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SUBJECT: The Transport of Contaminants during Storms in the
White Oak Creek and Melton Branch Watersheds

TO: L. D. Bates

FROM: D. K. Solomon, J. D. Marsh, D. S. Wickliff, I. L. Larsen and R. B. Clapp

MAR 02 1989

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The Transport of Contaminants during Storms in the
White Oak Creek and Melton Branch Watersheds

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March 1989

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Executive Summary

This report documents the transport of contaminants from SWSA 5 along two principle pathways: the saturated groundwater system and the intermittently saturated stormflow system. The results of a baseflow sampling effort and a dye tracer study, indicated that much of the transport through the saturated groundwater system occurs along discrete geologic features. These features appear to be related to the contact between the Maryville and Nolichucky members of the Conasauga shale. Three discrete sources of tritium to Melton Branch Stream (MBS) were identified and traced to SWSA 5 by measuring soil moisture and evapotranspiration along transects between MBS and SWSA 5.

The results of the stormflow sampling show a Sr-90 anomaly in SWSA 5 which is suggested by the mobility of H-3 and Sr-90 being similar in spite of the reactive nature of Sr-90. An empirical relationship between concentration and discharge was established for H-3 and Sr-90 in the Melton Branch Watershed. The relationship is of the form $C = AD^b$, where C is concentration of either H-3 or Sr-90, 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 stormflow, showed that 44% of the annual stream discharge occurred as quick flow, while only 16% of the H-3 and 27% of the Sr-90 occurred as quick flow. Since the 1988 water year was relatively dry, this shows that for SWSA 5 the saturated groundwater pathway is quite important in dry years. Data from other areas, such as SWSA 6 suggest that the stormflow 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 towards both the groundwater and stormflow systems.
- 2) The short-term effectiveness of remedial actions aimed at reducing the contaminant source depends critically on the mass of contaminants that are presently stored within the porous media. One of the hypotheses presented in this study suggests that the mass stored is low due to transport that occurs along fractures. If this is true, source-level remedial actions such as grouting, compaction, in-situ vitrification, etc. would result in reduced releases to streams within the first one or two years after remediation. If the mass of contaminants stored in the porous media is high, then only remedial actions which reduce the water flux will effectively reduce the release of contaminants to streams on a time scale of one or two 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.

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 for interpreting sampling results.

I. INTRODUCTION

This report is divided into two parts. The purpose of the first part is to document the field and laboratory methods, present final data, and give interpretations of that data developed using a model of the hydrogeologic processes occurring during the rapid transport of contaminants during storms in the White Oak Creek and Melton Branch Watersheds, and their implications for remedial action. This study began in October, 1987, and since that time more than 100 stream samples have been processed from three separate storm events. The results obtained are in both tabular and graphical form. The second part of this report is devoted to additional but related work on the identification of discrete sources of tritium in the Milton Branch watersheds. This part gives results of a dye tracer study, some additional storm surveillance, and a soil vapor survey.

Part I -- Contaminant Transport in Storms

A. Overview

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 laterally moving water, above the water table, during storm events is responsible for a large fraction (>50%) of the total contaminant load of streams. This contrasts with the traditional view that relatively steady, diffuse groundwater flow is the major pathway for contaminants to streams.

In order 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. Since 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 include tritium, strontium-90, cesium-137, and cobalt-60. In order 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 (or fluxes) using stream discharge data only. (The "flux" is actually mass flow since there is no area term in concentration times discharge. However, since the area at a sampling site is fixed, these terms are interchangeable for that particular sampling site.) Accurate estimates of contaminant releases are critical for a variety of reasons. For example, the total inventory of contaminants present within waste management areas (referred to as the source term), is critical for making remedial action decisions, but is completely undefined throughout most of the Oak Ridge Reservation. In an effort to help define the source term in Solid Waste Storage Area Six, Solomon et al. (1987) collected leachate samples directly from existing waste disposal trenches. As expected, the variability in leachate concentrations was enormous from trench to trench and was also highly variable in a single trench depending on recent hydrologic conditions. Although an inventory of disposed radionuclides was made, Solomon et al. (1987) found no correlation between observed radionuclide concentrations and values reported in the inventory. Thus identifying the source term directly by sampling trench leachates could require the collection and analysis of thousands of samples.

An alternative 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 which is bypassing local surface systems (i.e. deep groundwater recharge), previous work with water balances 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 measurements of contaminant fluxes in streams is also important for evaluations 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 prior to the remedial action.

B. Objectives

The objective of this study is to quantify the release of subsurface contaminants to streams in and around ORNL waste management areas. Specific objectives include:

1. The development of methods, using rating curves, to accurately measure the total contaminant discharge in streams.

2. A quantification of the ratio of the amount of contaminants which are released in a relatively slow manner to the amount of contaminants released rapidly during storm events along discrete pathways.

3. Identification of discrete sources of contaminants to streams and relate transport pathways to known geologic features.

II. METHODS

A. Selection of Analytes

Since it was not feasible to analyze for every possible contaminant a list of analytes which was thought to include the major contaminants present as well as span a variety of geochemical properties which affect transport in hydrologic systems, was made. The list of analytes includes, 1) tritium, 2) strontium-90, 3) gamma-emitting radionuclides (principally cesium-137 and cobalt-60) and stable (non-radioactive) trace metals.

Tritium was selected because its chemical form (HTO) results in conservative (non-reactive) geochemical behavior. Tritium is also a major contaminant of concern, especially in Solid Waste Storage Area Five. Strontium-90 is a divalent cation and can be sorbed by clay minerals due to the process of reversible cation exchange. As a result the movement of strontium-90 through hydrologic systems is attenuated and in general, strontium-90 will travel at a rate that is less than the average water velocity. Significant quantities of strontium-90 have been released into the environs of ORNL and thus represents a contaminant of major concern, especially since the regulatory limit for strontium-90 concentrations in drinking water is extremely low (8 pCi/l, EPA, 1980). Significant quantities of cesium-137 have also been introduced into the terrestrial environment. Cesium-137 is strongly, and irreversibly sorbed by aquifer materials and thus is only slightly mobile in the dissolved state; however, significant transport of cesium burdened sediments may be occurring.

Tritium, strontium-90, and cesium-137 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 spectroscopy (ICP) will be used to analyze a selected number of samples for trace metals. The results of the tritium, strontium-90, and cesium-137 analysis will be used for selecting samples for the ICP analysis.

B. Sample Collection

Samples have been collected from 3 separate sites: (1) White Oak Creek near monitoring station 3, (2) Melton Branch near monitoring station 4, and (3) a tributary of Melton Branch near monitoring station 4B. At White Oak Creek and Melton Branch, the samples were collected upstream of the pool created by the monitoring weirs. Because a pool did not exist at the Melton Branch Tributary Site, the samples were collected immediately downstream of the weir. The monitoring station locations are illustrated in Figure 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-liter 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 (0.95cm flexible tygon tubing) to the pipe with electrician tape. Several small notches were made in the tygon tubing to act as strainers for preventing any large debris from entering the sampler. 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 stream-bed particles from entering the tubing. All samplers were new prior to installation. The sample bottles were washed with a dilute (10%) HCl solution and rinsed several times with distilled water before sample collection.

The auto samplers were not slaved to any stream discharge or precipitation monitoring devices and thus it was necessary to operate the samplers at all times in order to assure 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 auto sampler were actually processed for radionuclide and contaminant analysis. Real-time hydrologic data from the Environmental Monitoring and Compliance Department's (EMC) 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 prior to stormflow, at peak flow, and after the stream had returned to baseflow conditions. Additional samples were also collected at intermediate times between these critical points on the stream hydrograph. Samples which were 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 0.45 μ 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, in a chronological fashion, beginning with the first sample collected.

The tygon tubing around the pump head was replaced whenever a group of samples were filtered from a different monitoring station.

Each filtered 1-liter stream-water sample was divided into three separate aliquots to facilitate the various analytical procedures. A 750 ml aliquot was placed in a Merinelli beaker and acidified to a pH less than 2 using hydrochloric acid. This aliquot-sample was gamma counted for cesium-137 and cobalt-60, and then analyzed for strontium-90 by Cerenkov radiation counting. A second, 50 ml aliquot was stored in a high-density polyethylene bottle to be analyzed for metals. These bottles were purchased pre-cleaned, having been subject to a dilute acid wash followed by thorough rinsing with distilled water. These samples were also acidified to a pH less than 2 with hydrochloric acid. A third, 150 ml aliquot was collected for tritium and anion analyses. Except for filtration, these 150 ml samples were untreated.

C. Sample Analysis

1. Gamma-emitting Radionuclides

Cesium-137 and cobalt-60 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 percent. 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 soft-ware programs which include peak-area determinations, background subtraction, nuclide 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 are routinely analyzed for Quality Control/Quality Assurance. The minimum detectable concentrations, defined as the concentration necessary to be present in the sample in order to report a number greater than zero 95% of the time (Pasternack and Harley, 1971), were approximately 5-6 pCi/l for both Cs-137 and Co-60 for a 6000 sec counting interval and 2-3 pCi/l for a 60,000 sec counting interval. These values should not be considered absolute but may range by several factors depending upon sample matrix composition, sample size, counting time, detector efficiency, and background contributions. Typically, samples having concentrations near these levels have a relative uncertainty of 40-60%.

