DAY,HR,MIN,TFLO
    60     FORMAT(I4,1X,I2,1X,I2,8X,I2,1X,I2,10X,E10.4)

```

```

JTIME=TCON(YR,MON,DAY,HR,MIN,SEC,SYR)
IF(JTIME.EQ.TSTART) GO TO 100
IF(JTIME.GT.TSTART) THEN
PRINT 75
75 FORMAT('FATAL ERROR, FLOW MEASUREMENT NOT MADE AT START TIME')
PRINT 300
READ(*,*) ANYKEY
STOP
END IF
GO TO 70
100 CONTINUE

C
C      COMPUTE CONSTANTS
C
BETA=(FEND-FSTART)/(TEND-TSTART)
GAMMA=(CEND-CSTART)/(TEND-TSTART)
BB=FSTART-BETA*TSTART
BG=CSTART-GAMMA*TSTART
TFLO=TFLO*FLOCON
NCOUNT=1
READ(10,60,END=150) YR,MON,DAY,HR,MIN,TFLO2
SPACE=TCON(YR,MON,DAY,HR,MIN,SEC,SYR)-JTIME
BACKSPACE 10

C
C      WRITE RESULTS TO UNIT 12 FOR PLOTTING
C
QFLO=0.
BFLO=TFLO
TFLX=TFLO*CSTART
QFLX=0.
BFLX=TFLX
WRITE(12,110) HT,HT,HT,HT,HT,HT
110 FORMAT(1X,'TIME',A1,'TFLO',A1,'QFLO',A1,'BFLO',A1
$'TFLX',A1,'QFLX',A1,'BFLX')
WRITE(12,112) JTIME,HT,TFLO,HT,QFLO,HT,BFLO,HT,TFLX,HT,
$QFLX,HT,BFLX 112 FORMAT(1X,E12.6,A1,5(E10.4,A1),E10.4)

C
C      BEGIN INTEGRATION OVER TIME
C
115 READ(10,60,END=150) YR,MON,DAY,HR,MIN,TFLO2
JTIME2=TCON(YR,MON,DAY,HR,MIN,SEC,SYR)
TFLO2=TFLO2*FLOCON

C
C      CHECK THAT FLOW DATA ARE ARRANGED CHRONOLOGICALLY
C
IF(JTIME2.LT.JTIME) THEN
PRINT 35,YR,MON,DAY,HR,MIN,SEC
PRINT 300 READ(*,*) ANYKEY
STOP
END IF

C
C      WARN IF SPACING BETWEEN FLOW VALUES IS NOT CONSTANT
C
SPACE2=JTIME2-JTIME

```

```

      IF(1.-ABS(SPACE2/SPACE).GT.0.00001) THEN
        PRINT 120,YR,MON,DAY,HR,MIN,SEC
120      FORMAT('WARNING!! SPACING BETWEEN FLOW MEASUREMENTS CHANGED
AT      $  TIME' ,/,I4,'/',I2,'/',3(I2,':'),I2)
        SPACE2=SPACE2
      END IF
C
C      COMPUTE BASEFLOW AND QUICKFLOW
C
      BFLO=BETA*JTIME2+BB
      QFLO=TFLO2-BFLO
      IF(QFLO.LT.0.) THEN
125      PRINT 125,YR,MON,DAY,HR,MIN,SEC
        FORMAT('WARNING!, TOTAL FLOW LESS THAN BASEFLOW AT TIME' ,/
          $  ,I4,'/',I2,'/',3(I2,':'),I2)
        END IF
C
C      COMPUTE MASS FLUX IN BASEFLOW AND QUICKFLOW
C
C
C      INTERPOLATE TO OBTAIN ESTIMATE OF CONCENTRATION AT
TIME=JTIME2
C
      CALL CONINT(NCON,MAXCON,TMC,MC,JTIME2,ETC,SYR)
      TFLX2=TFLO2*ETC
      BFLX=BFLO*(GAMMA*JTIME2+BG)
      QFLX=TFLX2-BFLX
      IF(QFLX.LT.0.) THEN
130      PRINT 130,YR,MON,DAY,HR,MIN,SEC
        FORMAT('WARNING!, TOTAL MASS FLUX LESS THAN MASSFLUX IN
          $  BASEFLOW AT TIME' ,/,I4,'/',I2,'/',3(I2,':'),I2)
        END IF
C
C      WRITE RESULTS TO UNIT 12 FOR PLOTTING
      IF(MOD(NCOUNT,ISKIP).EQ.0) THEN
        WRITE(12,112) JTIME2,HT,TFLO2,HT,QFLO,HT,BFLO,HT,TFLX2,HT,
          $QFLX,HT,BFLX
        END IF
C
C      COMPUTE THE RUNNING TOTALS
C
      TDIS=TDIS+SPACE2*(TFLO+TFLO2)/2.
      TMAS=TMAS+SPACE2*(TFLX+TFLX2)/2.
C
C      REASSIGN TFLO AND TFLX AND READ ANOTHER RECORD IF END OF STORM
C      HAS NOT YET BEEN REACHED
C
      TFLO=TFLO2
      TFLX=TFLX2
      JTIME=JTIME2
      IF(JTIME2.GE.TEND) GO TO 200

```

