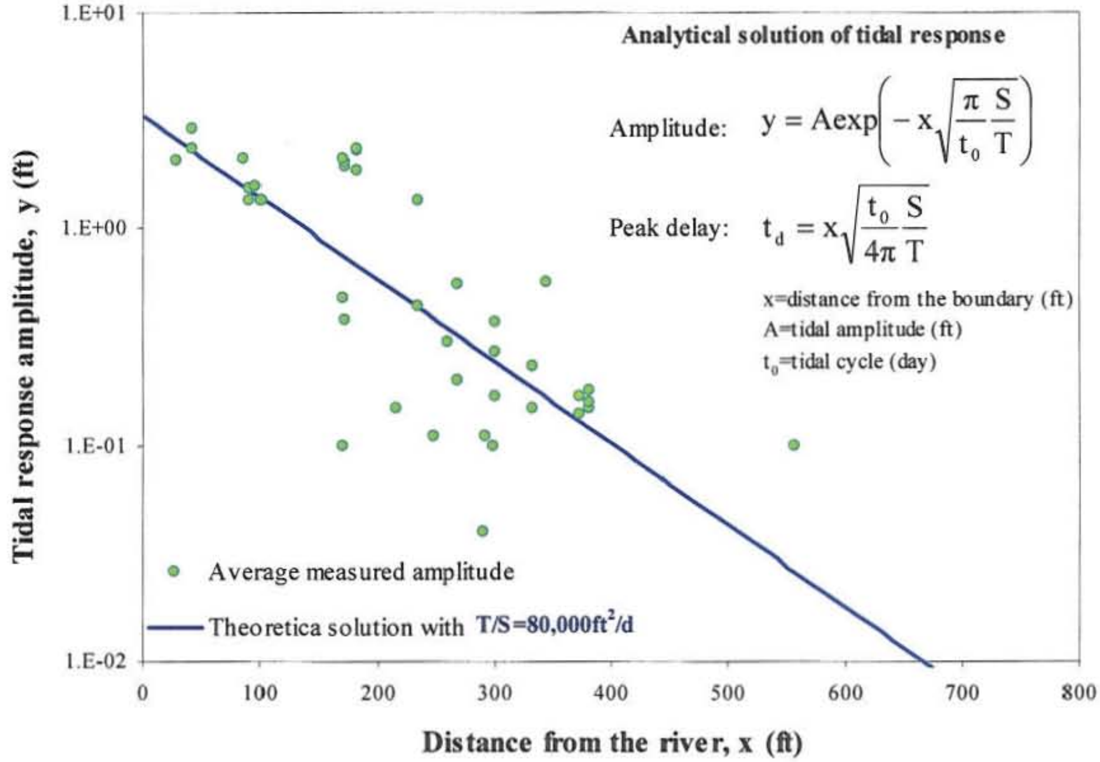

TIDAL RESPONSE VS DISTANCE FROM THE HUDSON RIVER

Fetter[38] provides an analytical solution for the theoretical piezometric response of an aquifer adjacent to a tidal boundary (see above graph). The assumptions upon which this solution is based are quite restrictive. In addition to the normal difficulties (aquifer heterogeneities, anisotropic properties, etc.) which limit the practical use of the solution in estimating aquifer properties, [39] it is not clear if water levels at the Site are responding to changes in the river level, changes in the Discharge Canal levels, or perhaps, a combination of both. Further complicating this issue, the concrete canal walls, and at some locations (not all) the concrete canal bottom, should clearly affect propagation of tidal fluctuations in the canal.

With these limitations noted, our review of data indicates that the hydraulic diffusivity[40] (transmissivity, T, divided by storativity, S) of the rock, as estimated by the tidal responses, is on the order of 80,000 ft^2/day. See the above graph and information in **Appendix K**.

As presented in **Section 6.5,** we believe the average transmissivity of the bedrock aquifer is typically in the range of 30 to 50 ft^2/day. Using a transmissivity of 40 ft^2/day and a diffusivity of 80,000 ft^2/day, it follows the storativity of the bedrock aquifer is on the order of $5x10^{-4}$. This value is in good agreement with the values we computed from an evaluation of the Pumping Test data and from the cubic equation (see **Section 6.5.1**).

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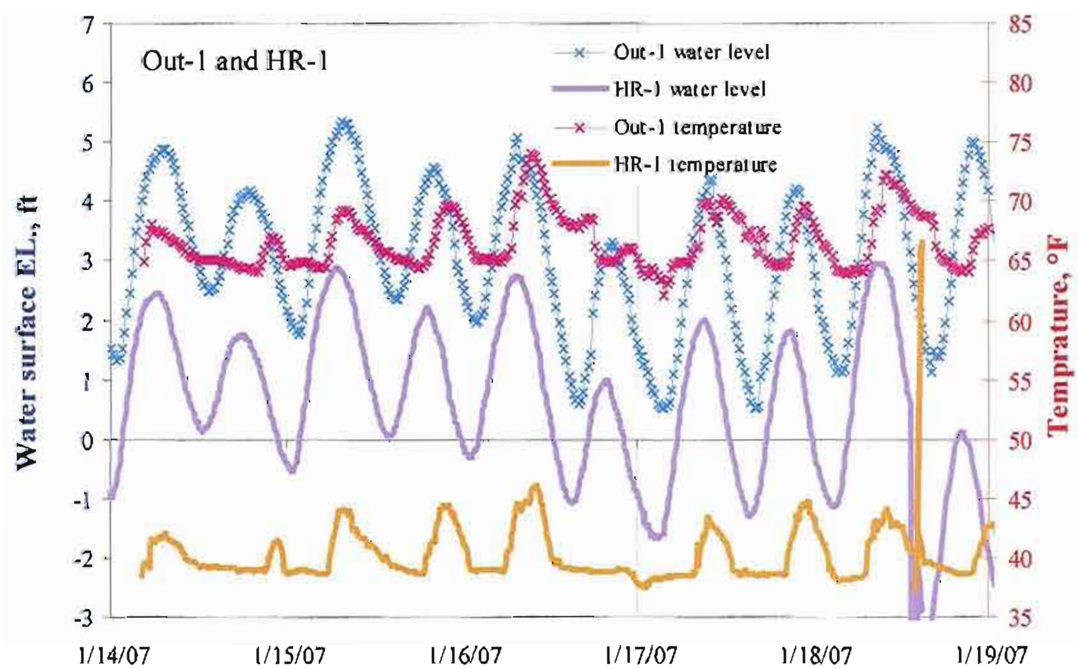
[38] C.W. Fetter, *Applied Hydrology*, Second Edition, Merrill 1988.
[39] Patrick Powers, *Construction Dewatering*, Second Edition.
[40] Freeze & Cherry, *Groundwater* Prentice-Hall 1979.

Another effect of river tidal changes is manifested in monitoring wells in close proximity to the river or Discharge Canal as follows. As the river approaches high tide, the groundwater gradients in proximity to the river become flatter, and at certain locations and tides, are reversed; that is, on a temporary basis, groundwater discharge to the river is generally slowed, and in at least some locations, groundwater flow normally to the river is reversed to then be from the river into the aquifer.

6.6.2 Groundwater Temperature

The cooling water intake structure is located North (upstream) of the cooling water discharge structure (see **Figure 1.3**). When the river is near high tide, the cooling water intake draws river water that contains discharge water[41] (i.e., river flow reverses and water begins to flow away from the ocean). At periods near low tide, the current in the river reduces or eliminates this circulation (within the river) of cooling water. A consequence of this tidal influence is that the temperature of water in the Discharge Canal, in addition to always being warmer than the river water, varies with tidal cycles. This is illustrated on **Figure 6.15** as well as the graph below, a double-axis graph to show the water level and temperature data collected in January 2007 from two stilling wells: Out-1, located at the southern end of the Discharge Canal, and HR-1, located in the cooling water intake structure of Unit 1[42].



WATER LEVEL AND TEMPERATURE RELATIONSHIPS FOR DISCHARGE CANAL AND HUDSON RIVER (JAN. 07)

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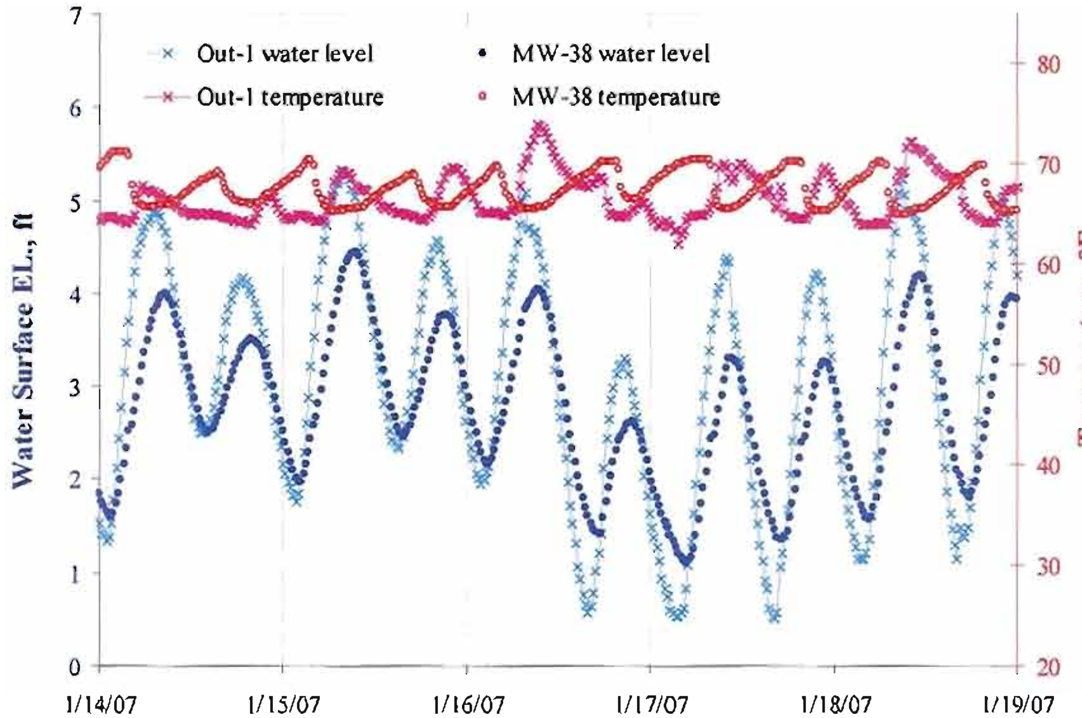
[41] The direction of the flow in the river is tidally influenced, which at periods near high tide, is to the North, away from the ocean.

[42] Unit 1 is inactive and this stilling well should provide a good measure of the river elevations with time.

Based on this information and water quality variations (see **Section 6.6.3**), we evaluated the potential for the Discharge Canal water to influence water quality at two locations originally proposed for southern property boundary monitoring[43], MW-38 and MW-48 (located adjacent to the canal and river respectively; see **Figure 1.3**).

6.6.2.1 Monitoring Well MW-38

Groundwater response to tidal influence of the cooling water Discharge Canal (at this location) is strong and appears to vary between tidal cycles. We note, however, that we observed responses from approximately 60% to at least 86% with an average of approximately 70%.



WATER LEVEL AND TEMPERATURE RELATIONSHIPS FOR DISCHARGE CANAL AND MW-38 (JAN. 07)

Additionally, at high tide the canal level is above the water level in MW-38 and at low tide the water level in MW-38 is above the level of the canal (see above graph). These data demonstrate the potential for water in the canal to migrate to the proximity of MW-38 during periods of high tide.

Groundwater temperature data collected from MW-38 indicate that canal water does in fact, at times, migrate to well MW-38. This is shown on the above graph

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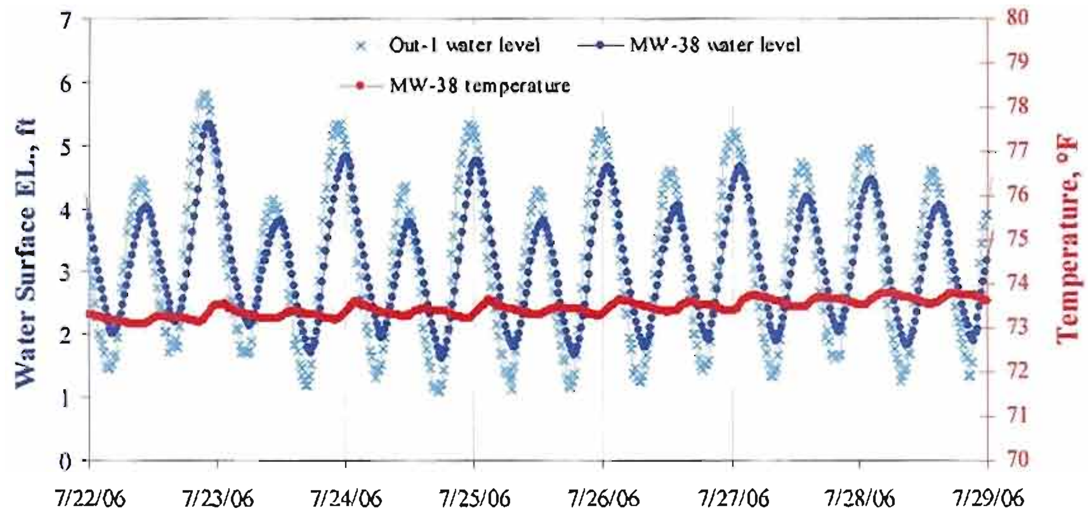
[43] The results of our analyses demonstrate that monitoring wells MW-38 and MW-48 are impacted by Discharge Canal water at various times. Therefore, these wells are not suitable for measuring southern boundary groundwater radiological conditions.

which shows water levels and temperatures collected in January 2007. In reviewing this graph, note that the temperature of groundwater in MW-38 is: 1) warmed significantly above ambient ground water temperatures (averaging approximately 70° F as compared to an ambient temperature of approximately 55° F); 2) on average, during this period, warmer than the canal water; 3) at its lowest temperature near high tide; and 4) increases in temperature while water levels in the well decline. These observations are consistent with groundwater discharge to the canal at low tide and canal water flow to the vicinity of well MW-38 during high tide.

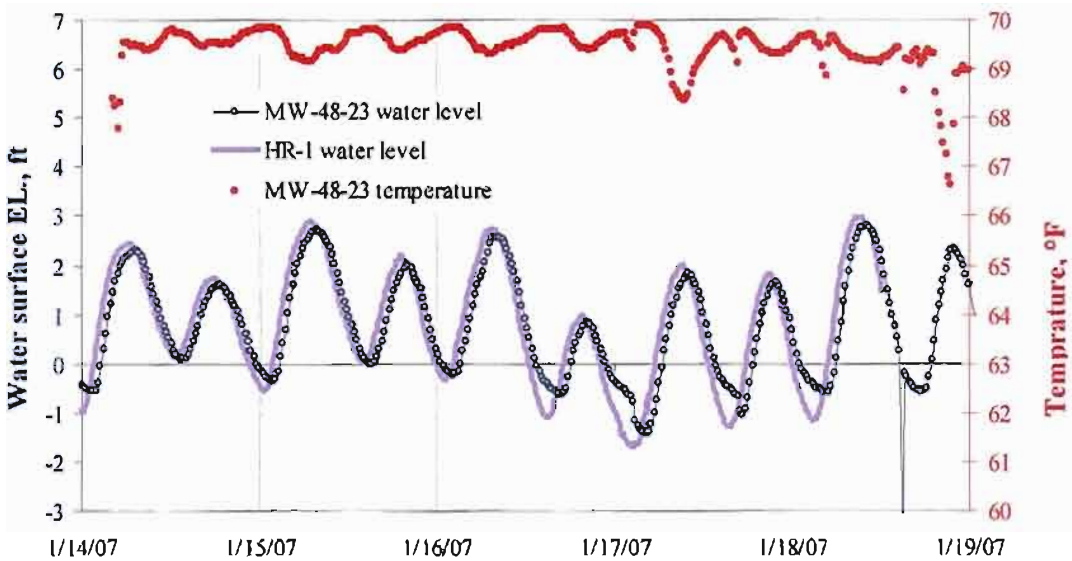


WATER LEVEL AND TEMPERATURE RELATIONSHIPS FOR DISCHARGE CANAL AND MW-38 (JULY 06)

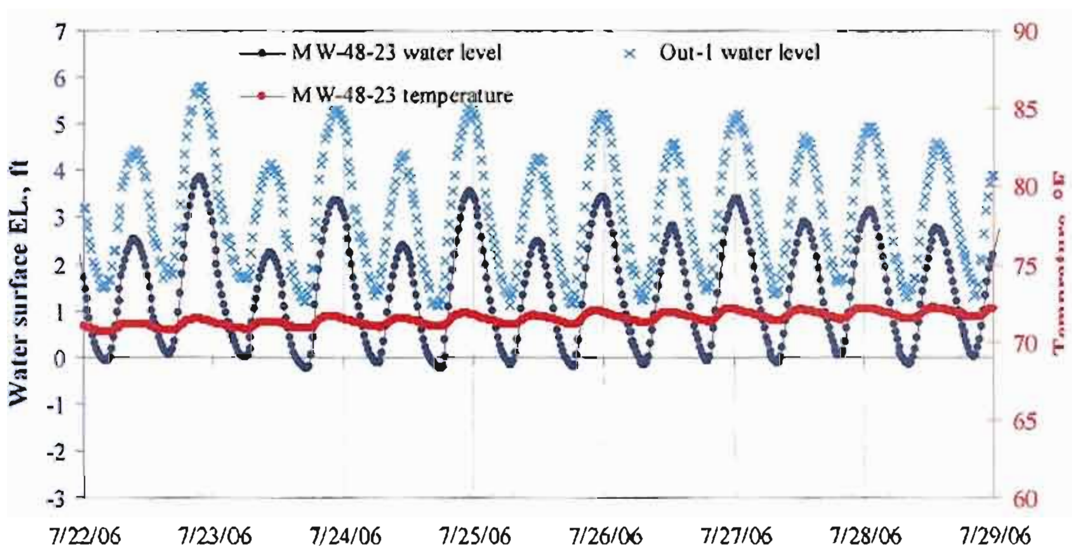
Data presented above, which is for MW-38 in the summer of 2006, while not as dramatic, supports our conclusion that groundwater in MW-38 is mixed, at times, with canal water. In reviewing this graph, note the canal water is significantly warmer than the groundwater, and that water temperature in the well water increases while the canal water level is above the level of water in the well.

6.6.2.2 Monitoring Well MW-48

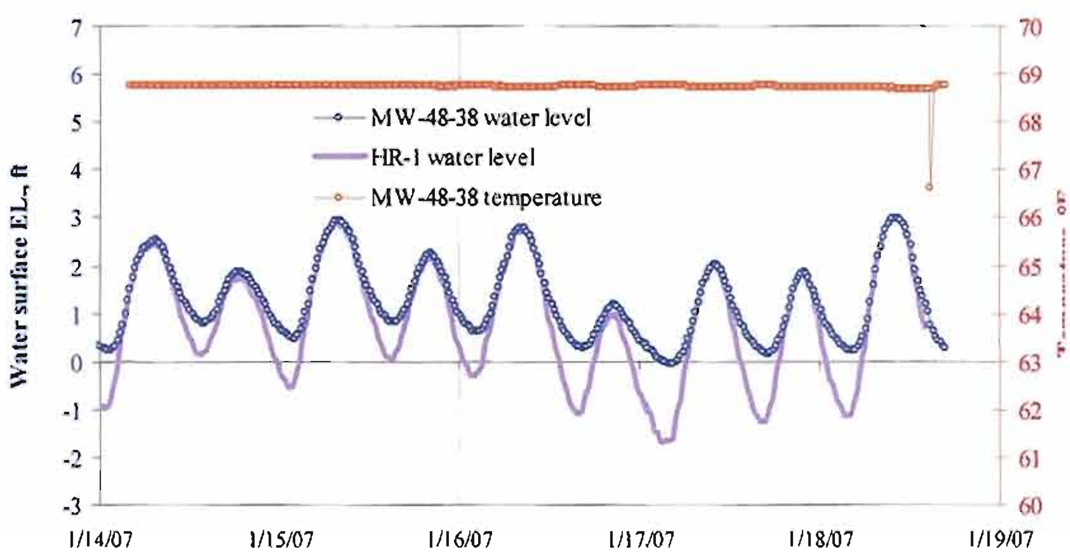
Water levels respond to tidal changes in both wells (MW-48-23 and MW-48-38) at the MW-48 location. The water levels and temperature variations in these two wells are presented and described below.



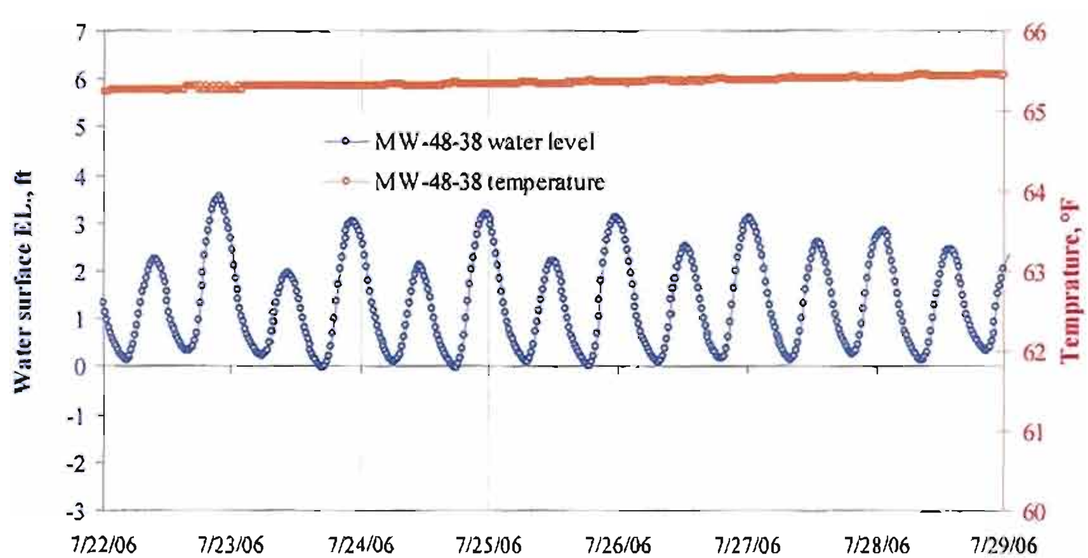
WATER LEVEL AND TEMPERATURE RELATIONSHIPS FOR HUDSON RIVER AND MW-48-23 (JAN. 07)



WATER LEVEL AND TEMPERATURE RELATIONSHIPS FOR DISCHARGE CANAL AND MW-48-23 (JULY 06)



WATER LEVEL AND TEMPERATURE RELATIONSHIPS FOR HUDSON RIVER AND MW-48-38 (JAN. 07)



WATER LEVEL AND TEMPERATURE RELATIONSHIPS FOR MW-48-38 (JULY 06)

At high tide, the level of water in both of these wells is very close to the river level, while at low tide, it is slightly above the river level and approximately 2 feet below the level of the Discharge Canal. The vertical gradient at this location is upward, with a stronger gradient at low tide. These data are consistent with anticipated trends, indicating groundwater discharge to the river occurs predominantly at low tide.

Note that the river water temperatures shown on graphs in this report are not representative of the temperature of the water in the river adjacent to monitoring wells MW-48. This is due to the location of river transducer HR-1, and tidal induced flows in the river. However, the elevated (above ambient) temperature of the groundwater at these locations (65 to 69° F) indicates it has been warmed by the Site's cooling water discharge.

The temperature of water in monitoring well MW-48-23 varies with some tide cycles, with the coolest temperature being near high tide in the winter, and the warmest temperature being near high tide in the summer. This pattern of temperature change is consistent with this monitoring well receiving river water at times of high tide.

The temperature of water in monitoring well MW-48-38 does not appear to vary with tidal cycles. We interpret these data to mean that physical water quality in monitoring well MW-48-38 is not typically influenced by large exchanges of river water[44]. The elevated groundwater temperature at this location, and the piezometric data, suggest, however, that flows created by purging of the well prior to sampling, at times of high tide, could induce river water flow to this location.

6.6.3 Aqueous Geochemistry

Routine groundwater monitoring indicated the presence of Tritium in a limited number of samples collected from monitoring wells MW-38 and MW-48. MW-38 was originally installed under the first phase of investigation to bound the southern extent of Tritium contamination at the Site along the cooling water Discharge Canal. However, subsequent sampling events indicated the presence of Tritium in groundwater at this location. The presence of Tritium in this well did not fit our CSM or what we knew of groundwater flow at the Site. A second well, MW-48, was installed at the southern Site boundary along the Hudson River to establish if any Tritium would potentially migrate off-Site. Tritium was detected intermittently in groundwater samples collected at this location as well. As neither of these locations was hydraulically downgradient of identified release areas, another mechanism other than groundwater migration from the release area was postulated. This mechanism involved releases from the legacy piping that conveyed contaminated water from the IP1-SFDS to the "E"-series stormwater piping that runs beneath the access road on the South side of the Protected Area and discharges stormwater to the cooling water Discharge Canal. While evaluating this hypothesis, we found evidence, as discussed in **Section 6.62**, that at certain tidal cycles, water from the Discharge Canal and the Hudson River may back flow into these groundwater monitoring wells. To help identify the source of Tritium in these two wells, we developed a focused water quality program specific to these wells. Generally, the water quality program involved analyzing select aqueous geochemical parameters in groundwater and surface water samples. Evaluation of these data can allow conclusions to be drawn regarding the source of the sampled water.

Both data sets (elevation and water chemistry) indicate that water collected from these wells may contain river or cooling water from the Discharge Canal. Based on these findings, we recommend that groundwater sample laboratory results from these well locations not be used to evaluate the extent of groundwater contamination or contaminant

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[44] Relatively large exchanges of water are required to overcome the thermal mass of the subsurface deposits surrounding the well bore. Therefore, while smaller exchanges of groundwater/river water may go undetected via temperature change, they may still be large enough to adversely impact radiological water quality, particularly in consideration of the data from the proximate well screens. Also see discussion in **Section 6.6.3**.

flux to the Hudson River and that these wells not be incorporated into the Long Term Monitoring Plan as Boundary Wells.

6.6.3.1 Sampling

Groundwater samples were collected from monitoring wells MW-38, MW-48-23, and MW-48-38 and from the Discharge Canal and Hudson River on January 19, 2007. These samples were analyzed for bicarbonate alkalinity (as $CaCO_3$), magnesium, sodium, calcium, sulfate, and chloride. The data was graphed on Stiff diagrams and is shown on **Figure 6.16**.

6.6.3.2 Water Quality Evaluation

GZA used the six water quality indicators (bicarbonate alkalinity [as $CaCO_3$], magnesium, sodium, calcium, sulfate, and chloride) to assess whether or not Discharge Canal and/or river water was present or mixed with groundwater at the two locations of interest (note that the MW-48 monitoring well location contains a shallow and a deep well). A summary of our findings follows.