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. Count times, and data reduction procedures were similar to those described above for the 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. This 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 have been expressed in units of pCi/liter of water since approximately 1 liter of water was filtered. The data have been decay corrected to the time of collection. The minimum detectable activity for filter samples for both Cs-137 and Co-60 was ~ 1.5 pCi/filter for a 6000 second count.

2. Strontium-90

After gamma-counting, two duplicate 20 ml aliquots of each filtered water sample were analyzed for Sr-90 via Cerenkov Radiation counting (Ross, 1969). This technique utilizes the high energetic beta particle emitted during the decay of Y-90 which is the daughter of Sr-90. 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 Sr-90 activity in each sample was calculated by comparing the net count rate of the sample to that of a Sr-Y-90 (Amersham) standard after correcting for background blanks which were about 5 counts per minute. The Sr-90 activities reported for each sample are the average of the two duplicates and counting errors are 1 sigma.

Due to the high energetic maximum decay energy of the Y-90 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 Cs-137, Co-60 and Sr-Y-90, the false signal contribution of Cs-137 and Co-60 is about 3% and 10% respectively, to the total Sr-Y-90 activity (Larsen, 1981). Although measurements of Sr-90 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 estimations of Sr-Y-90 concentrations in a cost-effective manner. For a given system the relative values should be useful for reflecting overall trends. The minimum detectable concentration for Sr-90 via Cerenkov radiation counting for 3600 sec. is approximately 40 pCi/L. Values reported near this concentration will typically have relatively high counting uncertainties.

An EPA quality assurance/quality control sample (6May88) containing Sr-90 was analyzed directly by Cerenkov radiation counting. Triplicate

samples indicated values of 18.7, 23.1, and 19.6 with an average of 20.5 ± 2.3 pCi/kg. This is in agreement with the expected value of 20.0 ± 1.5 and within the acceptable range of 17.4 to 22.6 pCi/kg.

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. Eight mls of the distillate were added to a liquid scintillation cocktail, and counted for 100 minutes 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 quench. This gives a quench corrected efficiency curve which can be used to automatically correct for quench in the samples. A series of four EPA standards of known activity were then distilled and counted using this quench corrected efficiency curve. The ratio of the average 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 was also analyzed. Quality control charts were kept for both the blank and the standard to monitor the performance of each run to insure good quality control. Most standards were within 10% of the known value with the highest error being 12.8%. An EPA cross-check was also run during the period of sample analysis and was within the two-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 ± 0.4 cpm. For a 100 minute 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 LLD's 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 1.5×10^6 pCi/L, all glassware was soaked in an acid bath and then rinsed with distilled water before use to assure that the blank did not increase with time.

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 was analyzed. These samples were screened and selected on the basis of the tritium, Sr-90, and gamma-emitting radionuclide data. The metal analyses were conducted by the Analytical Chemistry Division of ORNL using inductively coupled plasma (ICP) spectroscopy.

D. 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 ten minute discharge data were available for the Melton Branch (MBS) and White Oak Creek (WOC) sites, only a flow totalizer existed on the Melton Branch Tributary (MBT) site which was of limited use for this study. In addition, both the Melton Branch and White Oak Creek 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 Melton Branch 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).

III. RESULTS

A. Storms Sampled

Three separate storm periods have been sampled to date. These storms represent a range of stream discharge conditions which commonly occur on the Oak Ridge Reservation. For example, the peak discharge at Monitoring Station 3 on White Oak Creek for the 3 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 Melton Branch and from Monitoring Station 3 (MS 3) on White Oak Creek is shown in Figures 2 and 3, respectively.

Four major peaks of the stream hydrography were recorded at MS 4 at discharges of about 5,000, 18,000, 40,000, and 900,000 l/min. As discussed earlier, discharges above 60,000 l/min. were corrected using the Streamflow Synthesis and Reservoir Regulation (SSARR) model.

Four major hydrography 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 16th to 20th storm and thus only a limited number of samples were collected. Air temperatures were below freezing causing the intake lines of the auto samplers to become plugged with ice. This was especially a problem at the Melton Branch Tributary site. During peak discharge on White Oak Creek the floodplain on which the auto sampler was located was inundated by water approximately 1 m deep. This caused the sampler to over turn spilling all previously collected samples. A nylon tether line prevented the sampler from floating downstream. The sampler was placed back into service just prior to 0100 on the 20th.

A second series of samples were collected between February 2nd and 4th from all of the monitoring stations. A total of 30 samples were kept and processed for analysis during this period. Stream discharge from MS 4 and MS 3 are shown in Figures 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 since the cause of the problem during the January storm was corrected. No particular sampling problems were encountered during the February storm period.

A final series of samples were collected between May 3rd and 5th, 1988. Only Melton Branch and White Oak Creek were sampled. A total of 21 samples were collected. Stream hydrographs for MS 4 and MS 3 are shown in Figures 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.

B. Contaminant Concentrations versus Stream Discharge

The concentration of tritium, strontium-90, cesium-137, and cobalt-60 as functions of stream discharge at Melton Branch (MS 4) and WOC (MS 3) are shown in Figures 8 thru 14. Each figure shows concentrations of a single contaminant at a given monitoring station for all of the samples analyzed for the three storms combined.

An exponential relationship between concentration and discharge is apparent for both H-3 and Sr-90 at both MS 4 and MS 3. At low discharge values, significant dilution occurs as stream discharge increases; however, at a critical value of discharge, further dilution no longer occurs, but rather concentrations remain relatively constant with increasing discharge. As a result, the actual mass of both H-3 and Sr-90 being transported, rises dramatically during periods of high flow. The concentration versus discharge relationship for Cs-137 and Co-60 are a function of suspended sediment transport and thus do not parallel the H-3 and Sr-90 results.

C. Contaminant Concentrations versus Time

The concentrations of H-3, Sr-90, Cs-137, and Co-60 throughout the January, February, and May storm periods at Melton Branch (MS 4) and White Oak Creek (MS 3) are shown in Figures 15 thru 35. Melton Branch Tributary (MS 4B) radionuclide concentrations versus time are shown for the January and February storms only. Due to the unavailability of discharge data at MS 4B, this site was not sampled during the May storm.

IV. 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 while 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, then 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 assure that the clean-up objective would be met, since 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. Since 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 2000 pCi/l to 2.8 million pCi/l of H-3 and 36 pCi/l to 438 pCi/l of Sr-90 have been observed in this study. Characterizing the movement of these contaminants through the subsurface is extremely difficult due to: 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) is predominantly horizontal resulting in horizontal flow towards 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 zones of a large permeability contrast that exists 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. Since 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.

A. 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 thru 38 show the mass flow for H-3 and Sr-90 in Melton Branch for the January, February, and May storms, and Figures 39 and 40 show the H-3 and Sr-90 mass flow in White Oak Creek for the February and May storms. As noted earlier, 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, which is described in more detail in the following sections. The most significant feature of Figures 36 thru 40 is the increase in mass flow that occurs during storm periods. For example, the H-3 mass flow in MB during the January storm changes from 7.2 Ci/day to 42 Ci/day in less than 5 hours. The primary source of this H-3 is SWSA 5 which represents only about 7.91% of the MB watershed above the sampling point. Thus, the H-3 mass flow from SWSA 5 increased by about a factor of six during the January storm, assuming that all of the H-3 in Melton Branch originated in SWSA 5. The maximum H-3 mass flow during the January storm in MB was 55 Ci/day and was concurrent with peak discharge. Similar patterns of H-3 mass flow were observed during the February and May storms. In general, the H-3 mass flow increases with increasing discharge. Thus the maximum mass flow during the May storm was substantially less than the January and February storms.

As can be seen in Figures 36 thru 40 the Sr-90 mass flow also increases during storms. Although the absolute magnitude of the Sr-90 release is much lower than H-3, peak mass flow values for both H-3 and Sr-90 occur at the same time. For example, the Sr-90 mass flow increased from 2.6 to 15 mCi/day in less than 5 hours during the January storm. The maximum Sr-90 mass flow was 26 mCi/day and, like H-3, occurred at peak discharge of the January storm. The temporal pattern of Sr-90 mass flow was similar during the February and May storms.