```

IF(JTIME2.LT.TEND) GO TO 115
C
C      STOP EXECUTION IF CONTROL COMES HERE SINCE A FLOW MEASUREMENT
C      WAS NOT MADE AT TEND
C
      PRINT 140
140   FORMAT('FATAL ERROR, FLOW MEASUREMENT NOT MADE AT END TIME')
      PRINT 300
      READ(*,*) ANYKEY
      STOP
C
C      IF CONTROL COMES TO LABEL 150, END OF FLOW DATA FILE WAS
REACHED
C      BEFORE STORM ENDED
C
150 PRINT 155
155 FORMAT('FATAL ERROR, FLOW MEASUREMENTS DO NOT EXTEND TO END OF
      $ OF STORM')
      PRINT 300
      READ(*,*) ANYKEY
      STOP
C
C      WRITE SUMMARY RESULTS TO UNIT 13
C
200 CONTINUE
      OPEN(UNIT=13, FILE=OUTFILE, STATUS='UNKNOWN', POSITION='APPEND')
      WRITE(13,205) TITLE
205 FORMAT('*****
      $*****', //, A80, //)
      BDIS=(TEND-TSTART)*(FSTART+FEND)/2.
      QDIS=TDIS-BDIS
      BMAS=(TEND-TSTART)*(CSTART*FSTART+CEND*FEND)/2.
      QMAS=TMAS-BMAS
      CALL TINV(YR, MON, DAY, HR, MIN, SEC, SYR, TSTART)
      WRITE(13,208) YR, MON, DAY, HR, MIN, SEC
208 FORMAT(1X, 'STREAM SEPARATION BEGAN ON: ', I4, '/', I2,
      $'/', 3(I2, ':'), I2)
      CALL TINV(YR, MON, DAY, HR, MIN, SEC, SYR, TEND)
      WRITE(13,209) YR, MON, DAY, HR, MIN, SEC
209 FORMAT(1X, 'STREAM SEPARATION ENDED ON: ', I4, '/', I2,
      $'/', 3(I2, ':'), I2)
      WRITE (13,210)
210 FORMAT(1X, //, 20X, 'SUMMARY OF FLOW RESULTS', //, 1X, 'TOTAL
DISCHARGE'
      $, 5X, 'TOTAL QUICKFLOW', 5X, 'TOTAL BASEFLOW', /, 7X, 'M^3', 17X,
      $'M^3', 17X, 'M^3')
      WRITE(13,212) TDIS, QDIS, BDIS
212 FORMAT(4X, 3(E12.5, 8X))
      WRITE(13,215)
215 FORMAT(1X, //, 20X, 'SUMMARY OF MASS RESULTS', //, 1X, 'TOTAL MASS
RELEA

```

```

    $SE', 3X, 'MASS IN QUICKFLOW', 3X, 'MASS IN
BASEFLOW' ,/, 1X, 6X, 'KG', 20X,
    '$'KG', 17X, 'KG')

```

```

    WRITE(13, 212) TMAS, QMAS, BMAS
300 FORMAT('Hit any key to continue')
    END
    FUNCTION TCON(YR, MON, DAY, HR, MIN, SEC, SYR)

```

```

C
C     THIS FUNCTION CONVERTS DATE AND TIME INTO A SERIAL (JULIAN)
C     VALUE.  SYR IS THE STARTING YEAR AND IS USED TO ADD 365
C     (OR 366 FOR LEAP YEAR) TO THE SERIAL NUMBER IF YR=SYR+1
C     THIS IS USEFUL WHEN A GIVEN SIMULATION OCCURS OVER TWO
C     CALENDAR YEARS.

```

