ORNL/TM-2004/83

Summary of 2002/2003 Annual Monitoring Activities at the High Flux Isotope Reactor Site: Monitoring Period August 2002 through August 2003

February 2004

T. M. Bonine
Oak Ridge National Laboratory

R. H. Ketelle
Bechtel Jacobs Company, LLC

ORNL/TM-2004/83

SUMMARY OF 2002/2003 ANNUAL MONITORING ACTIVITIES AT THE HIGH FLUX ISOTOPE REACTOR SITE

Monitoring Period August 2002 through August 2003

Prepared for
Research Reactors Division
Oak Ridge National Laboratory

Authors:
T. M. Bonine, MS, PG, CHMM
Environmental Protection and Waste Services Division
Oak Ridge National Laboratory
and
R. H. Ketelle, MS, PG
Engineering Division
Bechtel Jacobs Company, LLC

Prepared by
OAK RIDGE NATIONAL LABORATORY
P.O. Box 2008
Oak Ridge, Tennessee 37831-6285
managed by
UT-Battelle, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

TABLE OF CONTENTS

FIGURES

TABLES

ACRONYMS

AL	action level
AMP	*Annual Monitoring Plan for the High Flux Isotope Reactor Site*
BCMP	*Baseline Characterization Monitoring Plan*
BJC	Bechtel Jacobs Company
CB	catch basin
CBMH	catch basin manhole
DNAPL	dense nonaqueous phase liquids
DOE	U.S. Department of Energy
DWS	drinking water standard
ECR	environmental compliance representative
EFD	eastern foundation drain
EPA	U.S. Environmental Protection Agency
EPWSD	Environmental Protection and Waste Services Division
ESH	environment, safety, and health
HFIR	High Flux Isotope Reactor
MDA	minimum detectable activity
MH	manhole
MSRE	Molten Salt Reactor Experiment
NEFD	northeast foundation drain
NNFD	Non-Reactor Nuclear Facilities Division
NPDES	National Pollutant Discharge Elimination System
OMP	*Operational Monitoring Plan for the High Flux Isotope Reactor Site – Final Design – Revision 3*
OF	outfall
ORNL	Oak Ridge National Laboratory
PVC	polyvinyl chloride
PWD	process waste drain
REDC	Radiochemical Engineering Development Center
RRD	Research Reactors Division
WAG	Waste Area Grouping

EXECUTIVE SUMMARY

This annual monitoring report for the High Flux Isotope Reactor presents and interprets the data obtained from August 2002 through August 2003. The primary purpose of the monitoring program is to provide early detection of releases to groundwater from HFIR operational activities or system failures. Additional objectives are to track the mass of the tritium plume in the vicinity of HFIR and to monitor potential sources of groundwater contamination located hydraulically upgradient of the HFIR.

During the August 2002 through August 2003 monitoring period, the discharge of tritium from the groundwater plume increased because of the above average rainfall. Normal annual average rainfall in Oak Ridge is approximately 54 inches compared to the 70 inches of rainfall recorded at the ORNL site for FY 2003. The increased rainfall caused higher recharge to the groundwater system, resulting in increased plume discharge from the bedrock zone into the rapid-flow discharge pathways monitored at the Building 7900 foundation drain and at points of storm water discharge. Tritium concentration action levels and notification requirements were exercised frequently during the winter of 2003 because of the increased plume discharge.

This report includes a summary of the evolution of the tritium plume and applies a water balance model and trended groundwater tritium concentration information to simulate the tritium concentration history observed in the building foundation drain.

1. INTRODUCTION

From October 2000 through January 2001, characterization monitoring was performed at the High Flux Isotope Reactor (HFIR) site in response to the discovery of the release of tritium from the HFIR process waste drain (PWD) and PWD weir. The characterization sampling was performed in order to determine the source of the tritium release. After January 2001, routine interim monitoring was performed to determine the effects of corrective actions[1] taken by the Research Reactors Division (RRD) on tritium concentrations at various points in the immediate vicinity of the HFIR complex. The routine interim monitoring program incorporated groundwater monitoring points and monitoring points where groundwater discharges to surface water. These monitoring points were chosen based on known sitewide hydrogeological conditions, the location of the tritium release site, locations and elevations of the Building 7900 foundation drains, and observed tritium concentrations during the initial characterization monitoring.

Information concerning the initial characterization is found in the *HFIR Tritium Investigation Interim Report* (ORNL 2001a). Data from the initial characterization monitoring effort as well as the routine interim monitoring program for the period of January–May 2001 formed the basis for the monitoring strategy outlined in the baseline characterization monitoring plan (BCMP). The BCMP was executed under the *Operational Monitoring Plan for the High Flux Isotope Reactor Site – Final Design, Revision 3* (ORNL 2002a) and was implemented during the June 2001–June 2002 period. Data from the BCMP was used to formulate the monitoring approach described in the *Annual Monitoring Plan for the High Flux Isotope Reactor Site* (AMP) (ORNL 2002b and 2003) for the 2002/2003 monitoring period. Correspondingly, results of the 2002/2003 AMP, in conjunction with data collected during the previous monitoring efforts, form the basis of the 2003/2004 AMP.

Results of the BCMP monitoring program are contained in the *Summary of Baseline Operational Monitoring Activities at the High Flux Isotope Reactor Site—Monitoring Period June 2001 through June 2002* (ORNL 2002c). Results of the 2002/2003 AMP monitoring program are reported in this document.

The AMP was implemented in August 2002 and was completed in August 2003. The AMP met the objectives set forth in the BCMP:

1. to provide early detection of releases to groundwater from HFIR operational activities or system failures;
2. to track the mass of the tritium plume in the vicinity of HFIR; and
3. to monitor potential sources of groundwater contamination located hydraulically upgradient of the HFIR.

---

[1]Reconfiguration of the PWD weir and repair of PWD line drain to prevent discharge of tritium to the subsurface.

2. DESCRIPTION OF THE HFIR SITE

The HFIR site is located in Melton Valley about one-half mile south of the Oak Ridge National Laboratory (ORNL) main plant facilities, which are located in Bethel Valley. The site slopes to the southeast and small stream valleys lie to the east and west of the HFIR complex. Surface water drainage from the site flows into Melton Branch via these small streams or through storm drains. Melton Branch is located south of the HFIR site and flows to the west into White Oak Creek. White Oak Creek ultimately discharges into the Clinch River. Details of the site hydrogeology and plume dynamics are discussed in Sect. 4.

The water table surface in Melton Valley is typically a subdued replica of surface topography. The dry season water table typically occurs at or slightly above the top of bedrock. Groundwater data gathered before the current tritium release indicate a water table high to the north of the HFIR and a general gradient toward the adjacent streams. Estimated groundwater flow directions are based on the generally observed tendency for groundwater to flow parallel to geologic strike (parallel to the orientation of the rock beds). Extensive historic investigations performed at Oak Ridge over several decades indicate that 90% or more of infiltrating precipitation (groundwater recharge) flows directly to the nearest stream. Because of this, in small watersheds, groundwater contaminants not subject to geochemical transport retardation, such as tritium, are readily detected in surface water samples.

The most significant observation for the HFIR facility—based on past and current water table conditions and other data related to the reactor facility—is that two flow regimes exist within the uppermost portion of the aquifer underlying the HFIR complex. A rapid-flow pathway[2] is associated with the shallowest groundwater flow into subsurface piping traces (HFIR building foundation drain and auxiliary piping to the south), and a slower flow pathway is associated with deeper groundwater flow beneath the site. The foundation drain and auxiliary waste piping systems gravity feeds to Melton Branch, forming a capture zone beneath and around the building. The existence of this capture zone suggests that the leakage from the HFIR would seep into the foundation drain system and waste piping ditch lines, resulting in flow to the southeast and southwest toward ultimate discharge through National Pollutant Discharge Elimination System (NPDES) outfalls at Melton Branch (Outfalls 281, 381, and 383).

3. MONITORING PERFORMED UNDER THE AMP DURING 2002/2003

As stated previously, the monitoring strategy outlined in the 2002/2003 AMP was based on the observations of tritium plume behavior during the BCMP monitoring period and an understanding of the site's piping infrastructure, hydrogeologic conditions, and the location of the release site. The 2002/2003 monitoring effort continued to encompass the three monitoring objectives outlined in Sect. 1; however, changes were made to several monitoring-point locations and monitoring frequencies based on the behavior of the

---

[2]See the *Summary of Baseline Operational Monitoring Activities at the High Flux Isotope Reactor Site - Monitoring Period June 2001 through June 2002*, November 2002, for details concerning a discussion of the rapid-flow pathway.

tritium plume. Additionally, action levels used as a screening tool for alerting ORNL management and U.S. Department of Energy (DOE) of a possible release from the HFIR were changed. A total of five subsurface drain systems and NPDES outfalls as well as nine groundwater monitoring wells were monitored during the 2002/2003 monitoring period. Figure 3.1 displays the locations of the various monitoring points sampled during the 2002/2003 monitoring period.

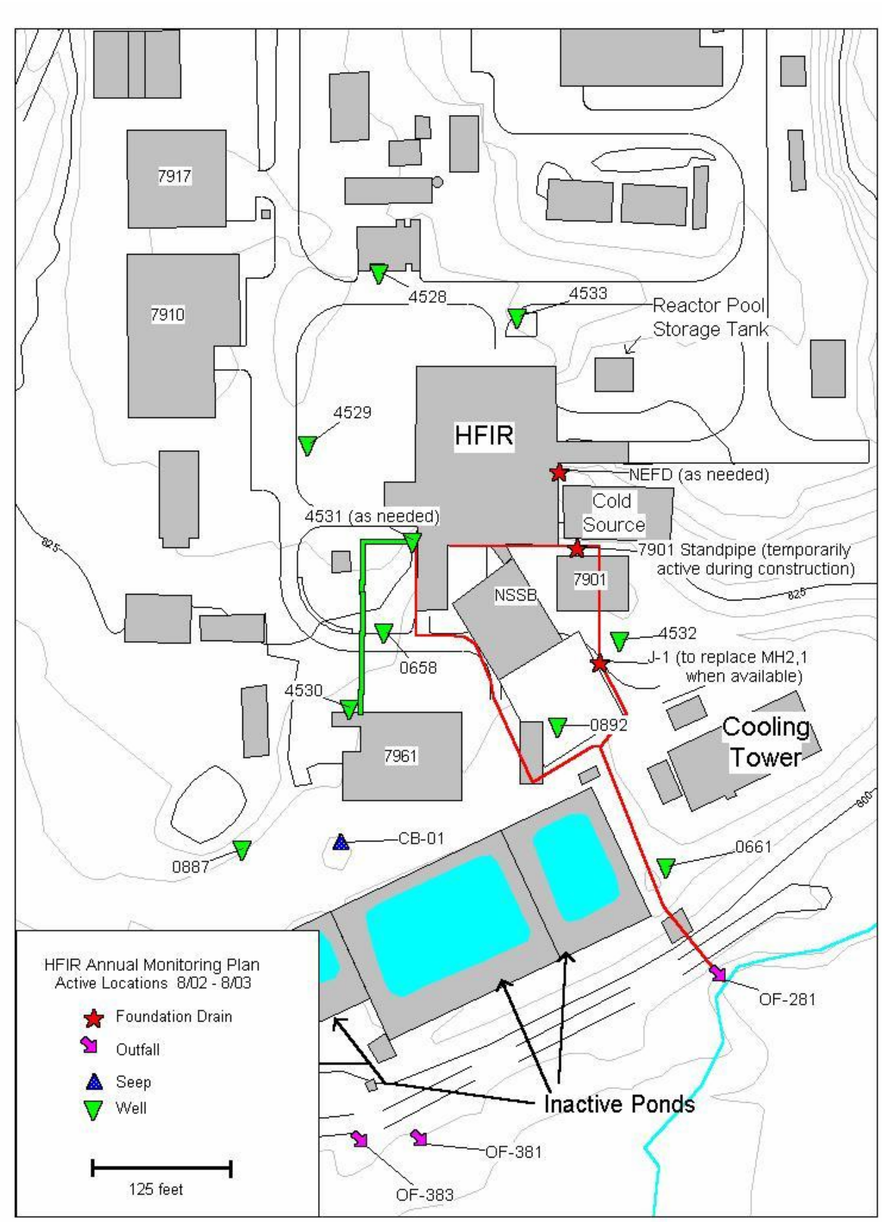

Fig. 3.1. Annual monitoring locations for the HFIR site for the 2002/2003 monitoring period.

Subsections 3.1 and 3.2 outline the monitoring efforts associated with the subsurface drain system and groundwater monitoring wells, respectively. Data collected from this monitoring program were reviewed and analyzed by personnel from RRD, Bechtel Jacobs Company (BJC), and ORNL's Environmental Protection and Waste Services

Division (EPWSD) on a routine basis. Data were also communicated to DOE, and meetings between DOE, ORNL, and BJC were held on a routine basis to discuss the data. Figure 3.1 displays the location of the various monitoring points sampled during the 2002/2003 monitoring period.

3.1 Drain System and NPDES Outfall Monitoring (Rapid-Flow System)

Two drain locations and three NPDES outfalls were monitored during the 2002/2003 monitoring period. A list of these locations is found in Table 3.1. These sampling points were chosen during the planning for the BCMP, and the choice was based on the initial characterization of the tritium release, results from the routine interim monitoring effort, known hydrogeologic conditions, review of piping drawings, and discussions with RRD operations personnel. All five points are located downgradient of the HFIR reactor building (Building 7900). The two drain systems (MH2,1/7901 Pit and CB-01) intersect shallow groundwater flow that transports tritium from the release area into the subsurface environment relatively rapidly (rapid-flowpath). Rapid flow to the southeast is intercepted by MH2,1/7901 Pit while rapid flow to the south-southwest is intercepted by CB-01. These five points were used for early detection monitoring and/or site release monitoring. The two drain systems outlined in Table 3.1 also were used in monitoring significant changes in tritium concentrations that followed the corrective actions taken to repair the PWD line.

The original topography of the HFIR site as well as the excavation for the HFIR building and the subsequent construction of the eastern foundation drain (EFD) heavily influences the drawdown of groundwater in the vicinity of Building 7900 to the extent that the HFIR building and EFD act as a localized groundwater drawdown zone. Localized flow of groundwater from both the eastern and western portions of the HFIR building is intercepted by the eastern portion of the Building 7900 foundation drain, and this water discharges through the EFD into a manhole (MH2) which is located southeast of Building 7900. Two drainage pipes from the Building 7900 foundation drain into MH2. These are identified as MH2,1[3] and MH2,2 on the map in Fig. 3.1. MH2,1 is directly connected to the EFD while MH2,2 is linked to the western foundation drain. Groundwater discharged from the foundation drain into MH2 flows into Melton Branch through NPDES Outfall 281. MH2,1 was sampled routinely as part of the EFD monitoring system during previous monitoring periods. During the 2002/2003 AMP monitoring period, MH2 was modified due to construction of the Small Angle Neutron Scattering (SANS) Guide Hall Building and concurrent upgrades to the piping of various systems in the vicinity of the HFIR cooling tower. This meant that sampling activities at MH2,1 were interrupted during most of the 2002/2003 monitoring period. While MH2 was modified, monitoring point 7901 Pit was used as a surrogate sampling location for MH2,1. Monitoring point 7901 Pit is a standpipe connected directly to the EFD and is located between the cold source building and Building 7901. MH2 was deemed no longer useful as a monitoring point because of the modifications made during the construction and was abandoned as a viable monitoring point during the 2002/2003 monitoring period.

---

[3]The MH2 monitoring point was designated as MH2,1 (piping from the EFD discharged into manhole MH2).

The rapid-flow pathway described above has a southern and western component. Groundwater discharge from the western portion of the HFIR site flows along existing piping which seeps into a catch basin manhole (CB-01) located to the southwest of Building 7900. CB-01 is a localized area of groundwater seepage that was monitored during the characterization, operational monitoring, and 2002/2003 AMP monitoring periods.

In accordance with the 2002/2003 AMP, 7901 Pit was monitored weekly. Monitoring point CB-01 was scheduled to be monitored quarterly but was not sampled during the autumn and winter quarters of the 2002/2003 monitoring period because the seepage emanating from the discharge area occurred beneath rip rap lining the catch basin. The rip rap hid the flow from the sampling technicians, and the monitoring point was reported dry during this period. Flow was later identified and captured by a sump well constructed at the site of the seepage in March 2003. Seepage rates were not measured during the monitoring period due to the presence of the rip rap.

NPDES outfalls OF-281, OF-381, and OF-383 were monitored during the 2002/2003 monitoring period under the aegis of the Radiological Monitoring Plan[4] (RMP) (ORNL 1999) which is part of the ORNL NPDES permit. During the 2002/2003 monitoring period, OF-281 and OF-381 were sampled quarterly under the RMP while OF-383 was sampled annually. In accordance with the 2002/2003 AMP, OF-383 was sampled quarterly. The results of the RMP monitoring program are reported through monthly radiological monitoring reports attached to the Discharge Monitoring Reports, which are submitted to the Tennessee Department of Environment and Conservation. The data collected for Outfalls 281, 381, and 383 for the RMP were used in the preparation of this report. Table 3.1 summarizes information regarding monitoring activities undertaken at the shallow drains and NPDES outfalls during the 2002/2003 monitoring period.

Table 3.1. Drain/NPDES outfall monitoring locations sampled during the 2002/2003 monitoring period[a]

Drain system or NPDES outfall	Monitoring point	Hydraulic position	Monitoring frequency	Purpose
Building 7900 foundation drain (East foundation drain – EFD)	MH2,1/7901 Pit	Downgradient	Weekly	Early detection monitoring

[4]Under this plan, Outfalls 281 and 381 will be sampled for tritium quarterly, and Outfall 383 will be sampled for tritium annually.

Table 3.1. (continued)

Drain system or NPDES outfall	Monitoring point	Hydraulic position	Monitoring frequency	Purpose
West side of HFIR complex	CB-01	Downgradient	Quarterly	Early detection monitoring
Outfall 281	OF-281	Downgradient	Quarterly (NPDES)	NPDES RMP and site release
Outfall 381	OF-381	Downgradient	Quarterly (NPDES)	NPDES RMP and site release
Outfall 383	OF-383	Downgradient	Quarterly Annually (NPDES)	NPDES RMP and site release

[a] See Fig. 3.1 for locations of the drain system sampling locations.

3.2 Monitoring of Groundwater

Groundwater flow is predominately through secondary porosity features such as fractures, joints, and other open spaces within the soil, saprolite, and bedrock beneath the HFIR site. This fracture flow represents the slow pathway flow regime at depth beneath the HFIR site. The shallow portion of the aquifer lying below the HFIR (within the soil, saprolite, and upper portion of bedrock) is of utmost concern from a monitoring perspective because any contaminant which may leak because of operational activities or system failures will likely find its way into deeper subsurface flow.

A number of groundwater monitoring wells are located downgradient of the HFIR building. These wells predate the discovery of the tritium leak. Most of these wells have not been sampled frequently over the past decade. Many of these wells were constructed to provide information on the groundwater flow regime in the vicinity of the process waste ponds located downgradient of the HFIR building. A total of six new shallow Geoprobe and bedrock wells were installed as a result of the tritium release. The locations of the wells used to monitor groundwater quality at the HFIR site were chosen based on the initial characterization of the tritium release and the behavior of the tritium plume during the interim routine monitoring period.

The new wells installed at the HFIR complex were screened at appropriate depth intervals to ensure that representative samples of groundwater can be collected. All of the new wells were flush mounted in order to protect the wells from vehicular traffic and to allow access to facilities.

3.2.1 Downgradient Wells

Wells 658, 892, 887, 661, 4530, 4531, and 4532 are located hydraulically downgradient of the tritium release area. The downgradient wells described below were used to track the movement of the tritium plume during the 2002/2003 monitoring period. Summary descriptions of the downgradient well locations, construction materials, depth, installation date, and 2002/2003 monitoring program sampling frequency are given in this section.

Well 658 is the closest bedrock well to the HFIR building (approximately 40 ft) and is located southwest of Building 7900. Well 658 is screened within the top portion of bedrock; consequently, it intercepts the shallow groundwater flow from the southern and western portion of Building 7900. Well 658 is constructed of 2-in.-diam polyvinyl chloride (PVC), is 26 ft deep, and was installed in February 1986. Based on previous monitoring, tritium is the only contaminant of concern at Well 658. Well 658 was sampled quarterly per the 2002/2003 AMP.

Well 892 is located approximately 100 ft south of Building 7900. Well 892 is screened to intercept groundwater flow within the upper portion of bedrock flowing to the south of Building 7900 toward Melton Branch. Well 892 is constructed of 2-in.-diam stainless steel, is 24.5 ft deep, and was installed in July 1985. Based on previous monitoring, tritium is the only contaminant of concern at Well 892. Well 892 was sampled quarterly per the 2002/2003 AMP. Well 892 was modified to accommodate construction of the SANS Guide Hall building during the 2002/2003 monitoring period.

Well 887 is approximately 230 ft to the southwest of Building 7900 and is a bedrock well also. It intercepts groundwater flow within the upper portion of bedrock to the west and south of Building 7900. Well 892 is constructed of 2-in.-diam stainless steel, is 29 ft deep, and was installed in July 1985. Based on previous monitoring, tritium is the only contaminant of concern at Well 887. Well 887 was sampled only once during the 2002/2003 monitoring period because of construction in very close proximity to the well which rendered the well inoperable for much of the monitoring period. Well 887 appears to mark a tritium concentration boundary zone to the west of the HFIR facility.

Well 661 was added to the BCMP monitoring scheme to aid in tracking the tritium plume to the southeast of Building 7900. Well 661 is located downgradient and approximately 250 ft south-southeast of the HFIR building. Well 661 intercepts groundwater flowing south-southeast of the tritium leak site. Based on previous monitoring, tritium is the only contaminant of concern at Well 661. Well 661 is constructed of 2- in.-diam PVC pipe, is 29.5 ft deep, and was installed in February 1986. Well 661 was sampled quarterly during the 2002/2003 monitoring period.

Well 4530 (P-4) is a shallow Geoprobe well located near the northwest corner of the 7961 facility (process waste tanks) and is located downgradient of Building 7900. It was installed as a result of the tritium release. Based on previous monitoring, tritium is the only contaminant of concern at Well 4530. Well 4530 is constructed of 0.5-in.-diam PVC pipe, is 13 ft deep, and was installed in March 2001. Well 4530 was sampled quarterly per the 2002/2003 AMP.

Well 4532 (P-5) is a downgradient shallow bedrock well located to the southeast of Building 7901. It was installed as a result of the tritium release. Based on previous monitoring, tritium is the only contaminant of concern at Well 4532. Well 4532 is constructed of 2- in.-diam PVC pipe, is 30 ft deep, and was installed in December 2001. Well 4532 was sampled quarterly per the 2002/2003 AMP.

Well 4531 (P-6) is a shallow hand-made well located downgradient and next to the process waste-drain, line-leak site. Well 4531was installed to monitor the PWD line repair during the BCMP period. Well 4531was not sampled during the 2002/2003 monitoring period. Groundwater levels are very low in this well during the wet season and generally nonexistent in the dry season. This makes it difficult or impossible to collect adequate amounts of groundwater for analysis. Well 4531 is constructed of 2-in.-diam PVC pipe, is 22.33 ft deep, and was installed in July 2001.

3.2.2 Upgradient Wells

Wells 4528, 4529, and 4533 are located hydraulically upgradient of the HFIR facility and downgradient of the Molten Salt Reactor Experiment (MSRE) and Radiochemical Engineering Development Center (REDC), and their respective pipelines. These wells serve to monitor any encroachment of tritium emanating from sources of tritium located upgradient of the HFIR. These wells also serve the purpose of alerting RRD and Non-Reactor Nuclear Facilities Division[5] (NNFD) personnel of any releases of tritium from the REDC facility and its associated pipelines. Summary descriptions of the downgradient well locations, construction materials, depth, installation date, and 2002/2003 monitoring program sampling frequency are found below.

Well 4528 (P-2) is a shallow Geoprobe well located upgradient of Building 7900. It monitors groundwater flow in the uppermost portion of the aquifer to the northwest of the HFIR facility in close proximity to the special building hot exhaust facility. It was installed during the investigation of the tritium release. Based on previous monitoring, tritium is the only contaminant of concern at Well 4528. Well 4528 is constructed of 0.5-in.-diam PVC pipe, is 16.5 ft deep, and was installed in March 2001. Well 4528 was sampled on a semi-annual basis per the 2002/2003 AMP.