In addition to H-3 and Sr-90, the measured concentrations of Cs-137, along with a variety of metals, were used to compute the total mass released during a storm. The total release of H-3, Sr-90, Ca, Na, SiO₂, and Cs-137 (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, which in part results from differences in the area of the 2 catchments: 3.91 km² for MB and 9.35 km² for WOC. Although stream discharge is greater, the total H-3 release in WOC is 2 to 10 times less than MB. This reflects the substantial release of H-3 from SWSA 5 into MB. Unlike H-3, the total Sr-90 release is greater in WOC by about a factor of 2. A significant portion of this Sr-90 is likely discharging from SWSA 4 and from the main plant area via 1st 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 during the February storm while 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 (eg. Maryville Limestone) the shale content is high. Since hydrous aluminium silicates are the primary minerals in shale, it is not surprising that MB streamflow is enriched in SiO₂ 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 would have substantially lower silica contents. This difference in silica release represents an important difference in the two watersheds. The cation exchange capacity of clay minerals (hydrous aluminium silicates) is very large relative to carbonate minerals which 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 Cs-137 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 Cs-137 and 2.10 mCi of dissolved Cs-137 were computed to be released in WOC. During the May storm, which had much less total stream discharge, the computed Cs-137 release was 0.602 mCi particulate-sorbed and 1.17 mCi dissolved. As expected, the release of particulate sorbed Cs-137 is a strong function of stream discharge since the stream velocity must be sufficient to suspend the particulate matter. The release of dissolved Cs-137 is also a function of stream discharge, but much less so than the particulate-sorbed fraction. The distinction between particulate-sorbed and dissolved is rather arbitrary and is based on passage through a 0.45 um filter. As a result, it is difficult to make further conclusions regarding the release of particulate-sorbed versus dissolved Cs-137 in this study.

B. Contaminant Pathways

From the H-3 and Sr-90 baseflow concentrations, there is no doubt that contaminants are being transported through the saturated groundwater system. As previously shown, the mass flow of contaminants such as H-3 and Sr-90 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 in a manner proportional 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 essentially constant and thus a change in the specific discharge (q) can only result 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 Solid Waste Storage Area Six (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 temporally saturated during storms. Since the saturated groundwater system below the water table would still be delivering contaminants to the streams, the horizontal 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 bathtubting during storms occurs, which could then result in rapid lateral transport.

The dynamics of streamflow generation is such that rapid movement of shallow stormflow 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 m³/day in less than 6 hours. Examination of the storm hydrographs (Figures 2 thru 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 prior to 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, while 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 most simple and easy 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 Figure 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. However, Huff (1978) found that the concentration of certain species are more strongly related to one of the stream flow components than the other. Furthermore, Solomon (unpublished data) found that changes in hydraulic heads near streams in SWSA 6 were correlated with delayed flow which was computed using a constant-slope separation line. Thus, it seems reasonable to associate delayed flow with groundwater discharge from below the water table, and quick flow with subsurface stormflow above the water table.

The concept of streamflow separation discussed previously 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. Since 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. Since 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 stream flow was given by:

$$\text{discharge} = 50 * \sin[2 * \pi * (\text{time} - .025)] + 51$$

and the concentration of some ion was given by:

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

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 line was 2230 m³/day/day for MB and 5330 m³/day/day for WOC. This slope is smaller by about a factor of 2 than the suggested value (Huff et. al, 1978) and was 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 Figures 42 thru 46. Approximately 60% of the H-3 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 H-3 release resulted from quick flow. In MB the fraction of Sr-90 resulting from quick flow was always greater than H-3 resulting from quick flow. Approximately 75%, 67%, and 27% of the Sr-90 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 Sr-90 release was less than the quick flow release of H-3 with about 50% and 1% resulting from quick flow during the February and May storms. One possible explanation for this difference is the release of Sr-90 from sources within the main plant area, and releases from SWSA 4.

The release of Cs-137 in quick flow was computed for the February storm in WOC. About 80% of the particulate-sorbed Cs-137 occurred as quick flow. About 41% of the dissolved Cs-137 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 using MASSFLO. In both MB and WOC Si release was slightly more associated with quick flow relative to Ca and Na. Although this is consistent with soil studies

conducted in SWSA 6 (Davis et al., 1984) which 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 m³) and was 24 mg/l for the February storm (52,600 m³). The average concentration of dissolved silica (expressed as SiO₂) 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 standard deviation being 38 mg/l. The 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 likely be within one 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, these results illustrate the non-static nature of ion concentrations in the shallow groundwater system.

C. Mode of Contaminant Release

An increase in mass flow of all measured species occurred during each of the monitored storms. The stream flow separation analysis suggests 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 remained constant during the January

storm, a total groundwater discharge of 54,000 m³ would be required to account for the Ca release if the saturated groundwater system were the only pathway transporting Ca. Since the storm lasted for 3.83 days, the average groundwater discharge would have to be 14,100 m³/day. Prior to the storm, the baseflow in MB was 1,700 m³/day and even at the end of the storm baseflow was only at 10,400 m³/day. 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 H-3 and Sr-90 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 H-3 release precedes Sr-90 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:

$$R = 1 + P_b K_d / n$$

where

P_b = dry bulk density of solids in the porous media

K_d = distribution coefficient

n = porosity of the porous media.

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

$$R = 1 + K_f / b$$

where

K_f = distribution coefficient per unit surface area

b = half of the fracture spacing.

Contaminants such as H-3 are geochemically conservative and thus K_d and K_f are 0 resulting in retardation factors equal to 1. The K_d for Sr-90 has been determined using a variety of laboratory and in-situ field experiments. Cerling and Spalding (1981) estimated an in-situ K_d for Sr-90 on stream sediments from the MB and WOC watersheds and reported average values of 82 and 20 ml/g respectively. The Sr-90 retardation factor depends on 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 Sr-90 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. Since only estimates of K_f and b are available, it can only be conclusively stated that the lower bound of the

retardation factor is greater than 1. The K_d values determined by Cerling and Spalding (1981) were obtained using stream gravels with 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 Sr-90 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:

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

$$R = 1 + 2.53 \text{ (cm)/b for WOC.}$$

Thus, the retardation factor for Sr-90 in a fracture porous media is near unity for half fracture spacings on the order of 100 cm; however, it could be much larger for smaller fracture spacings.

The results of the streamflow separation analysis suggest that significant transport of contaminants and major ions occurs in subsurface stormflow. Evaluating physical transport pathways using the data collected in this study depends critically on the nature of the contaminant source term. (The source term is a mathematical statement which describes the generation of dissolved contaminants from the bulk waste, as a function of time and space.) The following hypotheses have been considered; 1) a discrete pulse of contaminants is rapidly released during the onset of stormflow, or 2) the mass flux of dissolved contaminants at the source remains relatively constant such that a continuous release occurs throughout the storm.

If contaminants are being released at the source as discrete slugs during storms, the linear velocity of a reactive contaminant (V_c) such as Sr-90, relative to the linear velocity of a conservative species (V) such as H-3 can be described by the retardation equation,

$$V/V_c = R.$$

Since velocity is simply distance divided by time, we can rewrite the retardation equation as follows:

$$D * T_c / (D_c * T) = R$$

where

D = travel distance of a conservative species

T = travel time of a conservative species

D_c = travel distance of a reactive species

T_c = travel time of a reactive species.

If D equals D_c , we would thus expect the ratio of the travel time of a conservative species (T) to the travel time of a reactive species (T_c), to be equal to the retardation factor (R). The maximum separation between the H-3 and Sr-90 shown in Figures 47 and 48 is about 5 hours. Assuming that the average travel distance for Sr-90 is equal to the average travel distance for H-3, the cumulative release curves (Figures 47 and 48) can be used to estimate the retardation factor at a value of about 2. This value is obviously much too low for a granular porous

media but could be explained using a fractured porous media with an average fracture spacing of about 1 meter. It is not possible to defend the assumption that the average travel distance for Sr-90 and H-3 are equal since very little is known about the spatial distribution of contaminants in SWSA 5; however, the average travel distance for H-3 would have to be about 200 times the Sr-90 distance to produce the 5 hour separation using a retardation factor appropriate for a granular porous media ($R=400$). Since we have identified significant H-3 sources near MB it seems very unlikely that Sr-90 sources exist 200 times closer.

Although it is possible to explain the low apparent retardation of Sr-90 with a fractured flow system, another possibility exists that is associated with the concept of the distribution coefficient, K_d . Theoretically the distribution coefficient is defined as the change in the mass sorbed per unit mass of solids, with respect to the mass in solution per unit volume of solution. At low concentrations, this change is relatively constant and thus a single K_d value may be appropriate. As sorption sites are filled, K_d begins to change and approaches zero as solids become saturated with a given ion. Therefore, it is possible that the observed retardation results from near saturated conditions of sorption sites.

The hypothesis of a pulse release at the source during storms combined with the data presented in this report leads to a conclusion that relatively little retardation of Sr-90 is occurring. Solomon et. al (1988) collected a time series of trench leachate samples and found that leachate concentration varied greatly as a result of changing hydrologic conditions. Thus, it is possible that leachate generating mechanisms cannot keep pace with a large flux of stormflow, resulting in a slug-like release of contaminants.

If the release of contaminants at the source occurs continuously instead of discretely, retardation of reactive species will occur until the concentration at the exit point is equal to the concentration at the source. At this point in time retardation is obviously no longer a pertinent mechanism since the source concentration has arrived at the point of release. Although it is understood that long-term changes in the source term will certainly occur, the relatively small retardation of Sr-90 observed in this study could be explained by breakthrough of Sr-90 source concentration which is constant at the time scale required for transport to streams.