```

C
C     NOTE:   IF YR-SYR IS GREATER THAN 1, THE RETURNED VALUE
C             MAY BE INCORRECT SINCE LEAP YEAR IS NOT PROPERLY
C             ACCOUNTED FOR.

```

```

C
C     INTEGER YR, MON, DAY, HR, MIN, SEC, SYR
C           INTEGER IMON(12), LPYR, YRADD, SLPYR
C     DATA (IMON(I), I=1, 12)/0, 31, 59, 90, 120, 151, 181, 212, 243, 273, 304, 334/
C     LPYR=0
C     SLPYR=0
C     IF(MOD(YR, 4).EQ.0) LPYR=1
C     IF(IMON(MON).GE.59) IMON(MON)=IMON(MON)+LPYR
C     IF(MOD(SYR, 4).EQ.0) SLPYR=1
C     YRADD=(YR-SYR)*365+SLPYR
C     TCON=REAL(IMON(MON)+DAY-1+(REAL(HR)+(REAL(MIN)+REAL(SEC)/60.)/60.
C     $)/24.+YRADD)
C     RETURN
C     END
C     SUBROUTINE TINV(YR, MON, DAY, HR, MIN, SEC, SYR, TIME)

```

```

C
C     THIS SUBROUTINE CONVERTS A SERIAL (JULIAN) DAY INTO YEAR, MONTH
C     DAY, HOUR, MINUTE, SEC.  SYR IS THE YEAR WHICH CORRESPONDS TO
JULIAN
C     DAY 0.

```

```

C
C     NOTE:   IF TIME IS GREATER THAN 730 (OR 731 IF LEAP YEAR HAS
C             OCCURRED) THE FUNCTION MAY NOT CORRECTLY HANDLE LEAP
YEAR
C

```

```

C
C     INTEGER YR, MON, DAY, HR, MIN, SEC, SYR, LPYR, SLPYR
C     INTEGER IMON(13)
C     REAL TIME
C     DATA (IMON(I), I=1, 13)/0, 31, 59, 90, 120, 151, 181, 212, 243, 273, 304, 334,
C     $365/
C     SLPYR=0
C     LPYR=0
C     IF(MOD(SYR, 4).EQ.0) SLPYR=1

```

```

C
C     DETERMINE THE YEAR

```

```

C
YR==SYR+INT(TIME)/(365+SLPYR)
IF(MOD(YR,4).EQ.0) LPYR=1
IADD=(YR-SYR)*(365+SLPYR)

C
C   SET MONTH, DAY, YEAR, HOUR, MIN., SEC. IF TIME IS EXACTLY 365 (OR
366
C   IF LEAP YEAR HAS OCCURRED
C   IF(TIME.EQ.REAL(365+SLPYR)) THEN
      MON=1
      DAY=1
      HR=0
      MIN=0
      SEC=0
      RETURN
END IF

C
C   DETERMINE MONTH AND DAY
C
TIME=TIME+1.
IF((INT(TIME)-IADD).GT.59) TIME=TIME-REAL(LPYR)
DO 10 I=1,12
IF((INT(TIME)-IADD).GT.IMON(I).AND.(INT(TIME)-IADD).LE.IMON(I+1))
$ THEN
      MON=I
      DAY=INT(TIME)-IADD-IMON(I)
      END IF
10 CONTINUE

C
C   DETERMINE HOUR, MINUTES AND SECONDS
C
REM=TIME-INT(TIME)
HR=INT(REM*24.)
REM=REM*24.-HR
MIN=INT(REM*60.)
REM=REM*60.-MIN
SEC=NINT(REM*60.)

