ECF-Hanford-13-0037
Revision 0

# Development of Source Terms for Inclusion in Fate and Transport Modeling for Remedial Investigation/Feasibility Studies of the 200-BP-5 and 200-PO-1 Groundwater Operable Units

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

**P.O. Box 1600**
**Richland, Washington 99352**

**Approved for Public Release;**
**Further Dissemination Unlimited**

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INTERA, Inc.

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Assistant Secretary for Environmental Management

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***APPROVED***
***By Julia Raymer at 12:29 pm, Jun 24, 2015***

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# Development of Source Terms for Inclusion in Fate and Transport Modeling for Remedial Investigation / Feasibility Studies of the 200-BP-5 and 200-PO-1 Groundwater Operable Units

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# Terms

| | |
|---|---|
| CCUz | Cold Creek unit (geologic formation) |
| Cl | Chloride (element) |
| Cs-137 | Cesium-137 (isotope) |
| CHPRC | CH2M Hill Plateau Remediation Company |
| $C_{vz}$ | concentration in the vadose zone |
| ECF | environmental calculation file |
| H2 | Hanford Unit 2 (geologic formation) |
| HEIS | Hanford Environmental Information System (environmental database) |
| kg | kilogram (unit of mass) |
| m | meter (unit of length) |
| µg/L | micrograms per liter (unit of concentration) |
| mg/L | milligrams per liter (unit of concentration) |
| mm/yr | millimeters per year (unit of flux) |
| ML | megaliter |
| $NO_3$ | Nitrate |
| PNNL | Pacific Northwest National Laboratory |
| OU | Operable Unit |
| SZ | saturated zone |
| Tc-99 | technetium-99 (isotope) |
| U | uranium (element) |
| WMA | Waste Management Area |
| VZ | vadose zone |
| yr | year (unit of time) |

# 1 Purpose

The purpose of this environmental calculation file (ECF) is to estimate the future activity or mass flux of key groundwater contaminants from the vadose zone to the saturated zone within the 200-BP-5 and 200-PO-1 Groundwater Operable Units (OUs). Based on review of available information, two areas have been identified within these OUs where the continuing source from the vadose zone is likely to persist over the foreseeable future. The two areas are located within or around the Waste Management Area C (WMA C or C-Tank Farm area) and the B-complex (B-BX-BY Tank Farm area). The primary contaminants of concern that are likely to provide continuing source from the vadose zone are technetium-99, uranium, and nitrate. Figure 1 and Figure 2 show the location of WMA C and B-complex area respectively in relation to the Groundwater OU boundaries.