A final important possibility exists for the small Sr-90 retardation. Figure 49 shows that the concentration of Sr-90 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 Sr-90. This high correlation suggests that desorption processes are controlling the concentration and hence release of Sr-90. Cerling and Spalding (1981) have shown that significant sorption of Sr-90 by stream sediments occurs in MB and WOC. The concentration of Sr-90 in MB at the beginning of the January and February storms was greater than at

the end of these storms. Furthermore, Sr-90 concentrations dropped significantly during these storms. As a result, desorption of Sr-90 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 Sr-90 during the February storm, with the mass of Sr-90 that could be desorbed from stream sediments. The Sr-90 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 6.36×10^8 grams (computed using a stream reach of 1 km, sediment thickness of .2 m, a sediment width of 1.5 m, a porosity of 20% and a mineral density of 2.65 g/cc) with a Kd of 82 ml/g, we estimate that

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

of Sr-90 could be released as a result of desorption from stream sediments. The release of Sr-90 associated with quick flow during the February storm was 5.9 mCi. Thus, desorption of Sr-90 from stream sediments during storms, followed by sorption during periods of baseflow, could be an important mechanism. Conclusive statements however, will require a more accurate estimate of the mass of sediment which interacts with the stream during storms. Since desorption is not a viable mechanism for H-3 there is little doubt that subsurface stormflow transport is occurring; however, at least a portion of the Sr-90 release during storms may result from desorption. These calculations also suggest that in a groundwater system that is dominated by flow along fractures, stream sediments may be the most important retardation medium for shallow subsurface pathways that readily interact with the surface water system.

It is not possible, with the present data, to determine which of the previous hypothesis is dominant. Very little retardation of Sr-90 in stormflow is occurring in MB and WOC watersheds. It is critical that the process resulting in such little retardation be investigated. If rapid transport through a fractured porous media with a relatively small surface area available for sorption is occurring, the mass of reactive contaminants stored in the stormflow portion of the porous media would be small. As a result, the Sr-90 release in quick flow determined in this study, would be a measure of the of the actual Sr-90 source term in waste trenches. This would not represent the entire source term value since migration through the saturated groundwater system, where the retardation factor remains unknown, is certainly occurring. Furthermore, if the amount of stored mass is low, remedial actions that can reduce the source flux of Sr-90 (and presumably other contaminants) are likely to result in a fairly rapid decrease in the Sr-90 mass flow occurring along the stormflow pathway. If however, low retardation results from saturation of sorption sites, significant contaminant release in stormflow could continue long after the source flux is eliminated if the actual flux of water through the system remains unchanged. 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 which 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.

D. 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; rapid migration in subsurface stormflow with relatively little retardation of reactive ions, and migration through the saturated groundwater system with an unknown amount of retardation of reactive ions. 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 of a similar nature can evaluate changes. If future studies can establish the reason for the anomalously low retardation factor for reactive contaminants, it may then be possible to relate observed changes in contaminant release in streams, to changes in the actual contaminant source term.

Figure 50 shows the total release of both H-3 and Sr-90 as a function of total stream discharge in MB watershed. Since the contaminant release is a strong function of discharge, it is apparent from Figure 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. Since 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 which 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 Sr-90 to the total release of stable Sr for both the January and February storms in MB is shown in Table 2. The ratio of H-3 to stable Sr is also shown in Table 2. Measurements of stable Sr in WOC were only available for the February storm and the ratios of Sr-90 to stable Sr along with H-3 to stable Sr are included in Table 2. The ratio of Sr-90 to stable Sr is quite constant in MB. Thus, normalizing the total release of Sr-90 by the total release of stable Sr will effectively compensate for variations in rainfall providing a very good measure of Sr-90 release. Although the ratio of H-3 to Sr-90 is more variable, variations appear to be sufficiently small such that the stable Sr normalization will also provide an adequate index for annual H-3 releases.

The ratio of Sr-90 to stable Sr (known as the specific activity of Sr-90) has an additional interesting application. If all of the Sr-90 being released is presently the result of desorption from exchange sites, the rate of change of Sr-90 to stable Sr ratio should follow a first order decay curve with a decay constant equal to that of Sr-90. If however, additional Sr-90 is being supplied from trenches (i.e. a non-zero 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 Sr-90 release, it may be possible to evaluate the source term by measuring the specific activity of Sr-90 during the coming years.

E. Annual Release of H-3 and Sr-90 in Melton Branch

The relationship between concentration and discharge for H-3 and Sr-90 in MB is shown in Figures 51 and 52. Since a good correlation exists between concentration and discharge it is possible to create an empirical model which 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 due to releases from the main plant area that are more random in nature. 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:

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

where A and B are fitting parameters. This empirical model was combined with hourly streamflow data for the 1988 water year in order to estimate the annual release of H-3 and Sr-90 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 H-3 and Sr-90 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. Since 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. Prior to 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 H-3 and Sr-90 in MB. The following parameters were used for the concentration vs discharge relationship which was of the form:

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

for 3H

A = 8.116E7, B = -.5036 for total streamflow

A = 3.580E7, B = -.4141 for delayed flow

for 90Sr

A = 2896.5219, B = -.2837 for total streamflow

A = 2045.0947, B = -.2571 for delayed flow

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

The parameters for total release were estimated 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 m³ were considered to be delayed flow. A total of 68 storms were identified for the 1988 water year. Total stream discharge was 9.795×10^5 m³ and the total H-3 and Sr-90 releases were 1210 Ci and 0.242 Ci, respectively. About 44% of the stream discharge occurred as quick flow while only 16% of the H-3 and 27% of the Sr-90 release occurred as quick flow. Mean annual rainfall at ORNL is about 133 cm, while the rainfall during the 1988 water year was only 97.69 cm. It is likely that the fraction of quick flow will increase substantially during periods of average or above average rainfall.

F. 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 provide a meaningful average estimate at such hydrologically complex sites. The results of this study provide baseline values of groundwater and stormflow 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 sources to discharge points in MB. It is important that travel time estimates be made for both the groundwater and stormflow systems.

The use of H-3/He-3 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 H-3/He-3 dating should be collected near the observed H-3 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. Br-82 and Sr-90) should be conducted below the water table. Several existing ponds in Melton Valley could be used for these tests.

The results from this study suggest that travel times for conservative species in the stormflow system are very short. This finding should be reviewed when the results of stormflow tracer experiments, currently being conducted by the Environmental Sciences Division in Melton Branch and Walker Branch watersheds, become available. This study also suggests that retardation of Sr-90 is limited due to transport along fractures which allows little geochemical interactions to occur between contaminants and the porous media. This conclusion, however, cannot be adequately defended since alternative hypotheses can also explain the observed data. The most promising of these hypotheses, is the possibility that the increase in Sr-90 mass flow during storms results from desorption of stream sediments. This mechanism 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 Sr-90. A time series of leachate samples, collected from within a waste trench throughout a storm, would also aid in verifying the slug release hypothesis suggested in this report.

V. Summary

The transport of contaminants from SWSA 5 occurs along two principle pathways; the saturated groundwater system and the intermittently saturated stormflow system. The results of a baseflow sampling effort, and a dye tracer study indicate that much of the transport through the saturated groundwater system occurs along discrete geologic features. These features appear to be related to the contact between the Maryville and Nolichucky members of the Conasauga shale. Although it is possible that transport along discrete large-scale features results from a very discrete distribution of sources (i.e. the majority of the source existing in only a few trenches), it is more likely that groundwater transport rates throughout the majority of the site are

simply much less than transport rates near discrete features.

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. As stormflow moves through waste disposal areas, a significant flux of dissolved contaminants results, which are rapidly transported to streams. The mass flow of contaminants in streams increases during storms as a result of this stormflow transport. For example, the H-3 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 stormflow versus groundwater flow was examined by performing a hydrograph separation of MB and WOC streamflows. The fraction of stormflow 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 H-3 are considered conservative in that they do not react with the porous media as transport occurs. In contrast, contaminants such as Sr-90 readily 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 the mobility of H-3 and Sr-90 are similar in SWSA 5 in spite of the reactive nature of Sr-90. Hypotheses for explaining this anomaly include, 1) little interaction between Sr-90 and the porous media as a result of transport along fractures, 2) saturation of a limited number of sorption sites, 3) a source flux which is constant over the time scale required for transport to streams, and/or 4) desorption of Sr-90 from stream sediments during storms.

An empirical relationship between concentration and discharge was established for H-3 and Sr-90 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 H-3 release in MB was 1210 Ci while the total Sr-90 release was 0.242 Ci for the 1988 water year. Approximately 44% of the annual stream discharge occurred as quick flow, while about 16% of the H-3 release and 27% of Sr-90 release occurred as quick flow. The fraction of quick flow is likely to be substantially larger during years with average or above average rainfall.

The long-term performance of SWSA 5 cannot be predicted due to 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 due to transport along a fractured porous media, the lag time is 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 stormflow pathways. In addition to a dependence on the source term and lag time, the release of contaminants to streams along the stormflow 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 the stormflow 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 stormflow 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 with very similar rainfalls. The separation of groundwater transport from stormflow transport, and the analysis of the Sr-90 specific activity performed in this study, will allow comparisons between years that are climatologically dissimilar, if studies such as this are repeated in the coming years.