C
C   FIX PROBLEMS THAT ARISE FROM ROUND OFF ERRORS
C
IF(SEC.EQ.60) THEN
      MIN=MIN+1
      SEC=0
END IF
IF(MIN.EQ.60) THEN
      HR=HR+1
      MIN=0
END IF
IF(HR.EQ.24) THEN
      DAY=DAY+1
      HR=0
END IF

```

```

RETURN
END
SUBROUTINE CONINT(NCON,MAXCON,TMC,MC,JTIME2,ETC,SYR)
C
C   THIS SUBROUTINE PERFORMS LINEAR INTERPOLATION BETWEEN MEASURED
C   CONCENTRATION VALUES TO ESTIMATE A CONCENTRATION THAT ANY POINT
C   IN TIME THAT LIES WITHIN THE MEASURED RANGE OF CONCENTRATIONS
C
C   PARAMETERS
C
C   NCON          NUMBER OF MEASURED CONCENTRATION DATA POINTS
C   MAXCON        MAXIMUM NUMBER OF MEASURED CONCENTRATION POINTS
C                 USED FOR DIMENSIONING ARRAYS
C   TMC(I)        ARRAY OF MEASURED CONCENTRATION TIMES
C   MC            ARRAY OF MEASURED CONCENTRATIONS
C   JTIME2        SERIAL TIME OF DESIRED CONCENTRATION ESTIMATE
C   ETC           ESTIMATED CONCENTRATION RETURNED TO CALLING PROGRAM
C   SYR           STARTING YEAR OF SIMULATION, USED FOR INVERTING SERIAL
C                 TIME FOR ERROR MESSAGE
C
C   INTEGER MAXCON,NCON,YR,MON,DAY,HR,MIN,SEC,SYR
C   REAL TMC(MAXCON),MC(MAXCON),JTIME2,ETC
C
C   DETERMINE WHICH MEASURED VALUES BRACKET THE DESIRED VALUE
C   IN TIME, COMPUTE THE LINEAR INTERPOLATION, AND RETURN
C
C   DO 20 I=1,NCON-1
C   IF(JTIME2.GE.TMC(I).AND.JTIME2.LE.TMC(I+1)) THEN
C       SLOPE=(MC(I+1)-MC(I))/(TMC(I+1)-TMC(I))
C       B=MC(I)-SLOPE*TMC(I)
C       ETC=SLOPE*JTIME2+B
C       RETURN
C   END IF
20 CONTINUE
C
C   IF CONTROL REACHES HERE, THE MEASURED CONCENTRATIONS DO NOT
C   BRACKET THE DESIRED ESTIMATE IN TIME
C
C   CALL TINV(YR,MON,DAY,HR,MIN,SEC,SYR,JTIME2)
C   PRINT 30,YR,MON,DAY,HR,MIN,SEC
30 FORMAT('FATAL ERROR, DESIRED TIME OF ',I4,'/',I2,'/',3(I2,':'),I2,
$/,'DOES NOT LIE WITHIN RANGE OF MEASURED CONCENTRATION DATA')
PRINT 300
READ(*,*) ANYKEY
STOP
300 FORMAT('Hit any key to continue')
END

```



```

C      (I4,1X,I2,1X,I2,8X,I2,1X,I2,10X,E10.4)
C          JTIME TIME OF FLOW MEASUREMENTS, ENTERED AS
C              YYYY/MM/DD:HH:MM:SS
C          TFLO DISCHARGE AT TIME JTIME
C
C INTEGER YR,MON,DAY,HR,MIN,SEC,SYR
C     REAL JTIME1,JTIME2
C     LOGICAL QUIT
C     CHARACTER*64 INFILE,OUTFILE,FLOFILE
C     PRINT *, 'ENTER INPUT FILE NAME:'
C     READ(*,10) INFILE
C     PRINT *, 'ENTER OUTPUT FILE NAME:'
C     READ(*,10) OUTFILE
10    FORMAT(A64)
C     PRINT *, 'ENTER FLOW FILE NAME:'
C     READ(*,10) FLOFILE
C     OPEN(UNIT=8,FILE=INFILE,STATUS='OLD')
C     OPEN(UNIT=10,FILE=FLOFILE,STATUS='OLD')
C     OPEN(UNIT=11,FILE=OUTFILE,STATUS='UNKNOWN')
C
C     READ FLOW CONVERSION FACTOR AND HYDROGRAPH SLOPE
C
C     READ(8,*) FLOCON,BETA
C
C     READ DESIRED STARTING TIME, NOTE THAT A STORM MUST NOT BE
C     IN PROGRESS AT THIS TIME
C
C     READ(8,*) YR,MON,DAY,HR,MIN
C     SYR = YR
C     GSTIME = TCON(YR,MON,DAY,HR,MIN,0,SYR)
C
C     READ END TIME
C
C     READ(8,*) YR,MON,DAY,HR,MIN
C     GETIME = TCON(YR,MON,DAY,HR,MIN,0,SYR)
C
C     READ FLOW DATA UNTIL STARTING TIME IS REACHED
C
15    READ(10,20,END=28) YR,MON,DAY,HR,MIN,TFLO
C     SEC=0
20    FORMAT(I4,1X,I2,1X,I2,1X,I2,1X,I2,10X,E12.5)
C     TIME = TCON(YR,MON,DAY,HR,MIN,SEC,SYR)
C     IF(TIME.LT.GSTIME) GO TO 15
C     TFLO1 = TFLO*FLOCON
C     JTIME1 = TIME
C     GO TO 30
28    CLOSE(10)
C     PRINT *, 'ENTER NEXT FLOW FILE NAME:'
C     READ(*,10) FLOFILE
C     OPEN(UNIT=10,FILE=FLOFILE,STATUS='OLD')
C     GO TO 15
30    CONTINUE

```