- The river and canal samples are chemically similar and are dominated by sodium and chloride. The sodium and chloride contents are highest at the mid tide sampling event. These data indicate that at mid tide there was a greater vertical mixing of river water which caused the water to contain more sodium and chloride[45].
- The MW-48-23 samples collected at low, mid and high tide are all geochemically similar and are dominated by the sodium and chloride ions. However, the electrolyte concentration of these two ions is approximately half of that measured in the river or canal samples. Additionally, at low tide, there is slightly less sodium chloride and slightly more bicarbonate anion than at mid or high tide. We believe this indicates that at low tide, this location receives relatively more groundwater.
- Samples collected from MW-48-38 at low, mid, and high tide were generally all dominated by calcium and magnesium cations and chloride and bicarbonate anions. These samples also contained similar sodium, chloride, calcium, bicarbonate, magnesium, and sulfate electrolyte concentrations. However, at mid and high tide, there was somewhat more calcium, magnesium, and bicarbonate measured in these samples. It is further noted that the cation/anion imbalance for the MW-48-38 samples (except MW-48-38-L1) was greater than 5%. This indicates a lack of accuracy or the presence of unanalyzed ions in the groundwater samples. While samples from MW-48-38 currently appear more representative of groundwater than those from wells MW-38 and MW-48-23, it is not certain that they are always fully representative of groundwater only[46].

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[45] We believe the river and canal samples are similar (in part) because the river sample location was situated immediately down-river of the Discharge Canal outfall. In addition, the river sampling location visibly appears to remain within the discharge water heat plume. Therefore, the river samples are likely Discharge Canal water or at least mixed with what is being discharged from the canal.

[46] For example, 573 pCi/L of Tritium was detected in this interval on September 5, 2006. Tritium had never previously been detected and has since not been detected in this interval. It may be that this sample was misidentified in the field and the sample was actually obtained from the upper interval of this well where Tritium is routinely detected. However,

- The samples collected from MW-38 at low, mid and high tide are all geochemically similar and are dominated by the sodium and chloride ions. However, the electrolyte concentration of these two ions is less than half of that measured in the river or canal samples. Additionally, at low tide, there is slightly less sodium and chloride than at mid or high tide. We believe this likely indicates that at low tide, this location sees relatively more groundwater.

These data indicate that water samples collected from MW-38 and MW-48-23 are largely representative of the proximate surface water bodies at the Site. Recognizing the source of water in these wells, the other *chemistry data* (e.g., Tritium and Strontium) are suspect and should not be used for evaluation of groundwater contaminant migration or flux. Based on the available data, MW-48-38 may provide samples *more* representative of Site groundwater than MW-38 and MW-48-23. However, further analysis would be necessary to allow this well to be recommended as a southern boundary monitoring location, particularly in light of the above analysis pursuant to the proximate well screens and the potential for false positives. Given the demonstrated groundwater flow directions in this area[47], it is GZA's opinion that an additional southern boundary monitoring location (in addition to MW-51 and MW-40) is not required proximate to MW-48-38.

6.7 GROUNDWATER FLOW PATTERNS

A major purpose of this groundwater investigation was to identify the fate and level of groundwater contaminant migration. The contaminants of potential concern are soluble in groundwater, and at somewhat varying rates, move with it. This section provides a description of identified groundwater flow patterns in and downgradient of identified contaminant release areas. The piezometric data, shown in **Table 6.1**, which form the basis of this evaluation are independent of chemical data collected at the same monitoring locations. Consequently, our evaluation of piezometric data provides an assessment of where contaminants are expected to migrate in various time frames. Refer to **Section 9.0** for information on the observed distribution of contaminants and a discussion on discrepancies between anticipated and observed conditions.

Testing has indicated that the bedrock is sufficiently fractured to, on the scale of the Site, behave as a non-homogeneous, anisotropic, vertically porous media. This finding indicates that groundwater flow is perpendicular to lines of equal heads. This assessment appears particularly valid in horizontal (East-West & North-South) directions.

The nature of bedrock fracturing suggests the hydraulic conductivity is higher in the horizontal than in the vertical direction. Furthermore it appears the upper portions of the rock are more conductive than the deep rock except within the zone of higher hydraulic conductivity between Units 1 and 2. These findings suggest that the bulk of the

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it also is possible that this sample is reflective of river water induced into the well through sampling and/or the specific conditions existing at the time the sample was taken.

[47] While the representativeness of the chemistry data in these wells (MW-38, MW-48-23 and MW-48-38) is not certain, the groundwater elevation data is reliable for establishing flow direction.

groundwater moves at shallower depth, with small masses being reflected deeper into the rock mass than would be seen in anisotropic aquifer.

6.7.1 Groundwater Flow Direction

Groundwater elevations from pressure transducers at a representative low tide have been used to construct a potentiometric surface map of the aquifer beneath the Site (see **Figure 6.17**). We chose this data set after evaluating a number of piezometric data sets. More specifically we have mapped six groundwater conditions:

- Low tide during the drier portion of the year (2/12/07)
- High tide during the wetter portion of the year (3/28/07)
- Low tide during the wetter portion of the year (3/28/07)
- High tide during the drier portion of the year (2/12/07)
- Groundwater elevations at sample locations with the greatest Tritium impact during wet season
- Groundwater elevations at sample locations with the greatest Tritium impact during the dry season

Based on this evaluation, it appears that there is not a great deal of change in groundwater flow patterns over time (see **Appendix S**). However, as groundwater elevations have a smaller tidal response (amplitude) than the fluctuations of the river, low tide is a time with a relatively high degree of groundwater flux from the Site. Furthermore, low tide during the drier portion of the year likely represents a period of highest groundwater flux.

Groundwater flow is in three dimensions. A representative set of groundwater elevations was used to construct a cross-sectional groundwater contour map as shown on **Figure 6.18**. This figure is based on a 1:1 horizontal to vertical hydraulic conductivity. Because horizontal fractures transmit flow in only a horizontal direction, and vertical fractures transmit flow in both a horizontal and vertical direction, the aquifer is vertically anisotropic with a preference for horizontal flow. Conversely, if the vertical hydraulic conductivity decreases with depth, the groundwater flow should be driven deeper than shown on the figure, but would still ultimately discharge to the Hudson River. Based on the observed vertical distribution of piezometric heads, the deepest flow paths of potential interest for this investigation originate near Unit 2. Based on the observed vertical distribution of contaminants (see **Section 9.2**), these flow paths are limited to depths of between 200 and 300 feet below ground surface.

As discussed previously, groundwater flow patterns are also influenced by anthropogenic sources and sinks. The groundwater sources/sinks are shown on **Figure 1.3** and are summarized below:

- Unit 1 Chemical Systems Building (IP1-CSB) Foundation Drain: This drain discharges into the Sphere Foundation Drain Sump (SFDS) and is designed to maintain groundwater elevations beneath IP-1-CSB subbasement to an elevation of approximately 12 feet NGVD 29. The reported groundwater extraction rate from this drain is approximately 10 gallons per minute (gpm).

- IP1-NCD: This drain is designed to maintain groundwater elevations beneath the Unit 1 containment building (IP1-CB) and the Unit 1 Fuel Handling Building (IP1-FHB) at an elevation ranging from 33 to 42 feet NGVD 29. The reported groundwater extraction rate from this drain is approximately 5 gpm.
- Unit 2 Footing Drain: This drain is designed to maintain groundwater elevations beneath the Unit 2 Vapor Containment (IP2-VC) at an elevation ranging from approximately 13 to 42 feet NGVD 29. The long term flow rate from this drain is not known, but short term measurements made prior to and during the Pumping Test indicate it is likely on the order of 5 gpm.
- Unit 3 Footing Drain: IP3-VC is known to have a Curtain Drain. However, specifics of its construction were not available. It is known that a pipe that connects to the Unit 3 Curtain Drain is currently under water in a manhole Northeast of Unit 3. Due to this condition, it is unknown how much or whether or not this drain is removing groundwater.
- Unit 1, 2, and 3 storm drains: The storm drains surrounding Units 1, 2, and 3 were constructed of corrugated metal piping. These pipes and associated utility trenches have been shown to allow at least some infiltration/exfiltration. That is, depending on rainfall and location, these structures may either receive groundwater or recharge the aquifer.

6.7.2 Groundwater Flow Rates

In the interest of evaluating conditions when a relatively large amount of groundwater (and associated constituents) flux to the Hudson River occurs, our discussion of lateral groundwater flow direction focuses on the low tide potentiometric surface contours as shown on **Figures 6.19** and **6.20**. These groundwater contours show that groundwater generally flows toward the Site from the North, East and South, with a generally westerly flow direction across the Site with a gradient averaging about 0.06 feet per feet.

6.7.2.1 Seepage Velocities

We used Darcy's Law to estimate the average groundwater seepage velocity across the Site:

$$V = K * \frac{dh}{dl} * \frac{1}{n_e}$$

Where:

V = average linear groundwater velocity

K = hydraulic conductivity (0.27 feet/day [see **Section 6.50**])

$\frac{dh}{dl}$ = groundwater gradient (0.06)

n_e = effective porosity (assumed to be 0.0003 based on specific yield measured during Pumping Test)

Based on this equation and Site data, we computed the average groundwater seepage velocity to be on the order of 55 ft/day. This is an upper end estimate in that it does not account for the effect of dead-end fractures and irregularities in fracture apertures. That is, we believe the effective porosity is larger than that indicated by hydraulic testing. Also note that this is an average velocity with flow rate in individual fractures being controlled by the local gradient and hydraulic aperture of the fracture. Based on the tracer test (see **Section 7.3.2**), actual measured average seepage rates were substantially less than 55 ft/day.

6.7.2.2 Groundwater Flux

To estimate groundwater flows (i.e., groundwater mass flux) beneath the IPEC, a calibrated analytical groundwater flow model was constructed. This model was based on two independent equations, both of which provide groundwater flow estimates. The first of these equations is based on a mass balance. That is, on a long term average, the groundwater discharging from the aquifer is equal to the aquifer recharge. The second equation is "Darcy's Law", which states the flow per unit width of aquifer is equal to the transmissivity of the aquifer multiplied by the hydraulic gradient.

As discussed in the following subsections using Site-specific data for the governing parameters, both of these independent methods provided similar results. Because we were conservative (that is, we chose values for both equations that we believe may somewhat overestimate flows), we believe the model is appropriate for its intended use for estimating the mass of groundwater discharging to the Hudson River as part of dose impact computations[48]. Please note, this model is not, therefore, conservative for all purposes. For example, we believe it would likely overestimate the yield of extraction wells should they be developed at the facility.

While the calculated groundwater flux from the Site directly to the river (approximately 13 gpm) may intuitively seem small, it is consistent with our Conceptual Site Model and the identified hydrogeological setting.

<u>Mass Balance</u>

The mass balance approach recognizes that the only substantial source of recharge to aquifer is areal recharge derived from precipitation. Precipitation in the area reportedly varies from 49 inches per year (30-year average) to 36 inches per year (10-year average) at the IPEC Meteorological Station. Areal recharge is that portion of precipitation that reaches the water table (total precipitation minus run-off, evaporation and transpiration). The average areal recharge is dependent on total precipitation, the nature and timing of individual storm events, soil types, topography, plant cover, the percentage of impervious cover (roads, buildings, etc.) and precipitation recharge through exfiltrating

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[48] It is noted that the dose impact computations reported for 2006 were based on the mass balance model only. These analyses were completed prior to obtaining sufficient data to implement the Darcy's Law model. It is recommended that future dose impact computations also be based on the mass balance model, but with upgrades based on Darcy's Law analyses.

stormwater management systems. Based on our review of available information, we believe that the areal recharge at the IPEC is greater than 6 inches per year and less than 12 inches per year. For the purposes of this study, an average of 10 inches per year was used (see **Appendix S** for information on how we arrived at this average).

Topographic divides were used to defined the recharge area (see **Figure 3.1**). This provides a recharge area of approximately 4,000,000 square feet (92 acres) and a calculated recharge rate of 38 gpm. From this value, the 20 gpm extracted by pumping from foundation drains was subtracted (see **Section 8.0**). This approach, therefore, indicates that the groundwater discharge to the cooling water Discharge Canal and the Hudson River is approximately 18 gpm.

Darcy's Law

Darcy's Law is presented below:

$$Q = K * A * \frac{dh}{dl} = T * W * \frac{dh}{dl}$$

Where:

Q = volumetric flow (ft^3)
T = transmissivity (ft^2/day)
W = width of the streamtube

To estimate transmissivities, the aquifer was divided into two layers or zones: the upper forty feet; and between depths of 40 feet and 185 feet, the identified bottom of the significant groundwater flow field. In each of the zones, transmissivities were calculated using the geometric mean of hydraulic conductivity testing. The facility was further divided into 6 flow zones representing areas beneath pertinent Site features; and data East (upgradient) of the Discharge Canal was reviewed independently of that West (downgradient) of the Discharge Canal. This process, shown on the following four tables, provides an estimate of the groundwater flux passing beneath structures of interest that discharge to the cooling water Discharge Canal and the Hudson River. In reviewing these calculations, note the resulting total groundwater flow East of the canal is approximately 18 gpm, which indicates that the long term areal recharge to the aquifer is 10 inches per year, or 28% of the 10-year average precipitation recorded at the IPEC.

Unit	Transmissivity (ft^2/day)	Width (ft)	Hydraulic Gradient (ft/ft)	Volumetric Flow Rate (gpm)
Northern Clean Area	0.36	209	0.600	0.23
Unit 2 North	1.59	294	0.014	0.03
Unit 1/2	31.97	215	0.007	0.26
Unit 3 North	29.87	324	0.054	2.74
Unit 3 South	16.02	338	0.038	1.07
Southern Clean Zone	24.34	879	0.037	4.12
			Total➔	8.45

SHALLOW ZONE <u>BEFORE</u> CANAL (OVERBURDEN AND TOP 40 FEET OF BEDROCK)

Unit	Transmissivity (ft^2/day)	Width (ft)	Hydraulic Gradient (ft/ft)	Volumetric Flow Rate (gpm)
Northern Clean Area	0.36	209	0.600	0.23
Unit 2 North	1.59	221	0.038	0.07
Unit 1/2	31.97	146	0.022	0.52
Unit 3 North	29.87	316	0.013	0.61
Unit 3 South	16.02	248	0.011	0.24
Southern Clean Zone	24.34	879	0.037	4.12
			Total➔	5.79

SHALLOW ZONE <u>AFTER</u> CANAL (OVERBURDEN AND TOP 40 FEET OF BEDROCK)

Unit	Transmissivity (ft^2/day)	Width (ft)	Hydraulic Gradient (ft/ft)	Volumetric Flow Rate (gpm)
Northern Clean Area	10.77	209	0.068	0.80
Unit 2 North	10.77	294	0.030	0.49
Unit 1/2	62.15	215	0.023	1.61
Unit 3 North	37.65	324	0.022	1.41
Unit 3 South	22.02	338	0.040	1.55
Southern Clean Zone	19.66	879	0.043	3.83
			Total➔	9.69

DEEP ZONE <u>BEFORE</u> CANAL (FROM 40 TO 185 FEET BELOW TOP OF BEDROCK)

Unit	Transmissivity (ft^2/day)	Width (ft)	Hydraulic Gradient (ft/ft)	Volumetric Flow Rate (gpm)
Northern Clean Area	10.77	209	0.068	0.80
Unit 2 North	10.77	294	0.023	0.29
Unit 1/2	62.15	215	0.018	0.83
Unit 3 North	37.65	324	0.018	1.09
Unit 3 South	22.02	338	0.016	0.45
Southern Clean Zone	19.66	879	0.043	3.83
			Total→	7.25

DEEP ZONE <u>AFTER</u> CANAL (FROM 40 TO 185 FEET BELOW TOP OF BEDROCK)

GZA's groundwater flux calculations are used by Entergy to calculate radiological dose impact. Entergy currently estimates this dose based upon the precipitation mass balance approach alone. Refinements to this dose model are feasible utilizing the hydrogeologic data presented above. These refinements will improve the overall data fit of the flow model in concert with the long term monitoring program being implemented by Entergy.

The resultant dose assessments are expected to remain close to, or be somewhat lower than, what has already been estimated. It is recommended that Entergy evaluate the refinements to the existing model for inclusion in the next annual effluent assessment report.

7.0 GROUNDWATER TRACER TEST RESULTS

A tracer test was conducted to help assess groundwater migration pathways from IP2-SFP. As discussed in the following sections, the test also helped to confirm migration pathways from Unit 1. The test was designed to simulate a leak from IP2-SFP, in that the tracer (Fluorescein) was released directly to the bedrock at the base of the structure, immediately below the shrinkage cracks associated with the 2005 release. The bedrock surface at this location is approximately elevation 51 feet, and thus approximately 40 feet above the water table (as measured in the immediately adjacent MW-30 - see **Figure 7.1**). This approach was taken (recognizing it would complicate tracer flow paths relative to injection directly into the groundwater) to provide better understanding of the role of unsaturated bedrock in storing and transporting Tritium.

A major difference in the test, as compared to possible releases at IP2-SFP, is the rate of the injection. The 2005 Tritium release was measured at a peak rate of approximately 2 liters per day (0.005 gpm), as opposed to the tracer injection that occurred relatively instantaneously (as compared to the Tritium release) at a rate of approximately 3.5 gpm over approximately an hour. This higher injection rate was used to insure that a sufficient mass of Fluorescein was released at a known time. As anticipated, and discussed in subsequent sections, this practice appears to have enhanced the lateral spreading of the tracer in the unsaturated zone.

7.1 TRACER INJECTION

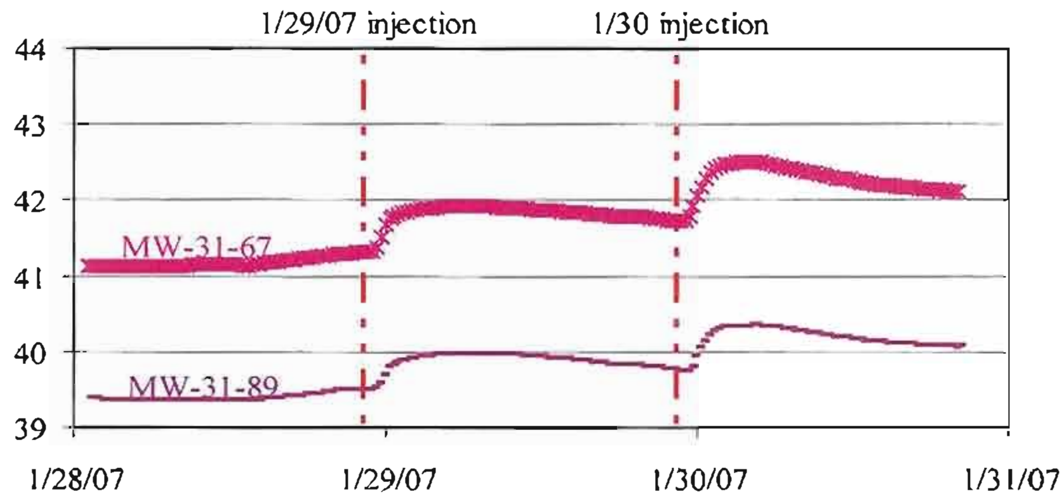
Preparation for the injection began on January 29, 2007 with the injection of potable water to test the ability of the injection point[49], T1-U2-1, to accept water and to pre-wet fractures. The first potable water injection was conducted on January 29, 2007. Five hundred gallons of water (measured using an inline totaling water meter) was introduced as fast as the water source would permit (approximately 8.5 gpm). The water level in the well did not rise significantly. The second potable water injection was conducted on January 30, 2007. A total of 1,012 gallons of tap water was introduced at a mean rate of approximately 8.3 gpm.

The piezometric data collected during that period from wells MW-30, MW-31, MW-33, MW-34 and MW-35 were reviewed for evidence of groundwater mounding. (Note: transducers were not installed in RW-1 and MW-32 on that date.) Mounding, on the order of 0.5 to 1 foot, was recorded at MW-31. No response was noted at the other four nearby monitored locations. Note that MW-31 is located upgradient of the injection point from a *saturated* zone groundwater flow perspective, and unsaturated zone flow in this direction is

[49] The injection point as shown on **Figure 7.2** is constructed from two-inch steel pipe that ends in a tee and perforated piping running directly on the bedrock surface, well above the water table. This perforated piping was covered with approximately 0.5 feet of crushed stone extending from the bedrock excavation face to the South face of the SFP, over a length of approximately 8 feet. The crushed stone was covered with filter fabric prior to placing the concrete mud-mat for gantry crane foundation construction; the mud-mat covers the entire bedrock excavation "floor" adjacent to the South side of the SFP.

consistent with the bedrock strike/dip directions. Based on the shape of the time response curve at MW-31, GZA believes that:

1. The center of the release to the water table was at some distance from MW-31 (see time lag), and;
2. Injected water was released to the water table over a longer duration than the two hour injection test. This opinion is based on the relatively slow decay of the mound at MW-31. This response is shown on the figure below:



PIEZOMETRIC GROUNDWATER RESPONSE TO WATER INJECTION

We have insufficient information to render an opinion on the shape or height of the tracer injection-induced groundwater mound. We note, however, because of the lower rate of the tracer injection, the short duration of the injection (see below), and the groundwater flow velocities, as derived from the tracer test, GZA believes mounding had relatively little effect (compared to unsaturated flow) on the lateral spreading of the tracer. That is, the life of the mound was not of sufficient duration to cause long term, widespread lateral migration in the groundwater.

The tracer injection was performed on February 8, 2007. It consisted of the release of 7.5 pounds of Fluorescein with 210 gallons of water. More specifically, prior to Fluorescein injection, 30 gallons of potable water was released to the well, this was followed by 10 gallons of a Fluorescein-water mixture, followed by 170 gallons of potable water (to flush the Fluorescein out of the well). This procedure resulted in a minimum initial average tracer concentration of 4,300,000 ppb.

7.2 TRACER CONCENTRATION MEASUREMENTS

The concentrations of Fluorescein in groundwater were routinely measured between February 8, 2007 and August 21, 2007[50] at 63 locations. This resulted in the collection analysis of 4,488 samples, including background samples, charcoal samplers and water samples. These data are tabulated and presented on time-concentration graphs in **Appendix N**.

Measurements of Fluorescein concentrations were made by two methods. The first is through aqueous sample analysis (1,969 individual samples). These water sample analyses provide direct concentration measurements, at the time of sampling, with a detection limit of less than 1 ppb.

A second method entailed desorbtion of Fluorescein from packets of activated carbon (carbon samplers) suspended in the groundwater flow path at multi-level sampling locations. This method provides a measure of the mass of Fluorescein moving through a monitoring well screen over the period the activated carbon is in the well. However, the actual concentration of Fluorescein in the groundwater is not determinable from this test. Among other things, carbon sample analyses are useful in establishing that the Fluorescein mass being transported by groundwater did not pass sampling locations between discrete sampling events. This was important for this study because of the potential for high transport rates (see **Section 6.0**).

7.3 SPATIAL DISTRIBUTION AND EXTENT OF FLUORESCEIN IN GROUNDWATER

The groundwater tracer test was developed primarily to identify groundwater migration pathways. We have divided our discussion on observed pathways into three subsections: unsaturated zone migration, the lateral distribution of Fluorescein, and the vertical distribution of Fluorescein.

Unsaturated Zone Transport

By design, Fluorescein was released atop the bedrock, in the unsaturated zone. The bedrock structure (strike and dip direction of bedrock fractures) therefore played a dominant role in controlling tracer migration to the water table. This is witnessed by the significant Fluorescein concentrations observed in the upgradient monitoring well MW-31 and MW-32 (see below) and at lower concentrations in the more distant and upgradient Unit 1 monitoring well MW-42.

The observed unsaturated zone migration to the South and East is consistent with the observed bedrock fracturing (see **Section 6.0**). This mechanism is also evidenced by data showing the highest Fluorescein concentration (49,000 pico-curies per liter - pCi/L)[51]

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[50] In addition to the routine sampling, specific wells were sampled for a longer period of time as part of short term variability testing (see **Section 9.0**).
[51] pCi/L is a standard unit of radiation measurement.

being found in well MW-32, located 60 feet to the South of the injection location, and not in MW-30, located immediately below the injection location.

In reviewing tracer test results, it should be recognized that the Fluorescein released at a single location on the bedrock was not released to the water table at a single location, rather, it reached the water table over an undefined area that likely extends to the East of MW-31, to the South to MW-42, and likely not far to the North of the injection well. As discussed in **Section 7.5**, this limits our ability to evaluate migration rates, but increases our ability to understand likely Tritium migration pathways from IP2-SFP.

The spreading of Fluorescein in the unsaturated zone was likely more pronounced than the spreading of Tritium because of the higher release rate. The tracer test, however, supports data that shows the Unit 2 plume to extend upgradient of the source area and laterally to Unit 1 to the South of IP2-SFB.

Lateral Distribution

Two conditions were selected to show the lateral distribution of Fluorescein in a manner illustrating conditions influencing the migration of groundwater in the vicinity of IP2-SFB. These are:

1. The maximum observed concentrations; and,
2. Conditions just prior to, and including, June 14, 2007.

While the maximum observed concentrations do not illustrate an actual condition, the resulting figure is useful in highlighting migration pathways. We chose June 14th because it represents conditions approximately 4 months after the injection. With estimated Fluorescein transport rates on the order of 4 to 9 feet per day (see **Section 7.4**), conditions proximate to that date clearly illustrate the effects of subsurface storage on both Fluorescein and Tritium[52].

Lateral Distribution – Maximum Observed Concentrations

The distribution of the observed maximum concentrations of Florescein, at any depth, in groundwater is shown on **Figure 7.2**. This figure was developed based on both the observed concentrations and our understanding of groundwater flow directions (inferred from groundwater contours). This figure does not show conditions at any single time; rather it represents our interpretation of the highest tracer concentration, at any time during the test, at a location. In reviewing that figure please note:

- The maximum observed tracer concentration was 49,000 ppb; approximately 1% of the calculated average injection concentration. We interpret these data to mean that there is considerable spreading and mixing of the tracer in the unsaturated and shallow saturated zones.

[52] Later dates were not selected because of the associated reduction in the sampling frequency and/or number of sampling locations.

- The 50 ppb contour represents approximately 1/100,000 the concentration of the injected tracer. Because Tritium concentrations in IP2-SFP are approximately 20,000,000 pCi/L this contour (50 ppb Fluorescein) represents the detection limit of a release of Tritium from IP2-SFP (at the injection well).
- The general shape of the resulting plume is strikingly similar to the observed Unit 2 plume, see **Figure 8.1**. This supports our interpretation of contaminant migration from IP2-SFP.
- Because tracer was detected in MW-42 and MW-53, the test can be used to help assess migration pathways from Unit 1. The observed distribution of Fluorescein in the vicinity of Unit 1 supports our interpretation of the migration of Strontium, with a westward migration towards the Hudson River in a fairly narrow zone (see **Figure 7.2**).
- The low concentrations to the West (downgradient) of the cooling water Discharge Canal (as compared to East of the canal) indicate the canal received a significant mass of the tracer, as opposed to direct discharge to the river.
- Concentrations found in Manhole Five (MH-5) indicate the IP-2 Curtain Drain received tracer (see **Section 7.5**).