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

1. Any remedial actions must be directed towards both the groundwater and stormflow systems.
2. The short-term effectiveness of remedial actions aimed at reducing the contaminant source depends critically on the mass of contaminants that are presently stored within the porous media. One of the hypotheses presented in this study suggests that the mass stored is low due to transport that occurs along fractures. If this is true, source-level remedial actions such as grouting, compaction, in-situ vitrification etc. would result in reduced releases to streams within the first one or two years after remediation. If the mass of contaminants stored in the porous media is high, then only remedial actions which reduce the water flux will effectively reduce the release of contaminants to streams on a time scale of one or two 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.
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 for interpreting sampling results.

Part II -- Identification of Sources of Tritium to Melton Branch Stream and Melton Branch Tributary

I. Introduction

The mass flow of tritium from SWSA 5 represents one of the major sources of contamination to the White Oak Creek watershed. The majority of this release occurs via Melton Branch Stream (MBS) and a tributary of MBS, MBT, which flow adjacent to the south and east boundaries of SWSA 5. Although the mass flow increases significantly during storms, high tritium concentrations in MBS during periods of baseflow indicate that contaminated groundwater from SWSA 5 is discharging into MBS and/or MBT.

Quantifying groundwater discharge is essential for understanding the groundwater flow system. Although it is possible to estimate groundwater discharge using Darcy's law combined with measurements of hydraulic conductivity and the hydraulic gradient, such calculations have a great deal of uncertainty due to the extreme variability of the hydraulic conductivity that exists on the Oak Ridge Reservation. An alternative method for estimating groundwater discharge is to continuously release a tracer upstream of the area of interest, and measure the dilution of the tracer along a reach of the stream where groundwater discharge is occurring. A dye tracer/geochemical study was therefore conducted during low-flow conditions in order to estimate the quantity and location of groundwater discharged along the stream reach from the V-notch weir on MBT downstream to just above Monitoring Station 4 (MS 4) on MBS. Subsequent studies followed to better define the location of tritium sources.

A. Dye Tracer/Geochemical Study

During low-flow conditions in June 1988, a fluorescent dye, rhodamine WT, was injected at the MBT weir at a continuous rate for 16 hours prior to sample collection and an additional 3 hours during collection. Hand-taken grab samples were collected at approximately 100 ft intervals along the stream reach beginning just upstream of MS 4 on MBS (Location 0) and ending just below the MBT weir (Location 35) (Figure 53). Each sample was separated into a 200 mL and a 50 mL aliquot. Tritium analyses were performed on the 200 mL aliquots using a procedure adapted from EPA Method 906.0 (EPA 1980). The stream water was distilled in an alkaline permanganate solution, added to a cocktail and counted for tritium on a liquid scintillation counter. Rhodamine WT dye concentrations were determined from the 50 mL aliquots. The fluorescence of the stream samples and of prepared dye standards was measured using a fluorometer. The dye concentrations of the samples were then determined from plots of concentration verses fluorescence.

During sample collection, temperature and specific conductance of the stream were measured at each location using a Hydrolab, Surveyor II water quality meter. The Hydrolab had been calibrated just prior to sampling.

Prior to and during sampling the stream reach, stream samples were collected at Location 0 near MS 4 with an ISCO automatic sampler. Samples were collected at 30 minute intervals in order to determine when the dye concentration reached steady state at Location 0.

Hydrologic data collected by the EMC automatic Data Acquisition System (DAS) at MS 4 was utilized in this study. A portable data-logger with a pressure transducer was installed at the MBT weir a few hours prior to sample collection. Stage height was converted to discharge values using a predetermined rating equation.

The procedure for calculating groundwater discharge using a dye tracer is outlined in Kilpatrick and Cobb, 1985. In order to use this technique, several conditions had to be met. First, the stream must be influent and have sufficient groundwater discharge such that a measurable dilution of the tracer occurs. Second, it is essential that the stream flow be at steady state. Finally, a steady state distribution of the tracer must exist within the stream reach of interest.

Although care was taken to match the field conditions as closely as possible to the theoretically ideal conditions, two problems arose in the dye tracer study that make it difficult to determine the quantity of groundwater discharged along the stream reach. The main problem is that discharges in both MBS and MBT were not at steady state (Figure 54). The lack of steady state in the streams may be a result of changes in evapotranspiration. This appears to be the case for MBS. The discharge of MBS tended to be greatest during periods of low evapotranspiration (i.e. night times). However, the lack of steady state in MBT is suspected to be a result of point sources of ORNL facility discharge, since high flow values occurred during periods of high evapotranspiration. A second problem, realized after sampling, was that the rhodamine WT dye concentration had not reached steady state in the lower reach of the stream. The streams were at extremely low flow conditions which resulted in a much longer than expected transient period. A plot of dye concentration at Location 0 versus time indicates that the dye concentration was approaching steady state (i.e. the slope of the curve decreases) (Figure 55). However, the dye concentration at location 0 continued to increase from 87 to 100 ppb during the sampling period. Steady state conditions needed to be met in both the streams and the dye concentration in order to estimate the amount of groundwater input.

The dye concentration in MBT ranged from 183 ppb to 201 ppb (Table 3). Samples from MBT show that no significant dye dilution occurred at the downstream locations. In fact, Location 20, which would be expected to have had the lowest concentration, actually had the highest concentration. The lack of steady stream discharge is likely responsible for the fluctuations seen in the rhodamine WT dye concentrations in MBT.

MBT joins with MBS between Location 20 and Location 19. The

following relationship can be estimated based on the amount of dye dilution which occurred: $QMBS = 1.36 QMBT$.

Under ideal conditions the decrease in dye concentration from Location 19 to Location 0 would indicate the amount of dilution caused by groundwater discharge into the stream reach. However, it is not possible to separate the effect of groundwater dilution from the effects caused by the lack of steady state in both the discharge and dye concentration at Location 0.

A second objective of the dye tracer-geochemical study was to examine the importance of discrete geologic features in controlling the movement of contaminants in groundwater. Both large scale features, such as regional thrust faults and formation contacts, and small scale features such as orthogonal sets of joints and fractures exist in the Melton Branch watershed. Fracture and joint sets have been mapped in detail in both the Maryville and Nolichucky formations which comprise the surficial geology in SWSA 5 (Dreier et al., 1987). Although fracture densities of 50 fractures/dm are common, it is difficult to determine by observation the relative importance of small scale features versus large scale features in controlling the transport of contaminants. Since the small scale features are pervasive throughout the watershed, a relatively diffuse pattern of contaminant discharge would occur if these features dominate the site hydrogeology. Alternatively, if the sparse large scale features are controlling solute movement, a much more discrete pattern of contaminant discharge would result.

Although it is difficult to quantify groundwater discharge based on the dye-tracer data, the results from the tritium analyses (Table 3) were very useful in indicating areas of contaminated groundwater discharge and thus for examining the diffuse versus discrete nature of contaminant transport. Tritium concentrations in MBT increased from essentially background conditions to 1,176 nCi/l. Since groundwater discharge was not significant enough to cause a dilution in the dye, the increase in tritium indicates highly concentrated sources of tritium. This also suggests that significant movement of contaminants may be occurring along pathways which are different than bulk groundwater pathways.

Tritium transported per unit time (mass flow) was calculated using the tritium concentration at each location and estimated values of stream discharge. The discharge at MS 4, 268 l/min, was used for the entire MBS reach. A value of 198 l/min for discharge at MBT (MS 4B) was calculated based on the dye dilution at the confluence of MBT and MBS. The tritium mass flow along the stream reach from Location 0 to Location 35 is shown in Figure 56. Only about 25.5% of the total tritium mass flow appears to be entering along diffuse pathways. There are two areas where contaminated groundwater is entering along discrete pathways causing large increases in the tritium mass flow.

Approximately 30% of the total tritium mass flow enters between Locations 12 and 11 (Figure 53). Amano et al. (1987) have reported elevated tritium concentrations in soil water and atmospheric moisture in the vicinity of the middle drainage tributary of SWSA 5.

Approximately 44.5% of the total tritium mass flow enters in the short reach between Locations 30 and 26. The contact between the

Maryville and Nollchucky Formations intercepts MBT in the area between these two locations. This contact may be a conductive pathway for the subsurface transport of tritium from SWSA 5 to MBT.

B. Additional Geochemical Studies

Since a significant amount of tritium enters MBT in the small reach between Locations 30 and 26, a visual field inspection of this reach was conducted on July 11, 1988, during low-flow conditions. During the inspection grab samples were collected at intervals (<100 ft) along this reach and analyzed for tritium in order to better pin-point locations of contaminated groundwater discharge. Some samples, collected near visible seeps, were also analyzed for gamma-emitting radionuclides by gamma-spectrometry and for Strontium-90 by Cerenkov Radiation counting (Ross, 1969).

Two discrete point sources of tritiated water were located on MBT between Locations 30 and 26 (Table 4). The most significant source is a single seep located 44 ft upstream from Location 26. The second source area is where 3 or 4 small seeps are located along a 20 ft reach just upstream from Location 29. The seeps were visible primarily because of an orange slime which was associated with the contaminated groundwater discharge. Samples collected near seeps (i.e. samples containing a significant amount of seep water) had extremely high concentrations of tritium and measurable concentrations of Sr-90 and Cs-137 (Table 5).