```

C
C     INITIALIZE GLOBAL VALUES
C
    GTFLO = 0.
    GBFLO = 0.
    GTMAS = 0.
    GBMAS = 0.
    NSTORM = 1
C
C     BEGIN MASTER LOOP OVER FLOW DATA
C
50    READ(10,20,END=40) YR,MON,DAY,HR,MIN,TFLO2
    SEC=0
    TFLO2 = TFLO2*FLOCON
    JTIME2 = TCON(YR,MON,DAY,HR,MIN,SEC,SYR)
    GO TO 45
40    PRINT *, 'ENTER NEW FLOW FILE, Q TO QUIT:'
    READ(*,10) FLOFILE
    IF(FLOFILE.EQ.'Q'.OR.FLOFILE.EQ.'q') CALL SUMRY(GTFLO,GBFLO,GTMAS
+ ,GBMAS,NSTORM,GSTIME,JTIME2,SYR)
    CLOSE(10)
    OPEN(UNIT=10,FILE=FLOFILE,STATUS='OLD')
    GO TO 50
45    CONTINUE
C
C     DETERMINE IF A STORM HAS STARTED
C
    IF(((TFLO2-TFLO1)/(JTIME2-JTIME1)).GE.BETA) THEN
    WRITE(11,47) NSTORM
47    FORMAT(1X,/, '-----
+-----', /'STORM NUMBER ', I3, /)
    CALL STORM(JTIME1, JTIME2, TFLO1, FLOCON, STFLO, SBFLO, STMAS, SBMAS,
+ QUIT, SYR, BETA, TFLO2)
    NSTORM = NSTORM+1
C
C     QUIT IS SET TO TRUE IF END OF FLOW RECORDS OCCURS IN STORM
C
    IF(QUIT) CALL SUMRY(GTFLO,GBFLO,GTMAS,GBMAS,NSTORM,GSTIME,
+ JTIME2,SYR)
C
C     ADD STORM VALUES TO GLOBAL VALUES
C
    GTFLO = GTFLO+STFLO
    GBFLO = GBFLO+SBFLO
    GTMAS = GTMAS+STMAS
    GBMAS = GBMAS+SBMAS
C
C     ADD BASEFLOW VALUES IF STORM DID NOT OCCUR
C
ELSE
    TFLO = ((TFLO1+TFLO2)/2.)*(JTIME2-JTIME1)
    GTFLO = GTFLO + TFLO

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      GBFLO = GBFLO + TFLO
      GTMAS = GTMAS+TFLO*BCONC((TFLO1+TFLO2)/2.)
      GBMAS = GBMAS+TFLO*BCONC((TFLO1+TFLO2)/2.)
END IF
      IF(JTIME2.GT.GETIME) THEN
          GETIME = JTIME2
          CALL SUMRY(GTFLO,GBFLO,GTMAS,GBMAS,NSTORM,GSTIME,GETIME,SYR)
END IF
      JTIME1 = JTIME2
      TFLO1 = TFLO2
GO TO 50
      END
C
C
SUBROUTINE STORM(JTIME1,JTIME2,TFLO1,FLOCON,STFLO,SBFLO,STMAS,
+SBMAS,QUIT,SYR,BETA,TFLO2)
      INTEGER YR,MON,DAY,HR,MIN,SEC,SYR
REAL JTIME1,JTIME2
LOGICAL QUIT
CHARACTER*64 FLOFILE
BACKSPACE 10
BB=TFLO1-BETA*JTIME1
BFLO1=TFLO1
TFLX1=TFLO1*CONC(TFLO1)
BFLX1=BFLO1*BCONC(BFLO1)
STFLO = 0.
SBFLO = 0.
STMAS = 0.
SBMAS = 0.
SSTIME = JTIME1
C
C      BEGIN INTEGRATION OVER TIME
C
115  READ(10,60,END=200) YR,MON,DAY,HR,MIN,TFLO2
      SEC=0
60   FORMAT(I4,1X,I2,1X,I2,1X,I2,1X,I2,10X,E12.5)
      JTIME2=TCON(YR,MON,DAY,HR,MIN,SEC,SYR)
      TFLO2=TFLO2*FLOCON
C
C      COMPUTE BASEFLOW AND QUICKFLOW
C
BFLO2=BETA*JTIME2+BB
QFLO=TFLO2-BFLO2
IF(QFLO.LT.0.) THEN
      QUIT=.FALSE.
      GO TO 250
END IF
C
C      COMPUTE MASS FLOW IN BASEFLOW AND QUICKFLOW
C
C      CALL CONG TO OBTAIN ESTIMATE OF CONCENTRATION AT TIME=JTIME2
C