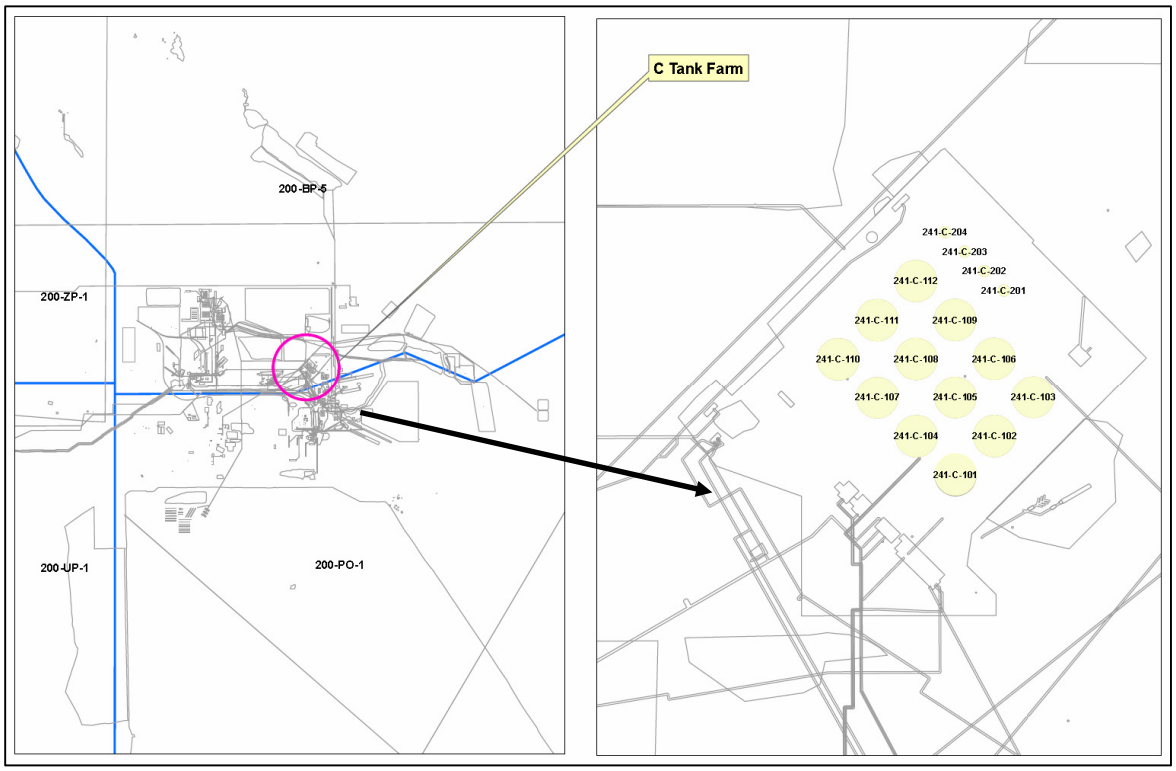



**Figure 1. Location of Waste Management Area C (WMA C) in Relation to the Groundwater OUs Along with a Detailed View**

# 2 Methodology

Two approaches were considered in order to calculate the mass flux of contaminants for the two areas. The first approach takes the plume definitions published in the Annual Groundwater Monitoring Reports (e.g., DOE/RL-2013-22, *Hanford Site Groundwater Monitoring Report for 2012*) and evaluates the mass flux of contaminants. This approach assumes that the areal extent of the plume is completely defined by the concentration contours presented in the Annual Groundwater Monitoring Reports and the plume has a uniform vertical concentration throughout the saturated thickness. The approach calculates the activity/mass within the plume definition for each year first and then takes the difference to calculate the activity/ mass flux added (or reduced) in a given year. Some considerations when using this approach are:

- It is relatively simple and can be performed quickly based on published information and interpretations;

Takes advantage of the readily available information from the Annual Groundwater Monitoring Reports over the past five years;

- Provides a first-order approximation on the mass flux and trends in determining the source strength;
- Biased towards increased plume areas where monitoring network based information is limited; and
- There is a possibility of combining various subplumes into one larger plume and thereby overestimating the mass within the plume.