C. Geochemical Study Following Storms

During rainstorm events, the tritium mass flow in MBS increased in a manner proportional to stream discharge. This increase indicates that significant tritium transport occurs in subsurface storm flow. In order to determine whether this subsurface storm flow occurred along the same discrete pathways as the flow during drier conditions, grab samples were collected following two rainstorms (on July 12 and 13, 1988) along the stream reach between Locations 26 and 30. The reach was sampled following the hydrograph peak when the discharge was still elevated yet not decreasing rapidly. During the second storm two samples of overland flow were collected before the water entered MBT just upstream from Location 29 where seeps had been noted earlier. The samples from the stream reach and overland flow were analyzed for tritium.

Stage height on a staff gage at MBT weir was recorded prior to and after sampling. The stage height was later converted to discharge values using a rating equation.

The tritium concentrations of the samples are given in Table 4. In Figure 57 the tritium mass flow was calculated using the tritium concentration at each location and the discharge of MBT measured at the weir just above Location 35. Downstream of Location 35, stream

discharge would increase as groundwater is discharged into MBT. Since a constant discharge value was used in the calculation of the tritium mass flow, the mass flow estimates of the downstream locations are likely low, especially following the storms.

During the periods of increased discharge following the rainstorms, a significant amount of tritium transport to MBT occurred along the same discrete pathways that were utilized during low-flow conditions.

The two samples of overland flow had tritium concentrations of 91 and 250 nCi/l. These values are much higher than rainwater concentrations and indicate the possibility that bathtubbing and subsequent overflowing occurs in the trenches in SWSA 5 during periods of heavy precipitation.

II. Soil Vapor Survey

Since a significant amount of tritium is transported to MBT along a discrete pathway and is discharged at the seep just upstream from Location 26, a soil vapor survey was conducted in the area west of the seep. If water with high concentrations of tritium is following a discrete pathway in the subsurface, it is likely that the soil vapor above this pathway would have elevated tritium concentrations.

Two methods were developed to collect tritiated water from the soil. The objective was to trace the contaminant pathway from the seep to SWSA 5. In the first method, a 1-in diameter well point was driven into the ground. Soil vapor was withdrawn by vacuum and condensed in a copper coil immersed in ice. The condensate was collected as it dripped into a flask. Condensed soil vapor was collected from 10 locations along 3 roughly N-S transects (Figure 58). In the second method, clear plastic bags, 2 ft x 3 ft, were placed on the ground for a few hours during the daytime. Evapotranspiration (ET) condensed on the underneath side of the bags and was easily collected. Roughly N-S transects of the bags were placed in SWSA 5 west of the seep on MBT (Figure 58). The condensed soil vapor samples and ET samples were analyzed for tritium by adding the condensed moisture directly to the cocktail and counting on a liquid scintillation counter.

Tritium concentrations of the condensed soil vapor ranged from 21 199 nCi/l (Table 6). Two of the locations, S1 and S3, did not yield sufficient amounts of water for collection, indicating drier soil conditions existed at these locations. In each of the 3 transects the center location consistently had higher concentrations of tritium. These higher values indicate that the tritiated water follows a subsurface pathway which trends E-W from the edge of trenches in SWSA 5 130 ft to the seep. Samples S7, S8 and S9 were significantly lower most likely because of a 2.5 in rain (on November 5, 1988) which may have caused much of the tritium to be flushed from the upper soil.

Tritium concentrations of the ET samples ranged from 11 to 30 nCi/l (Table 7). These concentrations are appreciably above background

but significantly lower than concentrations of the condensed soil vapor. Differences in tritium concentrations along a transect were not very large, yet seem to support the conclusion of an E-W trending pathway. The contact between the Maryville and Nolichucky formations is suspected to be the pathway for the contaminated groundwater, since the contact runs roughly E-W and intersects MBT in the area between Locations 30 and 26.

III. Conclusions

Contaminant transport from SWSA 5 to adjacent streams, MBS and MBT, occurs dominantly along discrete pathways rather than diffuse pathways. This transport occurs during both low-flow and storm-flow conditions. Tritium concentrations in soil vapor indicate that the contaminated water follows a subsurface pathway which trends E-W from the edge of trenches in SWSA 5 130 ft to a seep on MBT. The contact between the Maryville and Nolichucky Formations also trends E-W and intercepts MBT in the vicinity of the seep. This contact is likely a conductive pathway for the subsurface transport of tritium from SWSA 5 to MBT.

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TABLE 1 Total Release of Contaminants, and Major Ions in Melton Branch and White Oak Creek during storms.

stream	storm	discharge (m3)	3H (Ci)	90Sr (Ci)	Ca (Kg)	Na (Kg)	SiO2 (Kg)	137Cs-p (mCi)	137Cs-d (mCi)
Melton Branch	Jan.	196,000.	59.9	0.0228	1470.	664.	1090.	ID	ID
	Feb.	52,600.	30.6	0.0088	1230.	194.	348.	ID	ID
	May	3610.	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

NA = No Analysis

ID = Insufficient Data for reliable estimate

Table 2. Molar Ratios of 3H and 90Sr to Stable Sr in Melton Branch and White Oak Creek Watersheds

Stream	Storm	3H/Sr total flow	3H/Sr quick flow	90Sr/Sr total flow	90Sr/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

Table 3

MELTON BRANCH STREAM AND TRIBUTARY

LOCATION	APPROX. DISTANCE (feet)	SP COND* (uS/cm)	DYE CONC** (ppb)	TRITIUM CONC** (nCi/L)	TRITIUM MASS FLOW (uCi/s)
0	0	354	78	1941	8.68
1	92	356	85	1930	8.63
2	203	358	94	1870	8.37
3	289	359	96	1886	8.44
4	413	360	99	1880	8.41
5	525	359	102	1874	8.39
6	604	360	102	1874	8.38
7	666	359	108	1865	8.34
8	777	358	111	1905	8.52
9	863	361	115	1796	8.04
10	932	354	114	1751	7.83
11	1030	358	116	1832	8.20
12	1158	352	125	1257	5.62
13	1256	353	132	1217	5.44
14	1345	350	137	1258	5.63
15	1430	349	147	1210	5.41
16	1535	346	150	1146	5.13
17	1620	347	154	1071	4.79
18	1730	344	153	1001	4.48
19	1788	344	148	944	4.22
20	1847	325	201	1345	4.43
21	1932	323	197	1307	4.31
22	2030	324	192	1282	4.22
23	2122	323	192	1288	4.24
24	2224	323	189	1266	4.17
25	2322	321	190	1212	3.99
26	2427	323	187	1176	3.87
27	2526	319	183	360	1.19
28	2617	311	186	160	0.53
29	2722	309	187	156	0.51
30	2821	309	188	3	0.01
31	2929	307	186	3	0.01
32	3031	305	186	3	0.01
33	3125	306	188	3	0.01
34	3208	305	191	3	0.01
35	3339	306	194	3	0.01
MB Before HRT	1850	373			

* Conductivity

** Concentration

Table 4

MELTON BRANCH TRIBUTARY

DATE	07/11/88	07/12/88	07/13/88
DISCHARGE	254	371	1495
(L/min)			
LOCATION	TRITIUM CONCENTRATION (nCi/L)		
26	520	882	487
26-29	486	879	NA
26-44	369825	21757	3504
26-62	213	327	NA
27	240	298	141
27-40	113	242	NA
27-64	111	247	NA
28	107	255	99
28-38	110	260	NA
28-71	109	243	NA
29	103	246	76
29-20	122	211	NA
29-36	9	69	7
29-44	NA	18028	3806
29-62	2	3	4

NA Not Analyzed

Table 5

MELTON BRANCH TRIBUTARY NEAR SEEPS

LOCATION	DATE	CONCENTRATIONS (pCi/L)	
		Cs-137	Sr-90
26-44	07/11/88	477 +40	1470 +39
29-44	07/12/88	100 +30	58 +23

Table 6

TRITIUM FOUND IN SOIL VAPOR

LOCATION	DATE	CONCENTRATION (nCi/L)
S1	Oct 11 88	I
S2	Oct 11 88	35037
S3	Oct 11 88	I
S4	Oct 14 88	27757
S5	Oct 14 88	199375
S5.5	Oct 19 88	14962
S6	Oct 19 88	24038
S7	Nov 9 88	21
S8	Nov 9 88	60
S9	Nov 9 88	47

I Insufficient amount of water

Table 7

TRITIUM FOUND IN EVAPOTRANSPIRATION

LOCATION	DATE	CONCENTRATION (nCi/L)	DATE	CONCENTRATION (nCi/L)
ET 7	Nov 9 88	23	Nov 11 88	24
ET 7.5			Nov 11 88	23
ET 8	Nov 9 88	30	Nov 11 88	27 ⁿ
ET 8.5			Nov 11 88	28
ET 9	Nov 9 88	23	Nov 11 88	27
ET 9.5			Nov 11 88	23
ET 10			Nov 11 88	15
ET 11			Nov 11 88	18
ET 12			Nov 11 88	21
ET 13			Nov 11 88	18

Fig. 1. Map of the Melton Branch and White Oak Creek Drainage Basins.