Well 4529 (P-3) is a shallow Geoprobe well located to the west of Building 7900 and monitors groundwater flow in the uppermost portion of the aquifer to the north and west of the HFIR complex. It was installed because of the tritium release. This well is located in close proximity to waste lines which run from the MSRE and REDC to the waste tanks at 7961. Consequently, this well monitors potential sources of contamination located upgradient of the HFIR building. Based on previous monitoring, tritium is the only contaminant of concern at Well 4529. Well 4529 is constructed of 0.5-in.-diam PVC pipe, is 26.5 ft deep, and was installed in March 2001. Well 4529 was sampled on a semi-annual basis per the 2002/2003 AMP.

Well 4533 (P-1) is located north of Building 7900. It monitors groundwater flow through the upper portion of the bedrock and is immediately downgradient of the REDC. It was installed during the investigation of the tritium release. Based on previous monitoring,

---

[5]NNFD is the facility manager for the REDC, which is located hydraulically upgradient of the HFIR complex.

tritium is the only contaminant of concern at Well 4533. Well 4533 is constructed of 2-in.-diam PVC pipe, is 30 ft deep, and was installed in December 2001. Well 4533 was sampled on a semi-annual basis per the 2002/2003 AMP.

The northeast foundation drain (NEFD) is an access portal to the northern section of the EFD; consequently, the NEFD is not a well. It is located on the north and east sides of Building 7900 within the foundation drain system. The NEFD is considered an upgradient monitoring point and is thought to have a radius of influence of approximately 0.5 to 0.75 acres to the north, east, and west of Building 7900. The NEFD was not sampled during the 2002/2003 monitoring period.

Tables 3.2 and 3.3 summarize the information described above.

Table 3.2. Groundwater monitoring wells and drain sampled during the 2002/2003 monitoring period[a]

Groundwater well or monitoring point	Monitored zone	Monitoring frequency	Purpose
Well 658	Downgradient bedrock well	Quarterly	Recovery monitoring
Well 892	Downgradient bedrock well	Quarterly	Recovery monitoring
Well 661	Downgradient bedrock well	Quarterly	Recovery monitoring
Well 887	Downgradient bedrock well	Semi-annually	Recovery monitoring
Well 4530 (P-4)	Downgradient shallow well	Quarterly	Recovery monitoring
Well 4532 (P-5)	Downgradient shallow well	Quarterly	Recovery monitoring
Well 4531 (P-6)	Shallow well at PWD line repair site	As needed	PWD line break monitoring
Well 4528 (P-2)	Downgradient shallow well	Semi-annually	Upgradient monitoring
Well 4529 (P-3)	Upgradient shallow well	Semi-annually	Upgradient monitoring
Well 4533 (P-1)	Upgradient bedrock well	Semi-annually	Upgradient monitoring
NEFD	Foundation drain	As needed	Upgradient monitoring

[a] See Fig. 3.1 for locations of these monitoring points.

Table 3.3. Well details

Monitoring well	Northing[a]	Easting[a]	Well elevation[b]	Total depth	Date installed
658	16957.42	32445.06	819.69	26.00	02-24-86
661	16746.78	32702.61	811.18	29.50	02-21-86
887	16762.60	32312.90	816.41	29.00	07-19-85
892	16872.57	32600.83	813.56	24.50	07-29-85
4528	17278.48	32438.83	832.90	16.50	03-22-01
4529	17126.33	32372.52	832.20	26.5	03-26-01
4530	16889.02	32413.13	817.67	13.00	03-26-01
4531	17036.99	32469.92	830.71	22.33	Mid 07-01
4532	16949.95	32657.38	817.55	30.00	12-04-01
4533	17239.63	32565.08	833.04	30.00	12-04-01

[a]ORNL administrative grid coordinates.
[b]Measured from top of exterior casing.

During the 2002/2003 monitoring period, sampling of the drain, NPDES outfalls, and groundwater monitoring wells was performed by ORNL EPWSD personnel. All sampling was conducted in accordance with EPWSD sampling procedures. Where applicable, each of the listed wells underwent purging prior to sampling in order to induce formation water into the well so that a representative sample of formation water could be collected. Well purging was conducted by ORNL EPWSD personnel.

As with the early detection monitoring scheme outlined above, groundwater samples collected from the monitoring wells were analyzed for tritium in accordance with the 2002/2003 AMP. Samples collected during the 2002/2003 monitoring period were not analyzed for other radionuclides. The basis for the selection of tritium as the only contaminant of concern is found in the *Summary of Baseline Operational Monitoring Activities at the High Flux Isotope Reactor Site—Monitoring Period June 2001 through June 2002* (ORNL 2002c). Analyses of samples were performed by ORNL's Chemical Sciences Division and General Engineering Laboratory of Charleston, South Carolina. General Engineering Laboratory is a DOE-approved analytical laboratory, which met the requirements of the DOE Environmental Management Consolidated Audit Program and was part of the Integrated Contractor Purchasing Team Contract during the 2002/2003 monitoring period. The contract laboratory met all quality assurance/quality control requirements during the 2002/2003 monitoring period.

3.3 Action Levels and Notification

Two action levels were established for tritium concentrations for monitoring points 7901 Pit and CB-01 for the 2002/2003 monitoring period. Exceedence of Action Level 1 required confirmation sampling of the affected monitoring point. Action Level 2 required notification of RRD management of the exceedence and implementation of increased monitoring frequency at the both monitoring points. As described earlier in this report, 7901 Pit and CB-01are located along rapid-flow groundwater seepage pathways in two directions of contaminant movement away from the PWD release site. Rapid-flow pathways are identified as locations where solute concentrations change relatively rapidly compared to slower-moving groundwater in less permeable zones.

Interim action levels were established for the drain system monitoring points during the BCMP period. The levels for MH2,1 were 44,000 and 88,000 pCi/L for Action Levels 1 and 2, respectively, and the levels for CB-01 were 110,000 and 220,000 pCi/L for Action Levels 1 and 2, respectively. The interim action levels for these two points were based on observed variances of tritium concentration in time series and a review of storm event data collected from October 2000 to May 2001.

The action levels used during the 2002/2003 AMP monitoring period were 20,000 and 40,000 pCi/L for Action Levels 1 and 2, respectively for MH2,1/7901 Pit and 7,500 and 15,000 pCi/L for Action Levels 1 and 2, respectively for CB-01. Action levels established for the 2002/2003 monitoring period were based on extreme value statistical analysis (Gumbel 1958) of tritium concentrations observed during a portion of the 2002/2003 monitoring period which represented average precipitation amounts and baseline concentration conditions at both monitoring locations.

3.4 Deviations from Monitoring Specified in the 2002/2003 AMP

Deviation from the monitoring activities outlined in the 2002/2003 AMP did occur when action levels were exceeded. The Action Level 1 threshold for 7901 Pit was exceeded 15 times during the monitoring period (15 of 73 measurements). The Action Level 2 threshold for 7901 Pit was not exceeded during the monitoring period. The Action Level 1 threshold for CB-01was exceeded seven times during the monitoring period (7 of 7 measurements). The Action Level 2 threshold for CB-01 was exceeded four times during the monitoring period (4 of 6 measurements). A total of 73 and 7 samples were collected from 7901 Pit and CB-01, respectively, during the 2002/2003 monitoring period. A total of 52 and 4 samples were specified by the 2002/2003 AMP for 7901 Pit and CB-01, respectively. A total of six samples were collected from OF-383 during the monitoring period although the 2002/2003 AMP specifies only four samples need to be collected from this monitoring point.

The observed exceedences of action level thresholds at 7901 Pit and CB-01 were attributable to a pronounced increase in precipitation during the late autumn of 2002 through winter and spring of 2003 compared to the March–June 2002 period on which the 2002/2003 action levels were based. As described earlier and discussed in further detail in Sect. 4 of this document, rapid-flow and slower-flow discharge pathways exist within the soil/bedrock aquifer that lies beneath the HFIR reactor complex. The rapid-flow discharge pathway exists in the shallow portion of the aquifer and is monitored using monitoring points 7901 Pit, which monitors the EFD of the HFIR building, and CB-01, which monitors the southern flow path of the tritium plume. The slower-flow discharge pathway exists in the deeper, bedrock portion of the aquifer and is monitored through a series monitoring wells which are located up- and downgradient of the HFIR reactor building. Hydrologic response within the rapid-flow pathway is in terms of days or weeks while the response within the slower-flow pathway is in terms of months to years (Ketelle 1997). Since the inception of an environmental monitoring program at HFIR, tritium concentrations observed within the rapid-flow discharge pathway typically have been much lower than tritium concentrations observed in the slower, deeper groundwater discharge pathway.

Action levels were established in the 2002/2003 AMP in order to determine whether significant tritium concentration increases signaled potential releases of tritium from the HFIR reactor. Two action levels were derived utilizing extreme value statistical analysis data collected at MH2,1 and CB-01 during the period of March–June 2002. The action levels were based on data collected during the March through June 2002 period [during implementation of the *Operational Monitoring Plan for the High Flux Isotope Reactor Site* (OMP)]. The mean tritium concentrations at these monitoring points during this period were 8,300 pCi/L and 1,500 pCi/L, respectively, and precipitation averaged 4.83 in. per month over the same period. Action Level 1 required confirmatory sampling, and Action Level 2 requires the initiation of sampling of the rapid-flow discharge system monitoring points at the following frequencies: twice per week at MH2,1/7901 Pit/J-1 and once per month at CB-01. The increased frequency of sampling was required to determine whether an increase in tritium trend was observable.

Precipitation averaged 6.29 in. per month during the September 2002 through April 2003 period. Additionally, several high-to-moderate intensity storms occurred during the same period, releasing copious amounts of precipitation over relatively short periods of time onto the hydrologic "basin" in which the HFIR complex sits. Consequently the percentage of change in the average precipitation observed during this period was 42.7% greater than during the March–June 2002 period.

The extreme value statistical analysis of tritium concentrations performed to generate the action level thresholds was based, indirectly, on precipitation events during the March–June 2002 OMP period. Rainfall from the storm events observed during the fall 2002–early spring 2003 time interval exceeded the rainfall amounts affecting the tritium concentrations observed at MH2,1 and CB-01 during the March–June 2002 OMP period. The rainfall generated by the large number and intensity of storm events occurring during the September 2002 to April 2003 time interval has caused a significant increase in groundwater water elevations within the vicinity of the tritium leak site near the HFIR reactor building. As a result of the hydrologic stress imparted by the heavy precipitation from these storm events, deeper groundwater having higher tritium concentrations has been pushed upward in elevation by localized gradient changes causing a "piston push" of higher concentration (but diluted due to advective mixing) groundwater into the rapid-flow discharge system. This piston push of diluted higher concentration groundwater has been observed to increase the tritium concentrations at 7910 Pit and CB-01 after significant rainfall events to the point of exceeding the Action Level 1 threshold at 7901 Pit and the Action Level 2 threshold at CB-01.

The phenomenon of the piston push of diluted higher concentration groundwater from the deeper, slower-flow discharge system into the rapid-flow discharge system has been observed over several months. A more detailed discussion of this phenomenon is found in Sect. 4 of this report. The reason for the exceedences of the action level thresholds is attributable to the increase in precipitation discussed above. Additional leakage from the HFIR reactor building is not believed to be the cause of the exceedences of the action level thresholds. Therefore, the technical basis for deviating from the AMP and RRD procedure is predicated on observations of natural phenomena. Consequently, the requirement for confirmatory sampling after each exceedence of an Action Level 1 threshold at 7901 Pit/J-1 and CB-01 was suspended. Research Reactors Division and EPWSD personnel agreed that confirmatory sampling would be performed on an as-needed basis, based on consideration of precipitation effects on tritium concentrations. This deviation did not affect the actions required by the AMP or RRD procedure when Action Level 2 thresholds are exceeded.

Well 887 was sampled only once during the 2002/2003 monitoring period because of construction in very close proximity to the well which rendered the well inoperable for much of the monitoring period. Well 887 was slated to be sampled semi-annually during the 2002/2003 monitoring period. In addition, a total of two samples were collected from OF-383 during mid-October 2002. A total of four (quarterly) samples were to have been collected from this outfall per the 2002/2003 AMP. These samples were collected in error.

Although not specifically a deviation from the 2002/2003 monitoring plan, Well 4531 and the NEFD were not sampled during the monitoring period. The status of these monitoring points was “as needed” during the 2002/2003 sampling campaign, and as such, there was no reason to monitor either point during the 2002/2003 monitoring period.

4. HFIR TRITIUM PLUME CONCEPTUAL MODEL

4.1 Physical Setting of HFIR Site

The HFIR site is located in Melton Valley about one-half mile south of the ORNL main plant facilities, which are located in Bethel Valley. The site slopes to the southeast, and small stream valleys lie to the east and west of the HFIR Complex. Surface water drainage from the site flows into Melton Branch via these small streams or through storm drains. Melton Branch is located south of the HFIR site and flows to the west into White Oak Creek. White Oak Creek ultimately discharges into the Clinch River.

4.1.1 Site Geology and Soils

Bedrock underlying the HFIR site is composed of the Cambrian-age (approximately 500 to 600 million years old) Conasauga Group that was deformed during the Appalachian Orogeny (approximately 300 million years ago). The deformation caused folding, fracturing, and faulting of the bedrock and formed the extensive geologic structures of the Valley and Ridge Physiographic Province within which East Tennessee is located. As a result of the deformation, bedrock in Melton Valley generally dips to the southeast and contains small-scale folds and faults. Photographs of the foundation excavation for the

HFIR show that bedrock at the site dips steeply.

Bedrock beneath Melton Valley is divisible into several mapable geologic formations that are composed predominantly of shales interbedded with shaley limestone. The HFIR site is underlain by bedrock of the Maryville Limestone which is a shaley bedrock mass with approximately 50% limestone content. The limestones in the Maryville occur as calcium carbonate cemented shales, as assemblages of thin (2 to 20 cm) silty limestone beds, and less commonly, as relatively pure limestone beds up to about 1 m thick. The Maryville is described as a limestone; however, there is no evidence in Melton Valley that surface karst features have developed in the Maryville Limestone although fracture-controlled groundwater flow is known to occur in the bedrock zone. Weathering of the shaley and carbonate-interbedded bedrock coupled with the geologic structure produce an irregular bedrock surface that tends to reflect the overall topographic features of the area. During weathering, the limestone portions of the Maryville dissolve, leaving insoluble silt and clay materials that compose the remainder of the bedrock. The residuum thus formed retains the texture and structure of the parent bedrock, even to the detail of bedding planes, fractures, and folds. Groundwater seepage in the undisturbed residuum occurs primarily through open fractures such as bedding planes and cross cutting fractures, and in the saturated zone, the matrix materials between the open fractures are amenable to sluggish porous medium flow but more importantly provide retention of dissolved constituents in pore water.

4.1.1 General Groundwater Flow System Characteristics

Groundwater at the HFIR site occurs in an unconfined water table condition near the interface between the base of residuum and the top of bedrock. Monitoring data for the HFIR site since the accidental release of tritium from the broken PWD show that the groundwater flow system contains regions of flow that have strongly contrasting flow and transport characteristics. Data obtained at the HFIR site provide a basis for groundwater flow system analysis that helps quantify groundwater movement in the heterogeneous subsurface. The following sections of this report summarize the groundwater flow system using the behavior of tritium migration and discharge as a tracer that quantifies groundwater flow at the site. The groundwater system at HFIR is recognized to include rapid-flow zones and slow-flow zones.

Rapid-Flow Zone

Conceptually, the rapid-flow zones occur at shallow depths and include backfill in pipelines and other subsurface utility trenches, soils disturbed by site grading and construction activities, and building foundation backfill materials from Bldg. 7900 (assumed to be coarse gravel). In addition to the man-made, rapid-flow zones that dominate at the HFIR site, there may be some natural rapid-flow pathways such as local fracture zones and/or weathered bedrock zones that conduct groundwater rapidly. Groundwater flow in the rapid flow zones is similar to channel flow in that velocities are rapid, and dispersion of dissolved constituents is relatively low. In some areas, such as beneath the HFIR building and along some of the deeply buried utility lines, the disturbed soils that constitute preferred rapid-flow pathways penetrate the water table. Flow volumes in the rapid-flow zones are greatest during the wet nongrowing season

(December–April) and least during the drier growing season (May–November).

Slow-Flow Zone

Conceptually, the slow-flow zones are poorly connected fractures in weathered and unweathered bedrock that transmit groundwater much more slowly than the highly conductive rapid-flow pathways, and solute dispersion is higher than in the rapid-flow pathways. Dispersion causes spreading of solute along a groundwater flowpath with accompanied reduction in concentration downgradient. In the slow-flow component of the groundwater system, the direction of most groundwater movement is strongly influenced by the presence and orientation of fractures. The fracture sets in Melton Valley are dominated by the bedding plane partings and fractures within individual beds or lithologic units. Fractures that penetrate large volumes of bedrock at orientations that cross-cut the beds are sparse in proportion to the bedding-related fractures. This condition causes preferential groundwater seepage in the downgradient direction parallel to local geologic strike, which generally trends northeast and southwest. At the HFIR site, geologic strike is nearly parallel to the axis of Melton Valley, which is also nearly the same as the local survey grid system east-west direction.

Solute Transport Factors

Solute mass is moved in the groundwater flow system by advective transport downgradient along with the groundwater mass. Mechanical dispersion of the solute during advective transport causes the solute mass to spread laterally and longitudinally, thus reducing peak concentration downgradient of the initial source location. In addition to the effect of mechanical dispersion along the plume flowpath, solute mass tends to be held in pores of materials with significant matrix porosity because of diffusion of a portion of the solute mass into water-filled matrix pores. During the initial introduction of a concentrated solute mass into the heterogeneous porosity system, the strong concentration gradient between water in fractures and that in matrix material pores drives solute mass into the pores at matrix material surfaces while advective processes begin to act on the plume mass. As advection moves solute from the initial release away from the source area in the connected pores and fractures, the solute that moved into the matrix pores under the molecular diffusive process begins to move back into the active flow pathways by back-diffusion due to a reversal in concentration gradient. Because the concentration gradients are strongest in the source area at the time of release, the initial mass transfer of solutes into the matrix is more rapid than the back-diffusion mechanism that responds to weaker concentration gradients from the matrix to the fractures. This latter slow release of solutes from matrix pores back into the advective flow of the fractures prolongs the concentration recession limb of plume passage. Matrix porosity is expected to be highest in undisturbed residual soils/saprolite and in weathered bedrock that have a silt-like to clay-silt texture. Gravel materials used as excavation backfill and unweathered bedrock are expected to have lower matrix porosity than the weathered, native site materials.

4.1.2 Water Balance

Water balance is the term that describes the distribution of precipitation through the avenues of percolation into the soil, evapotranspiration through vegetation, recharge of the groundwater system, and runoff to surface streams. East Tennessee is in a climatic region that generally receives a surplus of rainfall relative to evapotranspirative moisture cycling although during periods of low rainfall in the growing season soil moisture deficits commonly occur. During periods of soil moisture deficit, percolation water that enters the soil column is rapidly absorbed to replenish the moisture deficit, and little groundwater recharge occurs until soil retention capacity is satisfied. When surficial soils are near their field capacity for water retention, additional percolation of water to provide groundwater recharge is controlled by the soil permeability (percolation rate). Rainfall in excess of the surficial soil percolation capacity runs off to local streams. Much of the direct runoff to surface water occurs through seepage in the stormflow zone (Solomon, et al. 1992).

The water balance for the HFIR site as well as the Oak Ridge Reservation includes

- Precipitation input,
- Evapotranspiration losses primarily from the stormflow (root) zone,
- Pore water storage and depletion in the active stormflow zone in soil,
- Surface water runoff when the stormflow zone is at saturation,
- Pore water storage and depletion in the vadose zone between the stormflow zone and the water table, and
- Water storage and discharge from the groundwater system.

A quantitative water balance model has been created to aid in analysis of the HFIR tritium plume behavior. A schematic of the water balance model and parameter estimates are shown in Fig. 4.1.

Input information for the model include

- Daily total precipitation data from the ORNL Tower C rain gage in Bethel Valley,
- Stormflow zone and vadose zone parameters from Rothschild et al. (1984) and Moore and Toran (1992), and
- Monthly evapotranspiration estimate averaged over 30 years (1961–1990) from the Coweeta Hydrologic Laboratory.

Calibration data include

- Melton Branch Weir flow data and
- Groundwater table response and recession data from wells at the HFIR site.

Figure 4.2 shows the modeled and measured runoff for the Melton Branch watershed for FY 2002 and through the first half of FY 2003. ORNL measures flow at the mouth of Melton Branch, and total monthly flow for each month was converted to inches of runoff from the watershed for purposes of comparing the measured runoff to the model calculated unit area runoff. Because the cooling tower blowdown discharge from the HFIR site is about 100 gpm, the blowdown discharge volume was subtracted from the measured runoff for each day the cooling tower was in operation. As summarized in the figure for FY 2002, the modeled basin runoff of 20.97 in. compares favorably with the measured runoff minus the blowdown contribution for the year (19.66 in.).

Figure 4.3 shows the modeled groundwater table response to rainfall compared to the measured water table response based on monitoring records for Wells 658, 887, and 892 in the HFIR plume area between December 2001 and June 2002. The modeled and observed water table responses to rainfall were generally similar through each storm sequence observed through this period. The difference in resolution between the computed daily responses and the data measured on a weekly frequency make quantitative comparison difficult; however, the general pattern and magnitude of response is considered a reasonably good fit.

The water balance model is used further in Sect. 4.2.2 to evaluate changes in concentration data observed in MH2,1, one of the key monitoring locations at the HFIR site.

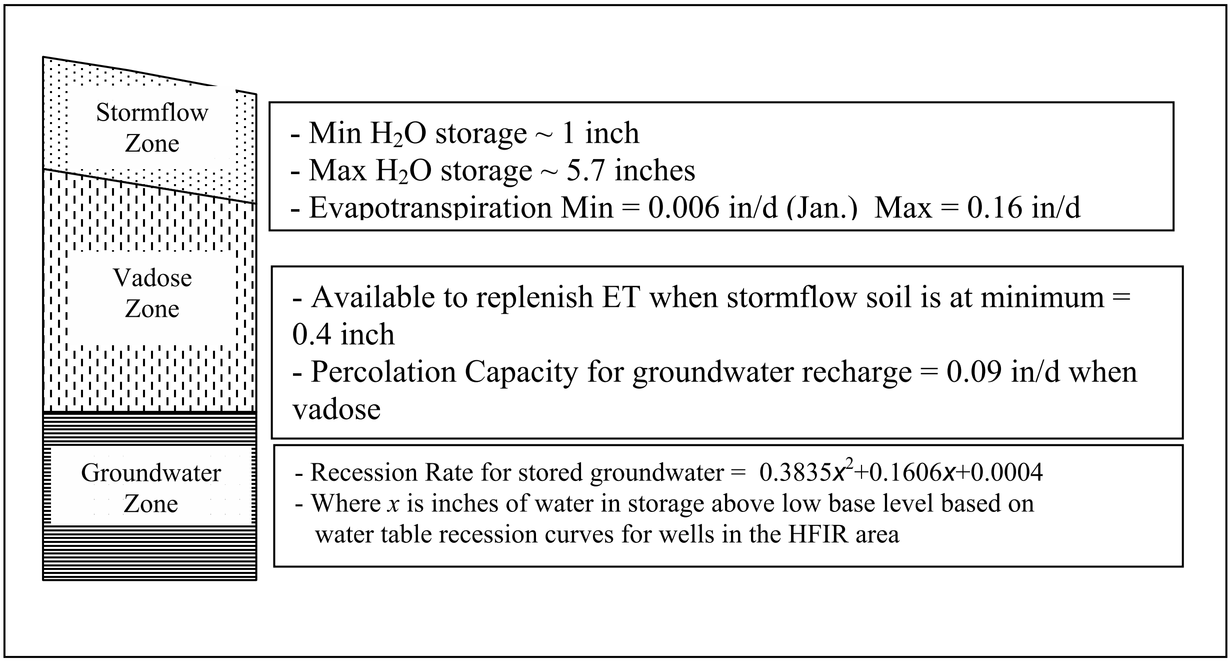

Fig. 4.1. Water balance elements and parameters.