Lateral Distribution – June 14, 2007

GZA's interpretation of the distribution of Fluorescein in groundwater proximate to June 14, 2007 is shown on **Figure 7.3**. Again, concentrations are the highest measured at any depth. While not ideal for the observed concentrations, the contour interval was selected to match the contour intervals shown on **Figure 7.2**. In reviewing that figure, please note:

- The shape of the plume is more representative of an ongoing release than of a four-month-old instantaneous release in a strong groundwater flow field. This supports other data which indicate water is stored in the unsaturated bedrock (and potentially within the upper water bearing zone) and is released to the groundwater flow field over time.
- The center of the Fluorescien mass in groundwater, in the release area, shifted to the North. (See data for wells MW-30 and MW-32 on **Figures 7.2** and **7.3**). GZA interprets these data to mean:
    - There is more storage in the unsaturated zone in proximity to IP2-FSB, than to the South or West; and
    - The relatively high injection rate resulted in more lateral spreading of the tracer than would have resulted from a slow, long duration release.

Vertical Distribution

The table provided below presents data on the vertical distribution of Fluorescein along the center line of the tracer plume (see **Figure 7.2** for well locations). It presents the maximum observed concentration at each depth and the approximate concentration[53] proximate to June 14, 2007.

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[53] Data estimated for the June 14th date are based on time concentration graphs (see **Appendix N**).

FLUORESCEIN CONCENTRATIONS

MW-31		MW-32		MW-30		MW-33		MW-111		MW-37	
Depth	Conc.	Depth	Conc.	Depth	Conc.	Depth	Conc.	Depth	Conc.	Depth	Conc.
53	1600 / 0.5	62	49,000 / 2	74	5690 / 2600	18	6.6 / 1	16	2.9 / 2.9	22	47 / 10
67	12,700 / 200	92	24,300 / 500	88	167 / 110					32	1.3 / ND
89	1810 / 3	140	15,300 / 6								
		165	4160 / 16								
		197	621 / 56								

1600 / 0.5 = Max. conc. / conc. proximate to 6/14/07 in µg/L
Depth = Below Ground Surface (Feet)
ND = Not Detected

The available data indicate the bulk of the Fluorescein was migrating at fairly shallow depths, although not always at the water table. As anticipated (consistent with the Conceptual Site Model), it also suggests the pathway becomes somewhat deeper downgradient of the injection point, likely being below the well screens at MW-33 and MW-111. The comparatively low concentrations at MW-111, as compared to Tritium concentrations, likely highlights the importance of unsaturated zone migration in groundwater contaminant distributions.

7.4 TEMPORAL DISTRIBUTION OF FLUORESCEIN IN GROUNDWATER

Groundwater samples were collected at regular intervals between February 8 and August 21, 2007[54]. These data are shown on graphs provided in **Appendix N** with selected information shown below. Interpretation of these graphs is complicated, beyond the normal difficulties associated with interpreting tracer test data in fractured rock. This is because the tracer was *not* injected directly to the water table, as would be more typical. Rather, the tracer was released at the top of the bedrock, in the unsaturated zone, so as to better mimic the behavior of the Tritium release from the cracks in the fuel pool wall; as was the primary objective of the tracer test. Therefore, the tracer then entered the groundwater regime at numerous locations due to unsaturated zone spreading from the release point. In addition, these numerous release points remained active over an extended period of time (months) due to storage in the unsaturated zone; see the previous subsection and **Section 8.1.2** for further discussion.

With these limitations noted, the following observations/interpretations are provided:

- At some locations, the release to the water table was rapid. For example, at monitoring well MW-32-62, located approximately 60 feet to the South of the injection point, the tracer arrival time[55] was approximately one day. Conversely, at MW-30-74, located adjacent to the injection well, the arrival time was approximately 25 days. See the following figures.

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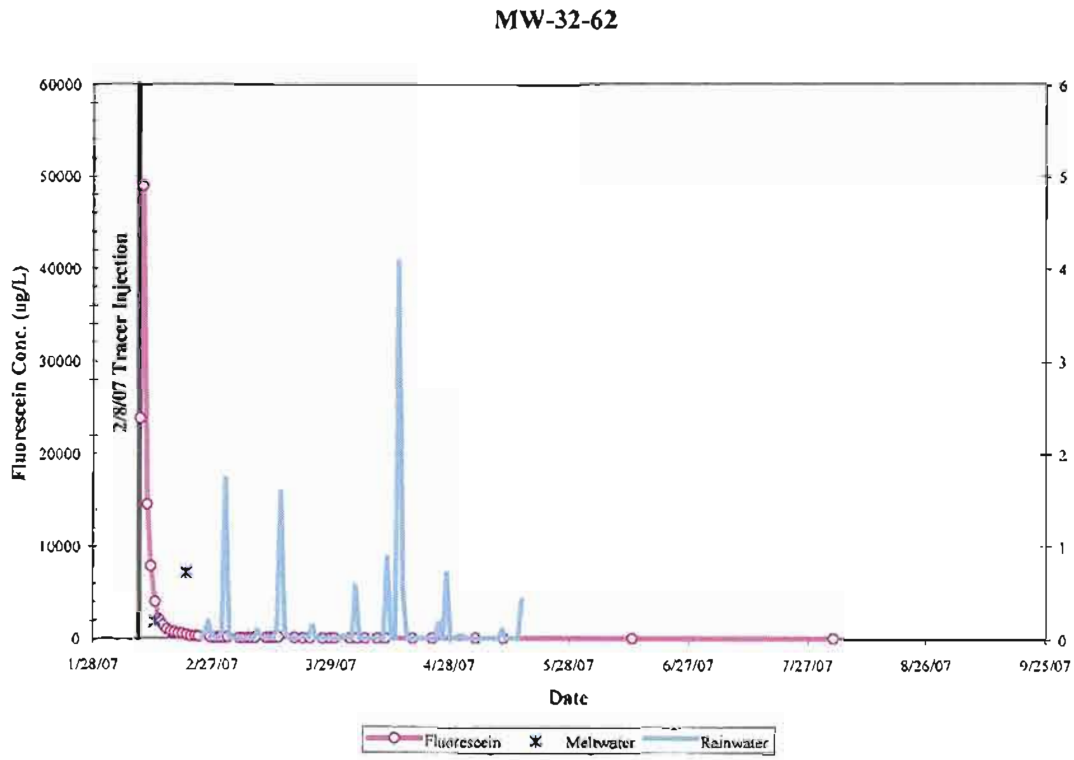
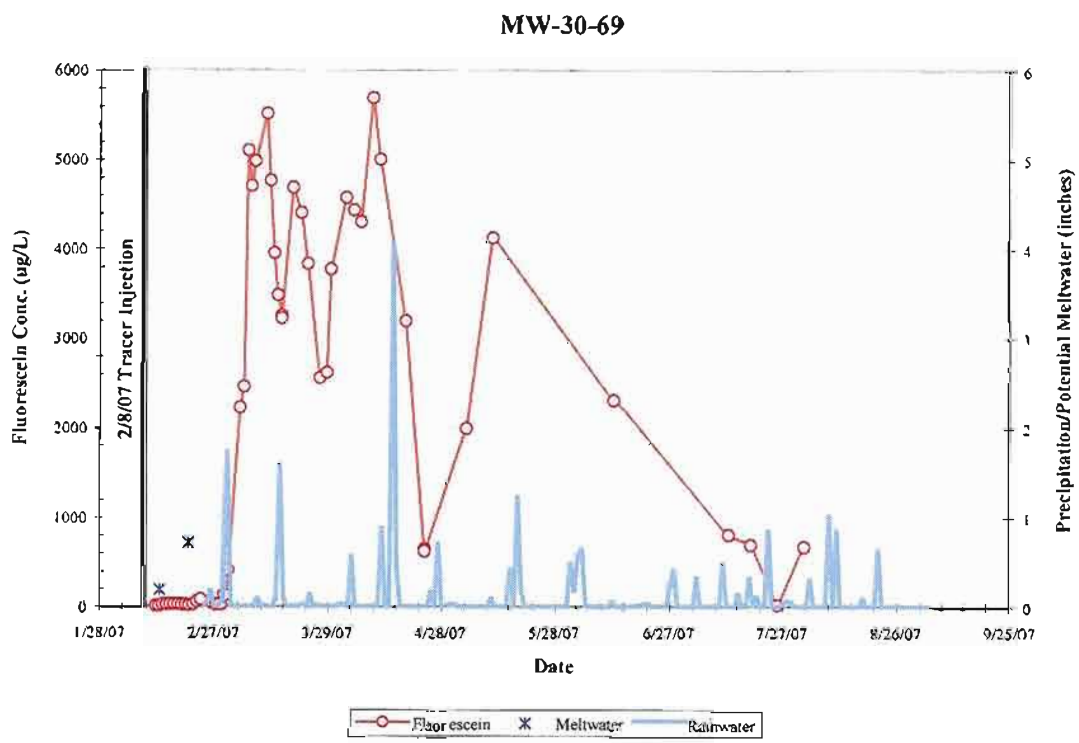
[54] In addition to the routine sampling, specific wells were sampled for a longer period of time as part of short term variability testing (see **Section 9.0**).
[55] Arrival times are generally established as the center of mass (often the peak) of the concentration vs. time graph.

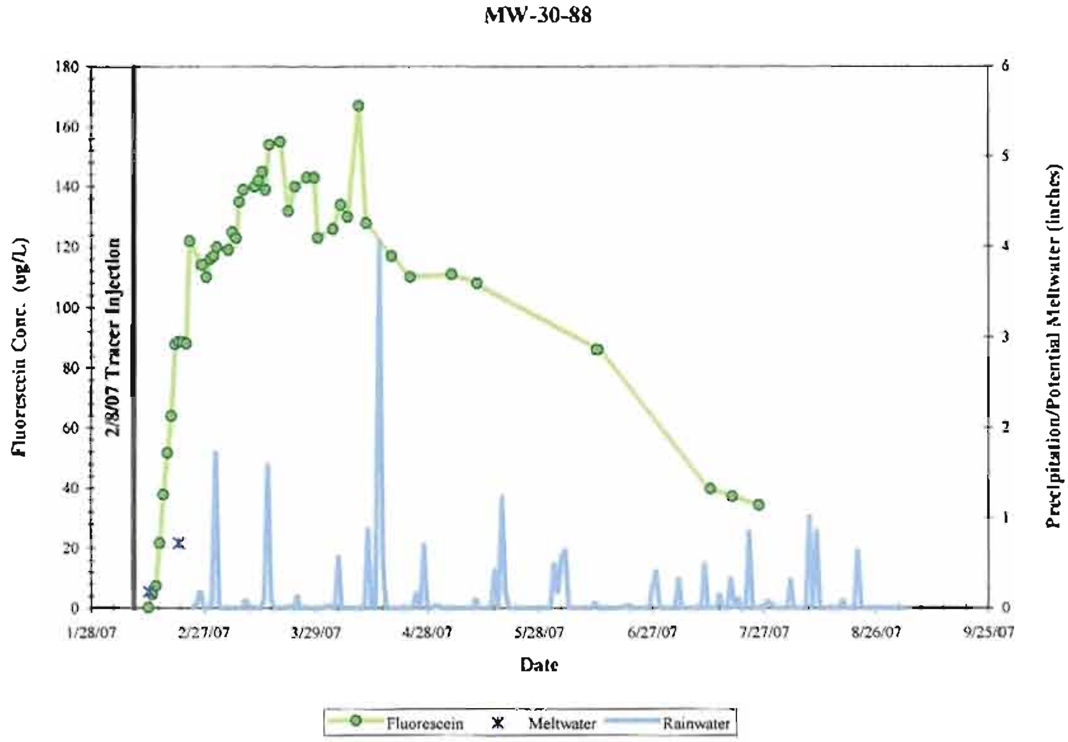


MW-32-62 FLOURESCEIN AND PRECIPITATION VS TIME



MW-30-69 FLOURESCEIN AND PRECIPITATION VS TIME

- In mid-June 2007, there was still an ongoing source of Fluorescein to the water table in the vicinity of IP2-FSP. This is evidenced by the time-concentration graphs for MW-30 -74 (see previous figure) and MW-30 -88, presented below:



MW-30-88 FLOURESCEIN AND PRECIPITATION VS TIME

- Because the locations and times of releases from the unsaturated zone to the water table are not known, it is difficult, at best, to estimate tracer transport velocities. However, as shown below, the average value appears to be on the order of 4 to 9 feet/day.

Well Location	Time of Arrival Date	Time (Days)	Distance (Feet)	Velocity (Ft/Day)
MW-33	3-5-07	25	110	4.4
MW-111	3-14-07	34	145	4.3
MW-37-22[56]	4-10-07	61	300	4.9
MW-55[57]	3-28-07	48	240	5 to 9

FLOURESCEIN ARRIVAL TIMES AND TRANSPORT VELOCITIES

[56] The source of the Fluorescein observed in MW 37-22 is uncertain. It may be entirely from migration in the bedrock slightly to the North of that location, or may be due, in part or in whole, to transport via storm drains and in the backfill around the Discharge Canal walls. See **Section 4.5**.

[57] The calculated velocity depends on which flow path is selected. Using a flow path from MW-32 (day of release) to MW-55, the calculated velocity is approximately 5 feet/day. Using a flow path between MW-53 and MW-55 (the Strontium flow path) the calculated velocity is 9 feet/day.

Also note, the carbon sampler data supports these estimates to the extent that no evidence of significant Fluorescein migration between aqueous sampling events was found.

The observed tracer migration rates are approximately 1/5 to 1/10 the calculated groundwater velocity of 55 ft/day, see **Section 6.7.2**. GZA attributes the difference between the "observed" and the "computed" transport velocities primarily to the effective porosity of the bedrock. That is, we believe the actual effective porosity is considerably larger (more on the order of 0.003) than that computed from our analyses of the Pumping Test (see **Section 6.5.1**); the aquifer response testing (see **Section 6.6.1**); or the hydraulic aperture of the bedrock (see **Section 6.5.2**). This slower transport velocity helps to explain the observed long term temporal variations in both tracer and Tritium groundwater concentrations, and supports the use of a porous media flow model. As a practical matter, this slower transport velocity encourages the use of conventional groundwater monitoring frequencies (quarterly or longer); and reduces concerns over the possibility of high concentrations of contaminants migrating by a monitoring location between sampling events.

7.5 FLUORESCEIN IN DRAINS, SUMPS AND THE DISCHARGE CANAL

Fluorescein was also detected within storm drain catch basins, foundation drain sumps, and the Discharge Canal. Fluorescein was detected in manholes MH-4, MH-5 and MH-6. In reviewing these data, note:

- MH-5 receives discharge from the IP2-VC Curtain Drain system. The presence of tracer in this manhole indicates that tracer entered the Curtain Drain system due to lateral spreading at the release point during injection. Once in the Curtain Drain system, the tracer migrated to MH-5.
- Water in MH-5 flows towards the cooling water Discharge Canal passing through MH-4, discharging at MH-4A.
- The concentrations detected in MH-4 are very similar to the Fluorescein concentrations detected in samples collected from MH-5, while Fluorescein was not detected in samples collected from the downstream manhole MH-4A. This suggests that either dilution in MH-4A reduced Fluorescein to below method detection limits, and/or the tracer is lost via exfiltration from piping between MH-4 and MH-4A. This loss (if it occurs) in conjunction with flow in the canal backfill, could explain the Fluorescein observed in MW-37. Available data are not adequate to fully address this issue. In any event, the test further demonstrates the need to account for the Tritium being transported in the IP2-VC Curtain Drain (see **Section 7.6**).
- In reviewing data, note that the tracer concentrations in MH-6 are lower than the concentrations observed in MH-5 (peak in MH-6 of 14.4 ppb as opposed to a peak in MH-5 of 43.1 ppb). We attribute the concentrations in MH-6 to groundwater infiltration in the area of the identified tracer plume. Also note the flow from MH-6 is to MH-5.

Fluorescein was also detected in the IP1-NCD, the IP1-SFDS, and the Containment Spray Sump (CSS). We have attributed the presence of tracer at these locations to unsaturated zone migration to the vicinity and West of MW-42. The concentration and arrival times at these three locations are not easily explained but, taken as a whole, are consistent with the observed migration of Tritium.

Fluorescein was detected at low concentrations, at various times, in carbon samples collected from the cooling water Discharge Canal. Because of the substantial dilution in the canal, the extended release of tracer to the canal and the low concentrations of tracer found in the samples, we believe these data represent background conditions[58], and cannot be used to evaluate the tracer test.

7.6 MAJOR FINDINGS

As an overview, the tracer test, supports our CSM and the observed distribution of contaminated groundwater. GZA also concludes that:

- Unsaturated zone flow is important to the migration of contaminants released above the water table in the vicinity of Unit 2. Bedrock fractures induce this flow to the South and East of the release.
- There is significant storage of contaminated groundwater above the water table or in zones of low hydraulic conductivity (homogeneities) in the saturated zone. These features allow a long-lived release of contaminants to the Site groundwater flow field.
- Observed tracer migration rates are lower than calculated theoretical migration rates. As a practical matter, this "migration" indicates that the use of the estimated average hydraulic conductivity (0.27 ft/day or $1x10^{-4}$ cm/sec) will overestimate the volume of groundwater migrating through a given area. That is, we attribute the lower transport velocity to be due, in part, to a lower average hydraulic conductivity.
- In our opinion, the tracer test, in conjunction with the Tritium release, indicates that the existing network of monitoring wells can be used to monitor groundwater at IPEC.

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[58] It is noted that Fluorescein is the primary colorant in automobile coolant anti-freeze. Therefore, leaks from cars to parking lot/road surfaces can impact surface water bodies via storm drain systems and/or direct runoff. Fluorescein was detected in the Discharge Canal prior to initiation of the tracer injection, further indicating its presence as background.

8.0 CONTAMINANT SOURCES AND RELEASE MECHANISMS

GZA conducted a review of available construction drawings, aerial photographs, prior reports, and documented releases, and interviewed Entergy personnel to assess potential contaminant sources. The primary[59] radiological sources identified were the Unit 2 Spent Fuel Pool (IP2-SFP) located in the Unit 2 Fuel Storage Building (IP2-FSB) and the Unit 1 Fuel Pool Complex (IP1-SFPs)[60] in the Unit 1 Fuel Handling Building (IP1-FHB. These two distinct sources are responsible for the Unit 2 plume and the Unit 1 plume, respectively.

No release was identified in the Unit 3 area. The absence of Unit 3 sources is attributed to the design upgrades incorporated in the more recently constructed IP3-SFP. These upgrades include a stainless steel liner (consistent with Unit 2 but not included in the Unit 1 design) and an additional, secondary leak detection drain system not included in the Unit 2 design.

The identified specific source mechanisms associated with the IP2-SFP and the IP1-SFPs are discussed in the following sections. We have segregated this source discussion based on primary contaminant type; those classified as primarily Tritium sources, as associated with the Unit 2 plume, and those classified as primarily Strontium sources, as associated with the Unit 1 plume. While the groundwater plumes emanating from their respective source areas can clearly be characterized using each plume's primary constituent, radionuclides other than Tritium and Strontium also exist to a limited extent and are fully addressed within the context of the Unit 2 and Unit 1 plume discussions[61].

Discussion of the two primary source types will be parsed further as follows:

- The Unit 2 (Tritium) plume source analyses will be split into: 1) "direct sources" defined as releases to the exterior of Systems Structures and Components (SSCs); and 2) "indirect storage sources" related to natural hydrogeologic mechanisms in the unsaturated zone (such as adsorption and dead-end fractures) and potential anthropogenic contaminant retention mechanisms (such as certain subsurface foundation construction details);
- The Unit 1 (Strontium) plume source analyses will be split into the mechanisms specific to the individual plume flow paths identified.

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[59] In addition to sources that directly impact groundwater, atmospheric deposition from permitted air discharges was also identified as a potential source of diffuse, low level Tritium impact to the groundwater.

[60] All of the pools in the IP1-SFPs contained radionuclides in the past. However, only the West pool currently contains any remaining fuel rods and all of the other IP1 pools have been drained of water. It is also noted that the Unit 1 West pool has been undergoing increased processing to significantly reduce the amount of radioactive material in the pools. Once fuel is removed, the IP1-SFPs will no longer constitute an active source of groundwater contamination.

[61] Contaminants associated with the Unit 2 leak were found to be essentially comprised of Tritium. The Unit 1 plume is comprised primarily of Strontium, but also includes Tritium and sporadic observation of Cesium-137, Nickel-63 and Cobalt-60 at low levels in some wells downgradient of the IP1-SFP (see **Figure 8.3**). Entergy accounts for all radionuclides that can be expected to reach the river in their required regulatory reporting of estimated dose impact.

8.1 UNIT 2 SOURCE AREA

The majority of the Tritium detected in the groundwater at the Site was traced to IP2-SFP. This pool contains water with maximum Tritium concentrations of up to 40,000,000 pCi/L[62].

The highest Tritium levels measured in groundwater (up to 601,000 pCi/L[63]) were detected early in the investigation at MW-30. This location is immediately adjacent to IP2-SFP and directly below the 2005 shrinkage cracks. As shown on **Figure 8.1**, the Tritium contamination ("the plume[64]") then tracks with downgradient groundwater flow[65] through the Unit 2 Transformer Yard, under the Discharge Canal and discharges to the river[66] between the Unit 2 and Unit 1 intake structures. During review of the following sections, it is important to recognize that only small quantities of pool leakage (on the order of liters/day) will result in the Tritium groundwater plume observed on the Site.

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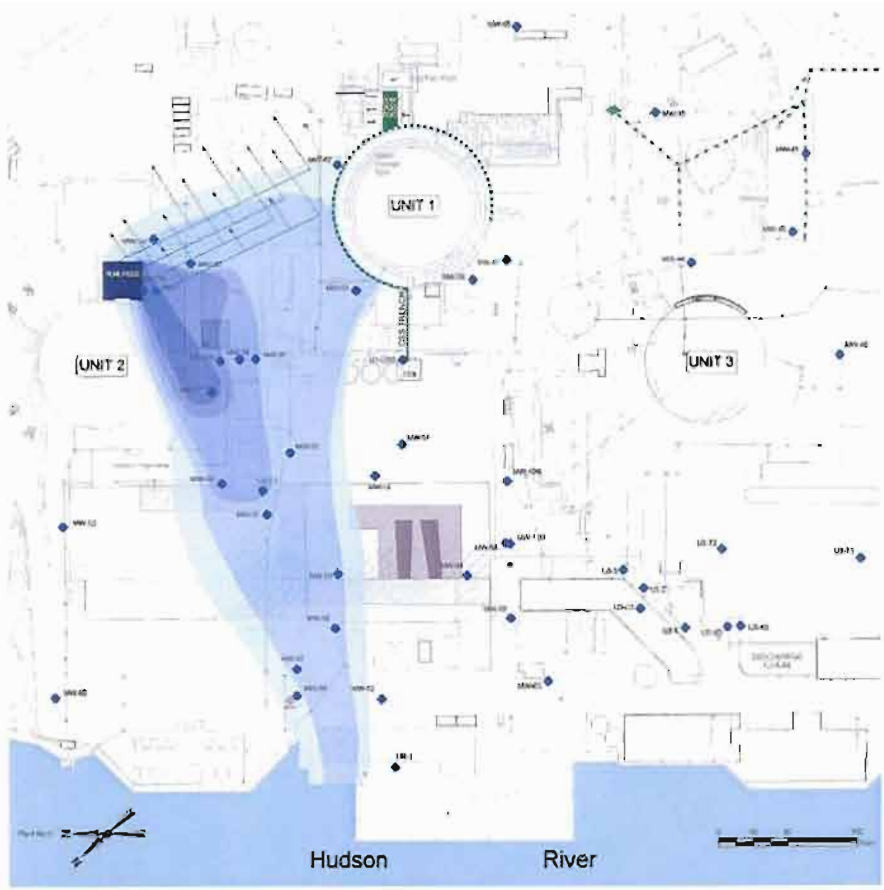
[62] In contrast, the levels of Tritium in the Unit 1 West pool are only on the order of 250,000 pCi/L. Strontium concentrations in IP2-SFP are on the order of 500 pCi/L.

[63] The 601,000 pCi/L Tritium concentration was measured during packer testing of the open borehole prior to multi-level completion. This value is therefore actually a *lower bound* estimate for depth-specific Tritium concentrations at that time. If the multi-level sampling instrumentation could have been completed prior to obtaining these data (not possible because the packer testing was required to design the multi-level installation), samples would have yielded *equal or higher concentrations*. This conclusion reflects the limited standard length and temporary emplacement of the packers used during the packer testing, and thus the greater potential for mixing and dilution between zones, as compared to the numerous packers permanently installed in the multi-level completions.

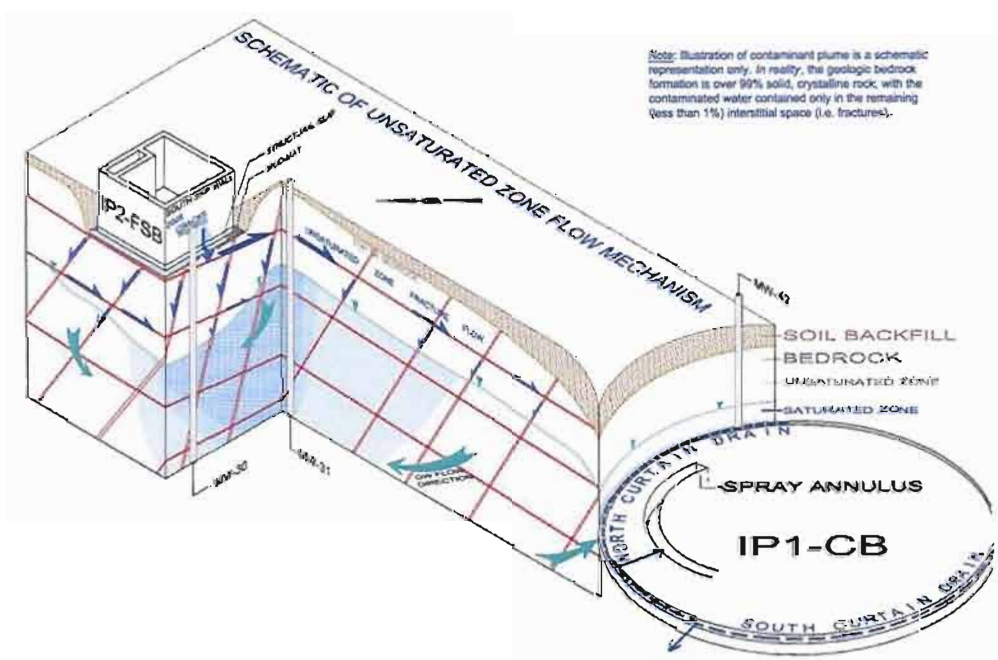
[64] It is noted that **Figure 8.1** does *not* show an actual Tritium plume; the isopleths presented contour upper bound concentrations for samples taken at *any time* and *any depth* at a particular location, rather than a 3-dimensional snapshot of concentrations at a single time. As such, this "plume" is an overstatement of the contaminant levels existing at any time. It should also be noted that the lightest colored contour interval begins at one-quarter the USEPA drinking water standard. While drinking water standards do not apply to the Site (there are no drinking water wells on or proximate to the Site), they do provide a recognized, and highly conservative, benchmark for comparison purposes). Lower, but positive detections outside the colored contours are shown as colored data blocks. See figure for additional notes.