Fig. 2. Melton Branch (MS-4) Hydrograph for the January 17-21, 1988 Storm Event. Dots represent sample collection points.

Fig. 3. White Oak Creek (MS-3) Hydrograph for the January 17-21, 1988 Storm Event. Dots represent sample collection points.

Fig. 4. Melton Branch (MS-4) Hydrograph for the February 3-5, 1988 Storm Event. Dots represent sample collection points.

Fig. 5. White Oak Creek (MS-3) Hydrograph for the February 3-5, 1988 Storm Event. Dots represent sample collection points.

Fig. 6. Melton Branch (MS-4) Hydrograph for the May 3-5, 1988 Storm Event. Dots represent sample collection points.

Fig. 7. White Oak Creek (MS-3) Hydrograph for the May 3-5, 1988 Storm Event. Dots represent sample collection points.

Fig. 8 Melton Branch (MS-4) Tritium Concentration vs Discharge for the combined January, February, and May 1988 Storm Events.

Fig. 9 Melton Branch (MS=4) Strontium-90 Concentration vs Discharge for the combined January, February, and May 1988 Storm Events.

Fig. 10 Melton Branch (MS-4) Cesium-137 Concentration vs Discharge for the combined January, February, and May 1968 Storm Events.

Fig. 11 Melton Branch (MS-4) Cobalt-60 Concentration vs Discharge for the combined January, February, and May 1988 Storm Events.

Fig. 12 White Oak Creek (MS-3) Tritium Concentration vs Discharge for the combined January, February, and May 1988 Storm Events.

Fig. 13 White Oak Creek (MS-3) Strontium-90 Concentration vs Discharge for the combined January, February, and May 1988 Storm Events.

Fig. 14 White Oak Creek (MS-3) Cesium-137 Concentration vs Discharge for the combined January, February, and May 1988 Storm Events.

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) Strontium-90 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.

WOC Storm Surveillance 19-21 Jan 1988

Strontium-90 Conc vs Time

Fig. 18. White Oak Creek (MS-3) Strontium-90 Concentration vs Time for the 19-21 January 1988 Storm Event.

Fig. 19. White Oak Creek (MS-3) Cesium-137 Concentration vs Time for the 19-21 January 1988 Storm Event.

MBT Storm Surveillance 17-20 Jan 1988

Fig. 20. Melton Branch Tributary (MS-48) Tritium Concentration vs Time for the 17-20 January 1988 Storm Event.

MBT Storm Surveillance 17-20 Jan 1988

Fig. 21. Melton Branch Tributary (MS-4B) Strontium-90 Concentration vs Time for the 17-20 January 1988 Storm Event.

Fig. 22. Melton Branch Tributary (MS-4B) Cesium-137 Particulate Concentration vs Time for the 17-20 January 1988 Storm Event.

MBS Storm Surveillance 3-5 Feb 1988

Fig. 23. Melton Branch Stream (MS-4) Tritium Concentration vs Time for the 3-5 February 1988 Storm Event.

MBS Storm Surveillance 3-5 Feb 1988

Fig. 24. Melton Branch Stream (MS-4) Strontium-90 Concentration vs Time for the 3-5 February 1988 Storm Event.

WOC Storm Surveillance 3-5 Feb 1988

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) Strontium-90 Concentration vs Time for the 3-5 February 1988 Storm Event.

WOC Storm Surveillance 3-5 Feb 1988

Cesium-137 Conc vs Time

Fig. 27. White Oak Creek (MS-3) Cesium-137 Concentration vs Time for the 3-5 February 1988 Storm Event.

MBT Storm Surveillance 3-5 Feb 1988

Fig. 28. Melton Branch Tributary (MS-4B) Tritium Concentration vs Time for the 3-5 February 1988 Storm Event.

MBT Storm Surveillance 3-5 Feb 1988

Fig. 29. Melton Branch Tributary (MS-4B) Strontium-90 Concentration vs Time for the 3-5 February 1988 Storm Event.

MBT Storm Surveillance 3-5 Feb 1988

Cs-137 Particle Conc vs Time

Fig. 30. Melton Branch Tributary (MS-4B) Cesium-137 Particulate Concentration vs Time for the 3-5 February 1988 Storm Event.

MBS Storm Surveillance 3-5 May 1988

Fig. 31 Melton Branch (MS-4) Tritium Concentration vs Time for the 3-5 May 1988 Storm Event.

Fig. 32 Melton Branch (MS-4) Strontium-90 Concentration vs Time for the 3-5 May 1988 Storm Event.

WOC Storm Surveillance 3-5 May 1988

Fig. 33 White Oak Creek (MS-3) Tritium Concentration vs Time for the 3-5 May 1988 Storm Event.

WOC Storm Surveillance 3-5 May 1988

Fig. 34 White Oak Creek (MS-3) Strontium-90 Concentration vs Time for the 3-5 May 1988 Storm Event.

WOC Storm Surveillance 3-5 May 1988

Fig. 35 White Oak Creek (MS-3) Dissolved and Particulate Cesium-137 Concentration vs Time for the 3-5 May 1988 Storm Event.

Melton Branch

Figure 36 Mass flow of 3H and 90Sr in Melton Branch at MS 4 during January storm (1 Kg 3H = 9.7201×10^6 Ci, 1Kg 90Sr = 1.3890×10^5 Ci).

Figure 37 Mass flow of ^3H and ^{90}Sr in Melton Branch at MS 4 during February storm (1 Kg ^3H = 9.7201×10^6 Ci, 1Kg ^{90}Sr = 1.3890×10^5 Ci).

Figure 38 Mass flow of ^3H and ^{90}Sr in Melton Branch at MS 4 during May storm (1 Kg ^3H = 9.7201×10^6 Ci, 1Kg ^{90}Sr = 1.3890×10^5 Ci).

Figure 39 Mass flow of ^3H and ^{90}Sr in White Oak Creek at MS 3 during February storm (1 Kg ^3H = 9.7201×10^6 Ci, 1Kg ^{90}Sr = 1.3890×10^5 Ci).

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

Figure 41 Method of hydrograph separation.

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

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

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

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

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

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

Figure 48 Cumulative release of ^3H and ^{90}Sr in quick flow in White Oak Creek during February Storm (1umole ^3H = 29.16 mCi, 1umole ^{90}Sr = 12.50 mCi).

Fig. 49 Melton Branch (MS-4) Strontium-90 vs Stable Strontium Concentrations for the January, February, and May 1988 Storm Events.

Figure 50 Relationship between 3H and 90Sr releases and stream discharge in Melton Branch.

Figure 51 Relationship between 3H concentration and streamflow in Melton Branch.

Figure 52 Relationship between 90Sr concentration and streamflow in Melton Branch.

Figure 53 Sampling locations on Melton Branch Stream and Melton Branch Tributary.

From June 14-16, 1988

Melton Branch (at MS-4) and Melton Branch Tributary hydrographs for June 14-16, 1988.

Figure 55 Rhodamine WT dye concentration versus time
at Location 0 on Melton Branch Stream.

Figure 56 Mass flow of 3H along Melton Branch Stream and Melton Branch Tributary.

Figure 57 Mass flow of 3H along a section of Melton Branch Tributary.

Figure 58

Soil vapor survey locations on southeast edge of SWSA 5.

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

Date	Time	Julian Date	Discharge Q (l/min)	Iritium 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)	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	185	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	45681	0.73	46.0	5.7	9.6	1.9	ND	ND	ND	ND	118	32
07/07/87	14:30A	340.596	-----	1647	4.11	39.4	1.8	16.7	0.6	3.5	3.1	ND	ND	46	24
07/07/87	14:35B	340.598	-----	1487	4.18	29.2	2.5	128.0	1.7	ND	ND	ND	ND	54	24

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)	Cd (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	NA	NA	NA	NA
05/03/88	20:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	14200	210	500	32100
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	10400	90	NA	28900
05/04/88	02:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10000	NA	NA	27100
05/04/88	07:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/04/88	12:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	17900	230	540	55900
05/04/88	15:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	9740	NA	230	27200
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	01:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	19200	2370	670	48800
07/07/87	14:30A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/07/87	14:35B	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 Stream (MBS) (Monitoring Station, MS-4)