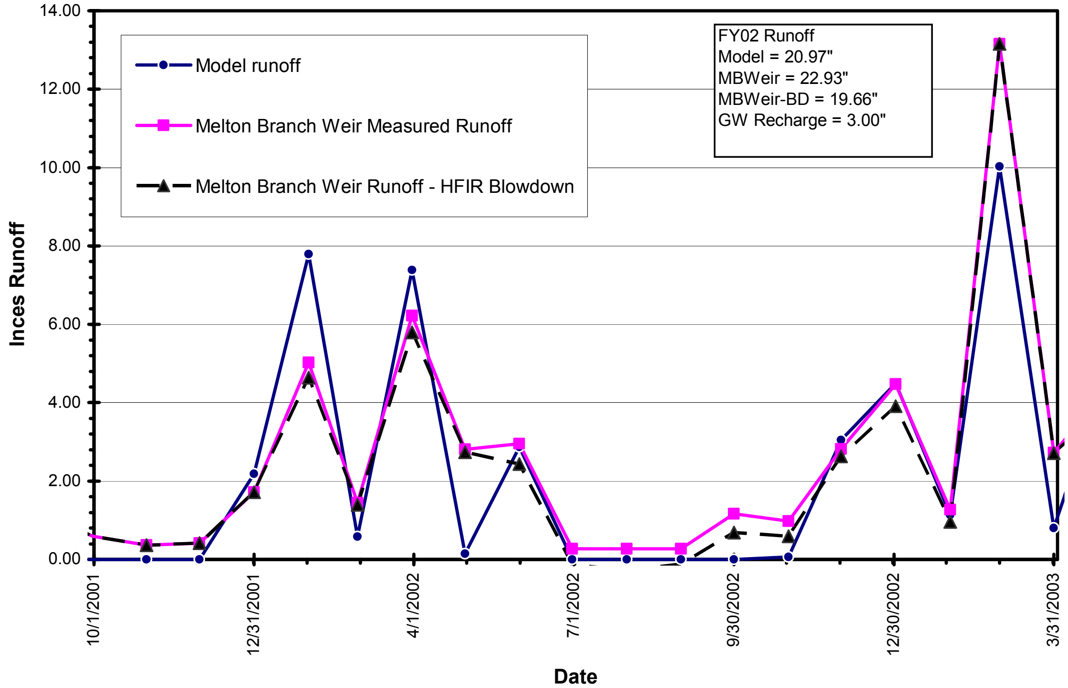

Fig. 4.2. Comparison of water balance model calculated runoff with measured Melton Branch Weir runoff.

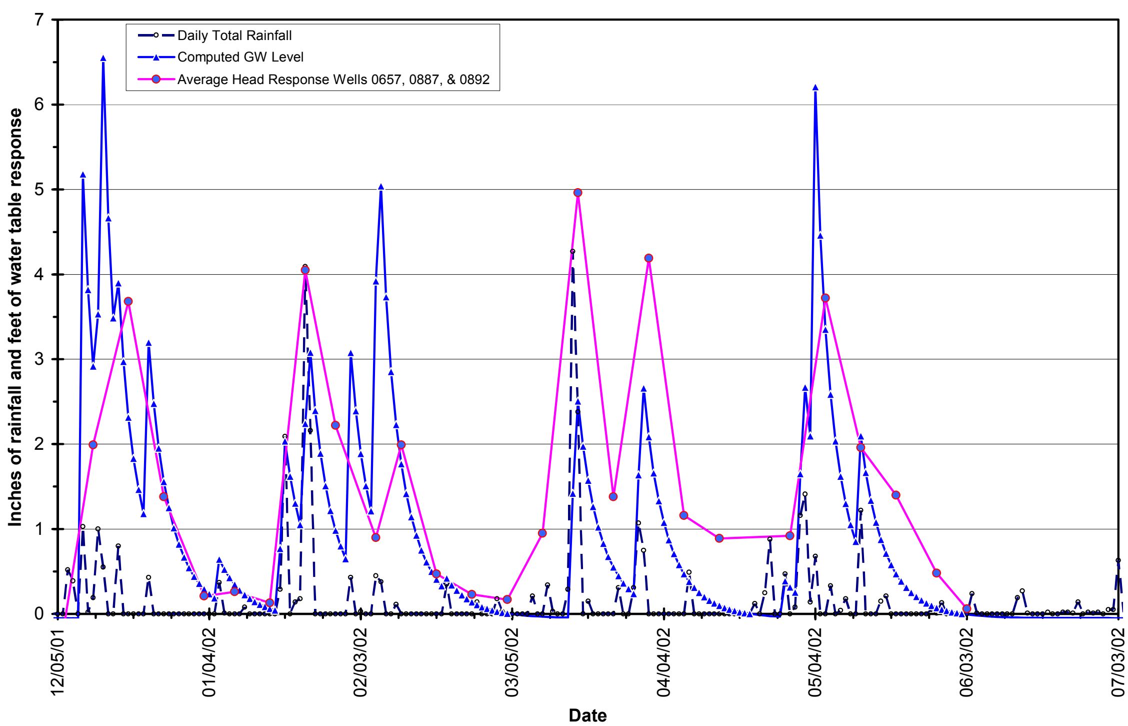

Fig. 4.3. Comparison of water balance predicted groundwater response and measured groundwater response at three wells at the HFIR site.

4.1.3 HFIR Site Data and Groundwater Flow System Description

Data gathered at the HFIR site has varied throughout the monitoring period that started in October 2000. The overall data set includes some groundwater level data, some flow volume data from storm drains and the HFIR building foundation drain, and a large amount of tritium concentration data from numerous monitored locations.

Groundwater levels were measured consistently in 3 wells on a monthly frequency from June through October 2001 and in 12 wells on a weekly frequency between November 2001 and June 2002 (Fig. 4.4). As shown by the well hydrographs, the magnitude of groundwater level fluctuations observed is greater in response to individual rainfall events than is the seasonal baseline fluctuation through the wet season. This response behavior is typical of shallow water table behavior throughout the ORR and may be enhanced in areas where natural soil profiles have been disturbed by construction.

The water table response to rainfall varies seasonally in response to changes in the soil moisture conditions. In East Tennessee, the distribution of rainfall throughout the year is fairly uniform although August, September, and October tend to have lower total rainfall than the other months. As important as rainfall to the water balance is the role of evapotranspiration in removing moisture from the soil column. During a typical annual cycle, evapotranspiration is near its minimum during the winter months from November through March to mid-April, and it reaches its peak in July. During the periods of most active evapotranspiration, significant (~1 in. water equivalent per week) amounts of water are removed from the soil profile. Unless frequent rain occurs to replenish the transpired moisture, a soil moisture deficit occurs. Until any soil moisture deficit is replenished, very little water can reach the groundwater table to recharge the aquifer. During the low evapotranspiration season, soils tend to remain near their field capacity for moisture retention, and even small rainfall events recharge to the groundwater table.

The water table surface south of the HFIR facility is strongly affected by the historic site disturbances and man-made features, such as the foundation drainage system and deeply buried utility pipes with pervious backfill. In Melton Valley, the dry season water table typically occurs at or slightly above the interface between deeply weathered bedrock (the saprolitic soils) and slightly to unweathered bedrock. During site construction activities, some of the excavations penetrated deeper than the normal water table elevation, and the backfill materials in those areas provide pervious channels for groundwater seepage along such features to points of discharge or inleakage to open drains.

Figure 4.5 is a map of the average water table elevations during the monitoring period. Groundwater data indicate a high water table north of the HFIR and a general gradient toward the adjacent streams. Water table contours are based on the combination of levels measured in the wells shown on Fig. 4.4 as well as probable groundwater levels inferred from elevations of foundation drains and storm drains that are known or suspected to act as French drains, suppressing water levels to the elevation of the base of the drain tile. Several groundwater flow pathways are indicated by arrows. These pathways are based on the combination of head gradient and locations of preferential groundwater flow pathways associated with underground utilities known to have acted as tritium seepage pathways.

In addition to routine groundwater level measurements, water flow volume measurements were made at the HFIR East Foundation Drain at MH-2,1 and in the Outfall 383 storm drain system at catch basin manhole (CBMH). MH-2,1 collects groundwater seepage from beneath the HFIR building, and CBMH collects discharge from seep CB-01 plus storm drain discharge from a paved area and possibly some groundwater inleakage between CB-01 and the CBMH. Figure 4.6 shows the measured flow volumes and the daily rainfall amounts for the two manhole locations. The manhole flow data show both rainfall event responses and the discharge relationship between the wet and dry seasons. MH-2,1 shows elevated base discharge volumes during the winters of both 2001 and 2002 with precipitation event spikes in discharge noted throughout the monitoring period. The CBMH monitoring record was affected by upstream discharge of cooling water during the period of June through September 2001, followed by low-flow volumes during the summer of 2001, and with a wet-season flow increase during autumn 2001 and winter 2002.

4.2 HFIR Site Tritium Plume Evolution

4.2.1 Plume Evolution 2000–2003

The distribution of tritium-contaminated groundwater at HFIR has changed gradually since the release was detected in autumn of 2000. Initial high concentrations of tritium in discharges from the rapid-flow system have diminished dramatically since the release was stopped and the process waste drain was replaced. Figures 4.7 and 4.8 show the tritium concentration history for rapid-flow and slow-flow monitoring locations during the time period October 2000 through September 2003. Location-specific monitoring results are described in Sect. 3 of this report.

Tritium concentration data have been contoured for three separate time periods since the release was detected—October 2000 through March 2001, June through December 2001, and January through June 2003. Figures 4.9, 4.10, and 4.11 show the average tritium concentration contours for each time period.

The concentration data for the first six months post-release (Fig. 4.9) show that the mass of tritiated water moved through the rapid-flow system from the leak area through MH2 and CB-01 to discharge via Outfalls 281 and 383. Rapid flow through deeply buried, abandoned process liquid waste line trenches created a seepage pathway that carried tritiated water to Outfall 381 via subsurface flow. Concentration data for the slow-flow monitoring locations available during the first six months showed that Well 658 had very high tritium concentrations, Well 892 had high concentrations, and other wells showed tritium concentrations difficult to distinguish from groundwater seepage apparently associated with

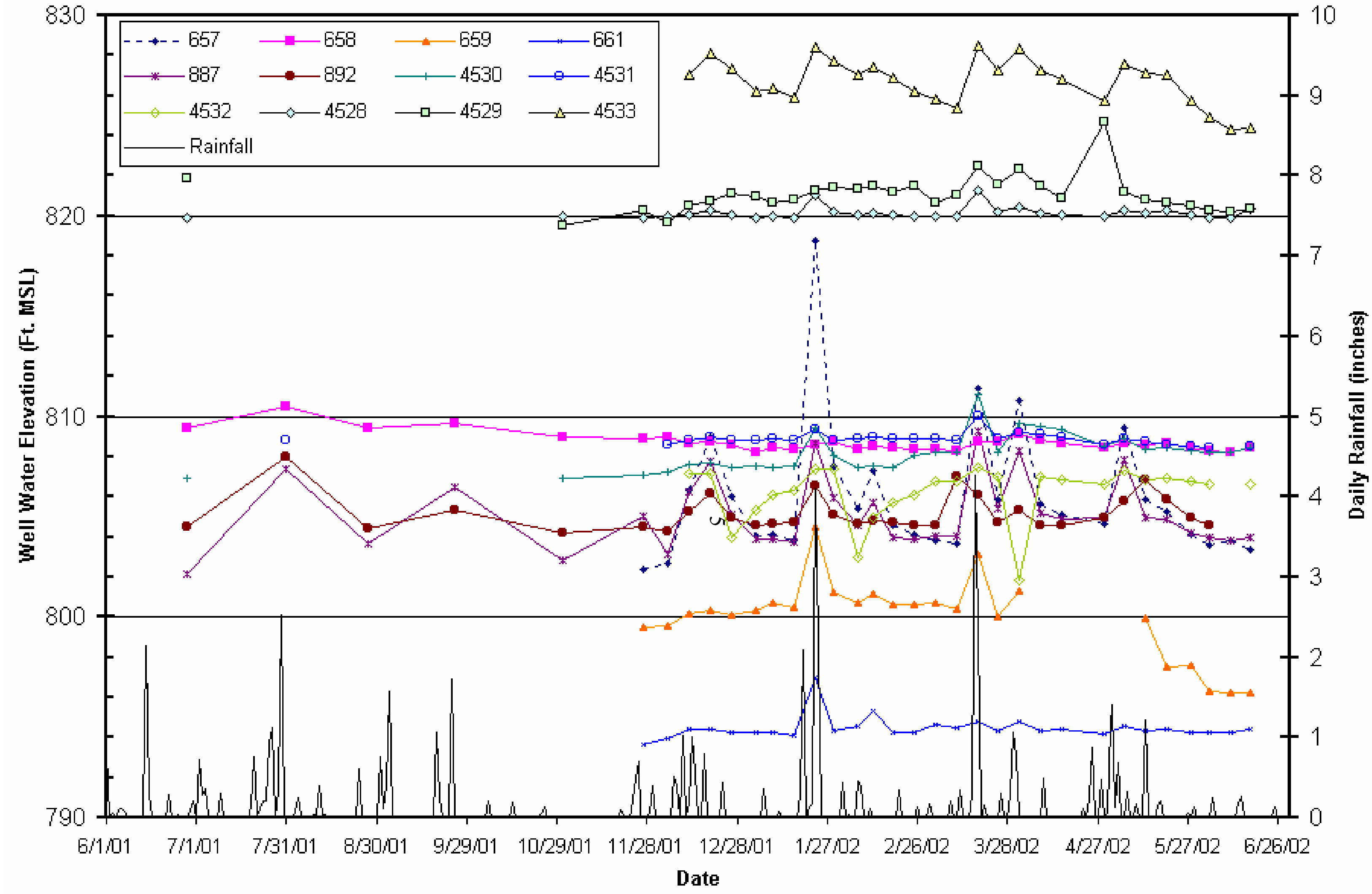

Fig. 4.4. Groundwater well hydrographs measured at the HFIR site and rainfall during each period.

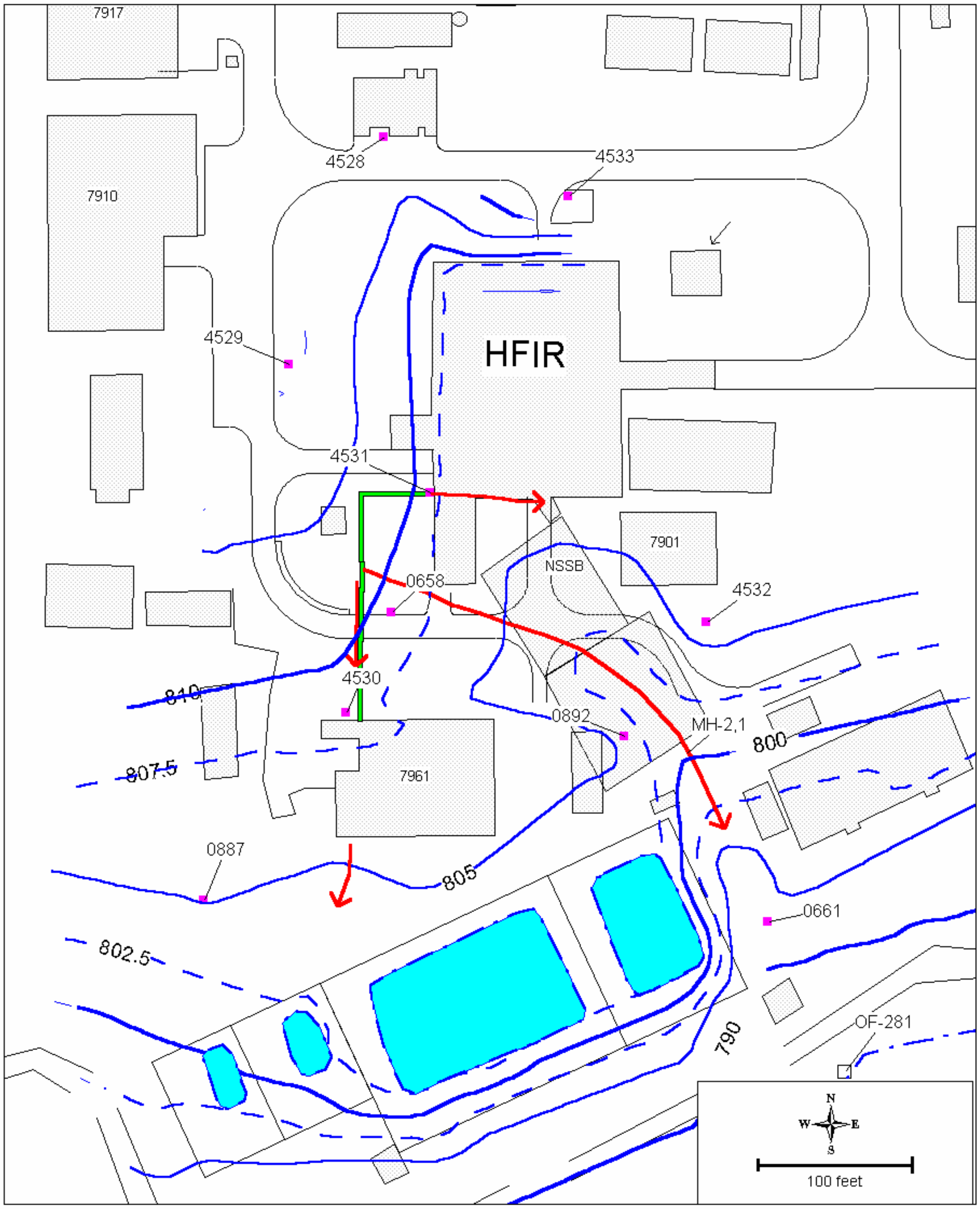

Fig. 4.5. Average water table configuration at the HFIR site.

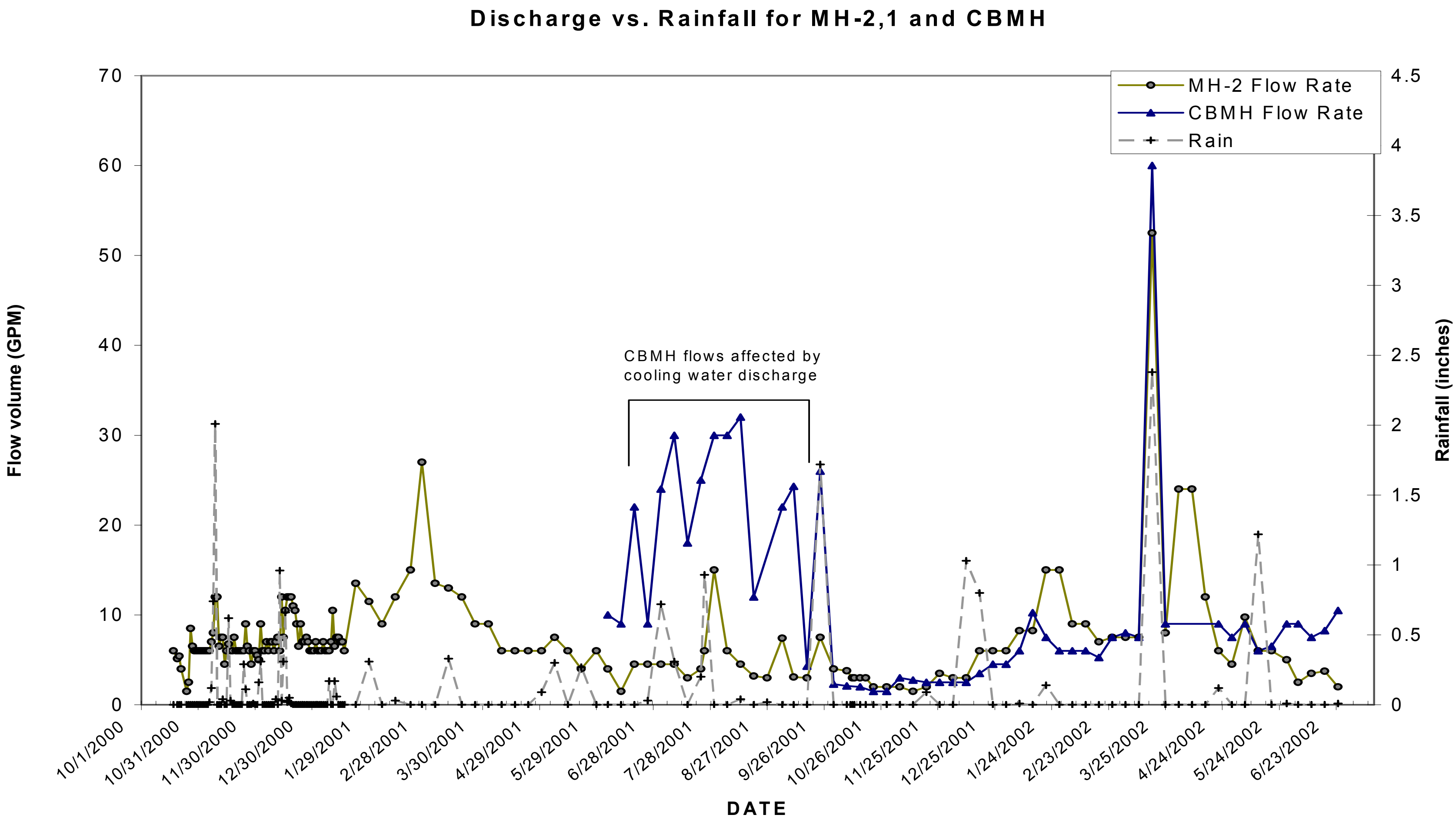

Fig.4.6. Discharge hydrographs and rainfall for Manhole 2,1 and the CBMH monitoring locations.

the wastewater ponds. During this time period, no data were available from the new monitoring wells (these wells were installed later).

Concentration data for the June through December 2001 period (Fig. 4.10) show that discharge and flushing through the rapid-flow pathways had reduced tritium concentrations substantially at MH2, CB-01, and the outfalls. In the slow-flow monitoring locations, concentrations at Well 658 had decreased while those at Wells 892 and 661 had increased. New monitoring locations became available at Wells 4528 through 4533. Of the new wells installed, only Well 4530 was located within the area of significant tritium contamination.

Concentration data for the January through June 2002 period are contoured in Fig. 4.11. Concentration time histories for the monitoring sites, shown in Figs. 4.7 and 4.8, indicate that between January and June 2002 continued flushing of rapid-flow pathways caused reduction of tritium concentrations at MH2, CB-01 and the outfalls. During this time period, the slow-flow zone monitoring data showed a continuing decrease in tritium concentration at Wells 658 and 4530, while Well 892 approached its peak tritium concentration, and near steady concentrations were observed at Well 661.

4.2.2 Plume Evolution During 2003 and Modeled Behavior at MH2,1

During 2003, the HFIR tritium plume monitoring data continued to verify the overall conceptual model of rapid-flow and slow-flow system components.

Groundwater monitoring data from Wells 658, 892, and 661 followed trends that were observed during the 2002 monitoring period (Figs. 4.7 and 4.8). Well 658 continued to decrease in tritium concentration at a nearly linear rate. Well 892 passed its peak tritium concentration during July of 2002, and during 2003, showed a downward concentration trend. During 2003, Well 661 showed a steadily increasing tritium concentration.

Monitoring data from MH2,1 and CB-01 showed that the rapid-flow system responded strongly to the higher than normal precipitation volumes that were experienced during the 2003 water year. As shown in Fig. 4.7, the tritium concentration at both of these rapid-flow system monitoring locations increased late in 2002 and reached concentrations similar to those observed in late 2001. In essence, the summer 2002 data in the rapid-flow system were lower than during prior and post wet seasons. This observation is consistent with the model that most of the tritium mass is retained in the slow-flow system component, and when groundwater levels rise in response to rainfall stress, tritium is discharged into the rapid-flow system.