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```

TFLX2=TFLO2*CONC(TFLO2)
BFLX2=BFLO2*BCONC(BFLO2)
QFLX=TFLX2-BFLX2
IF(QFLX.LT.0.) THEN
  PRINT 130,YR,MON,DAY,HR,MIN,SEC
130   FORMAT('WARNING!, TOTAL MASS FLUX LESS THAN MASSFLUX IN
    $ BASEFLOW AT TIME',/,I4,'/',I2,'/',3(I2,':'),I2)
  END IF
C
C   COMPUTE THE RUNNING TOTALS
C
STFLO=STFLO+(JTIME2-JTIME1)*(TFLO1+TFLO2)/2.
SBFLO=SBFLO+(JTIME2-JTIME1)*(BFLO1+BFLO2)/2.
STMAS=STMAS+(JTIME2-JTIME1)*(TFLX1+TFLX2)/2.
SBMAS=SBMAS+(JTIME2-JTIME1)*(BFLX1+BFLX2)/2.
C
C   REASSIGN TFLO AND TFLX AND READ ANOTHER RECORD IF END OF STORM
C   HAS NOT YET BEEN REACHED
C
TFLO1=TFLO2
BFLO1=BFLO2
TFLX1=TFLX2
BFLX1=BFLX2
JTIME1=JTIME2
GO TO 115
200  CONTINUE
  PRINT *, 'ENTER NEW FLOW FILE, Q TO QUIT:'
  READ(*,11) FLOFILE
11   FORMAT(A64)
  IF(FLOFILE.EQ.'Q'.OR.FLOFILE.EQ.'q') THEN
    QUIT=.TRUE.
    GO TO 250
  END IF
  CLOSE(10)
  OPEN(UNIT=10,FILE=FLOFILE,STATUS='OLD')
  GO TO 115
250  CONTINUE
  BFLO2=TFLO2
  TFLX2=TFLO2*CONC(TFLO2)
  BFLX2=BFLO2*BCONC(BFLO2)
  STFLO=STFLO+(JTIME2-JTIME1)*(TFLO1+TFLO2)/2.
  SBFLO=SBFLO+(JTIME2-JTIME1)*(BFLO1+BFLO2)/2.
  STMAS=STMAS+(JTIME2-JTIME1)*(TFLX1+TFLX2)/2.
  SBMAS=SBMAS+(JTIME2-JTIME1)*(BFLX1+BFLX2)/2.
  QDIS=STFLO-SBFLO
  QMAS=STMAS-SBMAS
  CALL TINV(YR,MON,DAY,HR,MIN,SEC,SYR,SSTIME)
  WRITE(11,208) YR,MON,DAY,HR,MIN,SEC
208  FORMAT(1X,'STREAM SEPARATION BEGAN ON: ',I4,'/',I2,
    '$'/',3(I2,':'),I2)
    CALL TINV(YR,MON,DAY,HR,MIN,SEC,SYR,JTIME1)
    WRITE(11,209) YR,MON,DAY,HR,MIN,SEC
209  FORMAT(1X,'STREAM SEPARATION ENDED ON: ',I4,'/',I2,