Date	Time	Julian Date	Discharge (l/min) (10-min Ave)	Iritium 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)	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	ND	ND	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	16.2	2.3	270	35
01/19/88	14:30	18.596	45539	336771	0.49	ND	ND	5.5	1.6	ND	ND	434.0	14.0	124	32
01/19/88	17:45	18.727	27673	346540	0.25	ND	ND	ND	ND	ND	ND	51.4	4.1	178	34
01/19/88	19:45	18.810	35696	539553	0.20	ND	ND	ND	ND	10.0	6.0	29.0	3.7	252	35
01/19/88	21:45	18.894	204545	275380	0.28	4.4	1.8	ND	ND	6.6	1.0	27.0	4.0	160	33
01/19/88	23:45	18.977	968308	141238	0.40	ND	ND	32.4	4.9	14.5	3.9	319.0	14.0	64	31
01/20/88	01:45	19.060	1048938	67707	0.59	ND	ND	24	4.0	11.5	4.0	176.0	11.0	22	30
01/20/88	03:45	19.144	197069	131448	0.41	ND	ND	4.0	0.6	11.0	9.0	35.8	3.3	92	32
01/20/88	07:45	19.310	44195	297145	0.28	ND	ND	ND	ND	ND	ND	22.7	4.0	102	31
01/20/88	15:45	19.644	17252	559791	0.20	ND	ND	2.0	1.9	ND	ND	31.0	3.3	163	33
01/21/88	01:45	20.060	11190	774519	0.17	ND	ND	ND	ND	ND	ND	ND	ND	208	60
02/03/88	24:00	34.000	8805	1365443	0.13	ND	ND	ND	ND	687.0	32.0	120.0	8.0	257	35
02/04/88	02:00	34.083	17155	1008774	0.14	ND	ND	ND	ND	11.1	2.6	21.0	0.9	166	33
02/04/88	04:00	34.167	18454	728943	0.17	ND	ND	5.8	2.1	ND	ND	55.0	6.0	184	33
02/04/88	06:00	34.250	46409	660280	0.18	4.7	4.6	ND	ND	ND	ND	28.0	3.5	216	34
02/04/88	08:00	34.333	88837	307983	0.27	5.0	3.7	ND	0.6	11.4	6.1	79.0	8.0	103	32
02/04/88	09:50	34.396	45690	290443	0.28	ND	ND	1.8	ND	ND	ND	42.0	2.0	128	32
02/04/88	12:00	34.500	31476	353512	0.25	ND	ND	ND	ND	ND	ND	20.0	2.0	135	33
02/04/88	15:00	34.625	21622	441308	0.22	ND	ND	1.9	0.4	ND	ND	7.7	0.6	163	33
02/04/88	21:00	34.875	13037	609474	0.19	ND	ND	ND	ND	4.9	1.9	9.0	2.0	166	33

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

Date	Time	Julian Date	Discharge (l/min) (10-min Ave)	Iritium 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)	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
Helton Branch Stream (HBS) (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	NA	NA	NA	NA	NA
01/18/88	01:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<7	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	NA	NA	NA	NA	NA
01/19/88	17:45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<7	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	NA	1800	95	1400	5776	20	4.3	NA	NA	NA	NA	NA
01/20/88	03:45	360	21	<0.3	12000	230	NA	2000	64	1800	4921	26	<4.0	9	NA	NA	NA	NA
01/20/88	07:45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<7	NA	NA	NA	NA
01/20/88	15:45	190	28	0.7	23000	34	NA	3500	66	3400	5562	46	<4.0	NA	NA	NA	NA	NA
01/21/88	01:45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<7	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	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/04/88	15:00	NA	24	0.5	20000	46	NA	3000	22	3000	5562	42	<4.0	<7	NA	NA	NA	NA
02/04/88	21:00	NA	33	0.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/05/88	08:00	NA	NA	NA	NA	400	NA	3800	34	3500	7060	49	<4.0	<7	NA	NA	NA	NA

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

Date	Time	Al (ug/l)	Ba (ug/l)	Be (ug/l)	Ca (ug/l)	Fe (ug/l)	K (ug/l)	Hg (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 Tributary (MBT) (Monitoring Station, MS-4B)

Date	Time	Julian Date	Initial 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)	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
01/21/88	09:00	19.375	2788	3.78	ND	ND	2.5	1.7	ND	ND	ND	ND	181	29
01/21/88	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	34.413	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-48)

Date	Time	Al (ug/l)	Ba (ug/l)	Be (ug/l)	Ca (ug/l)	Fe (ug/l)	K (ug/l)	Hg (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
01/13/88	01:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/13/88	03:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/13/88	05:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/13/88	09:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/13/88	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	3537	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

[illegible]

C PROGRAM VARIABLES

C INPUT PARAMETERS

CARD 1 (12.A80)

110


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C      CARD 4 (14,1X,5(12,1X),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
C          CEND      CONCENTRATION OF BASEFLOW AT TIME TEND
C          FEND      FLOW OF BASEFLOW AT TIME TEND
C      CARDS 5-NUMBER OF MEASURED CONCENTRATIONS VALUES
C      (14,1X,5(12,1X),5X,F10.2)
C          TMC(1)    TIME OF MEASURED CONCENTRATION VALUE, ENTERED AS
C                      YYYY/MM/DD:HH:MM:SS
C          MC(1)     MEASURED CONCENTRATION--NOTE: MEASURED CONCENTRATION
C                      VALUES MUST BE ENTERED IN CHRONOLOGICAL ORDER
C
C      STREAMFLOW FILE
C      CARDS 1-NUMBER OF FLOW MEASUREMENTS
C      (14,1X,12,1X,12,8X,12,1X,12,10X,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 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
C      HT=CHAR(9)
C
C      DIMENSION HINTS
C
C      DATA MAXCON /100/
C
C      INITIALIZE VARIABLES
C
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
C      1  FORMAT('Enter the concentration filename:')
C        READ(*,2) CONIN
C      2  FORMAT(A32)
C      PRINT 3
C      3  FORMAT('Enter the flow filename:')
C        READ(*,2) FLOIN
C      PRINT 4
C      4  FORMAT('Enter the plotting filename:')
C        READ(*,2) PLTOUT
C      PRINT 6
C      6  FORMAT('Enter the output filename:')
C        READ(*,2) OUTFILE
C
C      READ CONTROL PARAMETERS AND CONCENTRATION DATA FROM UNIT 8
C
C      OPEN(UNIT=8,FILE=CONIN,STATUS='OLD')

```

```

OPEN(UNIT=10, FILE=FLOIN, STATUS='UNKNOWN')
OPEN(UNIT=12, FILE=PLTOUT, STATUS='UNKNOWN')
READ(8,5) ISKIP, TITLE
5 FORMAT(12, 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(14, 1X, 5(12, 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(9,*) 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(14, 1X, 5(12, 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 ', 14, '/', 12, '/', 3(12, ':'), 12, /
$    , 'INPUT DATA MUST BE IN CHRONOLOGICAL ORDER')
    PRINT 300
    READ(9,*) 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(9,*) ANYKEY
    STOP
END IF

```

```

END IF
C
C   COMPUTE BASEFLOW AND QUICKFLOW
C
BFLO=BETA*JTIME2+BB
QFLO=TFLO2-BFLO
IF(QFLO.LT.0.) THEN
  PRINT 125,YR,MON,DAY,HR,MIN,SEC
125  FORMAT('WARNING1, TOTAL FLOW LESS THAN BASEFLOW AT TIME',/
$ ,14,'/',12,'/',3(12,':'),12)
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
  PRINT 130,YR,MON,DAY,HR,MIN,SEC
130  FORMAT('WARNING1, TOTAL MASS FLUX LESS THAN MASSFLUX IN
$ BASEFLOW AT TIME',/,14,'/',12,'/',3(12,':'),12)
END IF
C
C   WRITE RESULTS TO UNIT 12 FOR PLOTTING
C   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(9,*) 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(9,*) ANYKEY
STOP
C
C   WRITE SUMMARY RESULTS TO UNIT 13

```

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C
C   READ FLOW DATA UNTIL TSTART IS REACHED, CHECK THAT A FLOW MEASUREMENT
C   WAS MADE AT TSTART
C
70 READ(10,60,END=150) YR,MON,DAY,HR,MIN,TFLO
60 FORMAT(14,1X,12,1X,12,8X,12,1X,12,10X,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(9,*) 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,
     &SQFLX,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(9,*) 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',/,14,'/',12,'/',3(12,' '),12)
     SPACE=SPACE2

```

```

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: ',14,'/',12,
  $'/',3(12,' '),12)
  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: ',14,'/',12,
  $'/',3(12,' '),12)
  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
  INTEGER YR,MON,DAY,HR,MIN,SEC,SYR
  INTEGER IMON(12),LPYR,YRADD,SLPYR
  DATA (IMON(I),I=1,12)/0,31,59,90,120,151,181,212,243,273,304,334/
  LPYR=0
  SLPYR=0
  IF(MOD(YR,4).EQ.0) LPYR=1
  IF(IMON(MON).GE.59) IMON(MON)=IMON(MON)+LPYR
  IF(MOD(SYR,4).EQ.0) SLPYR=1
  YRADD=(YR-SYR)*365+SLPYR
  TCON=REAL(IMON(MON)+DAY-1+(REAL(HR)+(REAL(MIN)+REAL(SEC)/60.)/60.
  $)/24.+YRADD)
  RETURN
  END
  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
  INTEGER YR,MON,DAY,HR,MIN,SEC,SYR,LPYR,SLPYR
  INTEGER IMON(13)

```

```

REAL TIME
DATA (IMON(I),I=1,13)/0,31,59,90,120,151,181,212,243,273,304,334,
$365/
SLPYR=0
LPYR=0
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 ROUNDOFF 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 AT ANY POINT
C   IN TIME THAT LIES WITHIN THE MEASURED RANGE OF CONCENTRATIONS

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