The center of mass of the tritium plume—based on the area of peak concentration—has gradually drifted east-southeastward from the vicinity of Well 658 toward Well 892. Only two wells are available to provide data in the area, so it is not possible to infer what the tritium concentrations may be closer to the HFIR building and nearer to the building foundation drain system. The overall behavior of tritium concentrations in MH2,1

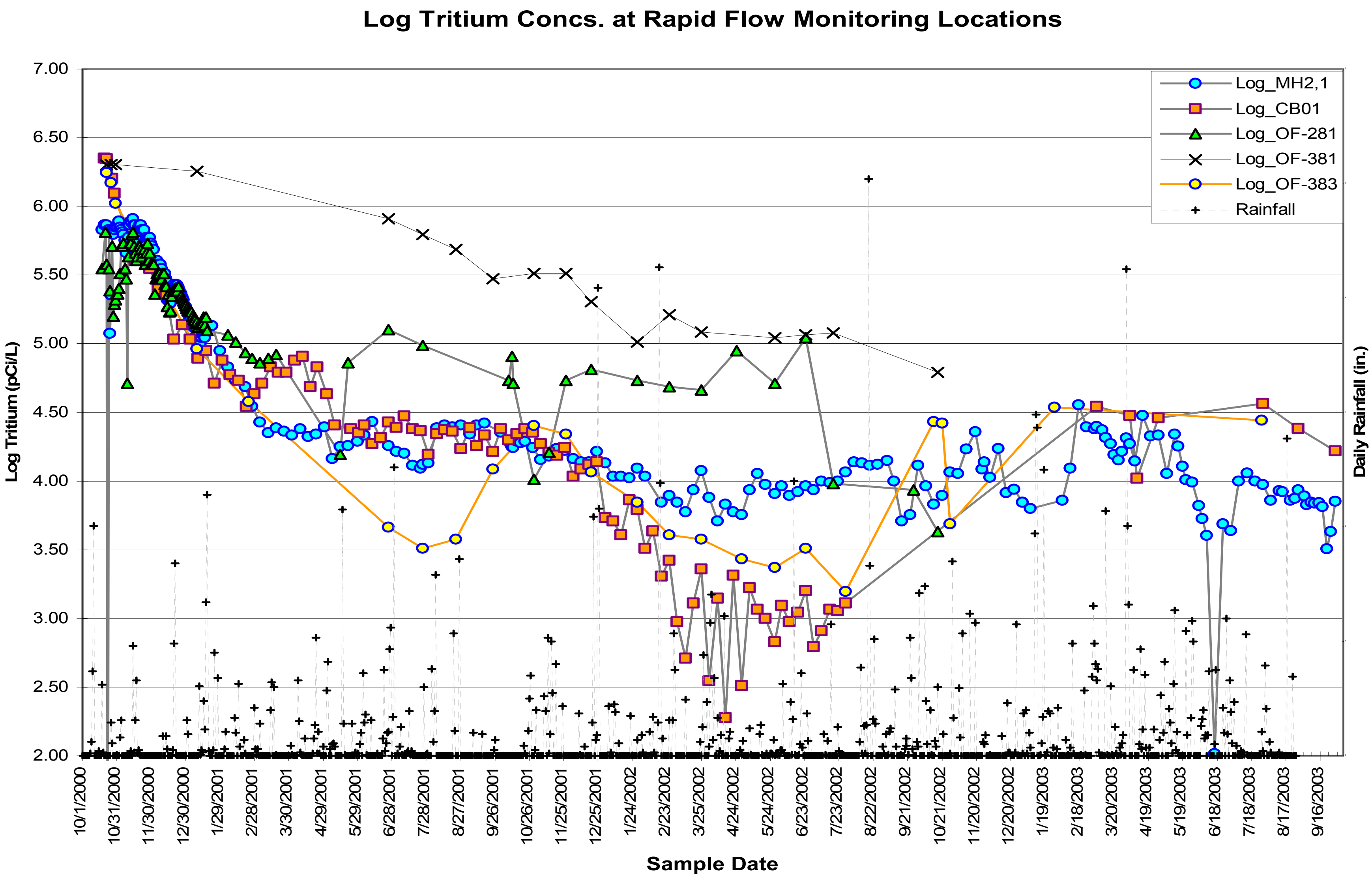

Fig. 4.7. Log tritium concentration measured in rapid-flow monitoring locations at the HFIR site.

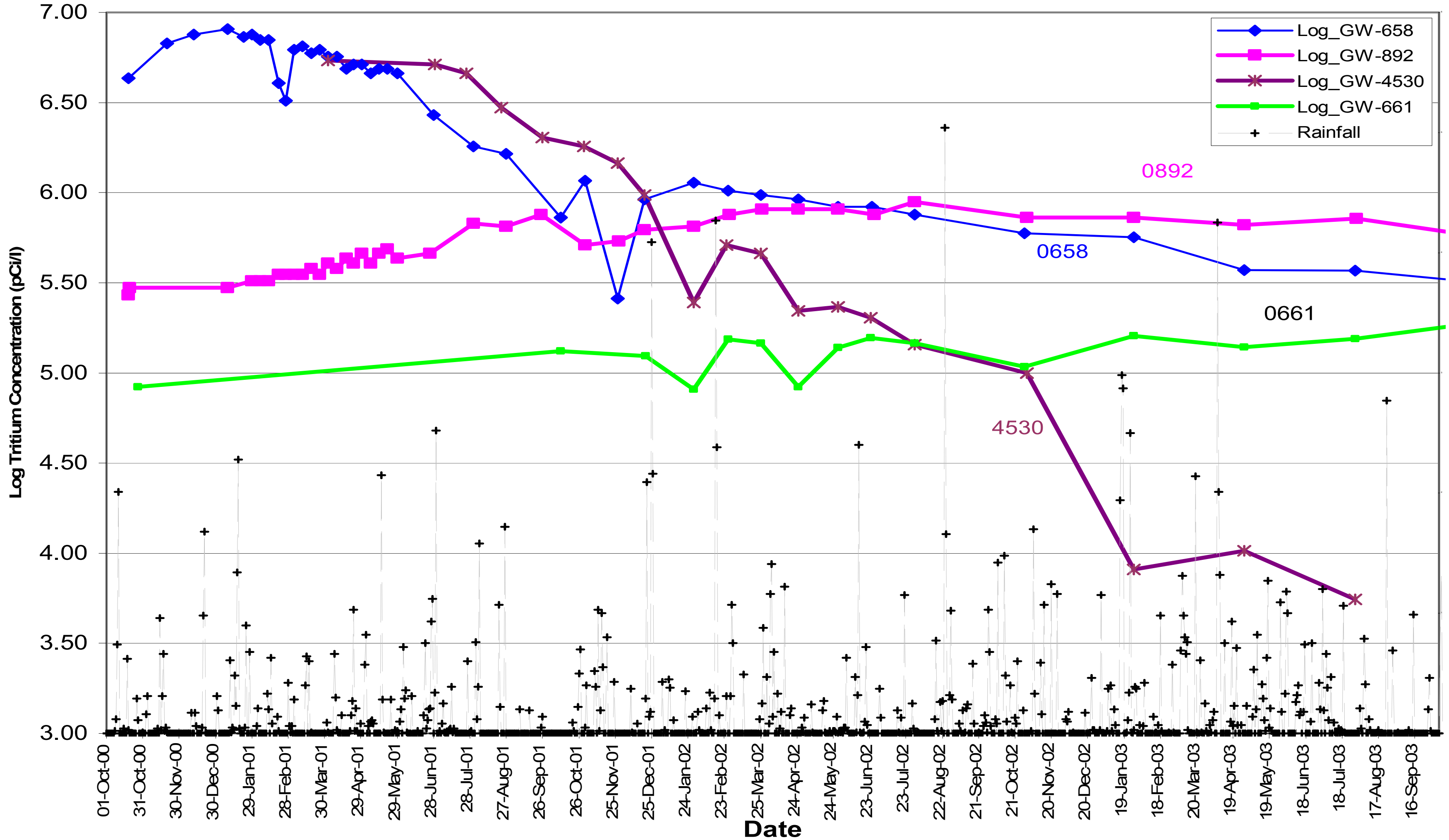

Fig. 4.8. Log tritium concentration measured in groundwater monitoring locations at the HFIR site.

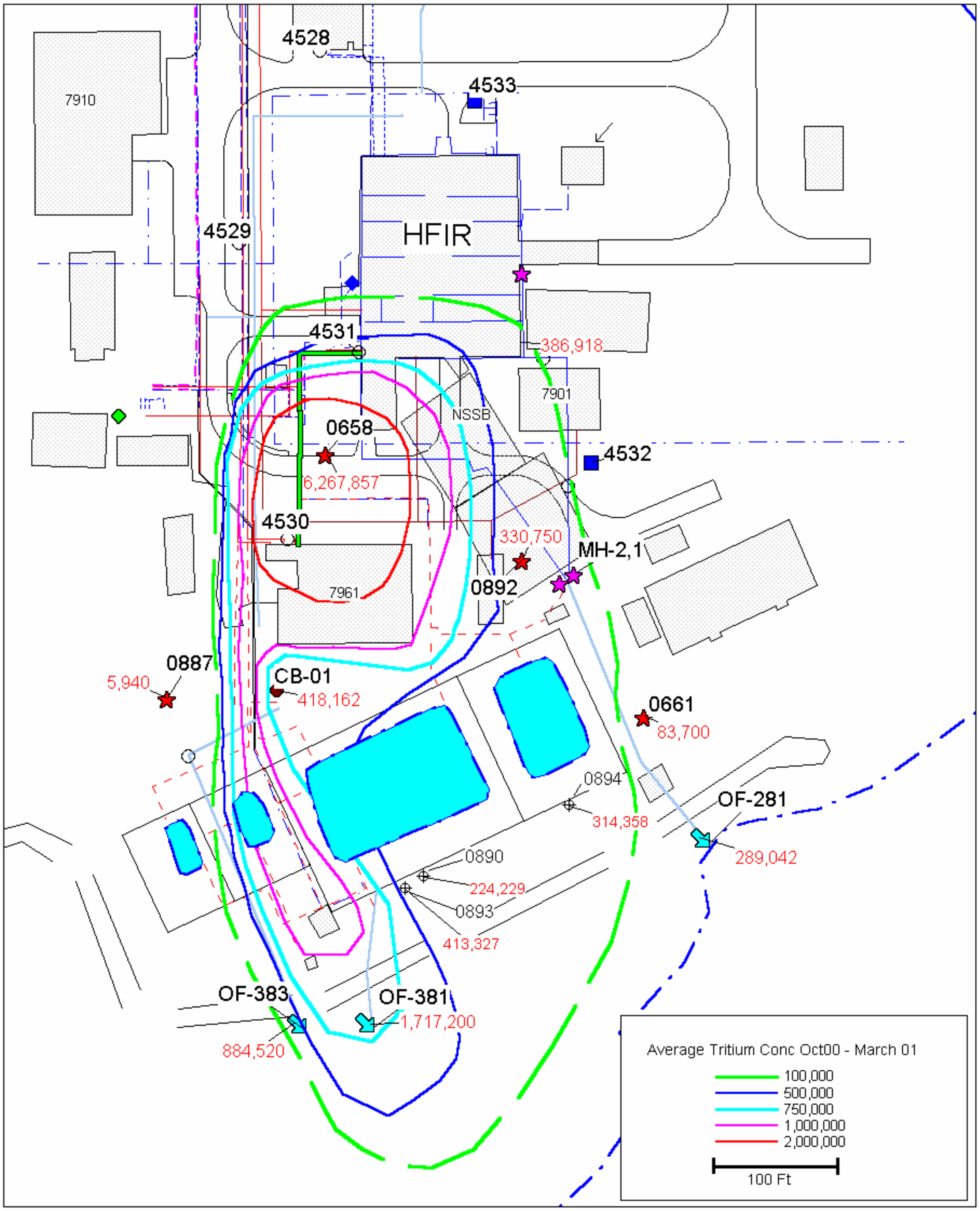

Fig. 4.9. Tritium concentrations at the HFIR site October 2000–March 2001.

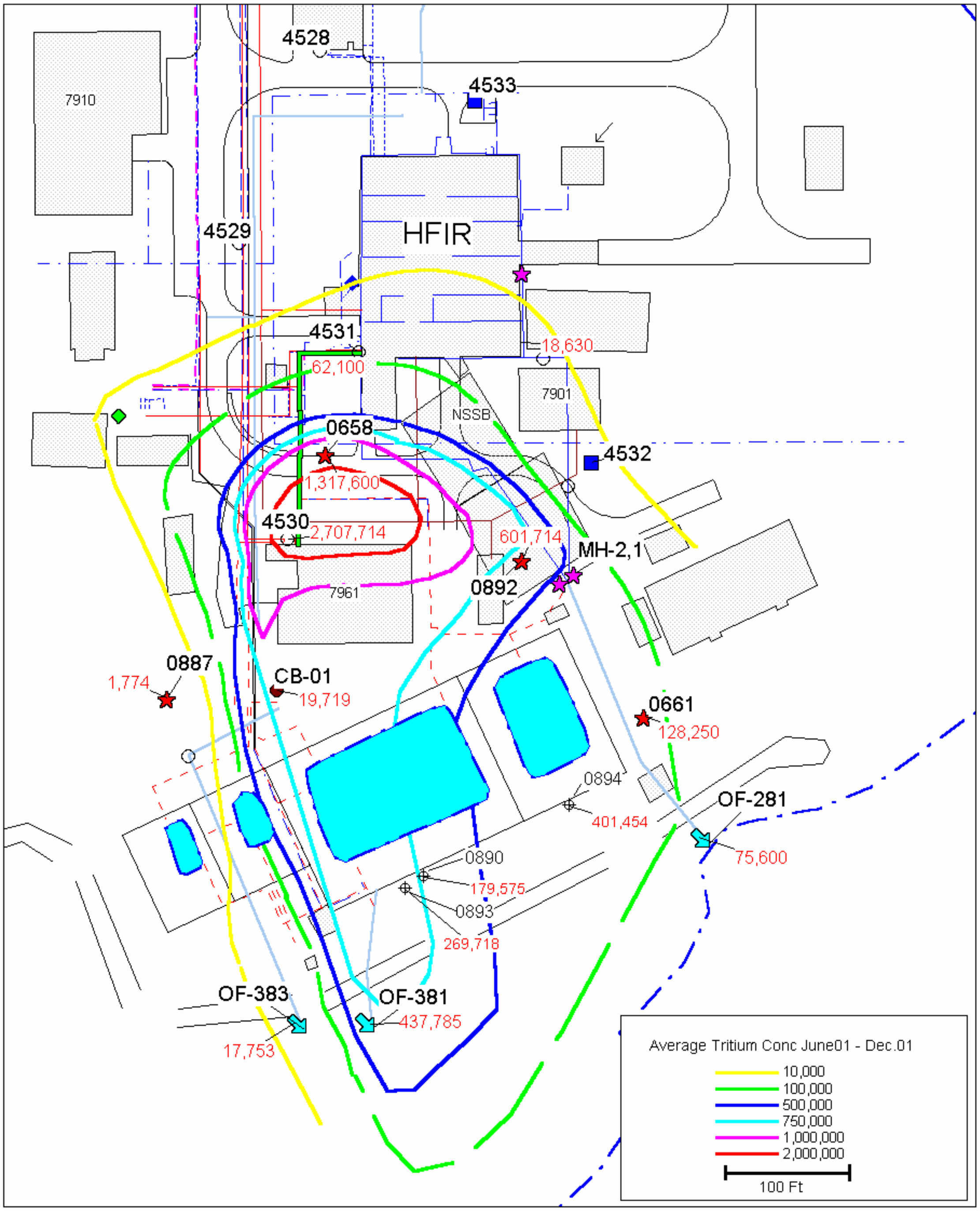

Fig. 4.10. Tritium concentrations at the HFIR site June–December 2001.

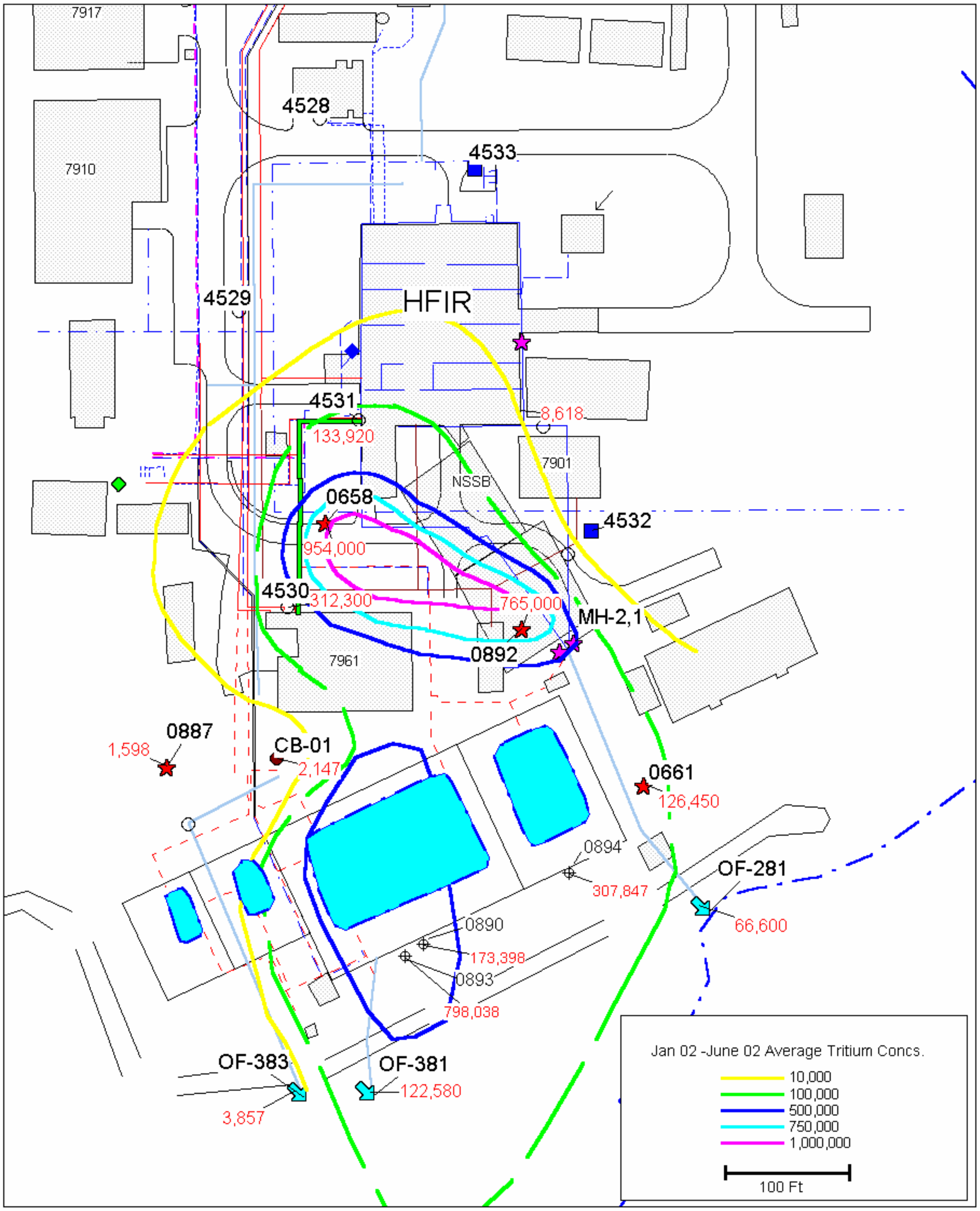

Fig. 4.11. Tritium concentrations at the HFIR site January–June 2002.

through time and the responsiveness to rainfall suggests that as the plume mass has migrated eastward; there has been an increase in the sensitivity of MH2,1 to rainfall-driven pulses of tritiated water discharge.

4.2.1 Water Balance Model Simulation of MH2,1 Tritium Concentrations

The water balance model was used to evaluate the rapid-flow system tritium concentration fluctuations. To simulate the tritium concentration at MH2,1 using the water balance model, the system was considered a two-component mixing model using Well 658 and MH2,1 as the mixing members and modeled groundwater level based on the water balance to calculate the daily tritium concentration at MH2,1.

The idealized tritium concentration data at Well 658 was calculated for each day based on two fitted equations to describe the concentration changes observed from October 19, 2000, through October 29, 2003.

The Well 658 concentration from October 19, 2000 through January 29, 2002, is described by the polynomial function:

$$c_t = -0.0017x^4+2.1613x^3-869.07x^2+105401x+4E+6$$

where c_t = estimated tritium concentration at Well 658 and x is days since October 19, 2000. Comparison of the calculated values from this polynomial with the measured data yields a coefficient of determination (r^2) of 0.97.

Since January 29, 2002, the tritium concentration at Well 658 is described by

$$c_t = 1E+6\ e^{-0.002x} +75{,}020$$

where c_t = estimated tritium concentration, and x = days since January 29, 2002. Comparison of this equation to measured tritium concentrations at Well 658 yields an r^2 = 0.98.

The lower tritium concentrations at MH2,1 were evaluated as a separate flow component or a small seepage component from the plume core that is a mixing member with higher concentration or higher volume of plume core groundwater during high-flow events. Data were selected from seven sample dates starting at March 12, 2001, that showed an apparent downward long-term concentration trend. The minimum tritium concentration trend at MH2,1 is described by the function

$$c_t = -2661.2\mathrm{Ln}(x) + 22{,}288$$

where c_t = tritium concentration and x = days since March 12, 2001. The r^2 for this relationship compared to the seven low-flow data points was 0.99.

The minimum ratio of MH2,1 tritium concentration to the Well 658 tritium concentration was approximately 0.2, suggesting a 5:1 mixing ratio of the lower tritium concentration groundwater with the higher tritium concentration groundwater.

Figure 4.12 shows the daily rainfall history; computed water table response to daily rainfall, including the influences of evaptranspiration and runoff of excess precipitation; measured Well 658 tritium concentrations; and the computed and measured tritium concentrations at MH2,1 since February 28, 2001. As expected, the modeled water table response shows little effect from rainfalls that occur between about May and November because of strong evapotranspirative water losses from soil and development of a soil moisture deficit during late summer and early autumn. The modeled daily MH2,1 tritium concentration signature shows spiked responses to numerous rainfall events, particularly during the months of November through May. Visible in the trend for the modeled MH2,1 behavior is the gradually decreasing slope based on the history of periodic low concentrations. Comparison of the measured MH2,1 tritium concentration with the modeled concentrations shows the obvious influence of elevated groundwater for many of the tritium concentration spikes measured. Not all of the measured tritium concentration behavior at MH2,1 conforms to the water balance model. Some obvious measured data responses to intense isolated storms during the dry season are not predicted by the water balance model. This is attributed to rapid infiltration of rainwater into open dessication cracks in soil that provide direct seepage pathways into fractures in the vadose saprolite zone and directly to the water table. Prolonged elevated concentrations observed during August 2002 may have been related to the position of the maximum mass area as it seeped through the area represented by Well 892. The very low concentration spike observed in early summer of 2003 was determined to be a statistical outlier from the MH2,1 dataset and is not explained by any known mechanism.

4.2.2 Projected Future Tritium Concentration Trends

The data analyses performed in support of the interpretations presented previously provide a conceptual basis to estimate the future tritium concentration behavior at several monitoring locations. The exponential decrease in tritium concentration trends observed at Wells 658, 892, and at MH2,1 suggest that the tritium concentrations at Well 658 and MH2,1 should continue to decrease with the possibility of additional precipitation-driven concentration spikes. Figure 4.13 shows the tritium concentration history and projected trend for Well 658 with an estimated concentration near 100,000 pCi/L through mid-2006. The tritium concentration decrease in the vicinity of Well 892 is extremely slow, and the projected exponential trend for decrease in that area indicates that concentrations may exceed 100,000 pCi/L until near the end of 2010. A significant uncertainty in future tritium concentrations at MH2,1 is the role of tritium in the vicinity of and slightly north of Well 892, which is beneath the new HFIR experimental facilities. If precipitation-driven tritiated groundwater pulses seep from that area to the east foundation drain, the seasonal tritium peaks at MH2,1 are expected to continue for several years (Fig. 4.14).