[65] It is recognized that low concentrations of Tritium likely extend to the South, all the way to Unit 1. This conclusion is supported by: 1) the low Tritium concentrations remaining in IP1-SFPs (250,000pCi/L); 2) the data from MW-42 and MW-53; and 3) the Tritium balance between that released by the IP1-SFPs leak and that collected by the NCD. The transport mechanism is through *unsaturated* zone flow which follows bedrock fracture strike/dip directions rather than groundwater flow direction (see schematic of unsaturated zone flow mechanism included below). The levels of Tritium detected *upgradient* of IP2-SFP in monitoring wells MW-31 and MW-32 are also due to unsaturated zone transport from IP2-SFP along the generally southerly striking and easterly dipping bedrock fractures (see structural geology analysis in **Section 6.0** and tracer test discussions in **Section 7.0**).

[66] As the Tritium moves under the Discharge Canal, a significant amount discharges directly to the canal before the plume reaches the Hudson River.



UNIT 2 BOUNDING ACTIVITY ISOPLETHS



IP2-SFP UNSATURATED ZONE FLOW MECHANISM

The IP2-SFP contains both the fuel pool itself as well as its integral Transfer Canal. IP2-SFP is founded directly on bedrock which was excavated to elevation 51.6 feet for construction of this structure. As such, this pool's concrete bottom slab is located approximately 40 feet above the groundwater (as measured directly below the pool in MW-30[67]). During construction, a grid of steel "T-beams" was embedded in the interior surface of the 4-to 6-foot-thick concrete pool walls. These T-beams provided linear weld points for the 6 by 20 foot stainless steel liner plates. Given this construction method, an interstitial space exists between the back of the ¼-inch-thick stainless steel pool liner and the concrete walls. The space is expected to be irregular[68] and its exact width is unknown, but nominal estimates of a $^1/_8$ to ¼ inch are not unreasonable for assessing potential interstitial volume. Using these estimates, the volume of the space behind the liner could be on the order of 1500 gallons. In addition, the degree of interconnection between the spaces behind the individual liner plates is also expected to be highly variable given the likely variability of weld penetration into the "T beams." Therefore, the travel path for pool water that may penetrate through a leak in the liner is likely to be highly circuitous.

8.1.1 Direct Tritium Sources

Two confirmed leaks in the IP2-SFP *liner* have been documented, as well as the 2005 shrinkage crack leak through the IP2-SFP concrete wall[69]. The first liner leak dates back to the 1990 time frame, under prior ownership. This legacy leak was discovered and repaired in 1992. With the more recent discovery of the concrete shrinkage cracks in September 2005, Entergy undertook an extensive investigation of the IP2-SFP liner integrity. Within areas accessible to investigation, no additional leaks were found in the liner of the pool itself. However, after draining of the IP2-SFP Transfer Canal in 2007 for further liner investigations specific to the Transfer Canal, a single small weld imperfection was detected in one of these liner plate welds. This was the only leak identified in the Transfer Canal where the entire surface and all the welds could be and were inspected. This second liner leak is expected to have released tritiated pool water into the interstitial space behind this area of the liner plates whenever the Transfer Canal was filled above the depth of the imperfection (the Transfer Canal is currently drained and this imperfection will be welded leak-tight prior to refilling the Transfer Canal). All identified leaks have therefore been terminated. While additional active leaks can not be completely ruled out, if they exist, the data[70] indicate they must be very small and of little impact to the groundwater[71].

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[67] While similar and lower groundwater elevations persist downgradient to the West, the shallow groundwater elevations are much higher (up to approximately elev. 45 feet) within only 50 feet to the East (MW-31) and Southeast (MW-32) of the pool.

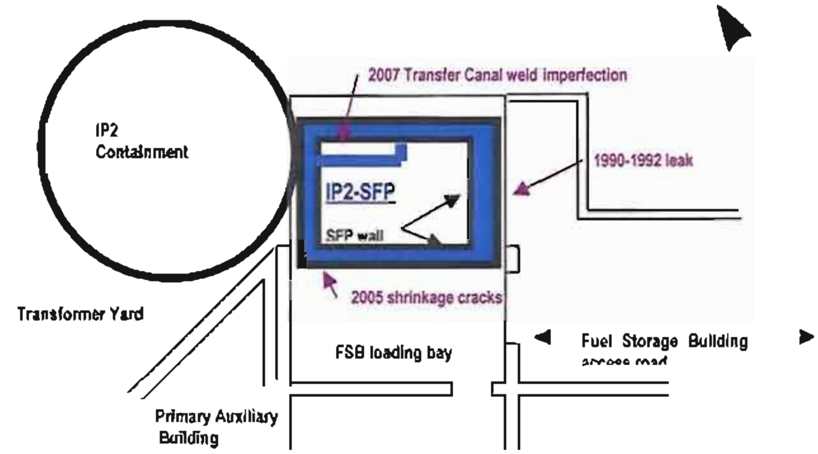
[68] The interstitial space width and uniformity will be related to the degree to which the concrete wall surface falls within a single plane. Because of the practicalities of forming and pouring concrete walls, we believe the surface is unlikely to be planer.

[69] While the 2005 leak from the shrinkage cracks does not appear to be related to a specific leak in the pool liner, it is considered a "direct source" because it still resulted in a release to the exterior of one of the plant's SSCs.

[70] These data include: monitored water levels in the SFP, with variations accounted for based on refilling and evaporation volumes; the mass of Tritium migrating with groundwater is small; and the age of the water in the interstitial space.

[71] For example, the 2005 shrinkage cracks still intermittently release small amounts of water; on the order of 10 to 20 ml/day. This water could represent a transient active leak, or it may just be due to residual water trapped behind the liner plates above the 2005 crack elevation still working its way slowly to the cracks. While this water is contained and prevented from reaching the groundwater, other such small leaks may exist which do reach the groundwater.

The three identified direct sources are discussed individually in the following paragraphs and shown on the figure below.



UNIT 2 FUEL POOL DIRECT SOURCE LOCATIONS

<u>IP2-SFP 1990-1992 Legacy Liner Leak</u> – This leak was first documented on May 7, 1992 when a small area of white radioactive precipitate was discovered above the ground surface on the outside of the IP2-SFP East concrete wall. This boron deposit exhibited radiological characteristics consistent with a potential leak from the pool. A camera survey was then conducted within the IP2-SFP to identify the location of the associated leak(s) in the liner. The survey initially revealed no damage to the liner. However, to further investigatory efforts, divers were utilized to visually inspect accessible portions of the liner. The divers found indications that the liner had been gouged when an internal rack had been removed on October 1, 1990. Two hundred and forty linear feet of the North and West IP2-SFP wall welds were then inspected and vacuum-tested to verify that the identified damage was isolated to this one case. No other leaks were identified, and on June 9, 1992, the leak was repaired.

Subsequent analyses conducted by the previous plant owner indicate that approximately 50 gallons per day could have leaked through the liner. This leak rate and the time scale of the release event would be expected to fill all the accessible interstitial space behind the liner[72]. Once the space behind the liner was filled to elevation 85 feet (the elevation of the 1990 cracks), water then began to leak out of the cracks in the concrete wall, with a maximum total release volume of up to 50,000 gallons. Given the very slow release rate (0.035 gal/min), the porous, hydrophilic nature of concrete, and the location of the leak at approximately five feet above the ground surface, a significant portion of the released water likely evaporated prior to entering the soils. However, given that the soils

[72] While the interstitial space was filling up to elevation 85 feet, any other cracks or joints in the concrete wall below this elevation, such as those identified in 2005, likely released contaminated water to the environment. As discussed below, it is hypothesized that with time, these subsurface cracks/joints may have become sealed due to precipitation of dissolved compounds, either carried with the pool water or derived from the concrete pool wall. This would have been required to allow retention of pool water in the interstitial space below elevation 85 feet after the liner leak was repaired in 1992, and thus subsequent leakage of the 2005 shrinkage cracks.

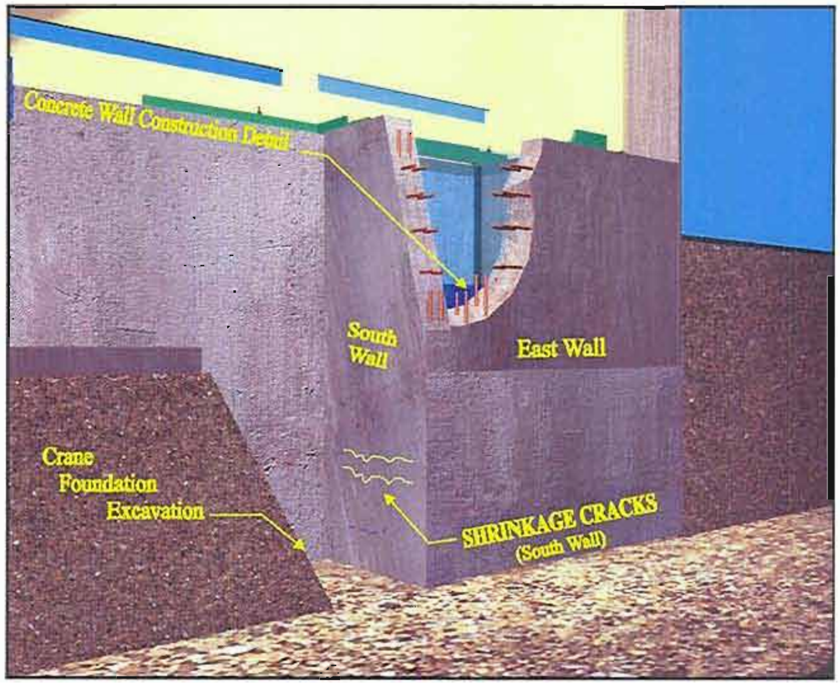
below the leak were found to be contaminated[73], it is clear that some portion of this release entered the subsurface. While Strontium and Cesium could have largely partitioned out of the pool water to the shallow soils, tritiated water would be expected to have continued to migrate downward to the groundwater.

IP2-SFP 2007 Transfer Canal Liner Weld Imperfection – As part of the recently completed liner inspections initiated by Entergy in 2005, the IP2-SFP Transfer Canal was drained in 2007 to facilitate further leak-detection efforts including vacuum box testing of the welds. These inspections discovered a single small imperfection in one of the liner plate welds on the North wall of the Transfer Canal at a depth of about 25 feet, which is approximately 15 feet above the bottom of the pool. All of the welds and the entire liner surface area of the Transfer Canal have been inspected by one or more techniques and no other leaks were found. Engineering assessments indicate this wall imperfection is likely from the original construction activity since there is no evidence of an ongoing degradation mechanism.

Given that the Transfer Canal is now drained, this weld imperfection is no longer an active leak site. However, the historic practice of maintaining water in the Transfer Canal likely resulted in a generally continuous release of pool water into the interstitial space behind the liner over time, and then potentially through the concrete pool walls and into the groundwater.

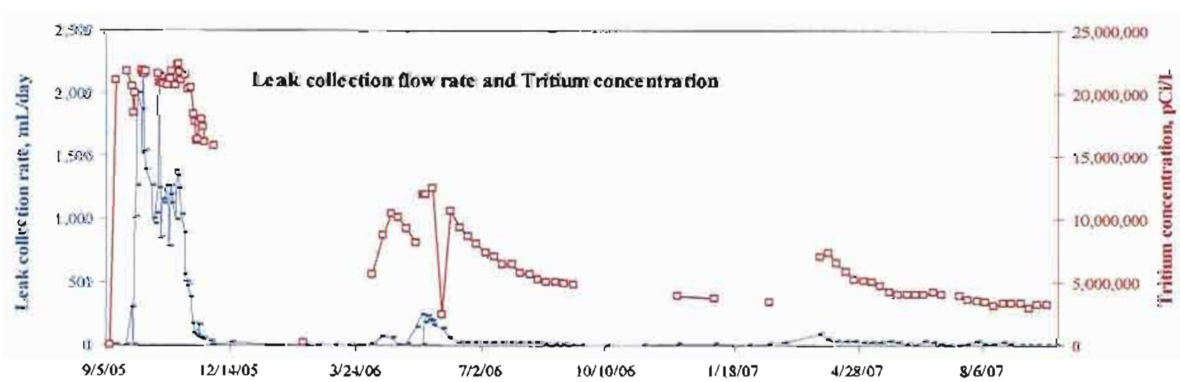
IP2-SFP 2005 Concrete Shrinkage Crack Leak - During construction excavation in September 2005 for the dry cask storage project, the South wall of the IP2-SFP was exposed and two horizontal "hairline" shrinkage cracks were discovered (see schematic below). These cracks exhibited signs of moisture, though fluid flow was not observed emanating from the cracks. To promote collection of adequate liquid volumes for sampling and analysis, the cracks were subsequently covered with a plastic membrane to retard moisture evaporation and enhance water vapor condensation. The trapped fluid was drained to a sample collection container. This temporary collection effort not only provided leak rate measurement capability and sufficient water for analysis, it also prevented further release to the groundwater.

[73] Approximately 30 cubic yards of radionuclide contaminated soils were excavated from the area in 1992.



UNIT 2 SFP 2005 SHRINKAGE CRACKS
IDENTIFIED IN SEPTEMBER 2005

Initially, the two cracks were found to be leaking at a combined average rate typically as high as 1.5 l/day (peak of about 2 l/day) from the time of crack discovery/initial containment through the fall of 2005. In early 2006, a permanent stainless steel leak containment and collection device was installed. This containment was also piped to a permanent collection point such that any future leakage from the crack could be monitored and prevented from reaching the groundwater. Subsequent monitoring through 2006 and into 2007 has indicated that the leakage rate had fallen off rapidly and become intermittent with an average flow rate of approximately 0.02 l/day, when flowing (see figure below presenting shrinkage crack flow rate and Tritium concentration over time). This small amount of leakage is permanently being contained and it therefore is not impacting the groundwater.



UNIT 2 2005 SHRINKAGE CRACK LEAK RATE AND TRITIUM LEVELS

Based upon two years of flow and radiological and chemical sample data, it appears that excavation of the backfill from behind the pool wall caused the shrinkage cracks to begin releasing water trapped in the interstitial space dating back to 1992. This release mechanism is hypothesized to have developed as follows:

- During the original construction, the fuel pool walls developed shrinkage cracks in the concrete upon curing, as is not atypical for concrete.
- When the pool walls were backfilled with soil, they flexed inward slightly in response to the soil pressures developed during backfill placement and compaction[74].
- The pool was then filled with water which exerts an outward pressure against the walls. However, little outward flexure would be expected given the stiffness of the compacted soil backfill, which assists the concrete walls in resisting outward bending motion due to the water pressure.
- The stainless steel pool liner was punctured in 1990 and began leaking. Over time, this leak filled the interstitial space between the liner and the concrete walls. tritiated pool water then likely first leaked out of the lower-most cracks/joints, such as those responsible for the 2005 leak (elevation 62 to 64 feet), and successively leaked out of higher imperfections until it reached the cracks at elevation 85 feet. At this point, leakage was detected and the leak was fixed in 1992.
- At some point during the leakage, the subsurface cracks apparently became plugged with precipitate which stopped the leakage. This allowed pool water to remain trapped behind the liner at an elevation above the 2005 shrinkage cracks, potentially as high as elevation 85 feet. To the extent that the subsurface cracks/joints in the concrete did not all become completely leak-tight, the interstitial space behind the liner was likely recharged by leakage from the Transfer Canal weld imperfection (up until Transfer Canal drainage in July 2007) and/or other small leak sites in the liner.
- With excavation of the soil backfill from behind the southern pool wall, the pressure exerted by the backfill material was sequentially removed from the top to the base of the concrete wall. The elimination of this inwardly focused backfill pressure allowed the outwardly directed water pressure in the pool to flex the wall outward. It is hypothesized that this motion, while limited, was sufficient to initiate leakage from the 2005 shrinkage cracks at a rate of approximately 1.5 l/day during the fall/winter of 2005.
- The released water is believed to be primarily residual water derived from the 1990-1992 liner leak. However, laboratory results for water samples initially collected from the crack in the September 2005 time frame yielded Cesium-137 to Cesium-134 ratios indicating that the age of the water was approximately 4 to 9 years old. This age does not directly correlate with the 1990-1992 release timeframe. Conversely, the water clearly had exited the pool many years ago. A potential explanation for this intermediate age water is the mixing of water from a then-current small leak in the liner with 1992 age water.
- Over time, the shrinkage crack leak reduced the elevation of the residual water trapped behind the liner to the elevation of the cracks. Beginning in 2006 and through 2007, the leak rate was observed to have quickly become intermittent with typical leak rates, when leaking, of only approximately 0.02 l/day. These

[74] While the 4-to 6-foot-thick concrete walls are stiff, some flexure is required for the walls to develop bending stresses.

subsequent water samples did not contain Cesium-134, indicating that this more recent crack water could, in fact, be old enough to be from the 1990-1992 leak[75].

- As a corollary to the above conceptual model, the intermediate-aged crack water may be partially comprised of leakage from the Transfer Canal weld imperfection. This release pathway could potentially explain the measured intermittent and variable leakage collected in the permanent containment system after 2005. The variations in water elevation and temperature in the Transfer Canal are consistent with this hypothesis. While the Transfer Canal leak water would be recent, it is likely that it would take a substantial amount of time to flow from the North wall of the Transfer Canal to the South wall of the IP2-SFP[76]. This hypothesis is therefore consistent with the lack of short-lived isotopes (as associated with SFP water) currently being found in the water from the shrinkage crack. A more significant leak rate with shorter transit times (e.g., the magnitude of the 1990-92 leak) would be expected to, and did previously show, short-lived radionuclide signatures.
- Although several additional theories have also been postulated and investigated, a definitive explanation of the apparent discrepancy in Cesium age ratios could not be definitively determined. This discrepancy from the early sample data when the crack location was first investigated was an important factor in Entergy's decision to perform intensive pool and ongoing Transfer Canal liner inspections.
- It can also be concluded from the above data and analysis that any ongoing active leak in the pool liner, if one exists, must be quite small. Otherwise, the limited volume of the interstitial space between the liner and the concrete wall would transport a more substantial leak to the shrinkage cracks in a short time and the water would thus show a young age[77].

8.1.2 Indirect Storage Sources of Tritium

The extensive testing of the IP2-SFP liners to date by Entergy provides evidence that all direct sources (i.e., releases from SSCs) of Tritium have been identified and are currently no longer contributing radionuclides to the groundwater[78]. However, the Unit 2 plume, while decreased in concentration relative to the samples taken just after

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[75] Cesium-137 was present at sufficient concentrations that if the water was "young", Cesium-134 would have also been present at concentrations above method detection limits. It is further noted that the two isotopes of Cesium should partition to solids at the same ratios. Therefore, preferential removal of the Cesium-134 due to partitioning to the concrete is not an explanation for the lack of this isotope in the more recent crack water samples.

[76] It is noted that the seepage path(s) from the liner leak on the North wall of the Transfer Canal to the shrinkage cracks on the southern pool wall is likely to be particularly circuitous. The interstitial space between these two liners can only be connected (if they are connected at all) at the gate from the Transfer Canal to the fuel pool and/or through imperfections in the concrete wall/floor waterstops or in the concrete itself (given the five-foot-thick concrete wall separating the Transfer Canal from the SFP itself).

[77] As a benchmark, pool water from a one-tenth of a gallon per minute leak would be expected to reach the shrinkage crack in less than two weeks given the estimated volume of the interstitial space.

[78] However, some small amount of leakage could still be ongoing from other potential imperfections in the liner and/or concrete pool wall; large ongoing leaks would result in conditions inconsistent with the measurements of both leak rate and water age collected from the 2005 shrinkage crack. A large leak would also be inconsistent with the reductions observed in the Tritium concentrations in the groundwater.

identification of the 2005 shrinkage crack leak[79], still exhibits elevated concentrations. If all of the releases to the groundwater were terminated, it would be expected that the Unit 2 plume would attenuate more quickly than observed[80]. As such, a subsurface mechanism appears to exist in the unsaturated zone under the IP2-FSP that can retain substantial volumes of pool water for substantial amounts of time. The existence of such a "retention mechanism" is also supported by both the results of the tracer test and the recent evaluation of contaminant concentration variability trends over short timeframes and precipitation events.

The tracer test results, discussed more fully in **Section 7.0**, indicate that:

- Tracer injection directly to the top of bedrock below the IP2-SFP above MW-30 did not result in arrivals at MW-30 in time frames expected for vertical transport through the fractured bedrock vadose (i.e., unsaturated) zone. In fact, the earliest arrivals and maximum tracer concentrations were detected in MW-31 and MW-32 at distances of greater than 50 feet from the injection location;
- Tracer concentrations in MW-30 took longer than expected to reach peak concentrations from the time of first arrival;
- The tracer concentration vs. time curves exhibit a "long tail;" and
- The tracer concentrations exhibit significant variation over short periods of time, which may be related to precipitation events moving tracer out of storage.

It is, therefore, apparent that once tracer, and thus tritiated water, is released from directly below the IP2-SFP, it does not flow directly down to the groundwater but can be "trapped" (held in storage) for substantial periods of time.

The Tritium concentrations in MW-30 were measured on a weekly basis between August 8 and August 30, 2007 (see **Section 9.3.1**). These data show significant variability in concentrations over these short timeframes. This variability appears to far exceed that which can be attributed to variation inherent in groundwater sampling or radionuclide analyses. Aliquots submitted for tracer concentration testing also showed similar trends. It appears that these variations may be the result of the displacement of water, as evidenced by both tracer and Tritium, from this storage mechanism by infiltration such as associated with precipitation events.

Based on the above summarized information, two indirect storage mechanisms are postulated to explain the persistence of the Unit 2 plume. The first is the storage of tritiated water in dead-end fractures in the unsaturated zone. The second is the potential for tritiated water from the SFP to be trapped in the blast-rock backfill above the "mud-mat[81]"

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[79] The earliest samples taken from directly below the SFP in MW-30 (open borehole and packer testing samples) yielded Tritium concentrations over 600,000 pCi/L. More currently, maximum concentrations detected have been below one-half of those initial concentrations.

[80] Rapid attenuation of the Tritium plume would be expected based on 1) Tritium's lack of partitioning to solid materials in the subsurface; and 2) the crystalline nature, low storativity and high groundwater gradients associated with the bedrock on the Site.

[81] Prior to constructing a structural base slab (typically 2 to 5 feet thick) for the fuel pool, a 6-to 8-inch-thick, lean concrete "mud-mat" is typically constructed over blasted bedrock to even out the irregular rock surface and provide a

which was placed prior to construction of the SFP structural base slab. A combination of these two indirect storage mechanisms, as discussed separately below, is a conceptual model that explains the observed Unit 2 plume behavior in the context of the termination of the identified direct release mechanisms[82].

<u>Dead-Ended Bedrock Fracture Storage</u> - Naturally occurring bedrock fractures, as discussed in **Section 6.0,** are seldom long, continuous linear features. Rather, they are more typically networks of interconnected, discontinuous fractures. These networks often contain many dead-ended fractures. While dead-ended fractures are not subject to advective groundwater flow, they still can contain high contaminant concentrations. Contaminants enter these fractures through osmotic pressures set up in the subsurface by concentration gradients (initially high concentrations at the fracture "mouth" and low concentrations within the fracture). Over time, these concentrations equilibrate through liquid-phase diffusion. Therefore, under conditions of high Tritium groundwater concentrations, such as likely occurred during the two year timeframe of the 1990-1992 liner leak, the dead-ended fractures would be expected to end up containing high Tritium concentrations. Once the liner leak was repaired, the input of Tritium to the groundwater would subside and the concentrations in the advective fractures would start to decrease. However, the high Tritium concentrations within the dead-ended fractures would then start to diffuse back out of the dead-ended fractures into the groundwater flowing past them, thus maintaining higher than otherwise expected Tritium concentrations in the groundwater.

Our computation of the volume of the naturally occurring dead-ended fractures in the unsaturated zone below the IP2-SFP yields fracture volumes which are unlikely to support the observed Unit 2 plume for the required time frames (years). However, two additional considerations substantially increase the dead-ended fracture volume: 1) the observed unsaturated flow to the East and Southeast (this migration pathway exposes many more fractures to the Tritium due to the bigger area involved); and 2) construction blasting (which creates more fractures in the bedrock remaining below the structure).

As demonstrated vividly during the tracer test, contaminants released to the bedrock at the bottom of the SFP travel at least 50 to 75 feet to the East and Southeast as evidenced by the high tracer concentrations quickly detected in the upgradient monitoring wells

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hard, flat surface upon which to set the reinforcing rod "chairs" (these chairs elevate the lowest layer of rods to provide sufficient concrete corrosion prevention cover).

[82] It is noted that we originally believed that the groundwater in the Unit 2 Transformer Yard was uncontaminated with Tritium prior to February of 2000. If true, this finding would be inconsistent with the storage mechanisms proposed. Our original conclusion was based on the sampling results at that time from MW-111; this well was sampled as part of the due diligence for property transfer to Entergy and was found not to contain Tritium above detection limits (900 pCi/L). However, interviews with facility personnel revealed that the sample was collected from the upper surface of the water table with a bailer. There was no attempt to purge the well to obtain samples representative of deeper aquifer water because the samples were taken primarily to look for floating oil in the well. Because this sample was collected from the upper groundwater surface (which will be most subject to infiltration by rain water) without adequate well purging, it is likely that this sample result was biased low. As discussed in **Section 9.0**, this well is subject to wide variations in Tritium concentrations due to rainfall events. Therefore, it is entirely plausible that no Tritium was detected above laboratory method detection limits even if Tritium were present at much higher concentrations deeper in the aquifer. As such, this February 2000 groundwater sample result should not be used to assess Tritium groundwater conditions at that time. See supporting data in **Section 9.3.1**.

MW-31 and MW-32[83]; the same behavior would be expected for Tritium. This wide areal distribution would substantially increase the volume of dead-ended fractures available for storage of contaminants.

In addition to naturally occurring fractures, the founding elevation of the SFP was achieved through construction blasting of the bedrock. While the bulk of the blasted rock was removed to allow construction, a zone of much more highly fractured bedrock typically remains after the founding elevation is reached. While these blast-induced fractures may be interconnected, they may not be fully connected to tectonic fractures that intersect the groundwater, and thus would be dead-ended. Therefore, contaminated water may be stored in these fractures and periodically escape in response to precipitation events.