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```

    $'/' ,3(I2,' '),I2)
      WRITE (11,210)
210  FORMAT(1X,/,20X,'SUMMARY OF FLOW RESULTS' ,/,1X,'TOTAL
DISCHARGE'
    $,5X,'TOTAL QUICKFLOW',5X,'TOTAL BASEFLOW' ,/,7X,'M^3',17X,
    $'M^3',17X,'M^3')
    WRITE(11,212) STFLO,QDIS,SBFLO
212  FORMAT(4X,3(E12.5,8X))
    WRITE(11,215)
215  FORMAT(1X,/,20X,'SUMMARY OF MASS RESULTS' ,/,1X,'TOTAL MASS
RELEA
    $SE',3X,'MASS IN QUICKFLOW',3X,'MASS IN BASEFLOW' ,/,1X,6X,'KG',20X,
    $'KG',17X,'KG')
    WRITE(11,212) STMAS,QMAS,SBMAS
    RETURN
END

SUBROUTINE SUMRY(GTFLO,GBFLO,GTMAS,GBMAS,NSTORM,GSTIME,GETIME,SYR)
CALL TINV(YR,MON,DAY,HR,MIN,SEC,SYR,GSTIME)
WRITE(11,10) NSTORM-1
10  FORMAT(//,'*****
    $*****',/,15X,'SUMMARY OF RESULTS FOR ENTIRE PERIOD' ,/,
    $'*****
    $*****',/,I3,' STORMS IDENTIFIED',/)
    WRITE(11,20) YR,MON,DAY,HR,MIN,SEC
20  FORMAT('ANALYSIS BEGAN ON: ',I4,'/' ,I2,
    $'/' ,3(I2,' '),I2)
    CALL TINV(YR,MON,DAY,HR,MIN,SEC,SYR,GETIME)
    WRITE(11,25) YR,MON,DAY,HR,MIN,SEC
25  FORMAT('ANALYSIS ENDED ON: ',I4,'/' ,I2,
    $'/' ,3(I2,' '),I2,/)
    WRITE(11,30) GTFLO,GBFLO,GTFLO-GBFLO
30  FORMAT('TOTAL DISCHARGE =' ,E12.5,' M^3' ,/, 'DELAYED FLOW
DISCHARGE
    ^ =' ,E12.5,' M^3' ,/, 'QUICKFLOW DISCHARGE =' ,E12.5,' M^3' ,/)
    WRITE(11,35) GTMAS,GBMAS,GTMAS-GBMAS
35  FORMAT('TOTAL MASS RELEASE =' ,E12.5,/, 'DELAYED MASS RELEASE ='
    ^ ,E12.5,/, 'QUICK MASS RELEASE =' ,E12.5,/)
    QPFLO=((GTFLO-GBFLO)/GTFLO)*100
    BPFLO=(GBFLO/GTFLO)*100
    WRITE(11,40) QPFLO,BPFLO
40  FORMAT('PERCENT OF DISCHARGE OCCURRING AS QUICKFLOW =' ,F8.4,/,
    $'PERCENT OF DISCHARGE OCCURRING AS DELAYED FLOW =' ,F8.4)
    QPMAS=(GTMAS-GBMAS)/GTMAS*100
    BPMAS=(GBMAS/GTMAS)*100
    WRITE(11,45) QPMAS,BPMAS
45  FORMAT('PERCENT OF MASS RELEASED IN QUICKFLOW =' ,F8.4,/,
    $'PERCENT OF MASS RELEASED IN DELAYED FLOW =' ,F8.4)
    STOP
    RETURN
END

```

C