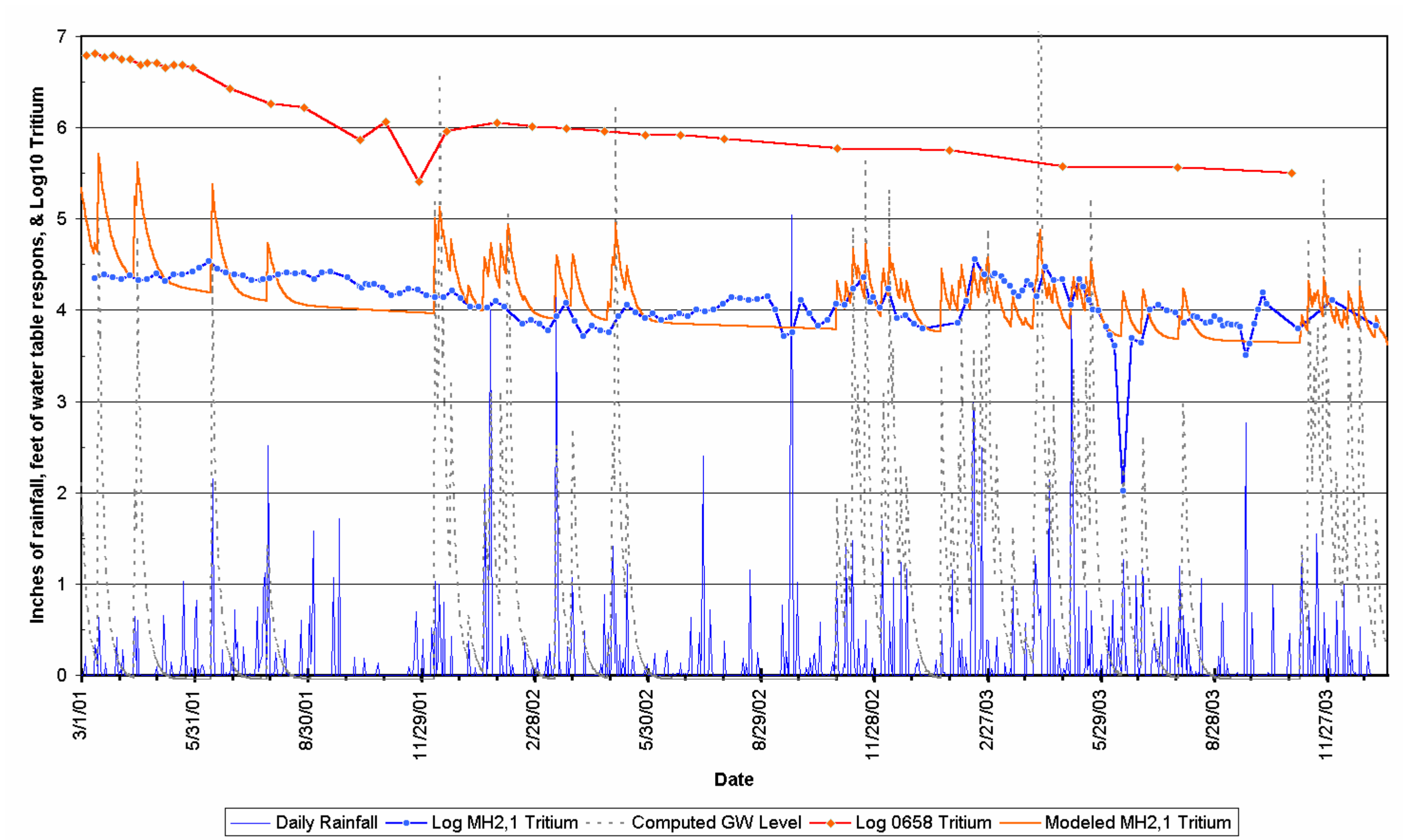

Fig. 4.12. Modeled and measured MH2,1 tritium concentration and measured Well 658 tritium concentration.

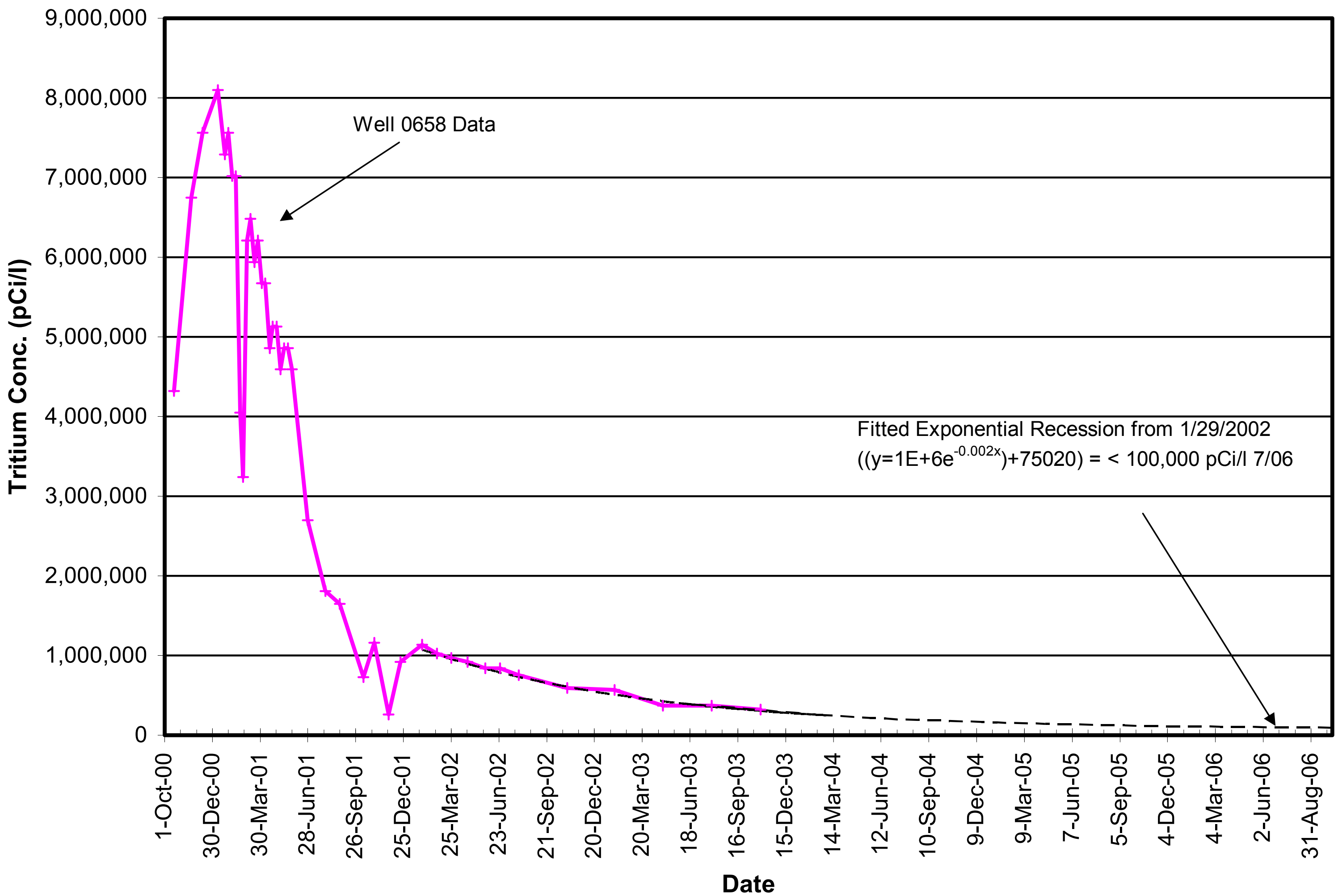

Fig. 4.13. Projected tritium concentration at Well 658.

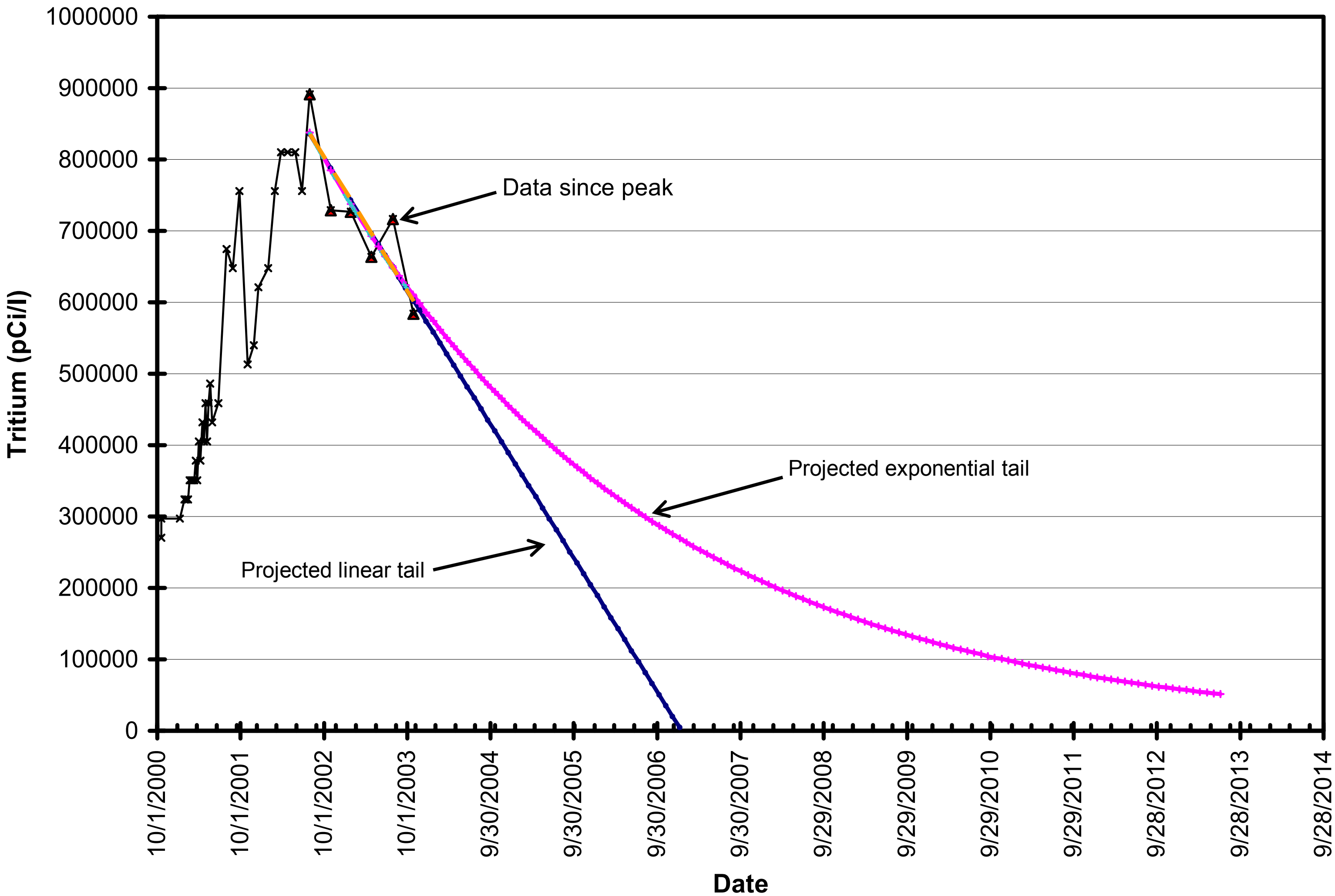

Fig. 4.14. Well 892 data and projected future tritium concentrations.

5. RESULTS OF 2002/2003 MONITORING PROGRAM

The drain systems, NPDES outfalls, and groundwater monitoring wells described in Sects. 3.1 and 3.2 of this report were monitored in accordance with the 2002/2003 AMP (see discussion on deviations from the 2002/2003 AMP, above). Sen's Slope/Mann-Kendall (Gilbert 1987) trend analyses were performed on the tritium monitoring data generated by the monitoring program and are reported below. The trends for the monitoring data for each of the monitoring points were tested at a level of significance (") of 0.01, 0.05, 0.1, and 0.2. In this report, an " level of 0.05 was used for the trend analyses, unless otherwise noted. Additionally, where the monitoring data were compared to an action level or the federal primary drinking water standard for tritium, the 95% confidence interval was used in the comparison. The confidence interval was based on the average or mean annual analytical result for the 2002/2003 data sets. Seasonal influences on the data sets analyzed were detected using the Kruskal-Wallis test (Gilbert 1987). An " level of 0.05 was used for the Kruskal-Wallis test. Note that seasonal effects were detected only in the 7901 Pit data set; seasonality was not able to be detected in the other monitoring point data sets given that there were insufficient samples collected at these locations during the 2002/2003 monitoring period. Removal of the seasonal effect from seasonal data was performed on the 7901 Pit data set in accordance with U.S. Environmental Protection Agency (EPA) methodology (EPA 1989) prior to performance of the Sen's Slope/Mann-Kendall trend analyses.

5.1 Results of 2002/2003 Drain and NPDES Outfall Monitoring (Rapid-Flow System)

The following descriptions briefly summarize the behavior of tritium concentrations at the drain and NPDES outfall monitoring locations during the 2002/2003 monitoring period.

7901 Pit: The raw monitoring data (data not deseasonalized) for the 7901 Pit (EFD) exhibited a slight downward trend in tritium concentration during the 2002/2003 monitoring period; however, the decrease in trend was not statistically significant. Likewise, deseasonalized monitoring data also exhibited a downward trend in tritium concentration but at a significance level of 0.2. In addition, the 95% confidence interval for the 2002/2003 7901 Pit raw and deseasonalized data sets did not exceed the Action Level 1 threshold of 20,000 pCi/L established in the 2002/2003 AMP. Figure 5.1 shows the time series history of tritium concentrations at 7901 Pit during the 2002/2003 monitoring period. The monitoring result shown below the minimum detectable activity (MDA) on Fig. 5.1 is a statistical outlier.

CB-01: Trend analysis performed on tritium monitoring data collected at CB-01 during the 2002/2003 monitoring period exhibited an upward trend in tritium concentration; however, the upward trend was not statistically significant. In addition, the 2002/2003 monitoring period 95% confidence interval tritium concentration at CB-01 did not exceed its Action Level 2 threshold of 15,000 pCi/L, although four individual analytical results exceeded this threshold during the monitoring period. The 95% confidence interval tritium concentration at CB-01 exceeded the monitoring point's Action Level 1 threshold of 7,500 pCi/L during the monitoring period. Figure 5.2 shows the time series history of tritium concentrations at CB-01 during the 2002/2003 monitoring period.

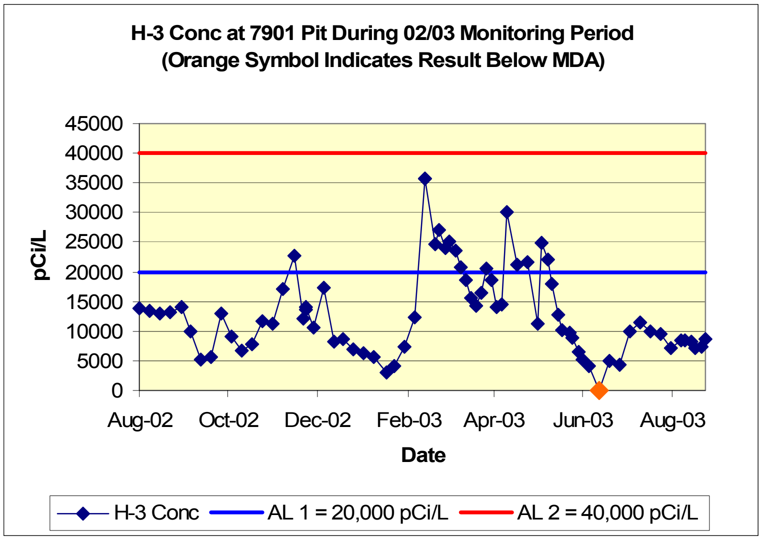

Fig. 5.1. Tritium concentrations at 7901 pit during 2002/2003 monitoring period.

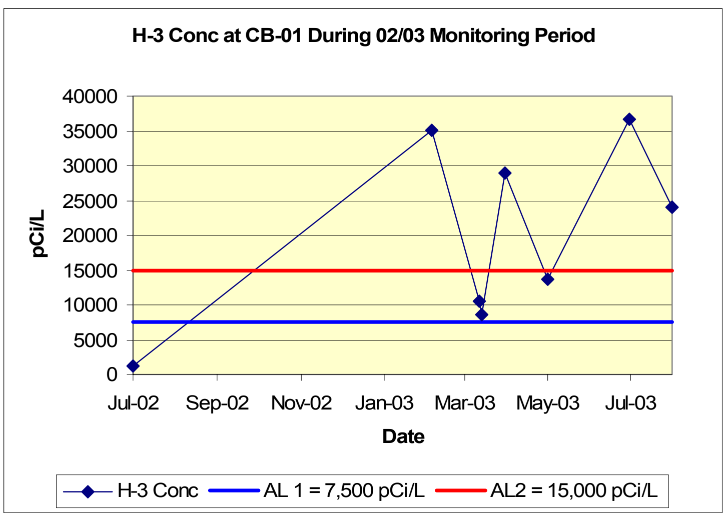

Fig. 5.2. Tritium concentrations at CB-01 during 2002/2003 monitoring period.

NPDES outfalls OF-281, OF-381, and OF-383 were monitored during the 2002/2003 monitoring period under the aegis of the RMP. Because OF-383 is monitored annually under the RMP, OF-383 was monitored quarterly under the 2002/2003 AMP to be consistent with the monitoring frequency for OF-281 and OF-381 outlined by the RMP.

OF-281: Trend analysis performed on tritium monitoring data collected at OF-281 during the 2002/2003 monitoring period for the NPDES RMP exhibited a downward trend in tritium concentration; the decrease in trend was not statistically significant. In addition, the 2002/2003 monitoring period 95% confidence interval tritium concentration at OF-281 did not exceed the drinking water standard (DWS) of 20,000 pCi/L for tritium. Figure 5.3 shows the time series history of tritium concentrations at OF-281 during the 2002/2003 monitoring period.

OF-381: Trend analysis performed on tritium monitoring data collected at OF-381 during the 2002/2003 monitoring period for the NPDES RMP exhibited a downward trend in tritium concentration at an " of 0.05. In addition, the 2002/2003 monitoring period 95% confidence interval tritium concentration at OF-381 exceeded the DWS of 20,000 pCi/L for tritium. Figure 5.4 shows the time series history of tritium concentrations at OF-381 during the 2002/2003 monitoring period.

OF-383: Trend analysis performed on tritium monitoring data collected at OF-383 per the 2002/2003 AMP exhibited an upward trend in tritium concentration, although the upward trend was not statistically significant. In addition, the 95% confidence interval for these data did not exceed the DWS of 20,000 pCi/L for tritium. Figure 5.5 shows the time series history of tritium concentrations at OF-383 during the 2002/2003 monitoring period.

5.2 Comparison of 2002/2003 NPDES Outfall to X-13 Weir Monitoring Data

To put the tritium concentrations being discharged from NPDES Outfalls 281, 381, and 383 in perspective, tritium concentration data collected during the 2002/2003 monitoring period from the outfalls and the X-13 (Melton Branch) Weir were compared. The X-13 Weir is located downstream of the HFIR complex and is a monitoring point that integrates surface water from surface water bodies within the Melton Branch watershed. Waste Area Grouping (WAG) 5 is within the Melton Branch watershed and is located downstream of the HFIR complex but upstream of Weir X-13. WAG 5 is a nonoperational, low-level radioactive waste disposal site,

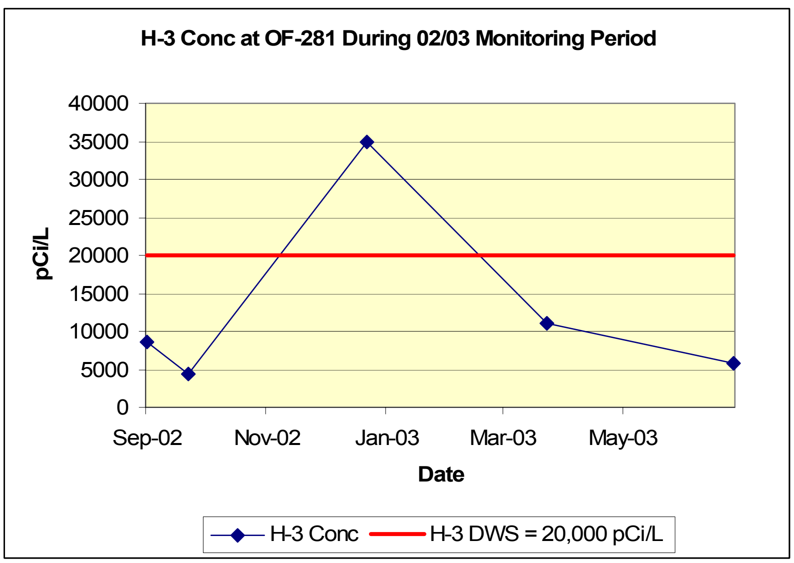

Fig. 5.3. Tritium concentrations at OF-281 during 2002/2003 monitoring period.

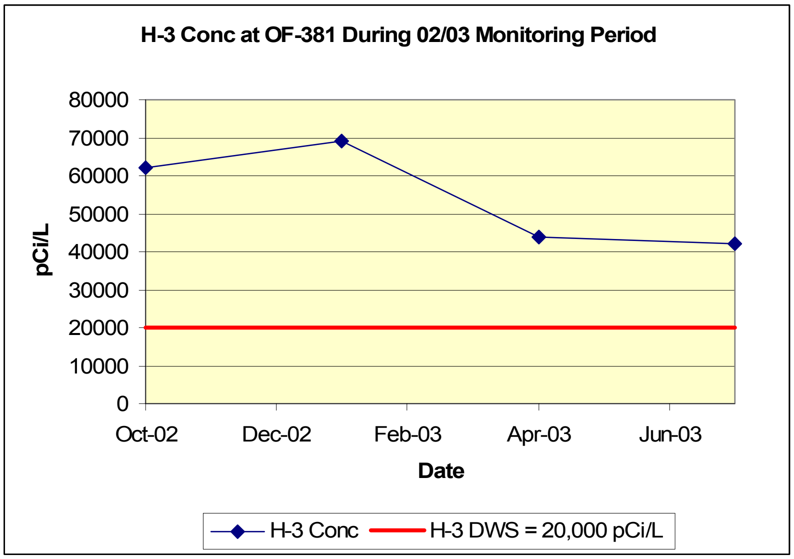

Fig. 5.4. Tritium concentrations at OF-381 during 2002/2003 monitoring period.

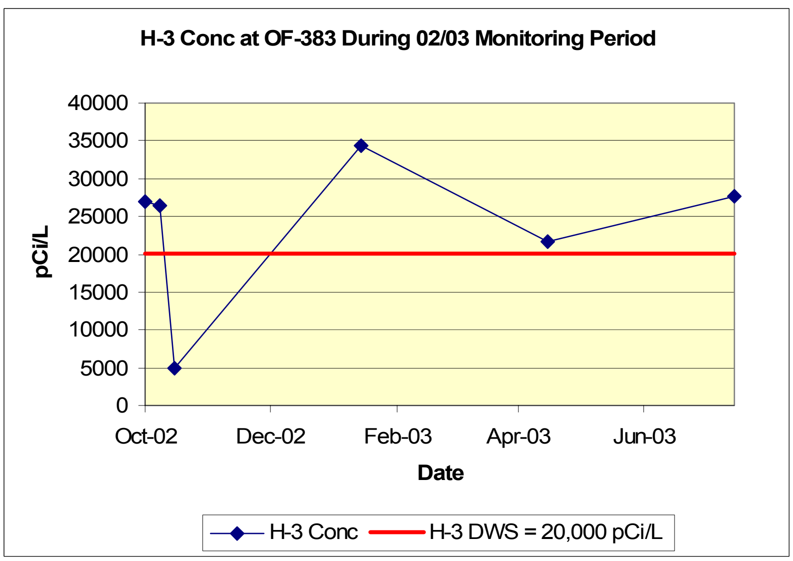

Fig. 5.5. Tritium concentrations at OF-383 during 2002/2003 monitoring period.

which is undergoing remediation under the Comprehensive Environmental Response, Compensation, and Liability Act. Tritiated wastes were disposed of in WAG 5 during its operational life, and tritium is one of the contaminants discharging from WAG 5 into Melton Branch.

Tritium concentration data from the four monitoring points were compared rather than tritium fluxes because flux data were not available for all of the outfalls. The 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles were calculated for each monitoring point, and these percentile concentrations are displayed in Fig. 5.6 and Table 5.1.

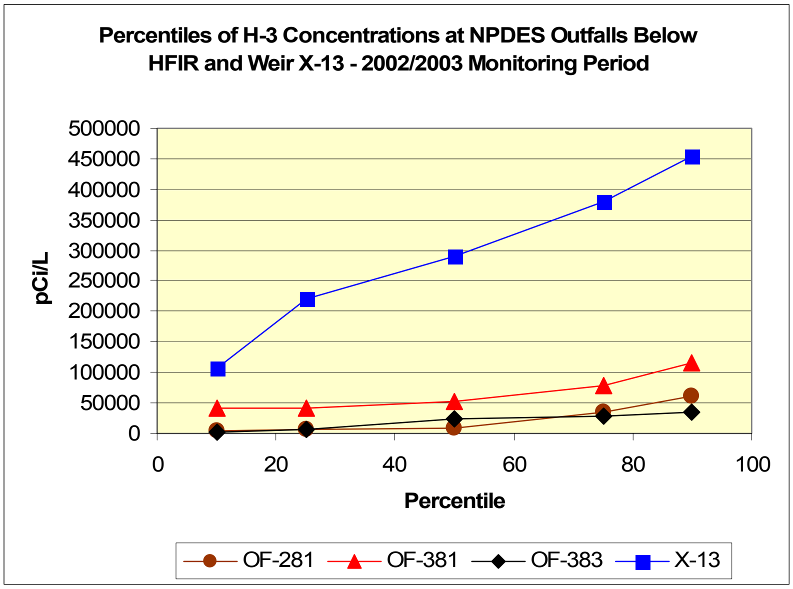

Fig. 5.6. Percentiles of H-3 concentrations at NPDES outfalls below HFIR and Weir X-13 during the 2002/2003 monitoring period.