<u>Blast-Rock Backfill Storage</u> - Following blasting of the bedrock to accommodate the IP2-SFP foundation, standard construction practice would have been to pour a mud-mat[84]. Based on construction photographs, it appears that the areal extent of the blasting was not much bigger than the dimensions of the structural slab for the SFP; this would be typical given standard contracting specifications and the cost of blasting. Therefore, it would be expected that the mud-mat was poured directly against the face of the bedrock excavation, without the use of forms. This hypothesis was confirmed visually during the 2005 excavation alongside the IP2-SFP for dry cask gantry crane foundation construction.

The concrete for a mud-mat is typically placed in a relatively fluid state to enhance self-leveling properties. As this fluid concrete is placed, it is typically pushed up against the perimeter forms, or in this case the bedrock face. This placement procedure would be expected to coat and seal off the fractures in the lower portion of the bedrock sidewalls. While the height above the surface of the mud-mat to which this seal would be formed is highly variable and occurrence-specific, it would not be unreasonable to find a 2-to 6-inch high "lip" of concrete against the bedrock. The net effect would have been to create storage volume above the mud-mat, between the sides of the subsequently constructed structural floor slab and the bedrock sidewalls directly at the base of the SFP. While this space was likely filled with blast-rock fill, the pore volume of this material available for pool water storage could easily be over 30 percent of the total volume. This results in a substantial storage volume when compared to that required to "feed" and maintain the Unit 2 plume over time.

During the 1990-1992 liner leak, a large volume of highly tritiated water appears to have been released from the pool, thereafter traveling down the exterior of the SFP concrete wall. This travel path would place the pool water directly into the hypothesized storage containment. Once full, additional pool water would overtop the containment, migrate into fractures that were not sealed off by concrete, and then travel through the unsaturated zone. Once in the unsaturated bedrock, some tritiated water would quickly

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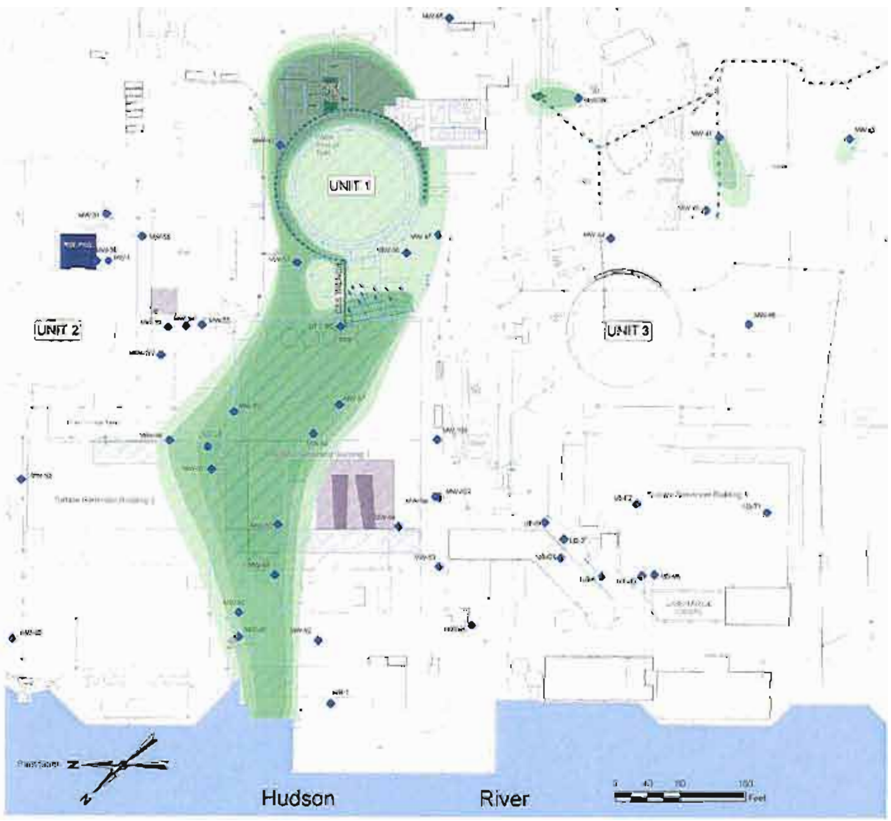
[83] Tracer reached MW-31 and MW-32 in less than four hours (time of first sample), thus supporting the conclusion of unsaturated zone transport to these locations.

[84] A 6-to 8-inch, lean concrete "mud-mat" is typically constructed over blasted bedrock to even out the irregular surface and provide a hard flat surface upon which to set the reinforcing rod "chairs" (these chairs elevate the lowest layer of rods to provide sufficient concrete cover for corrosion prevention).

reach the groundwater and some would be retained in dead-ended fractures, as discussed above. Over time, rainfall events would be expected to repeatedly displace pool water out of the containment and into the bedrock fractures. Contaminated water would therefore continue to impact the groundwater even if all active leaks from the pool were terminated. We believe this process could continue over substantial periods of time[85].

8.2 UNIT 1 SOURCE AREA

The Unit 1 contamination, as shown on **Figure 8.2** and the figure included below, is often referred to as the Strontium "plume"[86]. This is because the other radionuclides detected, including Tritium, Cesium-137, Nickel-63 and Cobalt-60, have a smaller radiological impact when compared to Strontium-90 and the Strontium is found in the entirety of the plume's areal extent, while the other contaminants are found only sporadically and in smaller subsets of the plume's area. The Tritium data for the Unit 1 plume is included on **Figure 8.1** and the Cesium-137, Nickel-63 and Cobalt-60 data are presented on **Figure 8.3**.



UNIT 1 BOUNDING ACTIVITY ISOPLETHS

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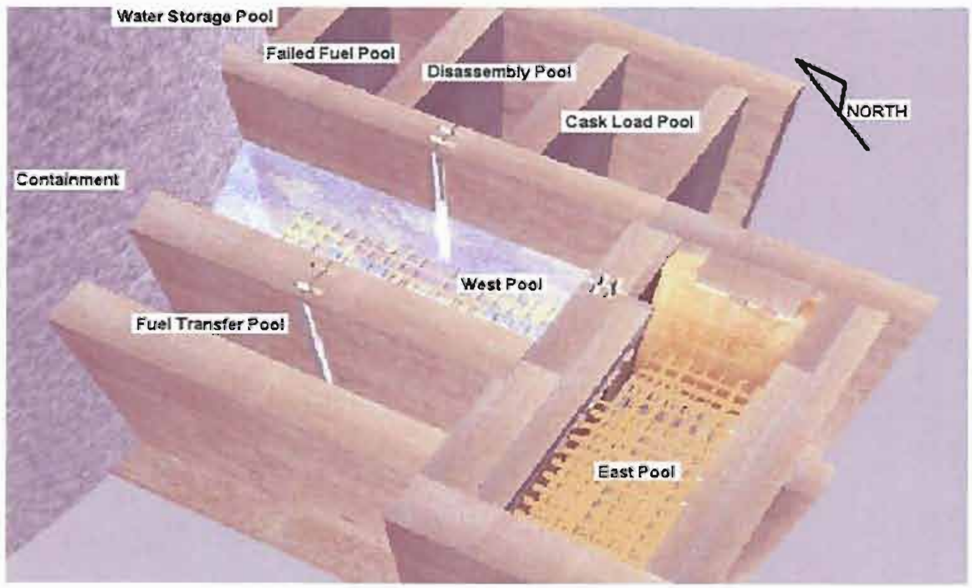
[85] See footnote No. 58 above relative to the reported Tritium results for MW-111 as sampled in May of 2000.

[86] It is noted that **Figure 8.2** does <u>not</u> show an actual Strontium plume; the isopleths presented contour upper bound concentrations for samples taken at *any time* and *any depth* at a particular location, rather than a 3-dimensional snapshot of concentrations at a single time. As such, this "plume" is an overstatement of the contaminant levels existing at any time. It should also be noted that the lightest colored contour interval begins at one-quarter the USEPA drinking water standard. While drinking water standards do not apply to the Site (there are no drinking water wells on or proximate to the Site), they do provide a recognized, and highly conservative benchmark for comparison purposes). Lower, but positive detections outside the colored contours are shown as colored data blocks. See figure for additional notes.

The highest levels of Strontium (up to 110 pCi/L) were originally found adjacent to the North side of IP1-SFPs in MW-42[87]. However, since Entergy began processing the pool water to remove the Strontium, the levels of Strontium (and other radionuclides) in this well have decreased. From MW-42, the Unit 1 "plume" tracks downgradient with the groundwater along the North side of the Unit 1 Superheater and Turbine Buildings[88]. As this plume approaches and moves under the Discharge Canal, it commingles with the Unit 2 plume, and discharges to the river[89] between the Units 1 and 2 intake structures, as does the Unit 2 plume. As discussed in **Section 6.0**, the plume track appears to follow a more fractured, higher conductivity preferential flow path in this area.

The source of all the Strontium contamination detected in groundwater beneath the Site has been established as the IP1-SFPs. The IP1-SFPs were identified by the prior owner as leaking in the mid-1990's, and are estimated to currently be leaking at a rate of up to 70 gallons/day. A schematic of this pool complex is included below.



UNIT 1 FUEL POOL COMPLEX

The IP1-SFPs were constructed of reinforced concrete with an internal low permeability coating[90]; stainless steel liners were not included in the design of these early fuel pools. The pool wall thickness ranges from 3 to 5.5 feet thick. The bottom of the IP1-SFPs is

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[87] The highest concentrations of the other contaminants associated with the Unit 1 plume, including Cesium-137, Nickel-63 and Cobalt-60 were also found in well MW-42. This location is very close to the IP1-SFPs and it is therefore not unexpected to find these higher concentrations of less mobile radionuclides near the source.
[88] This general introductory discussion of the Unit 1 plume is focused specifically on the "primary Unit 1 plume." Further more detailed discussion of the other "secondary Unit 1 plumes," which all originate from the IP1-SFPs, is provided in subsequent subsections.
[89] As is the case with the Tritium from the Unit 2 plume, some Strontium discharges directly to the Discharge Canal before the plume reaches the Hudson River.
[90] The original coating failed and was subsequently removed.

founded directly on bedrock, generally at elevation 30 feet[91]. As such, there is no significant unsaturated zone below the IP1-SFPs. While all of the pools have been drained except the West Pool, the other pools have all contained radionuclide at various times in the past. The West pool, which is approximately 15 feet by 40 feet in area, currently contains the last 160 Unit 1 fuel assemblies remaining from prior plant operations. This plant was retired from service in 1974.

The IP1-SFPs are contained within the IP1-FHB. The foundation system of the FHB and IP1-CB complex contains three levels of subsurface footing drains (see figure included below). The design objective of these drains, with the potential exception of the Sphere Foundation Drain (SFD)[92], appears to be permanent depression of groundwater elevations to below the bottom of the structures[93].

North and South Curtain Drains - The uppermost IP1-FHB drain encircles the Unit 1 FHB and IP1-CB. This footing drain, typically referred to as the Curtain Drain, is divided into two sections, the North Curtain Drain (NCD) and the South Curtain Drain (SCD). Each of these drains starts at a common high point (elevation of 44 feet) located along the center of the eastern wall of the FHB. These drains then run to the North and South, respectively, and wrap around the Unit 1 FHB and CB. The NCD then discharges to the spray annulus in the IP1-CB[94] at an elevation of 33 feet. From the annulus, the water is pumped for treatment and then discharged. The NCD flows at a yearly average of about 5 gpm carrying a Strontium concentration of 50 to 200 pCi/L (concentrations measured prior to reductions in Unit 1 pool water radionuclides via accelerated demineralization). The SCD pipe remains as originally designed with discharge to the Discharge Canal; however, the SCD is typically dry[95].

Chemical Systems Building Drain - The lowest level of the IP1-CSB (contained within the FHB) is also encompassed by a footing drain. The eastern portion of this drain begins at a high point elevation of 22 feet at its northernmost extent, located proximate to the IP1-CB, and then slopes to elevation 11.5 feet at its low point on the southern side of the IP1-CSB. The western portion of this drain begins at a high point elevation of 12.5 feet at its northernmost extent, again located proximate to the IP1-CB, and then slopes to elevation 11.5 feet at its low point on the southern side of the IP1-CSB. Both portions of the drain join at the southern side of the IP1-CSB where the common drain line runs below the floor slab and drains into the IP1-SFDS (bottom elevation of 6.5 feet). This drain typically flows

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[91] The bottom elevation of the individual pools range from a high elevation of 36 feet for the Water Storage Pool to a low of 22 feet for the Transfer Pool.

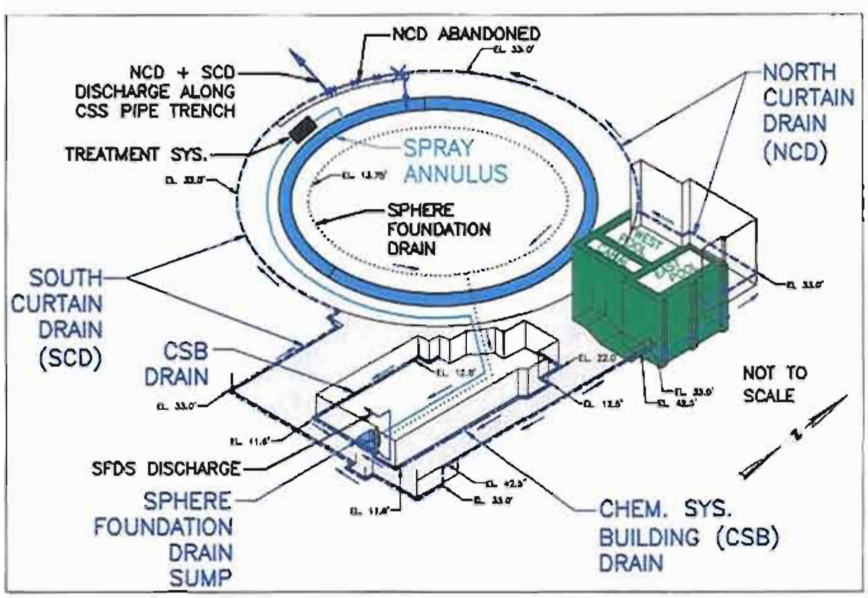
[92] The SFD is constructed at an elevation of 16.5 feet. It is above the bottom of the Sphere (elevation -11 feet) and completely encapsulated in either concrete or grout.

[93] The elimination of hydrostatic uplift pressures allows a "relieved design" to be used for the bottom concrete slabs of the structures. The alternative to a relieved slab design is a "boat slab design." In this case, the slab is heavily reinforced to resist hydrostatic uplift pressures. Boat slabs are more expensive to construct than relieved slabs, and thus are typically only used when it is not feasible to relieve the hydrostatic uplift pressures.

[94] This design modification within the IP1-CB, to allow storage of the footing drain water prior to treatment, was implemented by the former owner once the water was found to contain radionuclides. The initial Unit 1 design connected the two 12-foot perforated footing drain lines into a common 15-inch tee and drain pipe at the entrance to the Nuclear Service Building. This 15-inch footing drain pipe was collocated in the bedrock trench containing the spray annulus to CSS drain line.

[95] The lack of water in the SCD is consistent with the expected impact of the CSB drain given its proximity and lower elevation.

at a yearly average of 10 gpm carrying a Strontium concentration of not detected (ND) to 30 pCi/L.



UNIT 1 FOOTING DRAINS AND DISCHARGE SUMP

Sphere Foundation Drain - The third foundation drain below the IP1-FHB and IP1-CB complex is the SFD. This drain is located directly around the bottom portion of the Sphere and consists of: 1) nine perforated pipe risers spaced around the sphere and tied into a circumferential drain line at elevation 13.75 feet; 2) each vertical riser is surrounded by a graded crushed stone filter; and 3) all of which are within a clean washed sand which encompasses the Sphere from elevation 25 to 16.5 feet (the "sand cushion"). The sand cushion is "sandwiched" between the concrete foundation wall, the Sphere and the grout below the Sphere; it is open at the top, proximate to the annulus. As such, it appears that this drain does not interface with the groundwater, except to the extent that some leakage may occur through imperfections in joint seals. This drain is also connected to the SFDS through a valve.

During the development of the initial Conceptual Site Model, it was understood that the IP1-SFPs were currently leaking, but it was concluded that the footing drainage systems would contain any releases from the IP1-SFPs. This was also the conclusion of a previous analysis performed for the prior owner in 1994[96]. This conclusion was based on:

- The proximity of the drains to IP1-SFPs; in fact, the NCD runs along the North and East walls, and in conjunction with the SCD, completely encompasses the IP1-SFPs;
- The generally downgradient location of the drains relative to the IP1-SFPs;
- The elevation of the drains relative to the bottom of the IP1-SFPs;

[96] *Assessment of Groundwater Migration Pathways from Unit 1 Spent Fuel Pools at Indian Point Power Plant, Buchanan, NY*; The Whitman Companies, July 1994

- The elevation of the drains relative to the surrounding groundwater elevations[97];
- The continuous flow of the drains, even during dry periods; therefore, the groundwater surface does not drop below, and thus bypass, the drains;
- The reported predominant southerly strike and easterly dip of the bedrock fractures relative to the southerly location of the CSB footing drain; this expected anisotropy should extend the capture zone of this drain preferentially to the North towards the IP1-SFPs; and
- The existence of IP1-SFPs pool water constituents in the drain discharge[98].

In February 2006, Strontium was detected in the downgradient, westerly portion of the IP2-TY (downgradient of IP2-SFP). Given that Strontium could not reasonably be associated with a release from the Unit 2 SFP, the most plausible source remaining was the retired Unit 1 plant where: 1) the SFPs historically contained Strontium at approximately 200,000 pCi/L (prior to enhanced demineralization[99]); and 2) legacy leakage was known to be occurring. Based on this finding, we concluded that either: 1) an unidentified mechanism(s) must be transporting IP1-SFPs leakage beyond the capture zone of the footing drains[100]; or 2) other sources of Strontium existed on the Site. A number of plausible hypotheses potentially explaining each of these two scenarios were therefore developed, and then each was investigated further. During these investigations, additional detections of Strontium were also identified, including some relatively low concentrations in the area of Unit 3. However, with completion of the investigations and associated data analyses, it was concluded that *all of the Strontium detections could be traced back to leakage from the IP1-SFPs*. These Strontium detections can be grouped into five localized flow paths, each associated with a different IP1-SFPs release area. Collectively, these flow paths define the overall Unit 1 "plume[101]" as listed below:

- The primary IP1 flow path;
- The eastern IP1-CB_flow path;
- The southwestern IP1-CB_flow path;
- The IP1-CSS trench flow path; and
- The legacy IP1 storm drain flow path.

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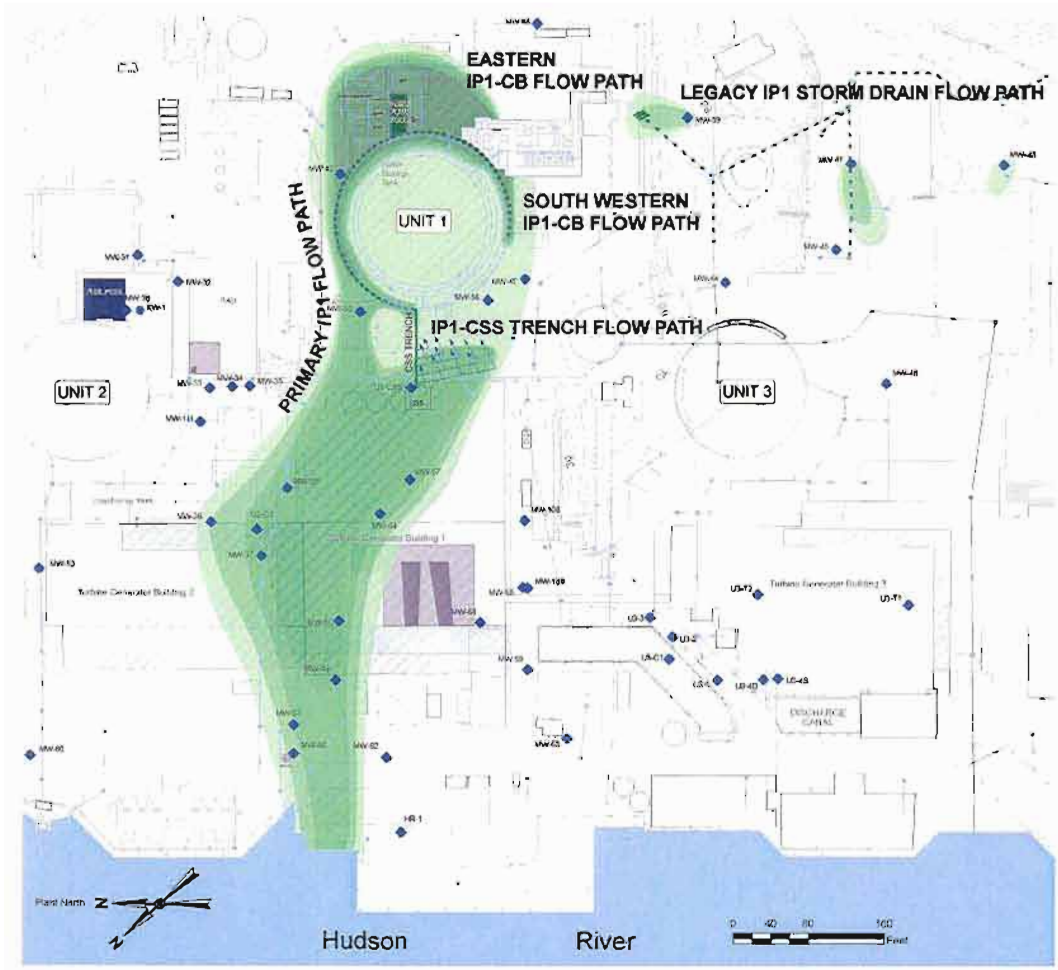
[97] This line of evidence remained supportive of the initial conclusion until the installation of MW-53, which occurred during the third phase of borings (after the discovery of Strontium in the groundwater).
[98] Drain water is treated prior to discharge as permitted monitored effluent.
[99] Strontium levels in IP1-SFPs have been more recently reduced to approximately 3,000 pCi/L under accelerated filtering through demineralization beds. Tritium concentrations in IP1-SFPs are on the order of 250,000 pCi/L.
[100] Once Strontium-contaminated pool leakage enters the groundwater, it is transported in the direction of groundwater flow; Strontium, as well as the other potential radionuclides, do not migrate in directions opposing groundwater flow (with the exception of diffusive flow which is insignificant as compared to advective flow under these hydrological conditions). Therefore leakage entering the groundwater within the capture zone of the footing drains is captured by those drains.
[101] The grouping of Strontium detections into contiguous "plumes" may be an over-simplification, and the detections may, in reality be due to small, isolated individual groundwater entry points and flow paths from the IP1-SFPs. This is likely to be particularly true pursuant to the IP1 Legacy Piping "flow path."



INDIVIDUAL UNIT 1 STRONTIUM FLOW PATH LOCATIONS

The discussions below are focused on the discovery and characterization of these individual flow paths, and the final mechanisms that best explain their existence. Other initially plausible mechanisms were also investigated as part of the Observational Method approach employed[102], but they did not remain plausible in light of the subsequently developed data and analyses, and are therefore not discussed herein. In addition, portions of the discussions below also relate to the concurrent investigation of other potential source areas across the Site. During review of the following sections, it is important to recognize that only small quantities of leakage are required to result in the groundwater plumes observed on the Site.

Primary IP1 Flow Path – Monitoring well MW-42 was initially installed to investigate the premise that contaminants may be leaking into the subsurface from the IP2-Reactor Water Storage Tank (RWST). However, the sample analysis made it clear that IP1-SFPs water was present in the groundwater at MW-42; the radiological profile was consistent with

[102] As indicated above, multiple initially plausible hypotheses potentially explaining the genesis of these flow paths were developed and investigated. These investigations proceeded in a step-wise, iterative manner consistent with the Observational Method, whereby various aspects of the Conceptual Site Model (CSM) were modified to develop an overall CSM that better fit all of the data. Not all mechanisms investigated remained plausible in light of all the data and analyses developed as part of this hypothesis-testing.

Unit 1 fuel pool water (low Tritium, high Strontium and Cesium). While IP1-SFPs leakage was known to be ongoing, this conclusion was *not* consistent with the CSM at the time which was predicated, in part, on containment of IP1-SFPs leakage by the footing drains (North and South curtain Drains, and the Chem. Sys. Building Drain).

An additional monitoring well, MW-53, was subsequently installed downgradient of MW-42 (on the Northwest side of the IP1-CB). Groundwater in this well was also apparently impacted by IP1-SFP water, thus resulting in the initial steps in the identification of the Unit 1 primary Strontium flow path. The groundwater elevations measured in MW-53 proved even more enlightening than the radiological profile. In the case of a *continuously flowing* footing drain such as the NCD, groundwater would generally be expected to be flowing into the drain over the entire length of the drain; the corollary to this conclusion is that the groundwater elevation would be above the drain invert along its entire extent. Otherwise, water flowing into the drain along its eastern, upgradient extent would exfiltrate the drain along its western, downgradient extent and thus, water would no longer discharge out of the end of the drain into the IP1-CB Spray Annulus; it would therefore *not* typically be *continuously flowing*. However, the groundwater elevation in MW-53 was measured at approximately elevation 9 to 10 feet, substantially lower than the water table elevation in MW-42 (35 feet) and the elevation of the NCD invert (33 feet). Therefore, it was found that only a portion of the groundwater which infiltrated the drain to the East was observed as continuous flow at the Spray Annulus collection point. The remainder of the water was exfiltrating along the drain further to the West[103], where groundwater elevations were below the drain invert and thus outside the capture zone of the drain.

Therefore, leakage from the IP1-SFPs was initially being captured by the NCD, but then during transport to the Annulus for collection and treatment, a portion of this leakage was discharging to the groundwater outside the capture zone of the drain. This leakage then migrates downgradient to the West with the groundwater and establishes the Unit 1 primary Strontium flow path.

Eastern IP1-CB Flow Path - A Strontium plume is shown on **Figure 8.2** as existing below the entire IP1-SFPs. With the exception of MW-42, there are no monitoring wells in this area to verify that this plume actually exists. However, it is known that the IP1-SFPs have and continue to leak, and the NCD and CSB footing drains have been shown to contain radionuclides consistent with that expected from IP1-SFPs' leakage. The locations of the specific release points are not known, but could be anywhere along the walls and bottom of the IP1-SFPs.

Once leakage from any of the above postulated points enters the groundwater, it will migrate either to the NCD or the CSB drain, depending on where the specific release point is located relative to these drains. Leakage located along the northeastern portions of the IP1-SFPs is likely to migrate to the NCD (elevation 33 feet), whereas leakage located more to the South and West is more likely to migrate to the lower CSB drain (elevation 22 to

[103] It is hypothesized that, in the past, the drain likely did not flow continuously. However, over time, the exfiltration rate has been reduced through siltation such that the drain can no longer release water over its western extent as fast as it infiltrates into the drain further to the East.