```

C  FUNCTION TCON(YR,MON,DAY,HR,MIN,SEC,SYR)
C
C      THIS FUNCTION CONVERTS DATE AND TIME INTO A SERIAL (JULIAN)
C      VALUE.  SYR IS THE STARTING YEAR AND IS USED TO ADD 365
C      (OR 366 FOR LEAP YEAR) TO THE SERIAL NUMBER IF YR=SYR+1
C      THIS IS USEFUL WHEN A GIVEN SIMULATION OCCURS OVER TWO
C      CALENDAR YEARS.
C
C      NOTE: IF YR-SYR IS GREATER THAN 1, THE RETURNED VALUE
C            MAY BE INCORRECT SINCE LEAP YEAR IS NOT PROPERLY
C            ACCOUNTED FOR.
C
C      INTEGER YR,MON,DAY,HR,MIN,SEC,SYR
C      INTEGER IMON(12),LPYR,YRADD,SLPYR
C      DATA (IMON(I),I=1,12)/0,31,59,90,120,151,181,212,243,273,304,334/
C      LPYR=0
C      SLPYR=0
C      IF(MOD(YR,4).EQ.0) LPYR=1
C      IF(IMON(MON).GE.59) IMON(MON)=IMON(MON)+LPYR
C      IF(MOD(SYR,4).EQ.0) SLPYR=1
C      YRADD=(YR-SYR)*365+SLPYR
C      TCON=REAL(IMON(MON)+DAY-1+(REAL(HR)+(REAL(MIN)+REAL(SEC)/60.)/60.
C              $)/24.+YRADD)
C      RETURN
C      END
C      SUBROUTINE TINV(YR,MON,DAY,HR,MIN,SEC,SYR,TIME)
C
C      THIS SUBROUTINE CONVERTS A SERIAL (JULIAN) DAY INTO YEAR,MONTH
C      DAY, HOUR, MINUTE, SEC.  SYR IS THE YEAR WHICH CORRESPONDS TO
C      JULIAN
C      DAY 0.
C
C      NOTE: IF TIME IS GREATER THAN 730 (OR 731 IF LEAP YEAR HAS
C            OCCURRED) THE FUNCTION MAY NOT CORRECTLY HANDLE LEAP
C      YEAR
C
C      INTEGER YR,MON,DAY,HR,MIN,SEC,SYR,LPYR,SLPYR
C      INTEGER IMON(13)
C      REAL TIME
C      DATA (IMON(I),I=1,13)/0,31,59,90,120,151,181,212,243,273,304,334,
C              $365/
C      SLPYR=0
C      LPYR=0
C      IF(MOD(SYR,4).EQ.0) SLPYR=1
C
C      DETERMINE THE YEAR
C
C      YR=SYR+INT(TIME)/(365+SLPYR)
C      IF(MOD(YR,4).EQ.0) LPYR=1
C      IADD=(YR-SYR)*(365+SLPYR)
C
C      SET MONTH, DAY, YEAR, HOUR, MIN., SEC. IF TIME IS EXACTLY 365 (OR 366

```

```

C      IF LEAP YEAR HAS OCCURRED
C
IF(TIME.EQ.REAL(365+SLPYR)) THEN
    MON=1
    DAY=1
    HR=0
    MIN=0
    SEC=0
    RETURN
END IF

C
C      DETERMINE MONTH AND DAY
C
TIME=TIME+1.
IF((INT(TIME)-IADD).GT.59) TIME=TIME-REAL(LPYR)
DO 10 I=1,12
IF((INT(TIME)-IADD).GT.IMON(I).AND.(INT(TIME)-IADD).LE.IMON(I+1))
    $ THEN
    MON=I
    DAY=INT(TIME)-IADD-IMON(I)
END IF
10  CONTINUE

C
C      DETERMINE HOUR, MINUTES AND SECONDS
C
REM=TIME-INT(TIME)
HR=INT(REM*24.)
REM=REM*24.-HR
MIN=INT(REM*60.)
REM=REM*60.-MIN
SEC=NINT(REM*60.)

C
C      FIX PROBLEMS THAT ARISE FROM ROUND OFF ERRORS
C
IF(SEC.EQ.60) THEN
    MIN=MIN+1
    SEC=0
END IF
IF(MIN.EQ.60) THEN
    HR=HR+1
    MIN=0
END IF
IF(HR.EQ.24) THEN
    DAY=DAY+1
    HR=0
END IF
RETURN
END
FUNCTION CONC(FLO)
C      PARATMETERS FOR TRITIUM
DATA A,B /8.116E7,-.5036/
C

```

```
C      CONVERT FLOW FROM M^3/DAY TO L/MIN
C
FLO=FLO*.69444
CONC=A*FLO**B
C
C      CONVERT CONC FROM pCI/L TO KG/M^3
C
CONC=CONC*1.0288E-16
RETURN
END

FUNCTION BCONC(FLO)
C      PARATMETERS FOR TRITIUM
DATA A,B /3.580E7,-.4141/
C
C      CONVERT FLOW FROM M^3/DAY TO L/MIN
C
FLO=FLO*.69444
BCONC=A*FLO**B
C
C      CONVERT BCONC FROM pCI/L TO KG/M^3
C
BCONC=BCONC*1.0288E-16
RETURN
END
```



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