Table 5.1 Percentiles of H-3 concentrations at NPDES outfalls below HFIR and Weir X-13 during the 2002/2003 monitoring period

Percentile	OF-281 H-3 concentration	OF-381 H-3 concentration	OF-383 H-3 concentration	X-13 H-3 concentration
10	4000	42000	1236.6	106000
25	5800	42000	7395	220000
50	8600	53000	24030	290000
75	35000	78075	27525	380000
90	61040	116190	35070	454000

As can be seen in Fig. 5.6 and Table 5.1, concentrations of tritium discharged from the HFIR complex NPDES outfalls were much lower than the tritium discharged from other areas of the Melton Branch watershed (including WAG 5 located downgradient of the HFIR complex during the 2002/2003 monitoring period).

5.3 Results of 2002/2003 Groundwater Monitoring (Slower-Flow System)

There are a number of groundwater monitoring wells located downgradient of the HFIR building that were installed during the 1980s. Most of these wells were not sampled on a frequent basis prior to the tritium release from the HFIR; subsequently, few tritium concentration data are available for these wells. Several wells were installed at the HFIR site as a result of the tritium released. These wells were installed to monitor groundwater at the soil/bedrock interface (shallow groundwater flow system) and the uppermost portion of the bedrock aquifer (deeper groundwater flow system). The shallow portion of the aquifer lying below the HFIR is of utmost concern from a monitoring perspective because any contaminant which may leak due to operational activities or system failures will find its way into the shallow subsurface as has been observed during the characterization of the tritium release at HFIR. The following descriptions briefly summarize the behavior of tritium concentrations at well and deep drain monitoring locations during the 2002/2003 monitoring period.

5.3.1 Downgradient Wells

The following is a brief summary of the tritium concentration behavior in downgradient wells sampled during the 2002/2003 monitoring period.

Well 658: Trend analysis of tritium monitoring data collected during the 2002/2003 monitoring period exhibited a statistically significant downward trend in tritium concentrations. In addition, the 95% confidence interval for the 2002/2003 monitoring data exceeded the DWS of 20,000 pCi/L during the monitoring period. Figure 5.7 shows the time series history of tritium concentrations at Well 658 during the 2002/2003 monitoring period.

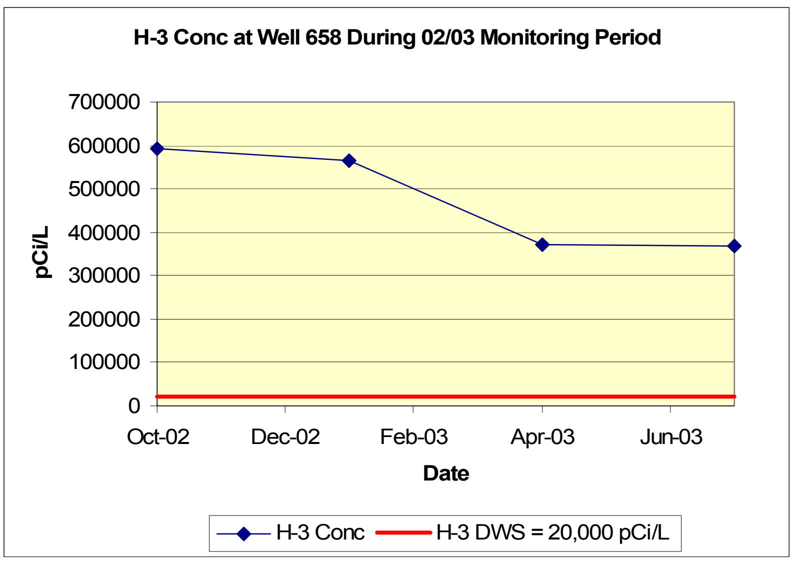

Fig. 5.7. Tritium concentrations at Well 658 during the 2002/2003 monitoring period.

Well 661: Trend analysis of tritium monitoring data collected during the 2002/2003 monitoring period for Well 661 exhibited a statistically insignificant upward trend in tritium concentrations. In addition, the 95% confidence interval for the 2002/2003 data exceeded the DWS of 20,000 pCi/L during the monitoring period. Figure 5.8 shows the time series history of tritium concentrations at Well 661 during the 2002/2003 monitoring period.

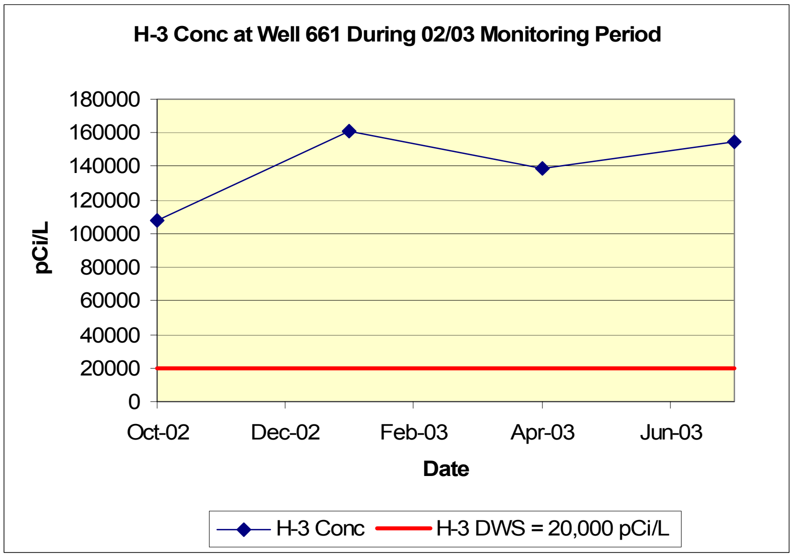

Fig. 5.8. Tritium concentrations at Well 661 during the 2002/2003 monitoring period.

Well 887: Well 887 was sampled only once during the 2002/2003 monitoring period because of construction in very close proximity to the well, which rendered the well inoperable for much of the monitoring period. The tritium analysis for the sample collected from Well 887 during the 2002/2003 monitoring period was 1910 pCi/L. Tritium concentrations in Well 887 during the BCMP were low (averaged about 1700 pCi/L) and the 95% confidence interval for tritium was well below the DWS of 20,000 pCi/L during that monitoring period. Additionally, the tritium concentration trend was essentially flat during the BCMP period (the trend exhibited a slight positive trend slope having no statistical significance). Well 887 appears to mark a tritium concentration boundary zone to the west of the HFIR facility.

Well 892: Trend analysis of tritium monitoring data collected during the 2002/2003 monitoring period exhibited a statistically significant downward trend during the monitoring period.[6] In addition, the 95% confidence interval for these data exceeded the DWS of 20,000 pCi/L during the monitoring period. Figure 5.9 shows the time series history of tritium concentrations at Well 892 during the 2002/2003 monitoring period.

[6]At a α level of 0.1.

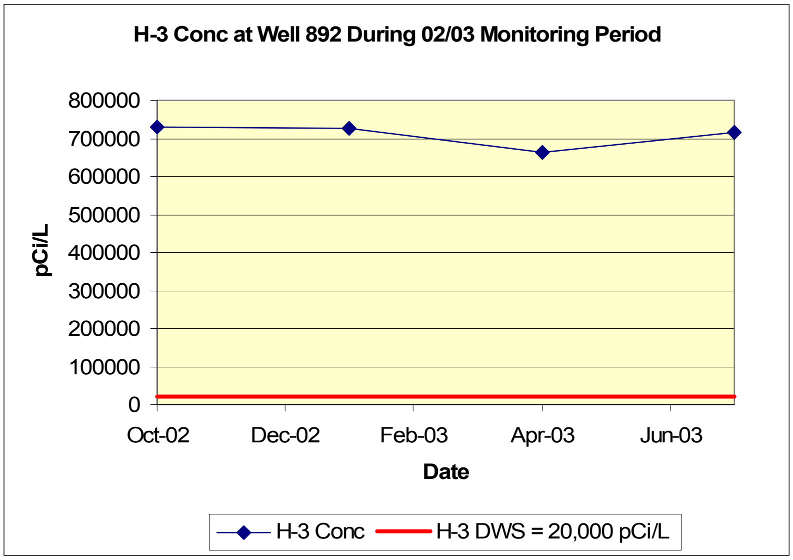

Fig. 5.9. Tritium concentrations at Well 892 during the 2002/2003 monitoring period.

Well 4530: Trend analysis of tritium monitoring data collected during the 2002/2003 monitoring period for Well 4530 exhibited a statistically significant downward trend in tritium concentrations (at a α level of 0.1.). In addition, the 95% confidence interval for these data did not exceed the DWS of 20,000 pCi/L for tritium. Figure 5.10 shows the time series history of tritium concentrations at Well 4530 during the 2002/2003 monitoring period.

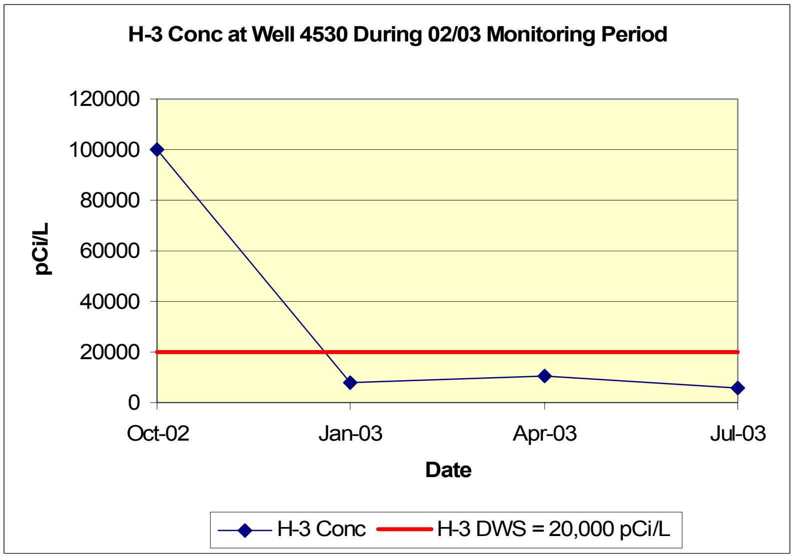

Fig. 5.10. Tritium concentrations at Well 4530 during the 2002/2003 monitoring period.

Well 4531: Given the nature of the static water level in this well, Well 4531 was not sampled during the AMP period. Groundwater levels are very low in this well during the wet season and generally nonexistent in the dry season. This makes it difficult or impossible to collect adequate amounts of groundwater for analyses, depending on the season. This monitoring point will be sampled for tritium only if data from other monitoring points listed in this document suggest the need to monitor the PWD line repair site.

Well 4532: Trend analysis performed on tritium monitoring data collected for Well 4532 during the 2002/2003 monitoring period exhibited an upward trend in tritium concentration; however, the upward trend was not statistically significant. In addition, the 95% confidence interval for these data did not exceed the DWS of 20,000 pCi/L for tritium. Figure 5.11 shows the time series history of tritium concentrations at Well 4532 during the 2002/2003 monitoring period.

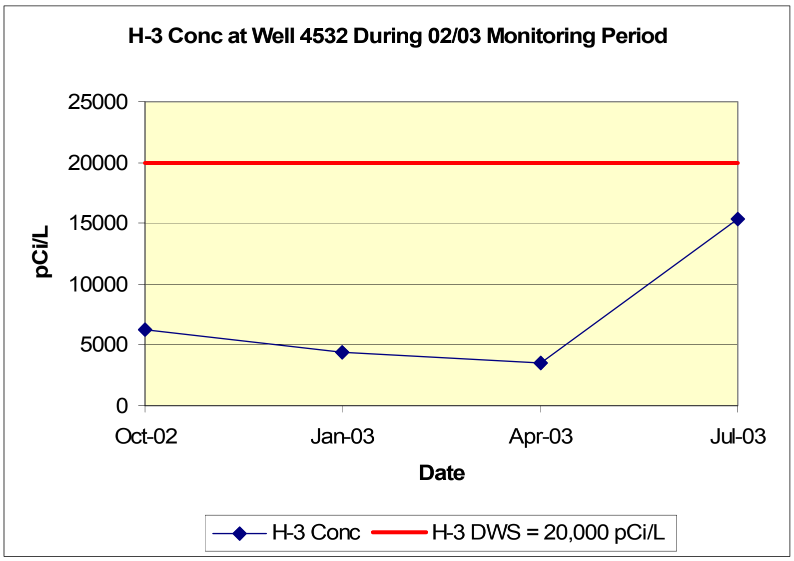

Fig. 5.11. Tritium concentrations at Well 4532 during the 2002/2003 monitoring period.

5.3.2 Upgradient Wells

The following is a brief summary description of the tritium concentration behavior in upgradient monitoring wells during the 2002/2003 monitoring period. The analytical results generated by samples collected from the upgradient wells serve as a basis of comparison (background levels) with the results from downgradient wells. These wells also serve the purpose of alerting RRD and Non-Reactor Nuclear Facilities Division[7] (NNFD) personnel of any releases from the REDC facility.

Well 4528: Trend analysis performed on tritium monitoring data collected at Well 4528 during the 2002/2003 monitoring period exhibited an upward trend; however, the upward trend was not statistically significant. In addition, the 95% upper confidence interval for these data was well below the tritium DWS of 20,000 pCi/L. Figure 5.12 shows the time series history of tritium

[7]NNFD is the facility manager for the REDC, which is located hydraulically upgradient of the HFIR complex.

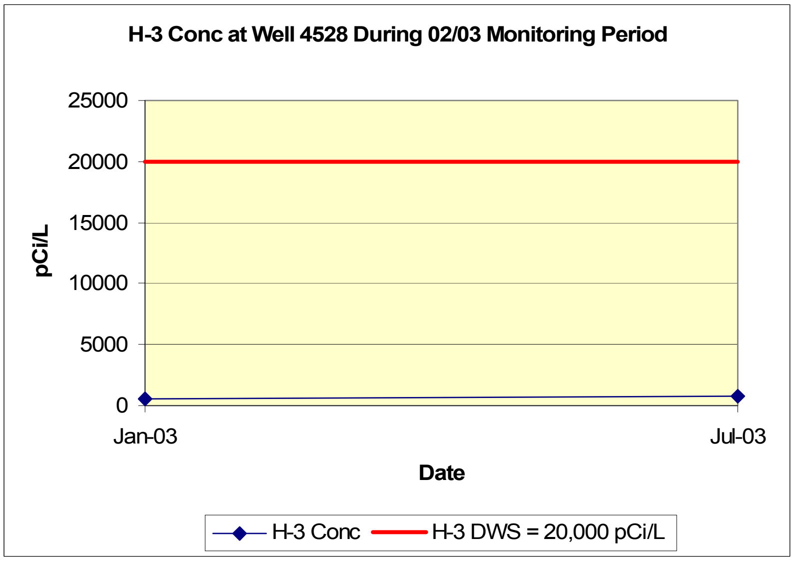

Fig. 5.12. Tritium concentrations at Well 4528 during the 2002/2003 monitoring period.

concentrations at Well 4528 during the 2002/2003 monitoring period.

Well 4529: Trend analysis performed on tritium monitoring data collected at Well 4529 during the 2002/2003 monitoring period exhibited an upward trend in tritium concentration; however, the upward trend was not statistically significant. In addition, the 95% confidence interval for these data was well below the tritium DWS of 20,000 pCi/L. Figure 5.13 shows the time series history of tritium concentrations at Well 4529 during the 2002/2003 monitoring period.

Well 4533: Trend analysis performed on tritium monitoring data collected at Well 4533 per the 2002/2003AMP exhibited an upward trend in tritium concentration; however, the upward trend was not statistically significant. In addition, the 95% upper confidence interval for these data was well below the tritium DWS of 20,000 pCi/L. Figure 5.14 shows the time series history of tritium concentrations at Well 4533 during the 2002/2003 monitoring period.

Northeast Foundation Drain: The NEFD was not sampled during the 2002/2003 monitoring period.

Table 5.2 summarizes the statistical analyses performed on the data accumulated during the 2002/2003 monitoring period and, along with the current understanding of the tritium plume behavior observed during the 2002/2003 monitoring period, is the basis for the recommendations

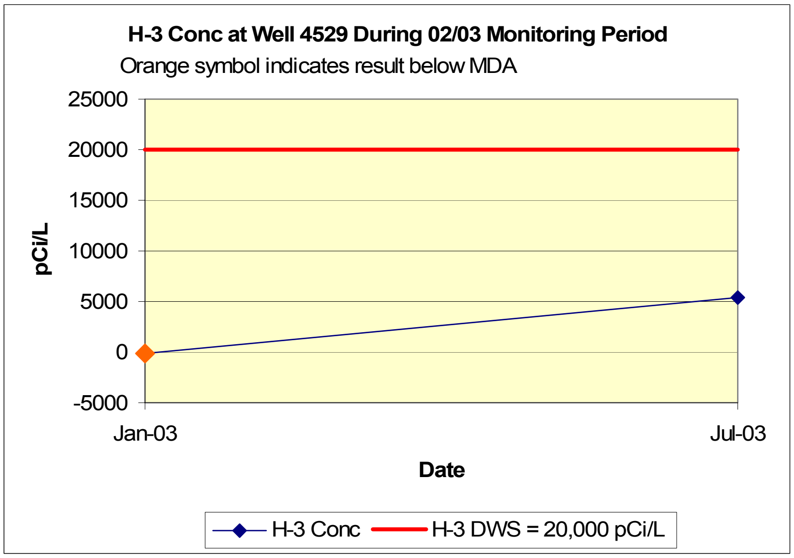

Fig. 5.13. Tritium concentrations at Well 4529 during the 2002/2003 monitoring period.

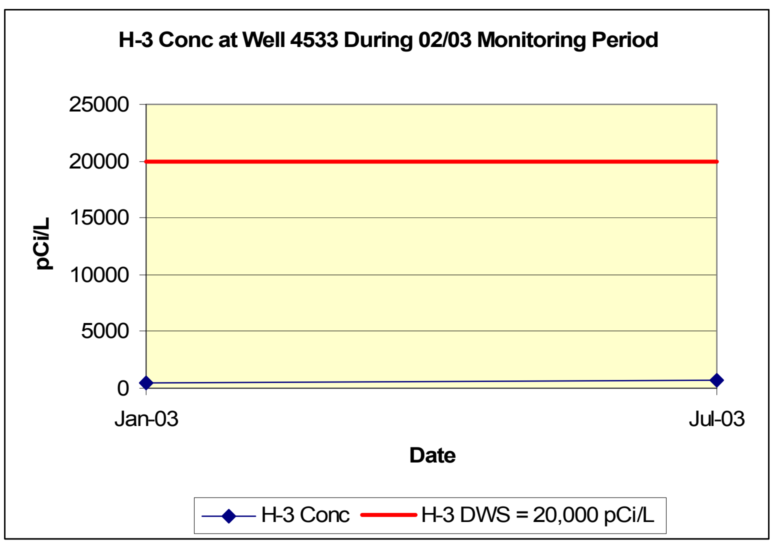

Fig. 5.14. Tritium concentrations at Well 4533 during the 2002/2003 monitoring period.

outlined in the following paragraphs. Action level thresholds outlined in the table are levels of concern set out in the 2002/2003 AMP. The DWS for tritium delineated in Table 5.2 is the federal primary drinking water standard found at 40 CFR 141. The DWS does not reflect compliance levels and is used in this report only for comparison with the results of the confidence interval calculations. *Exceedences of these criteria do not constitute*

Table 5.2. Statistical analysis summary: Monitoring points sampled during the 2002/2003 monitoring period

Monitoring point	Analyte	Seasonal effect detected?[a]	Action level (AL) threshold or DWS (pCi/L)[b]	AL threshold or DWS (pCi/L) exceeded during monitoring period?[c]	Trend	Statistical significance of trend[d]
7901 Pit (EFD)	Tritium	Yes	AL 1 – 20,000 AL 2 – 40,000	No No	Down Down	None (R) " of 0.2 (D)
CB-01	Tritium	Insufficient data	AL 1 – 7,500 AL 2 – 15,000	Yes No	Up	None
OF-281	Tritium	Insufficient data	20,000 (DWS)	No	Down	None
OF-381	Tritium	Insufficient data	20,000 (DWS)	Yes	Down	" of 0.05
OF-383	Tritium	Insufficient data	20,000 (DWS)	No	Up	None
Well 658	Tritium	Insufficient data	20,000 (DWS)	Yes	Down	" of 0.05
Well 661	Tritium	Insufficient data	20,000 (DWS)	Yes	Up	None
Well 887	Tritium	Insufficient data	20,000 (DWS)	Insufficient data	n/a	n/a
Well 892	Tritium	Insufficient data	20,000 (DWS)	Yes	Down	" of 0.1
Well 4530	Tritium	Insufficient data	20,000 (DWS)	No	Down	" of 0.1
Well 4532	Tritium	Insufficient data	20,000 (DWS)	No	Up	None
Well 4528	Tritium	Insufficient data	20,000 (DWS)	No	Up	None
Well 4529	Tritium	Insufficient data	20,000 (DWS)	No	Up	None
Well 4533	Tritium	Insufficient data	20,000 (DWS)	No	Up	None

[a]Seasonal effect detected by the Kruskal-Wallis test at a 5% significance level.
[b]Action level thresholds outlined by the table are levels of concern set out in the 2002/2003 AMP. The DWS for tritium is the federal primary drinking water standard found at 40 CFR 141. For the purposes of this report, the DWS for tritium is not considered a compliance level and is used in this report only for comparison with the confidence interval calculation results for those monitoring points not having an action threshold. *Exceedences of these criteria do not constitute regulatory non-compliances.*

Footnotes to Table 5.2, continued

[c]Exceedence of the values described under b, above, were based on either parametric or nonparametric confidence interval calculations, which were based on the *average annual analytical result for the 2002/2003 data set.* Parametric or nonparametric confidence intervals were calculated based on the results of the Shapiro-Wilk/Shapiro-Francia distribution test at a significance level of 5%. The parametric confidence interval calculation was performed for those data sets for which the distribution test indicated a normal distribution. Otherwise, a nonparametric confidence interval calculation was performed on the remaining data sets.

[d]If the significance of trend column does not contain a significance level (") or confidence level (CL), the trend is considered statistically insignificant per Sen's Slope/Mann-Kendall trend analysis. R and D codes indicate raw data and deseasonalized data, respectively.

regulatory non-compliances. All statistical tests footnoted below were performed using WQSTAT Plus statistical software (Intelligent Decisions Technologies 1998).

To put the 2002/2003 monitoring data described in the preceding paragraphs in perspective, plots of historical data for each of the monitoring points outlined in this report are found in the Appendix. Because there was concern that HFIR reactor operations may have had an effect on tritium concentrations in the EFD, plots of tritium concentrations at MH2,1/7901 Pit (EFD) versus the operational history of the HFIR reactor are found in the Appendix. Statistical correlation between operation of the HFIR reactor and tritium concentrations in groundwater monitored within the EFD is poor. A very small inverse relationship between reactor operation and tritium concentration in the EFD was identifed. The correlation coefficient (r) between these two attributes for the period of October 2000 through August 2003 is -0.34127 and the r value for the 2002/2003 monitoring period is -0.36875.

6. RECOMMENDED 2003/2004 HFIR SITE MONITORING PROGRAM

Based on analysis of data collected during the 2002/2003 monitoring period and the discussion of the HFIR tritium plume conceptual model in Sect. 4 of this report, it is recommended that the monitoring points listed in Tables 6.1 and 6.2 be sampled during the 2003/2004 monitoring period. The monitoring of these points will be implemented through the *Annual Monitoring Plan for the High Flux Isotope Reactor Site—Monitoring Period 2003–2004*. The monitoring approach carried out under the AMP will continue to meet the three objectives described in the 2002/2003 AMP and as outlined in Sect. 1 of this report. Figure 6.1 shows the locations of the various monitoring points recommended to be sampled during the 2003/2004 monitoring period.