11.5 feet). These scenarios, when considered for multiple potential release points, should result in Strontium flow paths that are all contained within the plume boundaries shown on the figure.

Southwestern IP1-CB Flow Path - As part of the investigations to identify other potential releases to the groundwater across the Site, low levels of Strontium (less than 3 pCi/L) were detected in monitoring wells MW-47 and MW-56. Groundwater contamination in this area was inconsistent with the known sources and the groundwater flow paths induced by the IP1-CSB footing drains. A summary of the investigations and analyses undertaken to identify the release mechanism responsible for this Strontium flow path follows.

Construction drawings indicate that the IP1-CB and the IP1-FHB were constructed with an inter-building seismic gap and stainless steel plate between the two structures. This construction detail creates a preferential flow path for any pool leakage through the western walls of the IP1-SFPs, as well as leakage from other locations which migrates to the western side of the IP1-SFPs[104]. While this "plate/gap" separates the structures all the way down through the structural foundation slabs, it likely would not have penetrated the mud-mat[105]. In addition, it would not be uncommon for the surface of the mud-mat to *not* be completely cleaned prior to pouring of the structural slab. Even small amounts of soil, mud, dust, etc. between the mud-mat and the structural slab above would result in a preferential flow path along the top of the mud-mat. Therefore, it is expected that pool leakage in this zone (between the structural slab and the mud-mat) could flow laterally and would still be isolated from the fractured bedrock below. It would then, in turn, also be isolated from the influence of the footing drains (both the NCD and the IP1-CSB drain). To the extent that the above hypotheses are correct, this leakage could then build up and flow along the plate and above the top of the mud-mat. With sufficient input of leakage from the pool, the elevation of this flowing water could also rise above the top of the IP1-CB footing[106].

With the above hypothesized conditions, pool leakage may migrate along the plate all the way around the IP1-CB to the South and West until it reaches the end of the plate (at the intersection of the perimeter of the IP1-CB with the IP1-FHB). At that location, the water would follow the top of the mud-mat (and/or top of footing) along the IP1-CB bottom slab further to the West[107]. This leakage flow path is highlighted on **Figure 8.2**. The leakage water would not be constrained to flow into the SCD given that this footing drain is dry. Once past the end of the plate, the pool leakage could enter the bedrock at multiple points, wherever it encounters bedrock fractures. Thereafter, the leakage would enter the groundwater and thus be constrained to migrate in the direction of groundwater flow.

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[104] This hypothesis is further supported by the presence of weeps of contaminated water (SFP leakage) in the eastern wall of the IP1-CB at the footing wall joint.

[105] While not shown on the constructions drawings reviewed "as required", construction photos show that a mud-mat was placed prior to rebar cage construction (also see discussion of rationale under Tritium source areas above). Given the consistent bottom elevations of both the VC and the SFPs structural concrete slabs, a single mud-mat was likely constructed.

[106] Leakage flow above the top of the footing (elevation 33 feet) to the East and Southeast of the VC would not be captured by the SCD given that this drain is dry.

[107] See discussion of likely mud-mat/bedrock excavation wall configuration and the impact of precipitation events in the section above under Tritium source areas.

As shown on the figure, pool leakage entering the groundwater along the South side of the IP1-CB would be expected to mound the groundwater somewhat. This is particularly true in this case given the leakage entry point within the "flat zone" encompassing the groundwater divide between flow to the river to the West and flow to the East to the CSB footing drain[108]. The portion of the pool leakage which flows West would form the southwestern IP1-CB Strontium flow path and thus explain the low levels of Strontium found in MW-47 and MW-56. From this point, the "plume" continues to flow West and joins the primary Strontium flow path.

<u>IP1-CSS Trench Flow Path</u> - During the course of the investigation for potential sources, MW-57 exhibited significant Strontium concentrations. Strontium was also detected in the upgradient IP1-CSS, located in the Unit 1 Superheater Building. This sump was investigated to evaluate the extent to which it may be associated with the contamination identified to the West, near the Discharge Canal. A retired subsurface pipe, designed to drain water from the Unit 1 Spray Annulus to the CSS, was determined to be the input source path for water observed within the sump. During Unit 1 construction, this pipe was installed within a 3-foot-wide trench cut up to 20 feet into bedrock, which slopes downward from the Spray Annulus to the CSS[109]. Construction drawings further indicate that this trench was backfilled with soil. This pipe had been temporarily plugged in the mid-1990's when contaminated water from the NCD was routed to the Spray Annulus. However, the temporary inflatable plug was later found to be leaking and the pipe was then permanently sealed with grout.

As part of our investigations, a monitoring well (U1-CSS) was installed horizontally through the East wall of the CSS at an approximated elevation of 4 feet. This horizontal well is connected to a vertical riser which extends to above the top of the CSS. Water levels in this well typically range from elevation 12 to 18 feet and respond rapidly to precipitation events.

Based upon available data, we believe the IP1-CSS is not a source of contamination to the groundwater. Inspections of the sump indicate the likely entry point for water periodically found in the sump is the pipe from the IP1 Spray Annulus, the joint between the concrete sump wall and the sump ceiling (the floor of the Superheater Building), and/or the joint in the sump wall where the pipe penetrates from the rock trench into the sump. These conclusions are based on:

- The groundwater elevations measured in U1-CSS are above the bottom of the CSS which is generally nearly empty (bottom elevation of 1.0 feet);
- The results of the tracer test confirmed that contaminated groundwater can enter the CSS when it is empty; and
- Visual inspections of the interior of the sump and associated piping.

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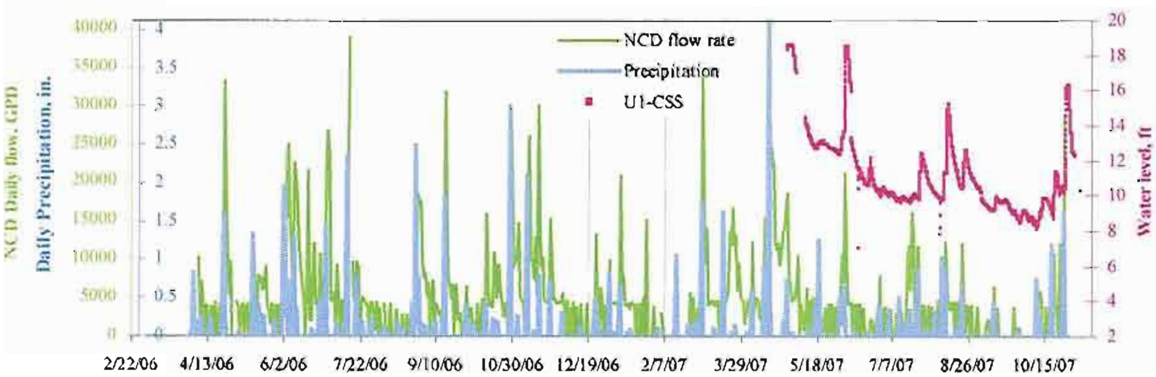
[108] While a groundwater divide must exist between the CSB footing drain and river to the West, the exact location of the divide is unknown.

[109] The trench bottom starts at elevation 22.75 feet at the Spray Annulus and slopes gradually to elevation 21.75 feet at a point 9 feet from the CSS. From this point, the trench slopes steeply to elevation 13 feeet at the CSS.

This sump is no longer in service as the system it supported is retired.

While the CSS itself does not appear to be a release point, we believe the associated bedrock trench between the Spray Annulus and the CSS is a source of contamination to the groundwater. As indicated above, the Spray Annulus is used to store releases collected from the IP1-SFPs by the NCD, which contains contaminants. The Annulus water has been historically documented as leaking into the pipe and surveys indicate that the pipe itself likely leaks into the trench. While the leak into the pipe from the Spray Annulus was sealed, other leakage inputs to the trench also likely exist. One such likely leakage path is for water to flow directly from the NCD through the drain backfill and abandoned piping[110] to the pipe trench. This flow path is supported by the trends in U1-CSS water elevation variation as compared to the NCD discharge rate (see figure included below).



UNIT 1 NCD FLOW, U1-CSS GROUNDWATER ELEVATION AND PRECIPITATION RELATIONSHIPS

These hypothesized leakage paths are highlighted on **Figure 8.2**. Once leakage enters the trench, it should flow along the sloped bottom until it finds bedrock fractures through which to exfiltrate. This leakage will then flow through the unsaturated zone along the strike/dip of the fractures until it encounters the saturated zone, and thereafter will follow groundwater flow.

Because of these hypothesized, but probable conditions, we concluded that leakage has exited the trench and impacted groundwater. Impacts directly to the groundwater below the pipe trench are characterized by Strontium concentrations in monitoring well U1-CSS. In addition, source inputs to the groundwater from the trench are also envisioned to have occurred farther to the South, where the groundwater flow would then carry contamination to MW-57, thus explaining the Strontium concentrations found in that well[111]. While southerly flow in this area is inconsistent with groundwater flow direction, source inputs can migrate from the bedrock trench to the South in the *unsaturated* zone near the

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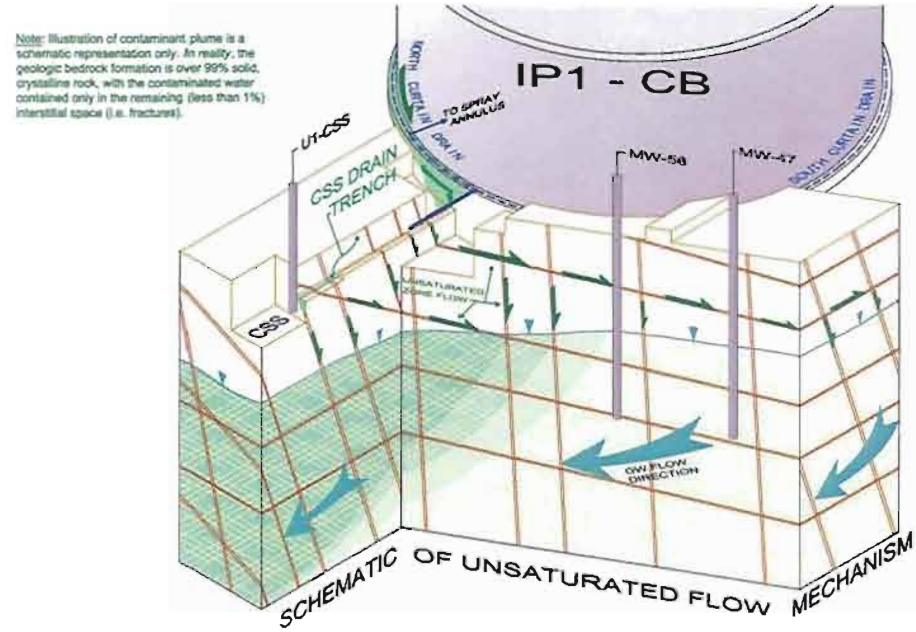
[110] As noted above, the NCD discharge was rerouted into the Spray Annulus when the NCD was found to contain contaminants by the previous owner. Prior to this modification, the footing drain was routed to a 15-inch drain line collocated in the CSS pipe trench. The abandoned piping and permeable backfill still exist and likely act as an anthropogenic preferential flow path.

[111] Monitoring wells U1-CSS and MW-57 do not appear to be in the groundwater flow path of the primary Unit 1 "plume."

CSS, where the unsaturated zone is relatively deep[112]. This hypothesized unsaturated zone flow path is shown on **Figure 8.2,** as well as the schematic included below.



IP1-CSS TRENCH UNSATURATED ZONE FLOW MECHANISM

In addition, the construction details of the Superheater East wall may also channel saturated flow to the South, depending on variation in groundwater elevations. These less direct leakage inputs then establish the southern portion of the source area for the CSS trench flow path such that the groundwater flow carries the "plume" through monitoring well MW-57, thus explaining the Strontium found in samples collected from this well[113].

__Legacy IP1 Storm Drain Flow Path__ – As summarized above, the CSB footing drain collects groundwater from the vicinity of the IP1-SFPs; this water has been documented to contain radionuclides. The contaminated water is then conveyed to the SFDS, located at the southern end of the CSB. In addition, historical events, including CSB sump tank overflows in Unit 1, have impacted the SFDS.

Prior to construction of Unit 3, water collected in the SFDS was pumped up to elevation 65 feet and discharged to the stormwater system on the South side of the Unit 1 CSB. The discharge was conveyed by these drains to the South towards catch basin U1-CB-9 (currently under the access ramp to Unit 3), and then West (U1 CB-10) under what is now the IP3-VC toward the Discharge Canal. This pathway was re-routed during construction of Unit 3 in the early 1970s to flow South from catch basin U1-CB-9, then further South towards catch basin U3-CB-A4 and subsequently to the Discharge Canal through the

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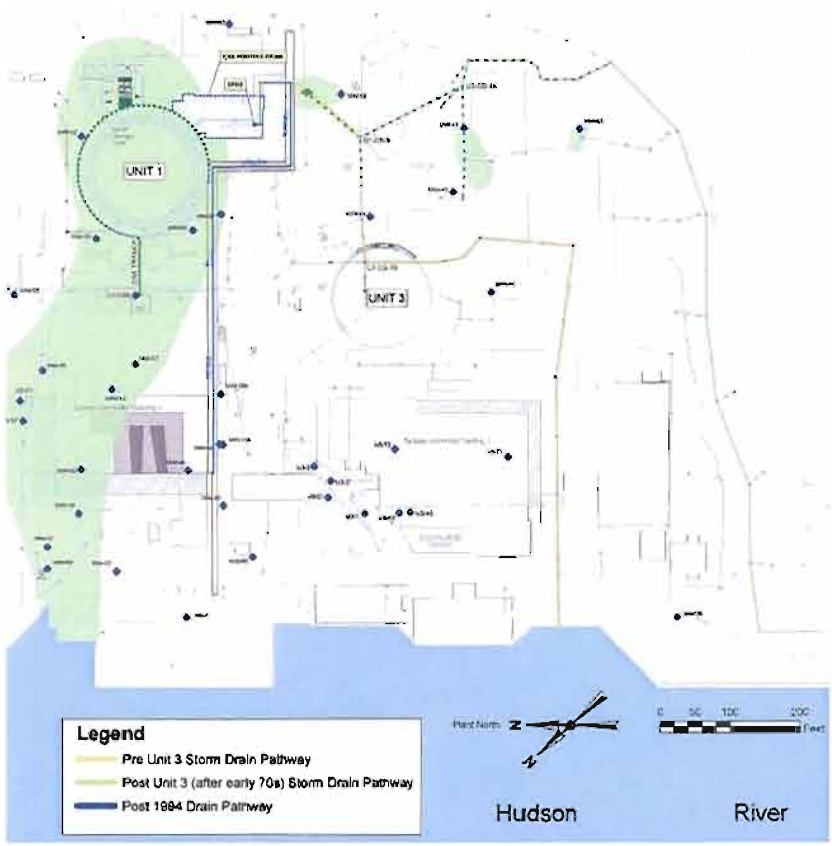
[112] The hypothesized southerly flow of a portion of the trench leakage to the South through the unsaturated zone is consistent with: 1) the strike/dip direction of major joint sets found on Site; and 2) the groundwater flow path from the resulting unsaturated zone input to the wells which identified this Strontium flow path.
[113] This well appears to be located outside, and upgradient of, the primary Unit 1 Strontium flow path to the North.

E-Series storm drains. (See figure included below and **Figure 8.2** where these pathways are also highlighted.)



DIFFERING SPHERE FOUNDATION DRAIN SUMP DISCHARGE PATHWAYS OVER TIME

A recent inspection of the storm drain system, including smoke tests and water flushing, has revealed that a number of pipes along these sections have been compromised and are leaking. Strontium found in groundwater on the South side of the Unit 1 FSB, and upgradient of Unit 3, is coincident with the locations of these stormwater pipes. Therefore, we concluded that some of the contaminated water discharged into these pipes exfiltrated, and then migrated downward through the unsaturated zone and contaminated the groundwater, thus resulting in the "legacy" storm drain flow path[114]shown on **Figure 8.2**.

In 1994, this discharge route was changed again, when contamination was detected in the effluent from the Unit 1 SFDS. The pipe leading from the SFDS towards Unit 3 was capped, and discharges were thereafter routed directly to the Discharge Canal through a series of interior pipes as well as a radiation monitor. As such, the storm drain lines to the

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[114] Three discrete isopleths have been drawn around MW-39, MW-41 and MW-43 given the measured concentrations greater than 2 pCi/L. However, it is expected that similar concentrations exist at other locations along the legacy piping alignment in addition to those shown on the figure. During the historic active discharge to the storm drains, it is expected that the individual leak areas would have resulted in commingling of the groundwater contamination into a single "plume" area. This "plume" would have then migrated downgradient across the Unit 3 area. With the cessation of discharge to the storm drains, the "plume" attenuated over time, leaving downgradient remnants which are still detectable as low level Strontium contamination in Unit 3 monitoring wells such as MW-44, 45 & 46, U3-T1 & 2, and U3-2.

South of Unit 1 no longer carry this contaminated water and they are therefore no longer an active source of contamination *to the groundwater*.

However, from a contaminant plume perspective, these historic releases still represent an ongoing legacy source of Strontium *in the groundwater* to the South side of Unit 1. This is because Strontium partitions from the water phase and adsorbs to solid materials, including subsurface soil and bedrock. The Strontium previously adsorbed to these subsurface materials then partitions back to, and continues to contaminate, the groundwater over time, even after the storm drain releases have been terminated.

As shown on **Figure 8.2**, low level residual evidence of this legacy pathway was identified in monitoring wells installed to South of Unit 1 during the course of the investigations proximate to potential sources associated with Unit 3. Strontium, Cesium and Tritium were detected in these wells at levels below the EPA drinking water standard. Three monitoring wells to the South of Unit 1 show "Legacy Storm Drain flow paths" drawn around them. These wells have yielded samples at one time/depth with Strontium concentrations greater than 2 pCi/L, or one-quarter of the Strontium-90 drinking water standard. While the actual extent of these Strontium concentrations is not known given that each has been drawn around a single point, they appear to be limited in extent (based on the data from the surrounding monitoring wells). It is also important to recognize that the specific locations of the historic releases from the storm drain lines are not known. In addition, once water has exfiltrated from the drain line, it moves generally downward in the unsaturated zone as controlled by the strike/dip direction of the specific bedrock fractures encountered. Therefore, legacy groundwater contamination does not have to be located immediately downgradient of the storm drain system (as exemplified by the Strontium found in MW-39 and tracer in MW-42). While three isopleths are shown on **Figure 8.2**, we believe it is possible that other areas in the general vicinity of this piping may exhibit similar groundwater concentrations. We have also concluded that the lower concentrations of Strontium detected in monitoring wells further downgradient, in the Unit 3 area, are also due to these historic, legacy storm drain releases.

9.0 GROUNDWATER CONTAMINATION FATE AND TRANSPORT

Strontium (the Unit 1 plume) and Tritium (the Unit 2 plume) are the radionuclides we used to map the groundwater contamination. The investigation focused on these two contaminants because they describe the relevant plume migration pathways, and the other Site groundwater contaminants are encompassed within these plumes.

While radionuclide contaminants have been detected at various locations on the Site, both the on-Site and off-Site analytical testing, as well as the groundwater elevation data, demonstrate that groundwater contaminants are not flowing off-Site and do not flow to the North, East or South. Groundwater flow and thus contaminant transport is West to the Hudson River via: 1) groundwater discharge directly to the river; 2) groundwater discharge to the cooling water canal, and 3) groundwater infiltration into storm drains, and then to the canal.

The primary source of groundwater Tritium contamination is the IP2-SFP. The resulting Unit 2 plume extends to the West, towards the river, as described in subsequent sections.

The source of the Strontium contamination is the IP1-SFPs. Previous conceptual models, based on information presented in prior reports, indicated that releases from the IP1-SFPs were likely captured through collection of groundwater from the Unit 1 foundation drain systems. However, based upon groundwater sampling and tracer test data, we now know that the Unit 1 foundation drain system, particularly the NCD, is not hydraulically containing *all* groundwater contamination in this area (see **Section 8.0**).

GZA's understanding of the Tritium source and Strontium source are discussed in more detail in **Section 8.0**. The plumes described on the figures in the following subsections are based on: 1) the isopleths bounding the maximum concentrations, as representative of "worst case conditions"[115] (**Figures 8.1** and **8.2**); and 2) the most recent laboratory data collected through August 2007, as representative of current conditions (**Figures 9.1, 9.2, 9.3** and **9.4**). While the figures showing upper bound isopleth concentrations do not show actual conditions, we believe these graphics are useful in developing an understanding of groundwater and radionuclide migration pathways.

In reviewing this section please note the plumes show our current understanding of how anthropogenic features influence groundwater flow patterns, in particular the various footing drains and backfill types used during construction. Also note that flow in the

[115] It is noted that these figures (**Figures 8.1** and **8.2**) do *not* show actual plumes; the isopleths present contoured upper bound concentrations for samples taken at *any time* and *any depth* at a particular location, rather than a 3-dimensional snapshot of concentrations at a single time. As such, these "plumes" are an overstatement of the contaminant levels existing at any time. It should also be noted that the lightest colored contour interval begins at one-quarter the USEPA drinking water standard. While drinking water standards do not apply to the Site (there are no drinking water wells on or proximate to the Site), they do provide a recognized, and highly conservative benchmark for comparison purposes). Lower, but positive, detections outside the colored contours are shown as colored data blocks. See figure for additional notes.

unsaturated zone plays an important role in both the timing of releases to the water table and in the spreading of contaminants.

Based upon the results of GZA's geostructural analysis, the extent of contaminated groundwater, the 72 hour Pumping Test, the tracer test and tidal response tests, we believe that the bedrock underneath the Site is sufficiently fractured and interconnected to allow the Site to be viewed as a non-homogenous and anisotropic porous media. Based on this finding, and because advection is the controlling transport mechanism, groundwater flow, and consequently contaminant migration in the saturated zone, is nearly perpendicular to groundwater contours on the scale of the Site.

9.1 AREAL EXTENT OF GROUNDWATER CONTAMINATION

Based on measured tracer velocities (4 to 9 feet per day; see **Section 7.4**), the limited distances between release areas and the river (typically less than 400 feet), the age of the plumes (years), and recent interdictions, we believe contaminant plumes have reached their maximum size and are currently decreasing in size. Consequently, our reporting in this section focuses on observed, "current" conditions (the summer of 2007). That is, we saw no need to mathematically predict future conditions.

9.2 DEPTH OF GROUNDWATER CONTAMINATION

Because of the location of Indian Point on the edge of the Hudson River, the width of the river, and the nature of contaminants of potential concern, groundwater flow patterns (and, consequently, contaminant pathways) are relatively shallow. Furthermore, as discussed in **Section 6.0**, the upper portion of the aquifer (typically, the upper 40 feet of the bedrock) has a higher average hydraulic conductivity than the deeper portions of the bedrock. Consequently, the center of mass of the contaminated groundwater is shallow.

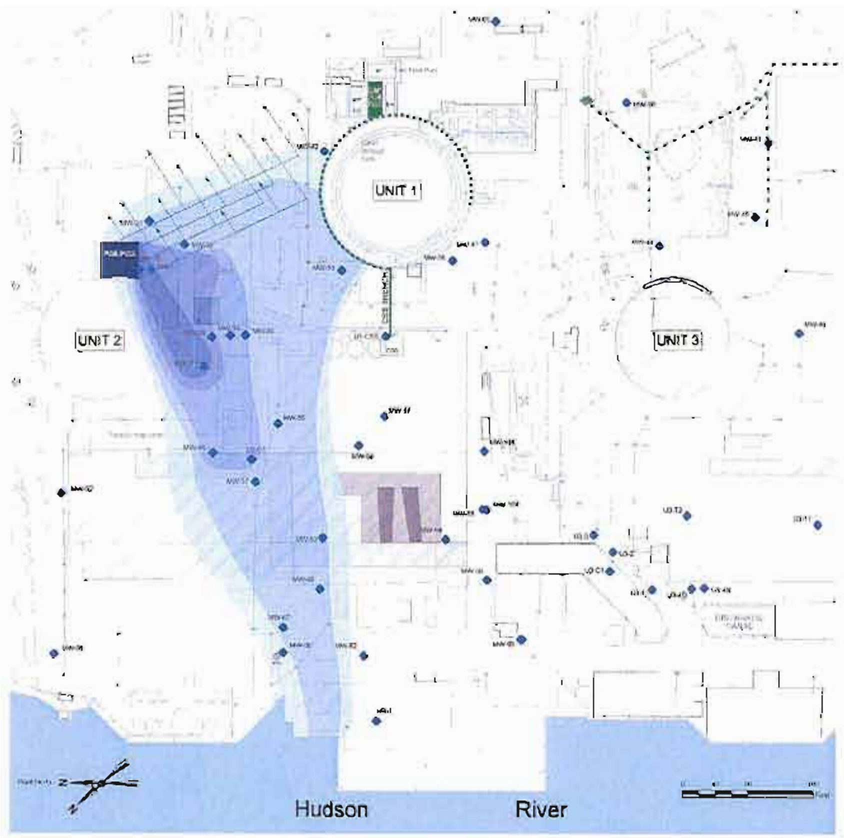
Figures 9.1 and **9.2** are cross sections which show the approximate vertical distribution of Tritium and Strontium, near the center lines of the Unit 1 and Unit 2 plumes, in the summer of 2007 ("current conditions"). In reviewing these figures, note that Strontium was not found below a depth of 105 feet in MW-67. We attribute the low concentrations of Tritium below a depth of 200 feet at this location, at least in part, to the downward migration of Tritium during our investigations. For example, by necessity, well RW-1 was an open wellbore for a period of time[116] which allowed vertical groundwater migration, along an artificial preferred pathway, deeper than would occur along ambient flow paths.

9.3 UNIT 2 TRITIUM PLUME BEHAVIOR

As shown on **Figures 8.1** and **9.3**, the Unit 2 plume exhibits Tritium concentrations originating at the IP2-SFP. The higher concentration isopleths are shown around the entire

[116] RW-1 is located immediately below the 2005 shrinkage crack leak (high Tritium concentrations in shallow groundwater). This well had remained as an open wellbore for periods of time in preparation for and during: 1) the drilling of the wellbore; 2) the packer testing; 3) the geophysical logging; and. 4) the Pumping Test. During these times, vertically downward gradients likely moved some Tritium to levels deeper than it would otherwise exist. When possible, this wellbore has been sealed over its entire length using a Flute Liner System.

pool area so as to include the location of the shrinkage crack leak in the South pool wall, the location of the 1992 leak on the East wall, and the location of the weld imperfection in the North wall of the IP2 Transfer Canal. We believe the core of the plume, as shown, is relatively narrow where Tritium flows downgradient (westerly) to MW-33 and MW-111 in the Transformer yard[117]. This delineation is based on: 1) the degree of connection[118] observed from MW-30 to MW-33 (as compared with that from MW-30 to MW-31 and/or MW-32) as being indicative of a zone of higher hydraulic conductivity limiting lateral dispersion; and 2) the localized increased thickness of the saturated soil in the vicinity of MW-111 (see **Figure 1.3**) which likely behaves as a local groundwater sink/source for westerly bedrock groundwater flow, prior to entering the associated backfill of the Discharge Canal.