6.1 Drain and NPDES Outfall Monitoring (Rapid-Flow System)

J-1: The SANS Guide Hall underwent construction during the 2002/2003 monitoring period. The SANS Guide Hall is located in close proximity to the HFIR building and Building 7901, and its construction necessitated the installation of a manhole located between the 7901 Pit and MH2. This manhole, designated as J-1, is connected to the EFD. Like 7901 Pit, J-1 is located in close proximity to, and downgradient of the original tritium release area as well as the HFIR building. As such, monitoring points J-1 and 7901 Pit are located to intercept the rapid-flow pathway away

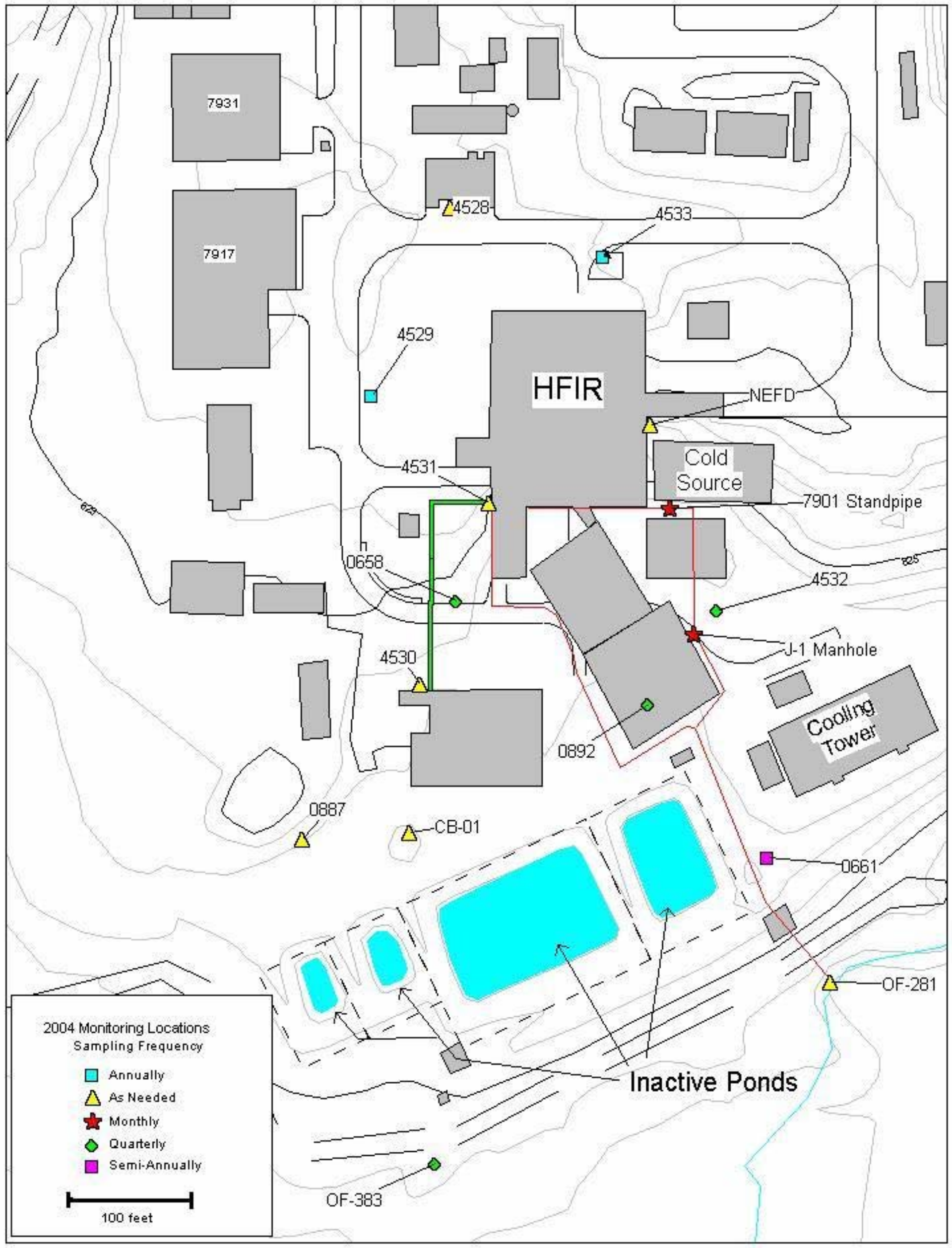

Fig. 6.1. Annual monitoring locations for HFIR site for the 2003/2004 monitoring periods.

from the HFIR building; subsequently, both of these points are in the flow pathway, which discharges groundwater directly into Melton Branch via OF-281. Replicate samples were collected from J-1 and 7901 Pit in order to determine the statistical correlation of tritium concentrations between these monitoring points. Given that both monitoring points are physically attached to the EFD, it was expected that a high degree of statistical correlation would be observed. A total of six replicate samples were collected from both points, and the resulting correlation coefficient calculated for these data was 0.99884. Therefore, J-1 can serve as an early detection monitoring point for any new releases from the area surrounding the HFIR building. Based on its location and the high correlation of tritium results with 7901 Pit, it is recommended that J-1 be used as the primary monitoring point during the 2003/2004 AMP monitoring period, and 7901 Pit be used as a backup or surrogate sampling location for J-1.

During the 2002/2003 AMP monitoring period, samples were collected weekly from 7901 Pit. Based on the decreasing trend in tritium concentration and the observation that the bulk of the tritium plume is moving to the southeast, it is recommended that the monitoring frequency for J-1 or 7901 Pit be changed to monthly for the 2003/2004 monitoring period.

CB-01: Analysis of tritium concentrations in monitoring wells located downgradient of the release site and the prevailing groundwater gradient in the vicinity of the of the HFIR building indicate that the bulk of the tritium plume mass is moving toward the southeast [toward J-1 and 7901 Pit (EFD) and Wells 892 and 661]. Although there remains some mass movement of tritiated water toward the south, the movement of the majority of the tritium plume toward the southeast obviates the need for continued monitoring CB-01 during the 2003/2004 AMP monitoring period. Comparative analysis of time series correlation of tritium concentrations, linear regression slopes, and analysis of variance tests using historical data collected at CB-01 and OF-383 indicate similar behaviors in tritium concentrations in time series (with little lag time between these points). Consequently, it is recommended that CB-01 be monitored on an as-needed basis during this monitoring period. In its place it is recommended that NPDES OF-383 be sampled during the 2003/2004 monitoring period. OF-383 will serve to monitor the continued movement of the tritium plume to the south and will also serve as a detection monitoring point.

OF-281 and OF-381: During the 2003/2004 monitoring period, Outfalls 281 and 381 will continue to be sampled quarterly as outlined in the RMP. Additionally, OF-383 will be sampled annually in accordance with the RMP during the 2003/2004 monitoring period.

OF-383: Because CB-01 will not be routinely sampled during the 2003/2004 AMP monitoring period, OF-383 will serve as a detection monitoring point as well as to monitor the continued movement of the tritium plume to the south (discharging into Melton Branch). The monitoring frequency prescribed under the RMP for OF-383 will not provide sufficient resolution that will enable seasonal effects to be observed. Consequently, it is recommended that OF-383 be monitored quarterly by RRD. The NPDES program will continue to monitor OF-281 and OF-381 quarterly.

Table 6.1 summarizes the rapid-flow system sampling locations, monitoring frequencies, and purpose of monitoring.

Table 6.1. Recommended drain system and outfall monitoring program during the 2003/2004 monitoring period[a]

Drain system or NPDES outfall	Monitoring point	Proposed monitoring frequency	Purpose of monitoring
Building 7900 East foundation drain (EFD)	MH2,1/7901 Pit	Monthly	Detection monitoring
West side of HFIR complex	CB-01	As needed	Detection monitoring
West side of HFIR complex	OF-383[b]	Quarterly	Detection monitoring and site release monitoring

[a]See Fig. 6.1 for locations of the drain system monitoring points.
[b]Outfalls 281 and 381 will continue to be monitored quarterly per the NPDES RMP.

6.2 Groundwater Monitoring (Slow-Flow System)

6.2.1 Downgradient Wells

Well 658: The tritium plume originated upgradient of, and in close proximity to, Well 658; subsequently, Well 658 has been in the path of the mass of the tritium plume as it has migrated downgradient to the south and southeast. Repairing the source of the tritium release coupled with continued movement of the plume to the south and southeast has resulted in the downward trend in tritium concentration observed during the BCMP and 2002/2003 AMP monitoring periods. Continued monitoring of Well 658 is recommended during the 2003/2004 monitoring period for the purpose of tritium plume mass tracking. It is recommended that quarterly monitoring of Well 658 continue during the 2003/2004 monitoring period.

Well 661: Well 661 was the furthermost routinely monitored well located downgradient of the source of the tritium release site. It intercepts the tritium plume as it moves from the source of the tritium release southeastward toward Melton Branch. It serves as the terminal monitoring well located southeast of the HFIR building. Therefore, it is recommended that monitoring of Well 661 continue during the 2003/2004 monitoring period for the purpose of tritium plume mass tracking. It is recommended that the frequency of sampling of Well 661 be changed from quarterly to semi-annually during the 2003/2004 monitoring period because the behavior and pathway of the tritium plume is well understood.

Well 887: Well 887 was sampled only once during the 2002/2003 monitoring period because of construction in very close proximity to the well, which rendered the well inoperable for much of the monitoring period. The tritium analysis for the sample collected from Well 887 during the 2002/2003 monitoring period was 1910 pCi/L. Tritium concentrations in Well 887 during the previous monitoring period (BCMP) were low (averaged about 1700 pCi/L) and the 95% confidence interval for tritium was well below the DWS of 20,000 pCi/L during that monitoring period. Moreover, the tritium concentration trend was essentially flat during the BCMP period (the trend exhibited a slight positive trend slope having no statistical significance). Well 887 appears to mark a tritium concentration boundary zone to the west of the HFIR facility. It is recommended that monitoring of Well 887 be performed on an as-needed basis during the

2003/2004 monitoring period based on the low tritium concentrations observed during the previous two monitoring periods.

Well 892: Well 892 is located midway between Wells 658 and 661 and is positioned in the midst of the mass of the tritium plume moving to the southeast. Therefore, it is recommended that monitoring of Well 892 continue during the 2003/2004 monitoring period for the purpose of tritium plume mass tracking. It is recommended that quarterly monitoring of Well 892 remain unchanged during the 2003/2004 monitoring period.

Well 4530: It is recommended that monitoring of Well 4530 be performed as needed during the 2003/2004 monitoring period. This recommendation is based on the observation that the mass of the tritium plume is moving toward the southeast which was demonstrated by the dramatic decrease in tritium concentration observed during the 2002/2003 monitoring period at Well 4530.

Well 4532: It is recommended that monitoring of Well 4532 continue quarterly during the 2003/2004 monitoring period. This recommendation is based on the observation that tritium concentrations have been relatively low during the BCMP and 2002/2003 monitoring periods. It is known that the bulk of the tritium plume is moving toward the southeast and the well's location marks a likely tritium concentration boundary zone in close proximity to, and east, of the HFIR building. It is recommended that quarterly monitoring of Well 4532 remain unchanged during the 2003/2004 monitoring period in order to accumulate data to confirm the presence of a tritium concentration boundary zone immediately to the east of the HFIR building.

Well 4531: It is recommended that Well 4531 be sampled as needed during the 2003/2004 monitoring period. Given the nature of the static water level in this well, Well 4531 was not sampled during the 2002/2003 monitoring period. Groundwater levels are very low in this well during the wet season and generally nonexistent in the dry season. Depending on the season, it is difficult or impossible to collect adequate amounts of groundwater for analysis. This monitoring well will be sampled for tritium only if data from other monitoring points listed in this document suggest the need to monitor the PWD line repair site.

6.2.2 Upgradient Wells

Well 4528: It is recommended that Well 4528 be sampled as needed during the 2003/2004 monitoring period because it is positioned to intercept groundwater flow from upgradient sources of potentially contaminated groundwater (as compared to Wells 4529 and 4533).

Well 4529: It is recommended that Well 4529 continue to be monitored during the 2003/2004 monitoring period, but less frequently based on the statistical analysis performed on the 2002/2003 monitoring data. It is recommended that the monitoring frequency at Well 4529 be changed from semi-annually to annually during the 2003/2004 AMP period. This well is located in close proximity to waste lines that run from the MSRE and REDC to the waste tanks at Building 7961. Consequently, this well monitors potential sources of contamination located upgradient of the HFIR building.

Well 4533: It is recommended that Well 4533 continue to be sampled during the 2003/2004 monitoring period to intercept any contaminant flow from facilities located hydraulically upgradient and to the east of Building 7900 (i.e., REDC), but at an annual frequency (based on the statistical analysis performed on the 2002/2003 monitoring data).

Northeast Foundation Drain: Although the NEFD was not sampled during the 2002/2003 monitoring period, it is recommended that the NEFD continue to be part of the upgradient monitoring program, on an as-needed basis. This point will only be sampled if data from other monitoring points listed in this document suggest concern that an upgradient source of contamination is affecting the northern section of the EFD.

Table 6.2. Recommended groundwater monitoring program during the 2003/2004 monitoring period[a]

Groundwater well or monitoring point	Monitored zone	Proposed monitoring frequency	Purpose of monitoring
Well 658	Downgradient bedrock well	Quarterly	Plume tracking
Well 892	Downgradient bedrock well	Quarterly	Plume tracking
Well 661	Downgradient bedrock well	Semiannually	Plume tracking
Well 887	Downgradient bedrock well	As needed	Plume tracking
Well 4530 (P-4)	Downgradient shallow well	As needed	Plume tracking
Well 4532 (P-5)	Downgradient shallow well	Quarterly	Plume tracking
Well 4531 (P-6)	Shallow well at PWD line repair site	As needed	PWD line break monitoring
Well 4528 (P-2)	Downgradient shallow well	As needed	Upgradient monitoring
Well 4529 (P-3)	Upgradient shallow well	Annually	Upgradient monitoring
Well 4533 (P-1)	Upgradient bedrock well	Annually	Upgradient monitoring
NEFD	Foundation drain	As needed	Upgradient monitoring

[a] See Fig. 6.1 for locations of these wells.

6.3 Recommended Analytical Parameters

It is recommended that samples collected from the monitoring points listed in Tables 6.1 and 6.2 continue to be analyzed for tritium during the AMP period. Tritium was chosen based on potential and actual sources within the HFIR complex and the frequency of detection of the other analytes monitored during the routine characterization and BCMP periods (gross radionuclides–alpha and beta and gamma emitters). Because of the chemical nature of tritium, it is not retarded in the subsurface environment such as many of the gross radionuclides. Therefore, tritium acts as a very good tracer in the subsurface environment. Consequently, the use of tritium monitoring will continue to be used to meet the three objectives outlined in Sect. 1 of this report. It is proposed that EPA Method 906.0, or equivalent, be used to analyze tritium samples collected during the 2003/2004 monitoring period. In addition, the samples collected during the AMP period will be analyzed by an approved analytical laboratory. The laboratory will provide prompt analytical results to EPWSD and RRD.

6.4 Recommended Action Levels and Reporting Protocols

Based on observations of tritium plume behavior and HFIR site hydrogeology, it is recommended that the EFD and OF-383 be used to track contaminant concentrations in the rapid-flow system during the 2003/2004 monitoring period. It is recommended that the data collected from these points continue to be compared to action levels to determine if significant contaminant increases signal potential releases to the environment from HFIR. Two action levels are established for the EFD and OF-383 monitoring points: an Action Level 1 threshold at which RRD will be notified and an Action Level 2 threshold at which RRD and EPWSD personnel will make a decision regarding the need for verification or increased sampling frequency. It is proposed that upon exceeding the Action Level 1 threshold, EPWSD notify the RRD environmental compliance representative (ECR) and RRD environmental safety and health (ESH) manager of the exceedence. Upon exceeding the Action Level 2 threshold, EPWSD will notify the RRD ECR and ESH manager of the exceedence and EPWSD and RRD ESH personnel will make a decision regarding monitoring options needed at the EFD and/or OF-383, i.e., the need for verification and/or increased sampling frequency at 7901 Pit/J-1 and/or OF-383. Additionally, EPSWD will advise RRD ESH personnel on monitoring frequency options that also should be considered for other monitoring points at the site when an exceedence of an Action Level 2 occurs. *Effects of antecedent precipitation on the exceedence of the action levels will be considered in deciding on the course of future monitoring actions to be taken.* The RRD ECR will document this action. As during the 2002/2003 monitoring period, RRD management has the responsibility to inform DOE of an exceedence of the Action Level 2 threshold during the 2003/2004 AMP period and to perform any systems analysis to determine whether a release has occurred.

6.4.1 Recommended Drain and NPDES Outfall Monitoring Action Levels

As stated to above, the continued use of action levels for tritium at J-1 and OF-383 is recommended during the 2003/2004 monitoring period to ensure that an appropriate response occurs in the event that tritium concentrations increase. The recommended action levels for J-1 and OF-383 are in Table 6.3. Action levels set forth for the 2003/2004 monitoring period were set using the proportion estimate statistical method (Intelligent Decision Technologies 1998) and were based on tritium concentrations observed within the EFD for the period of March 2001 through July 2003. This method was chosen in order to account for severe precipitation events which were observed at ORNL during the autumn of 2002 and winter and spring of 2003.[8] Short-term variations in tritium concentrations are expected within the EFD in response to seasonal precipitation variations and continuing lateral and vertical movement of the tritium plume. The action levels will be reviewed at the end of the 2003/2004 AMP period and modified based on observations of tritium trend, precipitation occurrence, and RRD systems input.

Specific instructions regarding responses to action levels and notification of DOE in the event of an observed increase in trend will be outlined in *Implementation of HFIR Monitoring Plan* (ORNL 2001b), RRD Procedure RTP-6, 2001 (as revised).

---

[8]These precipitation events resulted in several exceedences of action levels at 7901 Pit and CB-01 during the 2002/2003 monitoring period.

Table 6.3. AMP recommended action levels for drain system monitoring points for the 2003/2004 monitoring period

Drain system monitoring point	Action Level 1 tritium concentration (pCi/L)	Action Level 2 tritium concentration (pCi/L)
J-1/7901 Pit (EFD)	40,000	80,000
OF-383	40,000	80,000

6.5 Effective Date of Recommendations

All recommendations outlined in this report are part of the AMP. The AMP will become effective on October 1, 2003, and monitoring activities under the AMP will be completed on October 31, 2004. Schedules for monthly, quarterly, semi-annual, and annual monitoring will be outlined in the 2003/2004 AMP.

7. REFERENCES INCLUDING ADDITIONAL INFORMATION

EPA (U.S. Environmental Protection Agency), 1989. *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities-Interim Final Guidance*, EPA/530-SW-89-026, Office of Solid Waste, Waste Management Division, Washington, D.C.

Gilbert, R. O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. John Wiley and Sons, New York.

Gumbel, E. J. 1958. *Statistics of Extremes*. Columbia University Press, New York.

Intelligent Decision Technologies, Inc. 1998. *WQSTAT Plus User's Guide*. Longmont, CO.

Ketelle, R. H. 1997. *HFIR Site Hydrologic Information.*

Moore, G.K. and L.E. Toran, 1992, Supplement to a Hydrologic Framework for the Oak Ridge Reservation. ORNL/TM-12191.

ORNL. 1999. National Pollutant Discharge Elimination System Permit TN0002941, "Radiological Monitoring Plan for the Oak Ridge National Laboratory." June.

ORNL. 2001a. *HFIR Tritium Investigation Interim Report.* ORNL/CF-01/11. February.

ORNL. 2001b. ORNL Research Reactors Division. *Implementation of HFIR Monitoring Plan.* RTP-6, as revised. May.

ORNL. 2002a. ORNL Environmental Protection and Waste Services Division. *Operational Monitoring Plan for the High Flux Isotope Reactor Site—Final Design, Revision 3*. January.

ORNL.2002b. ORNL Environmental Protection and Waste Services Division. *Annual Monitoring Plan for the High Flux Isotope Reactor Site - 2002-2003 Monitoring Period*.

ORNL. 2002c. ORNL Environmental Protection and Waste Services Division and Bechtel Jacobs Company Engineering Division. *Summary of Baseline Operational Monitoring Activities at the High Flux Isotope Reactor Site – Monitoring Period June 2001 through June 2002.* November.

ORNL. 2003. ORNL Environmental Protection and Waste Services Division. *Annual Monitoring Plan for the High Flux Isotope Reactor Site - 2002-2003 Monitoring Period*. Revised February 2003.

Rothschild, E.R., D.D. Huff, B.P. Spalding, S.Y. Lee, R.B. Clapp, D.A. Lietzke, R.G. Stansfield, N.D. Farrow, C.D. Farmer, I.L. Munro. 1984. Characterization of Soils at Proposed Solid

Waste Storage Area (SWSA) 7. ORNL/TM-9326.

Solomon, D.K., G.K. Moore, L.E. Toran, R.B. Dreier, and W.M. McMaster. 1992, Status Report A hydrologic Framework for the Oak Ridge Reservation. ORNL/TM-12026.

Soong, T. T. 1981. *Probabilistic Modeling and Analysis in Science and Engineering*. John Wiley and Sons. New York.

APPENDIX

TIME SERIES PLOTS OF HISTORICAL HFIR DATA

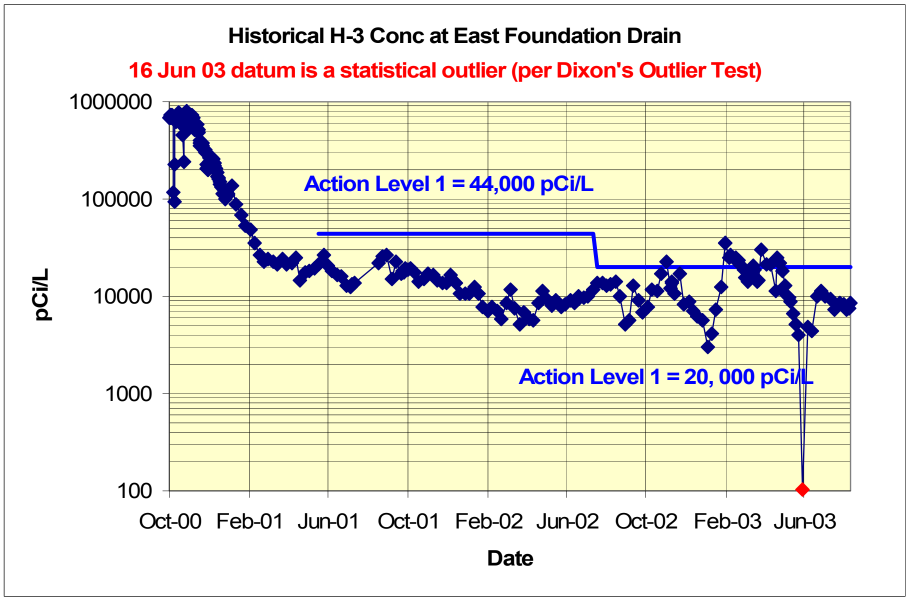

Fig. A-1. Historical tritium concentrations at the east foundation drain.

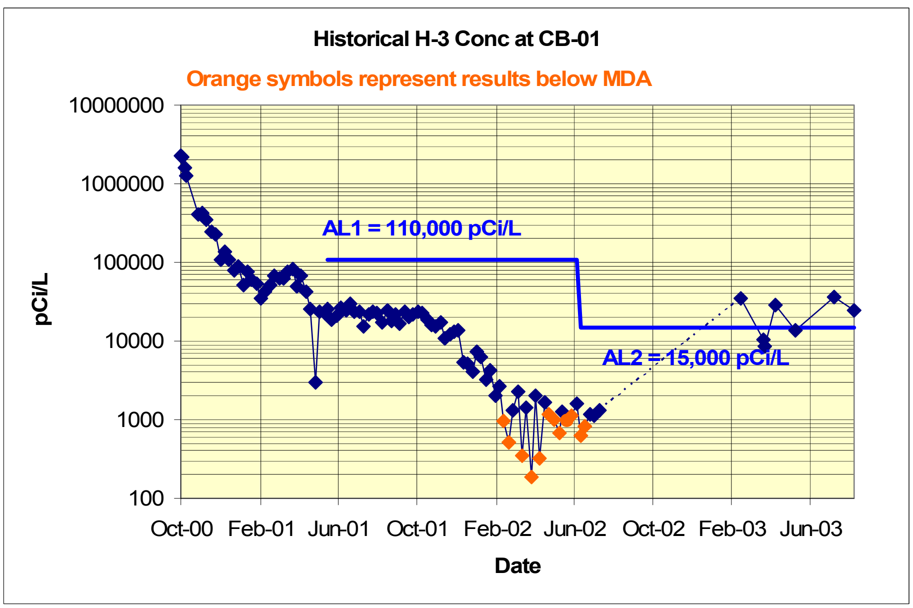

Fig. A-2. Historical tritium concentrations at CB-01.

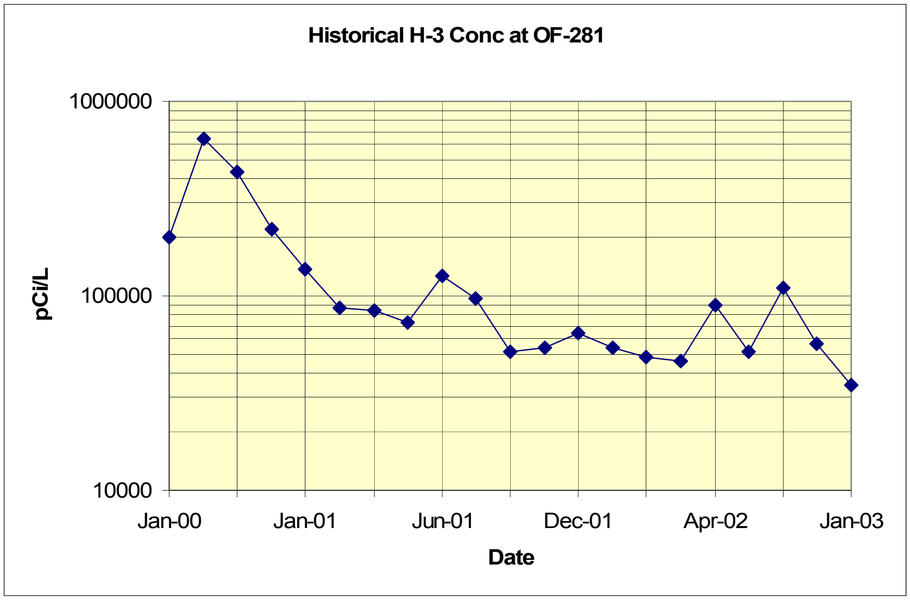

Fig. A-3. Historical tritium concentrations at OF-281.

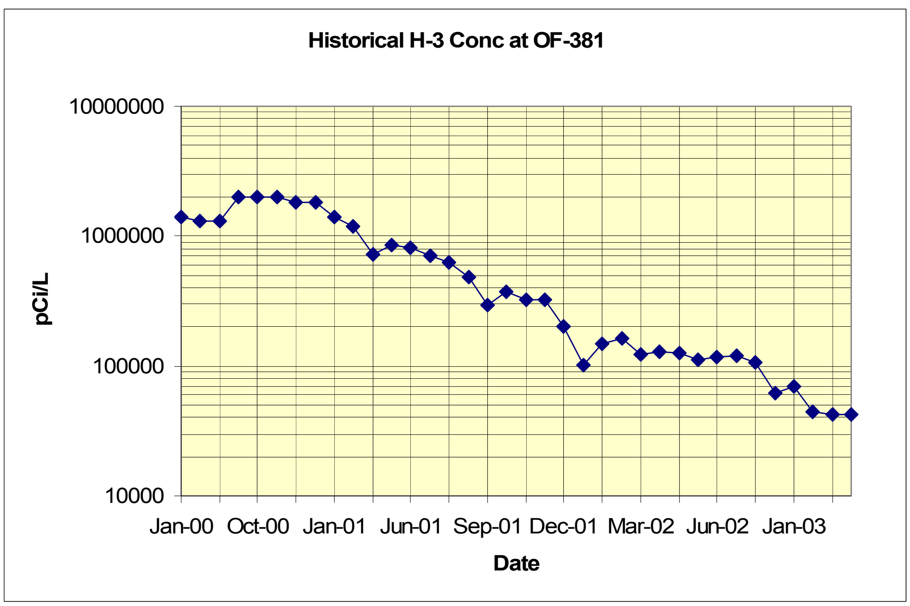

Fig. A-4. Historical tritium concentrations at OF-381.

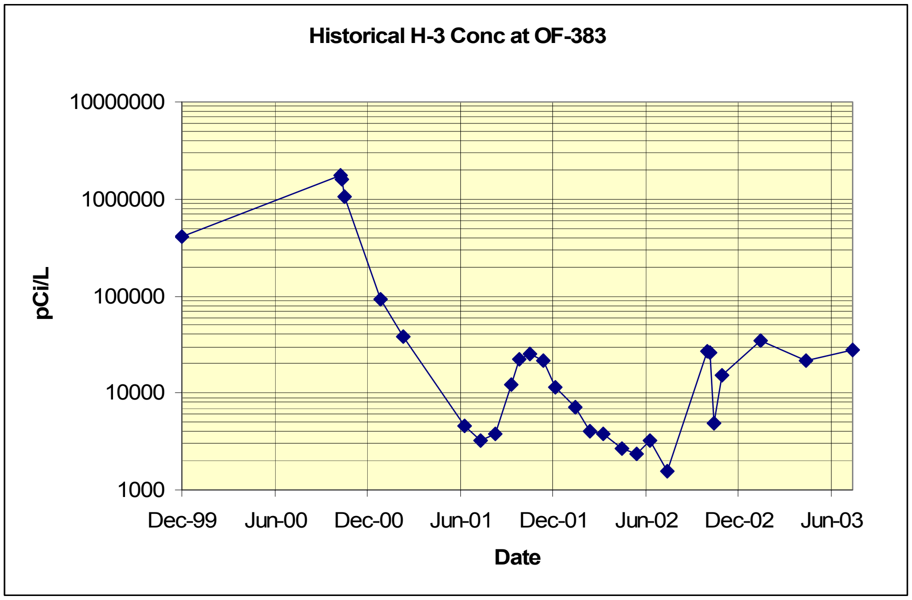

Fig. A-5. Historical tritium concentrations at OF-383.

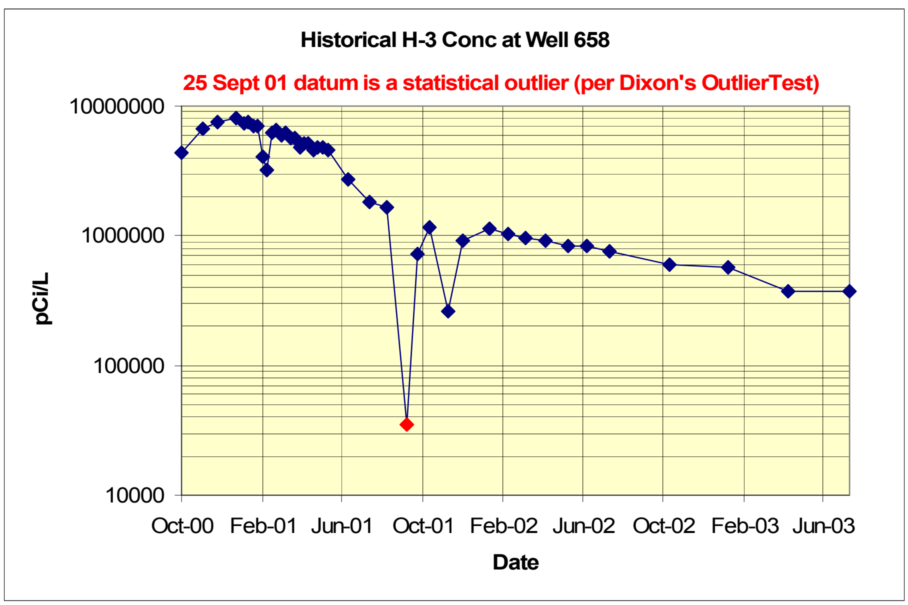

Fig. A-6. Historical tritium concentrations at Well 658.

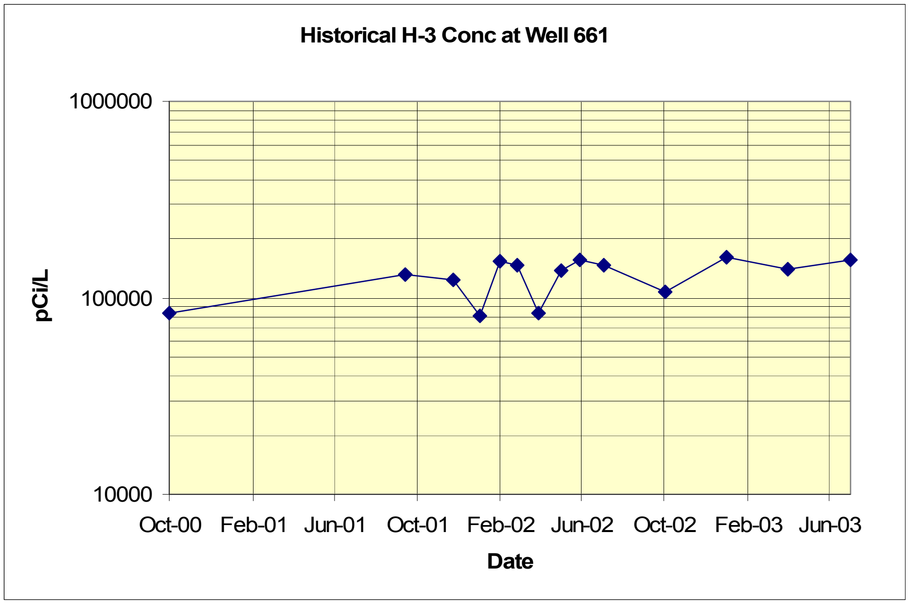

Fig. A-7. Historical tritium concentrations at Well 661.

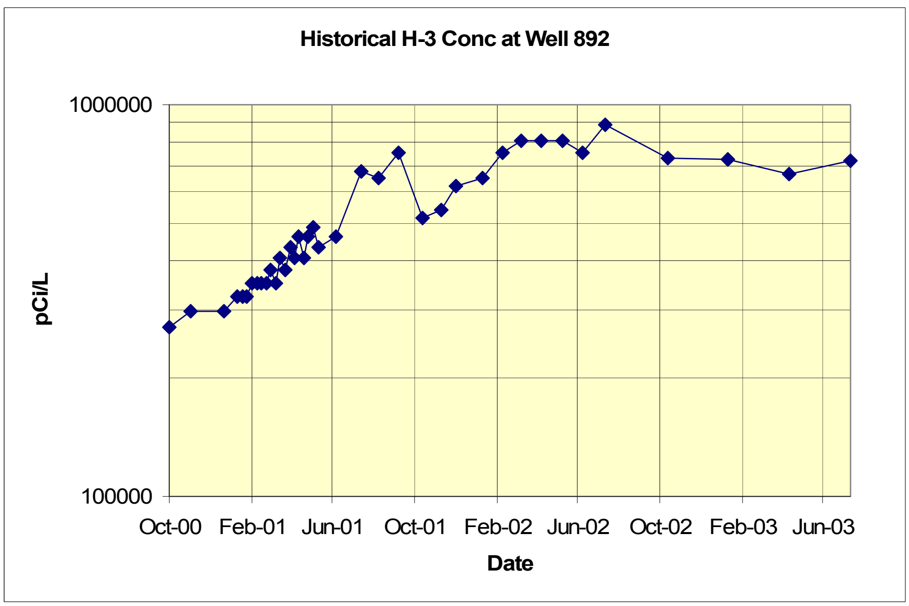

Fig. A-8. Historical tritium concentrations at Well 892.

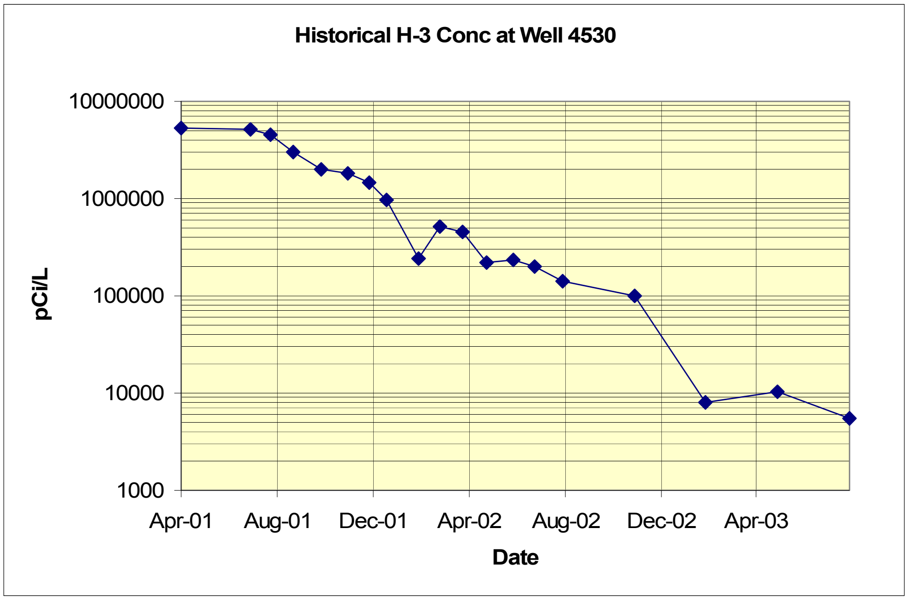

Fig. A-9. Historical tritium concentrations at Well 4530.

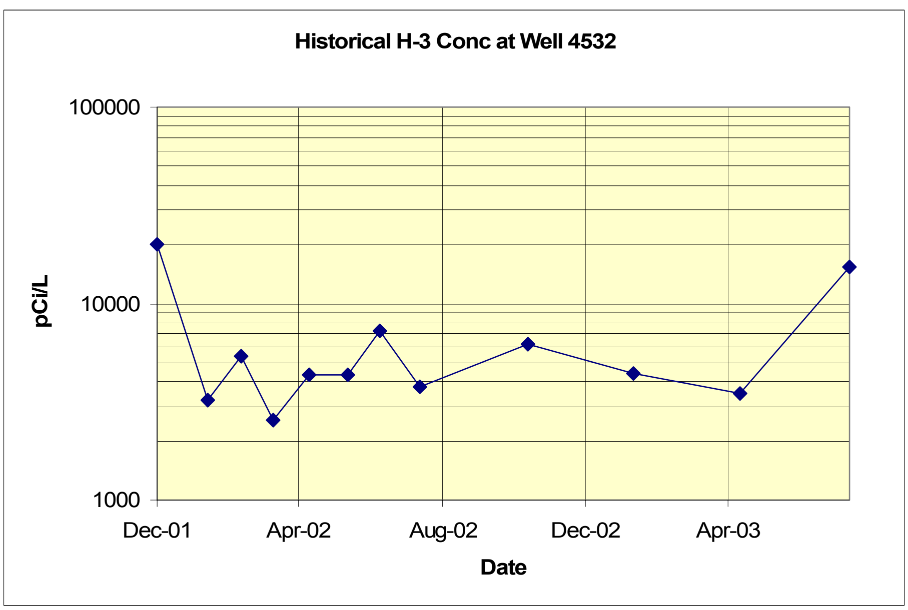

Fig. A-10. Historical tritium concentrations at Well 4532.

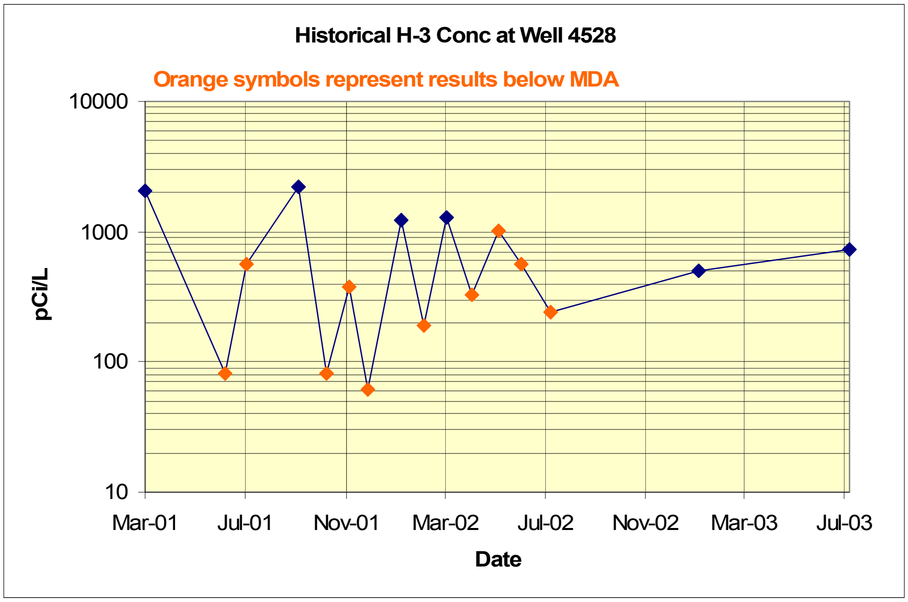

Fig. A-11. Historical tritium concentrations at Well 4528.

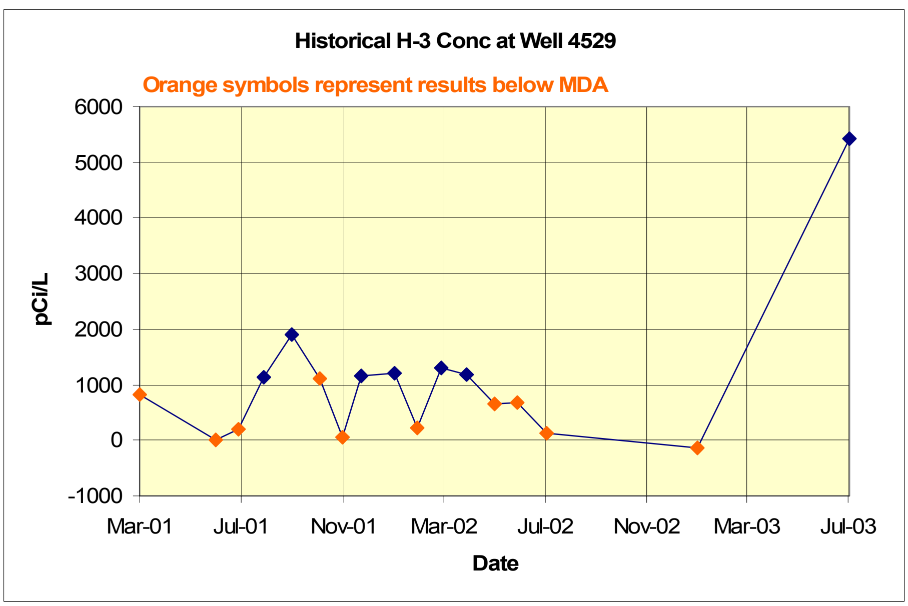

Fig. A-12. Historical tritium concentrations at Well 4529.

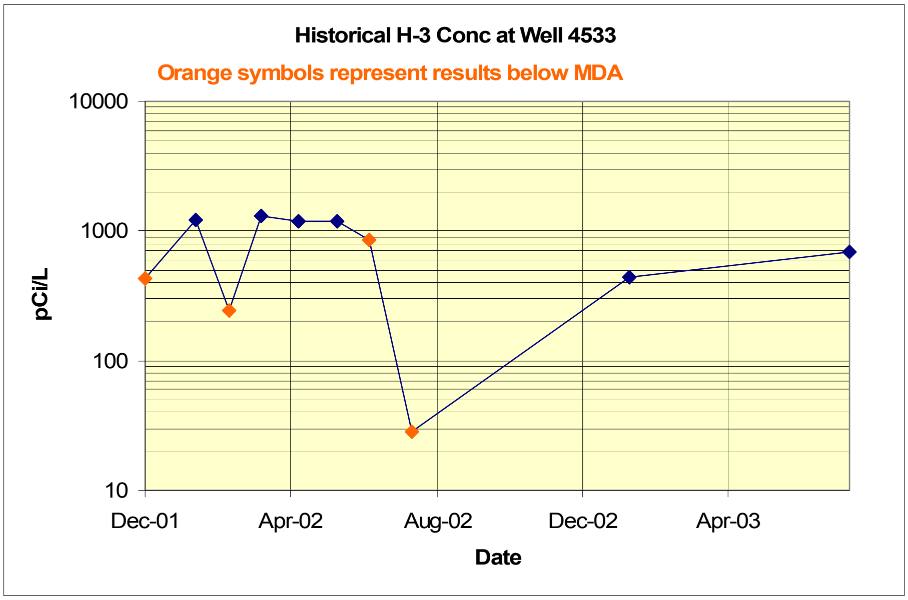

Fig. A-13. Historical tritium concentrations at Well 4533.

OPERATIONAL HISTORY VS. TRITIUM CONCENTRATIONS IN EFD

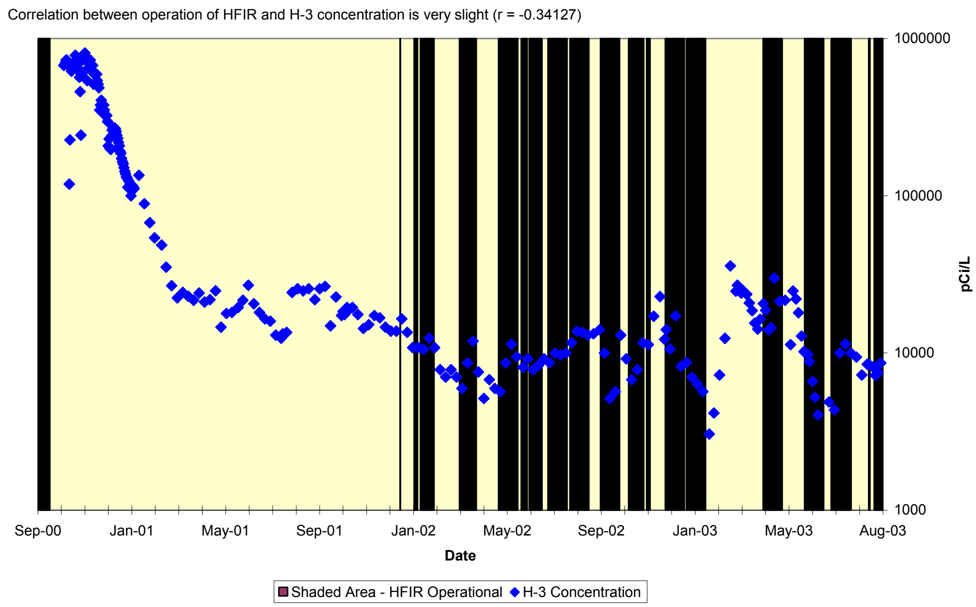

Fig. A-14. Operational history vs. tritium concentrations, October 2000 through August 2003, in the east foundation drain.

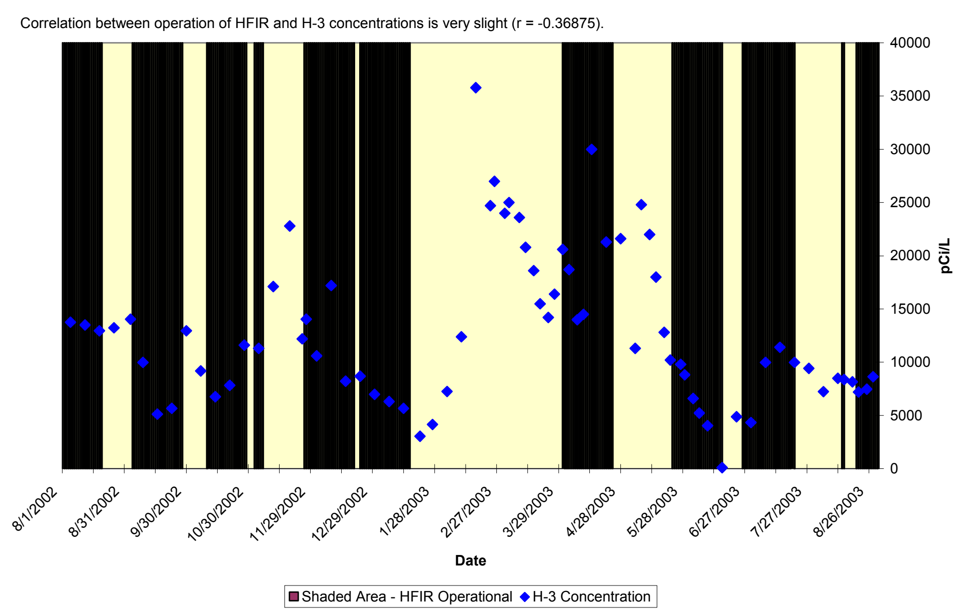

Fig. A-15. Operational history vs. tritium concentrations during 2002/2003 monitoring period in the east foundation drain.