BOUNDING UNIT 2 ACTIVITY ISOPLETHS

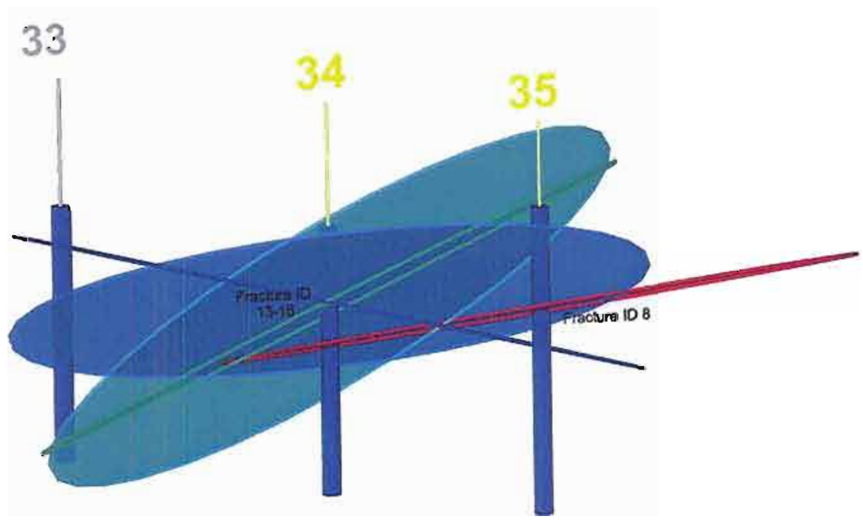
Tritium has been detected in MW-31 and MW-32, both of which are upgradient of the IP2-SFP. As evidenced by the tracer test (see **Section 7.0**) and hydraulic heads, this

[117] The bedrock in this area was excavated via blasting to allow foundation construction. As such, the upper portions of the bedrock are likely highly fractured in this area. In addition, the pre-construction bedrock contours (see **Figure 1.3**) indicate that the particularly deep depression in the bedrock in the Transformer yard in the vicinity of MW-111 (filled with soil down to elevation 0 feet) was likely excavated to serve as a dewatering sump. The associated deeper blasting-induced fracturing and the saturated soil backfill are also likely to further increase the transmissivity in this area.

[118] The degree of connection is inferred based on both the similar static water levels in MW-30 and -33 (separated by over 100 feet), as contrasted to the much higher water levels in MW-31 and -32 located about 65 feet from MW-30, and the rapid change in water elevation in MW-30 in response to water level perturbations in MW-33 (e.g., during drilling/sampling), with little or no response in MW-31 and -32.

occurrence involves gravity flow along bedrock fractures in the unsaturated portion of the bedrock beneath the IP2-SFP. This unsaturated flow direction is consistent with the dominant foliations (which strike to the Northeast and dip to the Northwest). This behavior is shown on the figure by dashed arrows and the isometric insert (see **Section 8.1**). This mechanism also accounts for some of the Tritium found near Unit 1 and is also supported by the results of the tracer test (see **Section 7.3**). However, once the contaminated water enters the local groundwater flow field, it migrates via advection in a direction generally perpendicular to the groundwater contours (i.e., with the groundwater flow).

In the IP2-TY, the plume is drawn as more dispersive in response to the concentrations measured in MW-34 and -35 as well as the high degree of connection observed between MW-33, -34 and -35 along an orientation transverse to the general groundwater flow direction. See the figure below for a schematic of the three dimensional fracture orientations in this area that account for the observed lateral dispersion. In this general area, the Unit 2 plume is bounded to the South by MW-54 and to the North by MW-52.



**Transmissive Fractures In MW-34 and MW-35
at Approximately Elevation 3**

3 - DIMENSIONAL BEDROCK FRACTURE ORIENTATIONS

At the western boundary of IP2-TY, Tritium flows into the highly conductive soil backfill found along the eastern wall of the Discharge Canal (see **Figure 1.3**). This conclusion is supported by both the groundwater elevations and Tritium concentrations in MW-36.

The groundwater elevations with depth in MW-36 indicate that once in the Discharge Canal backfill, the groundwater flows downward below the canal wall and, subsequently, into both the Discharge Canal (lower water elevation in the canal) as well as under the canal through the bedrock fractures (see **Section 6.7.2.2** for an estimate of the relative flows to these two discharge locations). Once on the western side of the Discharge Canal, as evidenced by groundwater elevations and Tritium concentrations in MW-37, -49, and

-67, groundwater flow and Tritium migration is to the Hudson River, via both bedrock and unconsolidated material along the riverfront.

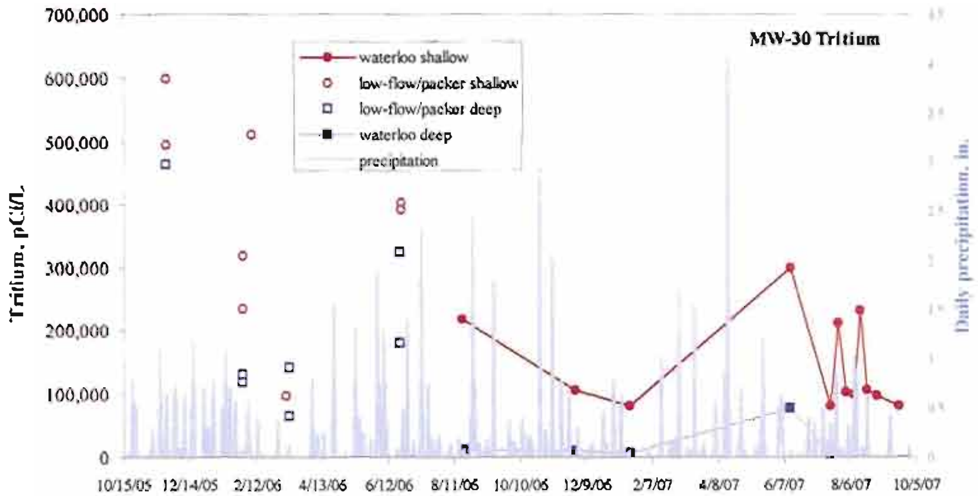
The specific flow path for the Tritium detected in MW-37-22 (located in the fill on the West side of the canal) is not certain. It is however associated with either: 1) upward groundwater flow into the backfill from the bedrock beneath the canal, as supported by the upward vertical hydraulic gradients; 2) groundwater flow into the blast rock fill on the West side of the canal, with northerly flow in the fill to, and around the North end of the canal and then southerly along the East side of the canal to MW-37; and/or 3) exfiltration from the stormwater piping between MH-4 and MH-4A into the fill on the western side of the canal, with a similar flow path as described in 2). See **Section 7.5** for additional information. Regardless of the upstream flow path to MW-37-22, the groundwater flow direction from this location is westerly toward the Hudson River. Also note that the exact pathway to this location does not change the results of the groundwater flux calculations to be used in radiologic dose impact assessments.

Both **Figures 8.1** and **9.3** show a southern component of flow as the Tritium migrates West towards the river. This pathway corresponds with the location of several East-West trending fractures zones and a fault zone. It is likely that this area is characterized by a zone of higher transmissivity that induces the contaminated groundwater to migrate as shown on these figures. We also note that it appears groundwater flow from higher elevations to the North also impedes a more northerly contaminant migration pattern.

9.3.1 Short Term Tritium Fluctuations

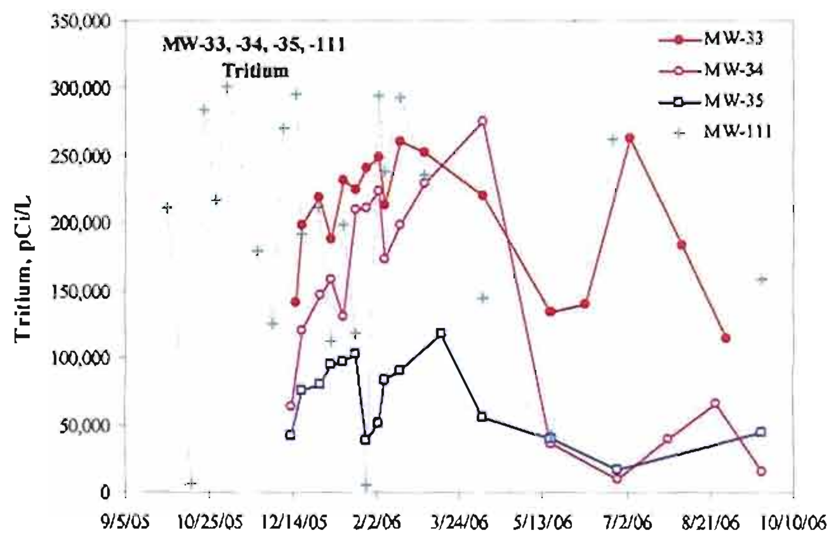
During our investigation, we observed short term fluctuating Tritium concentrations that we cannot reasonably attribute to a continuous release[119] (see **Table 5.1**). These fluctuations make drawing an accurate representation of a plume, on any single date, difficult because any single sample may not be representative of the overall water quality in proximity to the sampling location. In the case of Tritium associated with the IP2-FSB, we believe the fluctuations are associated with temporal variations in the release of Tritium-contaminated groundwater from the unsaturated zone to the water table. That is, we believe the unsaturated zone acts as an intermittent, ongoing source to the groundwater flow regime (see **Section 8.0**). The following graph shows the results of Tritium vs. time in samples collected from MW-30, located adjacent to the IP2-SFP.

[119] In addition, our review of sampling procedures and laboratory methods did not explain the variations observed in samples collected from monitoring well MW-30.



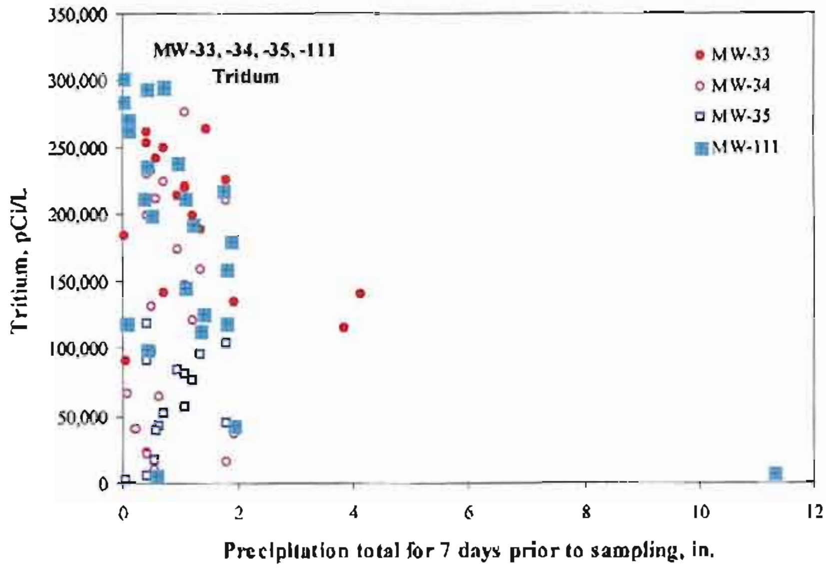
TRITIUM CONCENTRATIONS AND PRECIPITATION VS TIME FOR MW-30

Similar temporal variations in Tritium concentrations are observed in data generated by testing of samples downgradient of IP2-SFP at MW-33-34-35 and -111; see the following figure:



TRITIUM CONCENTRATIONS VS TIME FOR MW-33, -34, -35 AND -111

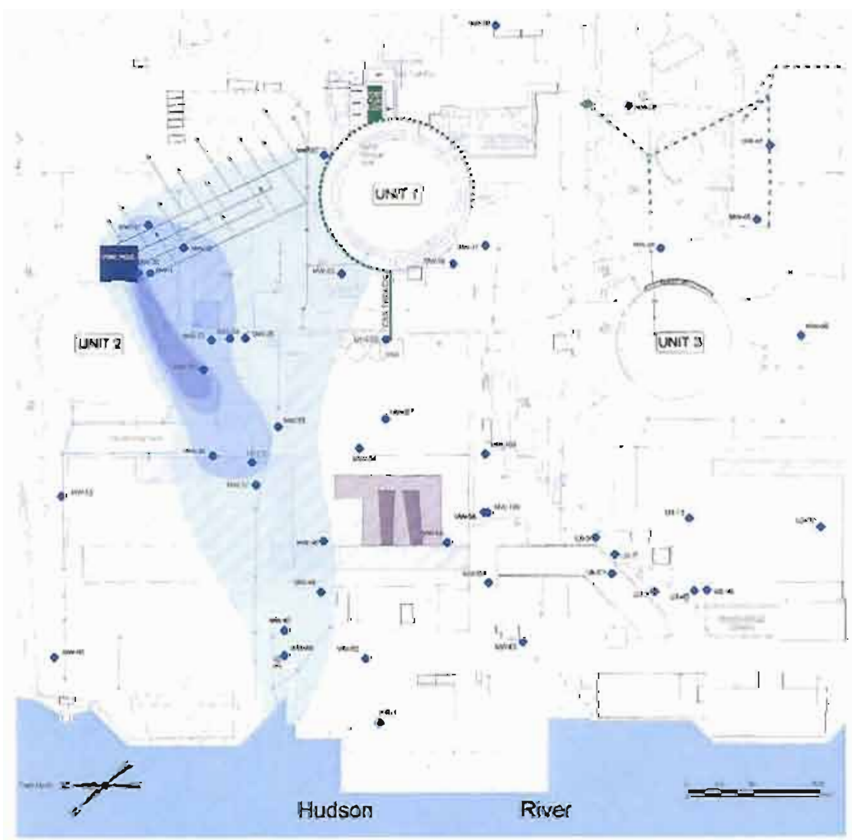
MW-111 is a shallow overburden well completed to a depth of 19 feet below ground surface (bgs). This well is located in a soil-filled bowl-shaped depression within the Transformer yard (see **Figure 1.3**). Consequently, the concentrations of Tritium in samples collected from MW-111 are more sensitive to precipitation (and the likely associated exfiltration from the proximate storm drain) than samples collected from other wells in this area (see above). In particular, note the substantial decrease in Tritium concentration as shown on the following graph, in samples collected after significant precipitation events in October 2005 and May 2006.



TRITIUM CONCENTRATIONS VS PRECIPTIATION

9.3.2 Long Term Variations in Tritium Concentrations

Recognizing the limitations posed by short term fluctuations, we constructed **Figure 9.3**, which shows the lateral extent of Tritium contamination in the late summer of 2007 ("current conditions").



CURRENT UNIT 2 PLUME

Our review of this figure, in conjunction with **Figure 8.1**[120] and **Table 5.1**, reveals the following:

- Despite interdictions, the lateral extent of the two plumes (i.e., the Tritium plume vs. the bounding isopleths) is similar. This indicates storage in the unsaturated zone remains important, and that previous releases did not generate significant groundwater mounding.
- The highest concentrations remain in the area of IP2-SFP. This is consistent with the observed relatively high (4 to 9 feet per day) groundwater transport velocities and an ongoing but smaller release from the unsaturated zone.
- Interdictions made at the IP2-SFP appear to have resulted in measurable reductions in Tritium groundwater concentrations over the entire Unit 2 plume length[121]. The larger reductions in Tritium concentrations are most evident in the source area, closer to the IP2-SFP (see table below).

ANALYSIS OF TRITIUM CONCENTRATIONS OVER TIME

Max. Observe (1) Tritium Concentrations (pCi/L)	Monitoring Well	Current (2) Tritium Concentrations (pCi/L)	Elapsed Time between Max. and Current Concentrations (days)	Current Conc. As Percent of Maximum
601,000	MW-30	92,000	657	15
302,000	MW-111	98,800	629	33
107,000*	RW-1	30,600	3	48
40,600	MW-31	37,700	39	93
44,400	MW-32	14,200	406	32
264,000	MW-33	23,000	390	9
276,000	MW-34	22,200	476	8
119,000	MW-35	5,950	510	5
55,200	MW-36	12,500	494	23
44,800	MW-37	6,680	400	72
3,980	MW-42	1,600	490	40
13,200	MW-53	8,050	346	61
13,100	MW-55	9,910	263	76
10,800	MW-50	4,500	427	42
9,100	MW-66**	9,100	0	100
4,860	MW-67**	4,860	0	100

* Sample obtained during Pumping Test.
** Only one sample analyzed.
(1) Any depth, any date at the indicated location.
(2) Maximum concentration, at any depth, reported during the last project sampling event at the indicated locations.

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[120] When comparing the Unit 2 (Tritium) plume shown on **Figure 9.3** with the bounding isopleths presented on **Figure 8.1**, the analyses/methods used to develop the bounding isopleths need to be fully considered – please refer to **Section 8.0**.

[121] As based on monitoring well data over the plume length down to and across the Discharge Canal to MW-37, as well as the apparent migration velocity of Tritium in the groundwater observed on-Site. Data from monitoring wells downgradient of MW-37 have not been sampled over a sufficiently long period of time to confirm this conclusion. Further analysis of the plume behavior will be conducted as the Long Term Monitoring Plan data is developed over time.

9.4 UNIT 1 STRONTIUM PLUME BEHAVIOR

Figures 8.2 and **9.4** illustrate the migration paths for Strontium. These flow paths represent Strontium originating from an ongoing legacy leak(s) in the IP1-FHB (see **Section 8.0**). This leak explains the Strontium levels detected in MW-42. This well is located in close proximity to the NCD[122], with the upper screen spanning the elevation of the drain (elevation 33 feet) and the lower screen located approximately 35 feet below the drain elevation. This well exhibits upward vertical gradients from the bedrock into the overburden and the NCD. Therefore, a release through a crack in the Water Storage Pool wall (also forms the wall of the FHB), for example, would flow down through the backfill and into the drain where it would enter groundwater near monitoring well MW-42. However, as described in **Section 8.0**, the NCD is not 100% effective in hydraulically containing leaks from the IP1-SFPs. Contaminated pool water collected along the eastern portion of the NCD is released from the NCD via exfiltration as the groundwater elevations drop below elevation 33 feet towards the West; this is one source mechanism responsible for the Unit 1 Plume.

BOUNDING UNIT 1 ACTIVITY ISOPLETHS

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122 It is noted that MW-42 is screened in the bedrock slightly North of the drain. As such, it is located hydraulically upgradient of the drain. The drain should therefore form a sink between the potential leaks and the well, thus capturing contaminants from the FHB further South, with the well only encountering groundwater flowing from the North to the South towards the drain (i.e., the well should not sample groundwater in communication with IP1-FHB leaks). However, during rain events, it appears that the groundwater elevations at the drain can increase to a point where the groundwater flow direction is temporarily reversed (flows from the NCD northward past MW-42) due to the high inflows associated with storm drain leaks (storm drains being repaired, and/or taken out of service). This flow reversal can deposit Strontium on fracture surfaces around MW-42, which later enters the well during purging.

The easternmost portion of the overall Unit 1 plume is shown to exist below the entire IP1-SFPs. GZA termed this the eastern Unit 1 CB Flow Path. Strontium-contaminated groundwater in this area will migrate either to the NCD or the CSB drain, depending on where the specific release point is located relative to these drains.

As discussed in **Section 8.0**, the overall Unit 1 plume also extends to the West towards MW-47 and MW-56. GZA termed this the southwestern Unit 1 CB Flow Path. Once the contaminated water enters the groundwater on the South side of Unit 1, it flows either East to the CSB footing drain or to the Northwest towards Hudson River, depending on the hydraulic gradient at the location where the release reaches the water table.

In addition, we believe the bedrock trench that contained the Unit 1 Annulus-to-CSS drain creates a preferential pathway (through the backfill within the bedrock trench), further aiding the transport of Strontium-contaminated groundwater to the West. GZA termed this the Unit 1 CSS Trench Flow Path. Once leakage enters the trench, it should flow along the sloped bottom until it finds bedrock fractures through which it will exfiltrate. This leakage will then flow through the unsaturated zone along the strike/dip of the fractures until it encounters the saturated zone, and thereafter will follow groundwater flow. This pattern is illustrated on **Figure 9.4** by dashed arrows to the West of Unit 1. It results in a spreading of Strontium-contaminated groundwater, which then flows with groundwater to the Hudson River.

Figures 8.2 and **9.4** also show the Strontium contamination related to releases from legacy piping. These historic releases from the drain pipes are currently manifested as sporadic, low level detections of Strontium in groundwater wells (MW-39, -41 and -43) along the legacy piping. Note, as shown, this spatial distribution of contamination is not a result of groundwater contaminant transport to the South; rather it is a result of multiple release points along the piping. In summary, this contamination represents residual contamination which has attenuated and decayed over time, and will not result in further significant migration.

Once outside the drain capture zone, the Strontium migrates West towards the lower groundwater elevations measured in the IP2-TY and along the walls of the Discharge Canal along the southern end of the IP2-TB (MW-36, -55, -37, -49, -50 and -67) (see **Figures 8.2** and **9.4**). A more southerly track is not anticipated because: 1) the higher groundwater elevations measured in MW-58 and -59 just to the South of the IP1 TGB; and 2) the likely existence of low conductivity concrete backfill along the inside of the IP1-TB walls, its subbasement, discharge piping and eastern Discharge Canal wall (as contrasted with the much higher conductivity blast-rock backfill likely used in the IP2-TY and along the outside of the IP1-TGB walls as well as adjacent to the upgradient IP1 structures).

In addition, as discussed in **Section 6.0** and shown on **Figure 6.2**, there are North-South trending faults in the vicinity of MW-49, MW-61, and MW-66, which are characterized by clay-rich fault gouge[123]. In GZA's opinion (see **Section 6.4.5**), these zones of low hydraulic conductivity limit the southerly extent of contaminated groundwater. In addition, this area is characterized by the two discrete plumes (Tritium and Strontium) commingling and following the same flow path West towards the Hudson River. We attribute this flow pattern to a zone of higher transmissivity located between Units 1 and 2. Also note this area of higher flow is accounted for in our groundwater flux calculations.

The Unit 1 plume in the Transformer yard area is shown as widening due to Strontium concentrations detected in MW-111 and MW-36. This widening may reflect the increased thickness of the saturated zone soil deposits around MW-111, or the presence of high conductivity backfill around the Discharge Canal. This conclusion is supported by the hydraulic heads that indicate groundwater flow to the North along the canal as discussed above pursuant to the Unit 2 plume and the tracer test. West of the Discharge Canal, the Strontium pathways correspond to those described for the Unit 2 plume in **Section 9.3**.

9.4.1 Short Term Strontium Concentrations

As observed with Tritium, it appears that Strontium groundwater concentrations fluctuate, over short durations, more than can be reasonably explained[124] (see **Table 5.1**)by a continuous release at generally constant concentration. We attribute these fluctuations to variations in flows in the IP1-NCD, which are directly influenced by precipitation events (see **Section 8.2**). That is, we postulate that as flows in the drain vary, so do the concentrations and/or volumes of Strontium contaminated water being released.

9.4.2 Long Term Variations in Strontium Groundwater Variations

We used the results of the last sampling event to construct the current Unit 1 plume (see **Figure 9.4** and **Table 5.1**). In reviewing that figure (see below), note the overall configuration is similar to that of the bounded Unit 1 plume (see **Figure 8.2**[125]). The major difference between these plumes is the decrease in concentrations shown in the immediate vicinity of the IP1-SFP[126]. We attribute this decrease in Strontium concentrations to the increased rate of demineralization of the IP1-SFPs water (overall source of the plume).

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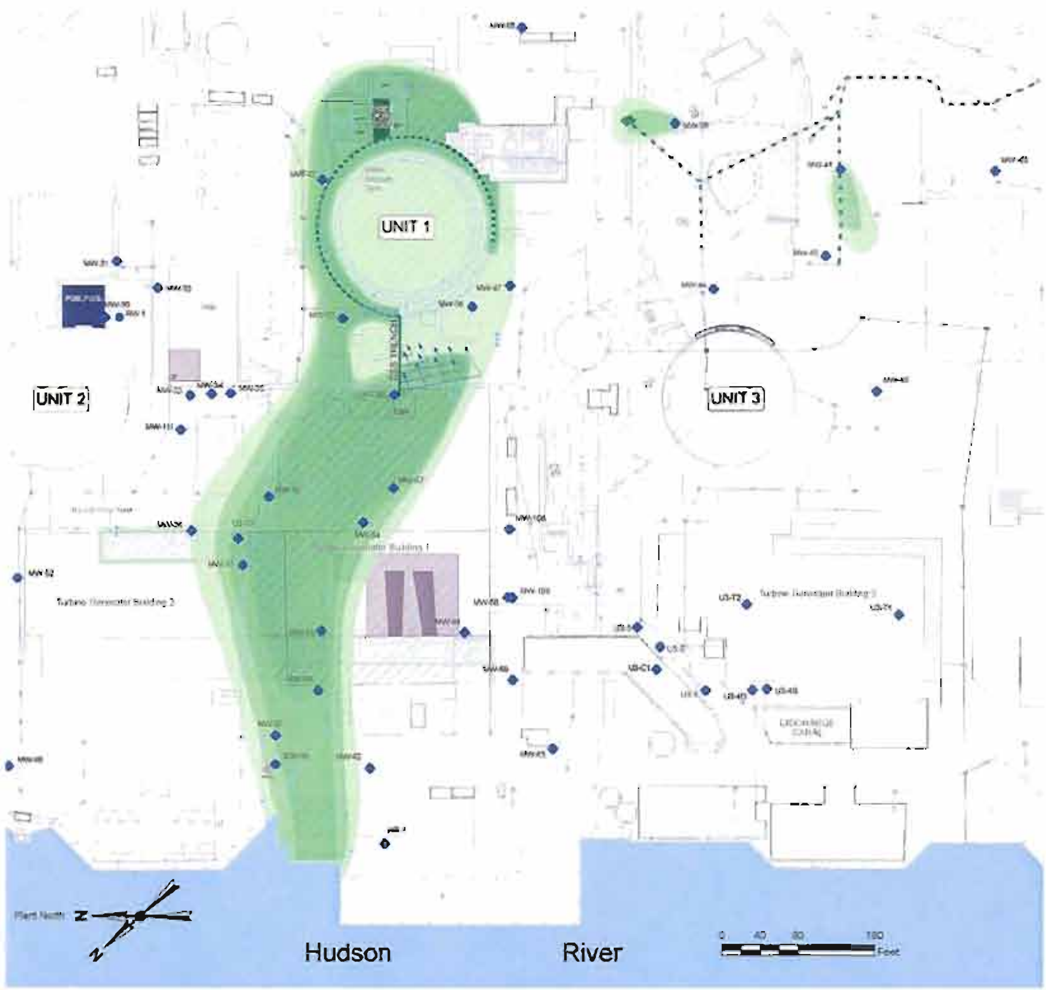
[123] This conclusion has been verified in the areas where the gouge was confirmed with split spoon sampling. See individual boring logs in **Appendix B** for further, more detailed, information.

[124] For example, our review of sampling procedures and laboratory methods did not explain the variations observed in samples collected from monitoring well MW-42.

[125] When comparing the Unit 1 (Strontium) plume shown on **Figure 9.4** with the bounding isopleths presented on **Figure 8.2**, the analyses/methods used to develop the bounding isopleths need to be fully considered – please refer to **Section 8.0**.

[126] It should be noted that the latest data just recently received (well after the report data-cut-off-date of August 31, 2007) for MW-42 shows an increase to 46 pCi/L. This increase, however, still remains within levels consistent with an overall reduction in concentrations in this area, as attributed to accelerated demineralization of the IP1-SFPs.



CURRENT UNIT 1 PLUME

However, because of the timing of the interdictions and, we believe, the slower groundwater transport rates for Strontium, overall the Unit 1 plume has not decayed to the extent the Unit 2 plume has decayed (see **Section 9.4.1**). In fact, due to what we attribute to short term Strontium fluctuations, at six of the well locations within the Unit 1 plume, the highest Strontium groundwater concentrations were observed during the last project sampling event (see the following table for additional detail). In reviewing both figures, note that they show what we believe are conservative estimates of the lateral distribution of the higher (25 pCi/L) Strontium groundwater concentrations.

ANALYSIS OF STRONTIUM CONCENTRATIONS OVER TIME

Max. Observed [1] Strontium Concentration (pCi/L)	Monitoring Well	Current [2] Strontium Concentration (pCi/L)	Elapsed Time between Max. and Current Concentrations (days)	Current Conc. As Percent of Maximum
110	MW-42	20.1	490	18 [3]
37	MW-53*	37	0	100
3.6	MW-47*	3.6	0	100
2.7	MW-56	2.4	332	89
26.8	UI-CSS*	26.8	0	100
21.9	MW-54	19.2	88	88
40.4	MW-55	34.0	263	84
45.5	MW-57	37.9	44	83
5.0	MW-36	2.3	483	46
29.8	MW-37	23.3	40	78
31	MW-50*	31	0	100
25.6	MW-49*	25.6	0	100
19.1	MW-67**	19.1	0	100**
6.2	MW-66**	6.2	0	100

* Current concentration is the maximum concentration of samples analyzed at this monitoring well.
** Only one sample analyzed.
(1) Any depth, any event, at the indicated location.
(2) Any depth, on the date of the last project sampling event, at the indicated location
(3) It should be noted that the latest data just recently received (well after the report data-cut-off-date of August 31, 2007) for MW-42 shows an increase to 46 pCi/L.

10.0 FINDINGS AND CONCLUSIONS

At no time have analyses of existing Site conditions yielded any indication of potential adverse environmental or health risk, as assessed by Entergy as well as the principal regulatory authorities. In fact, radiological assessments have consistently shown that the releases to the environment are a small percentage of regulatory limits, and no threat to public health or safety. In this regard, it is also important to note that the groundwater is not used as a source of drinking water on or near the Site.

Consistent with the purpose of the investigations, we have developed six major supporting conclusions which are described in the following subsections. Based on our findings and conclusions, we are recommending completion of source interdiction measures with Monitored Natural Attenuation as the preferred remedial measure. Refer to **Section 11.0** for more information, including our reasons for making this recommendation.

10.1 NATURE AND EXTENT OF CONTAMINANT MIGRATION

The primary groundwater radiological contaminants of interest are Tritium and Strontium. Other contaminants (Cesium-137, Nickel-63 and Cobalt-60) have been detected, but are limited to areas that have groundwater pathways dominated by Tritium and/or Strontium, and are accounted for in Entergy's dose calculations.

Groundwater contamination is limited to Indian Point's property and is not migrating off-property to the North, East or South. The contamination migrates with the Site groundwater from areas of higher heads to areas of lower heads along paths of least resistance, and ultimately discharges to the Hudson River to the West. This is supported by the bedrock geology, multi-level groundwater elevation data and the radiological results from analytical testing. The nearest drinking water reservoirs are located at distances and elevations which preclude impacts from contaminated groundwater from the Site and there is no nearby use of groundwater.

a. The Site is located over a portion of the aquifer basin where Site-wide ambient groundwater flow patterns, both shallow and deep, have been defined. These flows are towards the Site from higher elevations to the North, East and South. Groundwater flow on Site enters the Hudson River through: footing drains (which discharge to the Discharge Canal); the Discharge Canal; the storm drain system; or direct discharge. The results of over two years of investigations demonstrate that the off-Site groundwater migration to the South, as originally hypothesized by others prior to these investigations, is not occurring.
b. Surface water samples collected from the Algonquin Creek, the Trap Rock Quarry and from the drinking water reservoirs do not exhibit impacts from the Site.
c. The Hudson River is the regional groundwater sink for the area. We found no Site data, published information, or other reasons suggesting that groundwater would migrate beneath the river. To the contrary, based on the area's hydrogeologic setting and all available information, we are confident that groundwater beneath the Site discharges to the river.

d. Because of the hydraulic properties of the bedrock, the bedrock aquifer on-Site will not support large yields, or accept input of large volumes of water.
e. There are no identified off-Site uses of groundwater (extraction or injection) proximate to the Site that influence groundwater flow patterns on the Site. Furthermore, we have no reason to believe that potable or irrigation wells will be installed on or near the Site in the reasonably foreseeable future, in part because municipal water is available in the area.
f. Groundwater flow at the Site occurs in two distinct hydraulic regimes that are vertically connected, bedrock and overburden soils. Most of the groundwater flow and contaminants are found in the bedrock fractures. No evidence of large scale solution features exist in the rock cores obtained from any of the bedrock borings advanced at the Site; i.e., no open voids such as tunnels, caverns, caves, etc., sometimes referred to as "underground rivers," were found. Our on-Site investigatory findings are consistent with that expected for the Inwood Marble. Therefore, this work eliminates from concern solution feature flow associated with karst systems. The second regime is groundwater flow in the unconsolidated soil deposits. This includes groundwater found in native glacial and alluvial deposits, as well as groundwater flow in anthropogenic structures such as blast rock fill and utility trenches. These flow paths, while potentially complicating migration patterns, all terminate at the Hudson River.
g. While groundwater movement in the bedrock is controlled by fracture patterns, the high degree of fracturing allows groundwater flow to be effectively represented and modeled on a Site-wide scale using the well developed techniques derived for porous media[127].

10.2 SOURCES OF CONTAMINATION

The investigations identified two sources of radiological contamination. The IP1-SFPs and the IP2-SFP/Transfer Canal. The IP1-SFPs are the primary source of Strontium groundwater contamination, while the IP2-SFP is the primary source of Tritium groundwater contamination. No evidence of releases from Unit 3 have been identified during this investigation.

During the course of GZA's and Entergy's investigations, we have identified the sources of leakage associated with the IP2-SFP and Transfer Canal. These sources have been eliminated and/or controlled by Entergy. Specifically, Entergy has: 1) confirmed that the damage to the liner associated with the 1992 release was repaired by the prior owner and is no longer leaking; 2) installed a containment system (collection box) at the site of the leakage discovered in 2005, which precludes further release to the groundwater; and 3) identified a weld imperfection in the Transfer Canal liner that, once identified, was prevented from leaking further by draining the Transfer Canal. This weld imperfection was then subsequently repaired by Entergy (completed in mid December 07). Therefore, all identified leaks have been addressed. Water likely remains between the IP2-SFP stainless

[127] While fracture-specific numerical models exist, they are less well developed and less flexible than porous media-based models. The use of a porous media representation requires some level of approximation, particularly on small scales of tens of feet. However, the fracture flow models also require substantial approximations based on fracture statistics and are thus, more problematic at this Site than a porous model.

steel liner and the concrete walls, and thus additional active leaks can not be completely ruled out. However, if they exist at all, the data[128] indicate they must be very small and of little impact to the groundwater.

Our investigations also identified the source of all the Strontium contamination detected in groundwater beneath the Site as coming from the Unit 1 Fuel Pool Complex (IP1-SFPs). The IP1-SFPs were identified by the prior owner as leaking in the mid-1990's. All of the pools have been drained by Entergy except the West Pool, which currently contains the last 160 Unit 1 fuel assemblies remaining from prior plant operations. This plant was retired from service in 1974. Following detection of radionuclides associated with IP1-SFPs in the groundwater, Entergy, as part of their already planned fuel rod removal and complete pool drainage program, accelerated efforts to further reduce activity in the IP1-SFPs through demineralization..

The on-Site tracer test demonstrated that aqueous releases in the vicinity of IP2-SFP are stored *above the water table* in either: 1) unsaturated zone dead-end fractures; and/or 2) anthropogenic foundation details such as blast-rock backfill over a mud-mat (see **Section 8.1.2**). This impacted unsaturated zone water is then periodically released to the groundwater over time as driven, for example, by infiltration of precipitation. Consequently, subsequent releases *to the groundwater* can continue for significant durations after the initial leak has been terminated. In addition, the tracer studies further demonstrate that the migration rates for the Tritium plume *in the groundwater* can be slowed down as compared to the groundwater itself. This reduction in Tritium plume migration velocity occurs when impacted groundwater encounters, and becomes "entrapped" by dead-end fractures, both naturally occurring fractures and those created by excavation blasting during Site construction[129].

The radionuclides identified in the Unit 3 area are related to historic legacy leakage from IP1, and reflect what remains of the plume that has been naturally attenuating since approximately 1994. The pathway to the Unit 3 area was via the IP1-SFDS and then to the storm drain system which transverses along the southeastern portion of the Site; <u>not</u> via groundwater flow to the South (see **Section 8.2**). Exfiltration from this storm drain system had, in turn, resulted in contamination of the groundwater along the storm drain piping. The Sphere Foundation Drain Sump no longer discharges to the storm drain system and this legacy release pathway had therefore been terminated because the associated piping was capped in 1994.

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[128] These data include: monitored water levels in the SFP, with variations accounted for based on refilling and evaporation volumes; the mass of Tritium migrating with groundwater is small; and the age of the water in the interstitial space.

[129] Once contaminants enter dead-end fractures, they no longer migrate with the groundwater flow. However, this "entrapped contamination" does re-enter the flow regime over time due to turbulent flow mixing at the fracture opening as well as diffusion.

10.3 GROUNDWATER CONTAMINANT TRANSPORT

Based on our assessment of the bedrock's hydraulic properties, the area's hydrogeologic setting, the properties of the contaminants, the age of the releases, interdictions made to eliminate or reduce release rates, and the distances between the source areas and the Hudson River, we believe the groundwater contaminant plumes have expanded to their maximum extent and are now decreasing in size. In this regard, the Unit 2 Tritium plume is decreasing faster than the Unit 1 Strontium plume, as anticipated. These conclusions are based on the data available which, given the aggressiveness with which Entergy implemented the investigations, is compressed in duration[130]. Therefore, ultimate confirmation of these conclusions will require monitoring over a number of years to allow ranges in seasonal variation to be adequately reflected in the monitoring data. During long term monitoring, GZA further anticipates that contaminant concentrations in individual monitoring wells will fluctuate over time (increasing at times as well as decreasing, as potentially related to precipitation events), and that a future short term increase in concentrations does *not*, in and of itself, indicate a new leak. In addition, it is also expected that some areas within the plumes will exhibit faster decay rates than others. Both behaviors are commonly observed throughout the industry with groundwater contamination sampling and analyses, and therefore, conclusions pursuant to plume behavior must be evaluated in the context of all of the Site-wide monitoring data. Overall, however, GZA believes that the continuing monitoring will demonstrate decreasing long term trends in groundwater contaminant concentrations over time given the source interdictions completed by Entergy. It is also further emphasized that even the *upper bound* Tritium and Strontium groundwater concentration isopleths presented on **Figures 8.1** and **8.2** result in releases to the river which are only a small percentage of the regulatory limits, which are of no threat to public health.

a. The major groundwater transport mechanism is advection. Sorption retards the migration of radiological contaminants other than Tritium relative to groundwater advection rates, while Tritium, within hydraulically interconnected fractures, can migrate at rates that approach the groundwater seepage velocity.
b. The Unit 2 contaminant plume is characterized by Tritium in the groundwater. Over the last two years, the highest Tritium concentrations in the Unit 2 plume have decreased (see **Table 5.1** and **Figures 8.1 and 9.3**). However, the center of mass of the Unit 2 plume is not rapidly migrating downgradient, and remains in proximity to the IP2-SFP. While a small active leak can not be ruled out completely, this behavior is also consistent with the identified role of unsaturated zone (above the water table) storage of historic releases, with precipitation-induced infusion of this entrapped water into the groundwater regime over time.
c. The Unit 1 contaminant plume is primarily characterized by Strontium concentrations in the groundwater, though near the physical pool area other isotopes are present as expected due to proximity. Over the last two years, the highest Strontium concentrations in the Unit 1 plume have decreased (**Table 5.1**). These decreases in concentration are consistent with a reduction in Strontium

[130] It is noted that a number of key monitoring installations have only recently been completed, and monitoring rounds spanning multiple seasons are not yet available.

concentrations in the Unit 1 West Fuel Pool via pool water recirculation through demineralization beds. While the physical leak(s) in this fuel pool still exist, the source term to the groundwater has been reduced through reduction in the contaminant concentrations in the leak water. It is noted, however, the Unit 1 Strontium decreases are more modest and are generally more limited to the immediate source area than that observed for Tritium at Unit 2. The slower rate of plume decay is not unanticipated give the adsorption properties of Strontium. Further planned interdictions include removal of the fuel rods and draining of the pool water, which will permanently eliminate the West Fuel Pool as well as the entire IP1-SFP complex as a source of contamination to the groundwater. With elimination of this source, natural attenuation will reduce Strontium concentrations in the Unit 1 plume over time.

10.4 GROUNDWATER MASS FLUX CALCULATIONS

During the project (over the past two years), as testing progressed and more information became available, we refined methods to calculate the groundwater flux and associated radiological activity to the Hudson River. As described below, we have developed a procedure which is scientifically sound, relatively straight-forward, and appropriately conservative. Groundwater flow rates are provided to Entergy, who computes the radiological dose impact.

a. Migration of radionuclides to the river is computed based on groundwater flow rates, in combination with contaminant concentrations within the flow regime. This information is then used in surface water models to compute radiological contaminant concentrations in the river and thus potential dose to receptors.
b. To assess the validity of the precipitation mass balance method used to date for computing groundwater flux across the Site, GZA also performed groundwater flux computations using an independent method based on Darcy's Law. Thus, the results from two widely accepted groundwater flow calculation methods were compared against each other. The first, the precipitation mass balance method, is a "top-down" procedure based on precipitation-driven water balance analyses. The second, based on Darcy's Law, is a "bottom-up" method using hydraulic conductivity and flow gradient measurements. These two methods resulted in estimated groundwater flow values which were in agreement, providing a high degree of confidence in the values obtained relative to their impact on subsequent dose computations and risk analyses.
c. The original groundwater flux computations were developed for two separate areas of the Site. The northernmost area included both the Unit 2 and Unit 1 plumes. The southernmost area encompassed Unit 3. This bifurcation of the Site was established given: 1) the co-location of the Unit 2 plume and the Unit 1 plume near the western boundary of the Site just upgradient of the river; 2) the much lower contaminant concentrations in the Unit 3 area; and 3) the amount of data available at that time. Current data, derived from a greater number of groundwater elevation and sampling points than reflected in earlier data, show the Site can be divided into six separate areas. The computations were further separated into shallow and deep flow regimes given: 1) the generally higher hydraulic conductivity in the shallow

portion of the bedrock, and 2) the generally more elevated contaminant concentrations in the shallow flow regime.

d. The groundwater contaminant concentrations used for the radiological dose computations were obtained primarily from the analysis of samples taken from the recently completed multi-level wells specifically installed for this purpose. These wells are located downgradient of the Unit 2 and Unit 1 infrastructure[131] and are positioned within the plumes and just upgradient of where the groundwater discharges to the river and Discharge Canal. The multi-level nature of these wells allows the groundwater to be sampled over at least five separate elevations in the bedrock, in addition to the overburden layer above. Sampling zones specifically targeted the most pervious depths within the bedrock boreholes. As such, the groundwater samples encompass the full depth of the contaminant plume, from the upper soil zones to depths where the contaminant concentrations have fallen off to insignificant levels. The high number of samples over the depth of the plume provides a higher degree of confidence that the significant flow zones are accounted for. The high number of vertical sampling zones also provides a higher level of redundancy relative to the longevity and efficacy of the monitoring network over time.

10.5 GROUNDWATER MONITORING

The current groundwater well and footing drain monitoring network is consistent with the objectives of the NEI Groundwater Protection Initiative[132]. Wells have been installed and are currently being monitored to both detect and characterize current and potential future groundwater contaminant migration to the river, as well as, in concert with specific footing drain monitoring, provide earlier detection of potential future leaks associated with the existing infrastructure.

a. The network of 59 monitoring well locations and over 140 sampling intervals/locations, has allowed us to identify groundwater flow patterns. A subset of this network will provide an adequate long term monitoring system.
b. Existing and potential sources have been identified, and monitoring is in place to both evaluate current conditions and identify future releases, should they occur.
c. The nature and extent of contamination is known and reporting requirements are in place.

10.6 COMPLETENESS

Investigations at the Site have been broad, comprehensive, and rigorous. Major components of the field studies include: detailed acquisition of geologic information; automated long duration collection of piezometric data; vigorous source area

[131] The multi-level sampling network is concentrated in the Unit 2 and Unit 1 areas given that this is where contaminant concentrations are by far the highest. The individual monitoring wells located downgradient of Unit 3 are judged sufficient for computations in this area given the low contaminant concentrations measured, even in the typically more contaminated shallow flow regime.

[132] NEI developed a set of procedures/goals for nuclear plants to assess the potential for releases of radionuclides to potentially migrate off-Site.

identification; comprehensive aquifer property testing, including performance of a full scale Pumping Test; and large-scale confirmatory contaminant transport testing, in the form of an extensive tracer test. The results of this systematic testing program are in agreement with conditions anticipated by our Conceptual Site Model. Based on our review of findings, we have concluded that the field studies conducted at the Site have addressed the study objectives.

a. There is no need to monitor groundwater at off-Site locations. The density and spacing of on-Site monitoring wells is adequate to: 1) demonstrate that contaminated groundwater is migrating to the Hudson River to the West, and not migrating off of the property to the North, East or South; 2) monitor the anticipated attenuation of contaminant concentrations; 3) identify future releases, should they occur; and 4) provide the data required to compute radiological dose impact.
b. Hydraulic conductivity is the most important aquifer property. We have completed more than 245 hydraulic conductivity tests, including a full-scale Pumping Test. Therefore, we believe no future aquifer testing is required. In addition, the contaminant plumes have reached their maximum spatial extent. Therefore, there is no need for contaminant transport modeling.
c. The sources of releases to the groundwater have been identified. In addition to monitoring, actions have been taken to reduce or eliminate these releases. Therefore, we believe no future source characterization is required.
d. All information indicates Monitored Natural Attenuation is the appropriate remedial response and is GZA's recommended approach (see **Section 11.0**). The existing monitoring network will serve this remedial approach. Therefore, no design phase studies are required.

11.0 RECOMMENDATIONS

Based upon the comprehensive groundwater investigation and other work performed by Entergy, GZA recommends the following:

1. Repair the identified Unit 2 Transfer Canal liner weld imperfection (completed mid December 2007);
2. Continue source term reduction in the Unit 1 pool via the installed demineralization system;
3. Remove the remaining Unit 1 fuel and drain the pools; and
4. Implement long term monitoring consistent with monitored natural attenuation, property boundary monitoring, future potential leak identification, and support of ongoing dose assessment.

It is GZA's opinion that our investigations have characterized the hydrogeology and radiochemistry of the groundwater regime at the Site. Therefore, we are not recommending further subsurface investigations (see **Section 10.0**). Based upon the findings and conclusions from these investigations, as well as other salient Site operational information, we recommend the completion of source interdiction measures with Monitored Natural Attenuation (MNA) as the remediation technology at the Site. In no small part, this recommendation is made because of the low potential for risk associated with groundwater plume discharge to the Hudson River.

Monitored Natural Attenuation is defined by the United States Environmental Protection Agency as the reliance on natural attenuation processes (within the context of a carefully controlled and monitored clean up approach) to achieve Site-specific remedial objectives within a time frame that is reasonable compared to other methods. The "natural attenuation processes" that are at work in the remediation approach at this Site include a variety of physical, chemical and radiological processes that act without human intervention to reduce the activity, toxicity, mobility, volume, or concentration of contaminants in soil and groundwater. These primarily include radiological decay, dispersion, and sorption.

MNA is typically used in conjunction with active remediation measures (e.g., source control), or as a follow-up to active remediation measures that have already been implemented. At IPEC, active remedial measures *already implemented* include elimination (e.g., repair of the Unit 2 1990 liner leak and repair of Transfer Canal weld imperfection in mid-December 2007) and/or control (e.g., installation of a collection box to capture moisture from the IP2 shrinkage cracks) of active leaks, and reduction of the source term in the Unit 1 fuel storage pool through demineralization, with subsequent planned removal of the source term (fuel rods) followed by complete draining of the IP1-SFPs.

Remediation

1. Our recommendation of MNA principles includes source term contaminant reduction as an integral part of this remediation strategy. Data demonstrating plume concentration reductions over time, as considered along with other salient

Site information, are consistent with a conclusion that the interdiction efforts to date (both current and in the past) have resulted in: 1) termination of the identified Tritium leaks in the IP2-SFP; 2) identification of an imperfection in a Unit 2 Transfer Canal weld which has been repaired; 3) reduction in IP1-SFP contaminant concentrations; and 4) elimination of Sphere Foundation Drain Sump discharges to the storm drain piping East of Unit 3. As such, these interdictions have resulted in the elimination and/or control of identified sources of contamination to the groundwater, as required:

a. Over the last two years, the highest Tritium concentrations in the Unit 2 plume have decreased. These data are consistent with a conclusion that the leaks responsible for the currently monitored Tritium plume are related primarily to the previously repaired 1992 legacy liner leak and the imperfection in the Transfer Canal weld. With the implemented physical containment of the associated 2005 "concrete wall crack leaks" and the repair of the Transfer Canal liner, the source of contamination to the groundwater has been reduced and controlled.
b. Over the last two years, the highest radionuclide concentrations in the Unit 1 plume have decreased. These decreases are consistent with a reduction in the concentrations in the Unit 1 West Fuel Pool via pool water recirculation through demineralization beds. While the physical leak(s) in this fuel pool still exist, the source term to the groundwater has been reduced due to treatment of the source water. Further planned interdictions include removal of the fuel rods and draining of the pool water, which will permanently eliminate the West Fuel Pool as a source of contamination to the groundwater.
c. The Unit 1 plume in the Unit 3 area has been attributed to a historic legacy discharge from the Sphere Foundation Drain Sump (SFDS) through the storm drain system which traverses along the southeastern portion of the Site. Leaks from this storm drain system have, in turn, resulted in past contamination of the groundwater along the storm drains, with subsequent groundwater migration westward, through Unit 3 toward the river. The SFDS no longer discharges to the storm drain and the Strontium concentrations in the Unit 3 groundwater have decreased to low levels, consistent with natural attenuation processes.

2. GZA selected Monitored Natural Attenuation as the remediation strategy because:

   a. Interdiction measures undertaken and planned to date have, or are expected to, eliminate/control active sources of groundwater contamination.
   b. Groundwater flow at the Site precludes off-Site migration of contaminated groundwater to the North, South or East.
   c. Consistent with the Conceptual Site Model, no contaminants have been detected above regional background in any of the off-Site monitoring locations or drinking water supply systems in the region.
   d. The only on-Site exposure route for the documented contamination is through direct exposure. Because the majority of the Site is capped by

impermeable surfaces, there is no uncontrolled direct contact with contaminants.

e. Our studies indicate that under existing conditions, the spatial extent of the groundwater plume will decrease with time.
f. Groundwater is not used as a source of drinking water on the Site or in the immediate vicinity of the Site, and there is no reason to believe that this practice will change in the foreseeable future.
g. Groundwater associated with the Unit 1 foundation drainage systems is captured and treated to reduce contaminants prior to discharge to the Discharge Canal, consistent with ALARA principles.
h. At the locations where contaminated groundwater discharges to the Hudson River, the concentrations have been, and will continue to be, reduced by sorption, hydrodynamic dispersion and radiological decay. No detections of contaminants associated with plant operations have been found in the Hudson River or biota sampled as part of the required routine environmental sampling.
i. More aggressive technologies would alter groundwater flow patterns and, therefore, in our opinion, offer no clear advantages.

Long Term Monitoring

1. The second primary requirement for implementation of MNA is a demonstration that contaminant migration is consistent with the Conceptual Site Model. In particular, rigorous monitoring is required to demonstrate reductions in source area contamination, reductions in plume contaminant concentrations, and reduction in contaminant discharge to the river over time. The initial implementation stages of this monitoring process were begun nearly two years ago as part of the investigations summarized herein. As outlined above, reductions in maximum groundwater plume contaminant concentrations have already been documented. The elements for long term monitoring, consistent with the objectives of the NEI Groundwater Protection Initiative, are in place. We further note:

    a. Groundwater wells have specifically been installed, and are currently being monitored, to both detect and characterize current and potential future off-Site groundwater contaminant migration to the river. Additional wells have also been installed for monitoring of other Site property boundaries.
    b. Monitoring wells have also been installed just downgradient of identified critical Structures, Systems and Components (SSCs). These wells, in concert with specific footing drain monitoring, provide earlier detection of potential future leaks associated with the power generating units than would be possible with boundary wells alone.
    c. Monitoring wells have been strategically placed to monitor the behavior of the plumes identified on the Site.
    d. MW-38 and MW-48 should be excluded from the monitoring plan as samples from these wells are generally indicative of a mixed groundwater

and Discharge Canal/river water condition and, therefore, are not completely groundwater specific[133].

e. The long term monitoring plan should include action levels, which if exceeded, trigger further analysis and/or investigations, potentially leading to implementation of an interdiction plan, if required.

f. A number of individual vertical sampling zones were included in nearly all the monitoring well installations, particularly within the contaminant plumes and at the location of plume discharge to the river. These individual vertical monitoring zones provide a significant level of vertical resolution and also provide a substantial degree of redundancy relative to the longevity and efficacy of the monitoring network over time[134].

g. While previous and current dose calculations are both reasonable and conservative, we recommend that, with the accumulation of additional Site-specific hydrogeologic information, the calculations be modified to incorporate Site-specific transmissivities and groundwater gradients. Entergy has agreed that Site-specific model information will be utilized in the next NRC required annual assessment of dose from this pathway. Our specific recommendations (which will include additional trend information in early 2008) will be provided under separate cover for Entergy's incorporation to support the annual report.

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[133] See **Section 6.6.3** for further discussion pursuant to this conclusion.

[134] The level of redundancy designed into the long term monitoring network anticipates and allows for the loss of a number of monitoring zones without significant impact to the adequacy of the monitoring system.