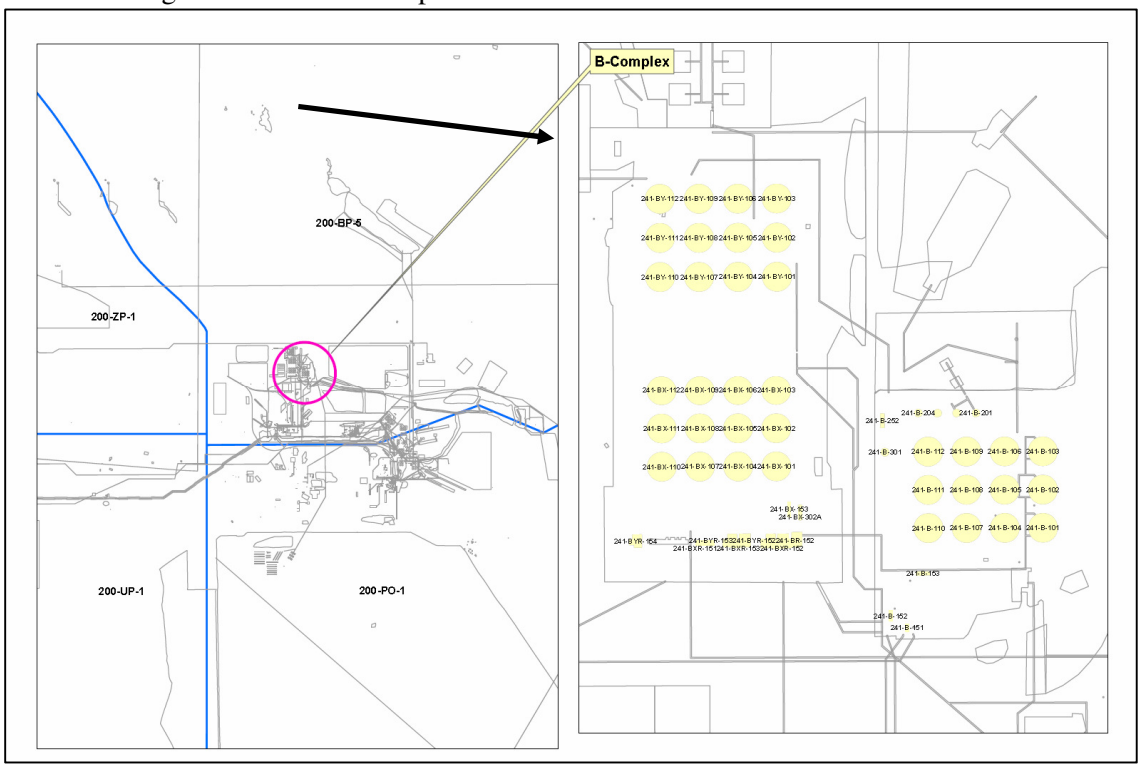



**Figure 2. Location of B-Complex in Relation to the Groundwater OUs Along with a Detailed View**

The second approach for estimating mass flux of contaminants from vadose zone to the saturated zone is an empirical approach based on re-evaluation of the dataset over the past ten years (or longer) and determining the plume extent by integrating most up-to-date site conceptual models, flow paths, and major ion chemistry. The method uses readily available information from *Hanford Environmental Information System* (HEIS) and is consistent with the information presented in DOE/RL-2009-127, *Remedial Investigation Report for the 200-BP-5 Groundwater Operable Unit*. In this approach, the activity/mass flux is calculated using a control volume approach by recognizing that the spatial extent of the entire plume is not well understood but the zone of highest concentration is relatively well defined. This zone of highest concentration is used to define the control volume and based upon the flow rate through this control volume and observed changes in dissolved concentration the mass flux from the vadose zone is derived.

Figure 3 shows the conceptual representation of the empirically based control volume approach. In this approach it is assumed that the amount of activity/mass that is flushed by the flow of water (pore volumes flushed) within a one-year period is replaced by the equal amount of activity/mass from the deep vadose

zone, as a result mass within the control volume stays constant over that one-year time period. This approach assumes that without mass being sustained by the vadose zone the contaminant plume within the control volume will be flushed out and the concentrations would drop sharply due to highly transmissive nature of the unconfined aquifer within this area. Based on the available information on the conceptual site models and the observed concentrations in the monitoring wells it is reasonable to assume that continued persistence of plumes in certain areas is a direct reflection of the continuing mass flux from the deep vadose zone.

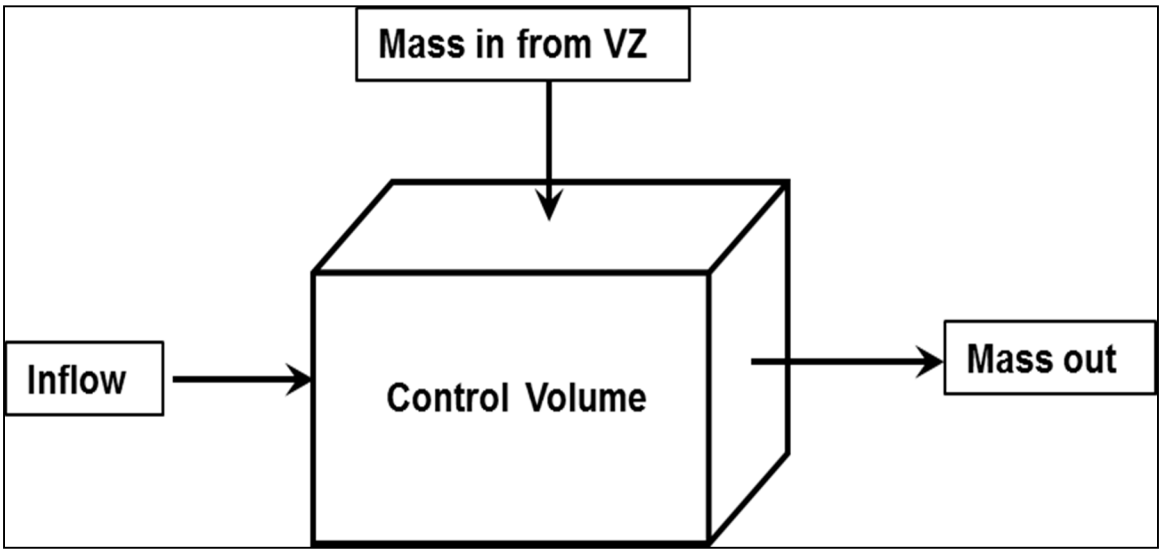



**Figure 3. Conceptual Model for the Vadose Zone Flux Calculation**

The acitivty/mass flux calculations through the saturated zone control volume is performed by assuming Dupuit conditions in the unconfined aquifer (nearly undisturbed water table conditions with horizontal flow). More specifically, the Dupuit's theory has the following assumption:

- The water table or free surface is only slightly inclined
- Streamlines may be considered horizontal and equipotential lines are vertical
- Slopes of the free surface and hydraulic gradeint are equal.

For a three dimentional steady-state system, the groundwater flow equation is defined as:

$$\frac{\partial^2 h_x}{\partial x^2} + \frac{\partial^2 h_y}{\partial y^2} + \frac{\partial^2 h_z}{\partial z^2} = 0 \qquad \text{Equation 1}$$

where $h_x$, $h_y$, *and* $h_z$ are the hydraulic head in the $x$, $y$, and $z$ directions.

The vadose zone mass flux is assumed the only source to the saturated zone. The approach uses the following mass balance equation:

$$\left(\frac{M}{\Delta t}\right)_{UZ} = (Q_s \Delta C)_{SZ} \qquad \text{Equation 2}$$

where the left hand side is the mass flux from the vadose zone (g/yr or Ci/yr) and the right hand side is the saturated zone mass flux defined by flow rate ($Q_s$) times the change in concentration ($\Delta C$).

Equation 2 describes that the net change of mass in the system depends on the change of concentration assuming the flow in the system remains unchanged. The assumptions for this equation are:

- The mass flushed out in a year from control volume in the saturated zone would be equal to the mass derived from the vadose zone, and
- Concentration within a control volume is assumed to stay relatively uniform over a one-year period (and can be approximated by taking the median value from the observed concentrations within that year).

The calculation details for implementing Equation 2 are presented below:

Flux from VZ to sustain SZ Plume = (Total Activity in SZ Plume) × (Pore Volumes Flushed in a Year) Equation 3

Total Activity in SZ Plume = Plume Concentration × Plume Area × SZ Thickness × Porosity

Pore Volume Flushed in a year = 365 days/Residence Time (days) within the control volume

Residence Time = (Control Pore Volume)/ Qs

$$Q_S = KiA$$ Equation 4

Control Pore Volume = (Total Volume within a Concentration Contour × Porosity)

where $A$ is the representative plume width perpendicular to the flow multiplied by the screened interval, $K$ is the hydraulic conductivity, and $i$ is the hydraulic gradient.

# 3 Assumptions and Inputs

The assumptions associated with the calculation methodology have been discussed in the previous chapter. No further assumptions are made.

The input parameters that were used in the calculation are listed in Table 1. For WMA C, input parameters were taken from RPP-RPT-46088, *Flow and Transport in the Natural System at Waste Management Area C.* For B-complex, parameters were taken from PNNL-19277, *Conceptual Models for Migration of Key Groundwater Contaminants through the Vadose Zone and Into the Unconfined Aquifer below the B-Complex.* The estimate of inventory released from the WMA C tanks and unplanned releases are taken from RPP–ENV-33418, *Hanford C-Farm Leak Assessments Report*.

**Table 1. Parameters Used for Flux Calculation**

| Area | Hydraulic Conductivity (m/day) | Total Porosity | Hydraulic gradient (m/m) | Average Saturated Zone Thickness (m) |
|---|---|---|---|---|
| WMA-C | 3,000 | 0.30 | 1E-5 | 14 |
| B-Complex | 10,000 | 0.12 | 1E-5 | 2 |

# 4 Software Applications

The source term calculation for WMA-C and B-Complex area is a very simple calculation using the empirical equations. These calculations were performed primarily using Excel®[1] spreadsheets on a desktop with ID INTERA-00465. The hardware is a Dell®[2] Precision E7200 with a 3.07-GHz Intel® Core™ i7 CPU processor and 6 GB of RAM loaded with the Windows®[1] 7, 64-bit operating system. ARCGIS 10.0 has also been used for plume visualization, manipulating data and creating the maps.

# 5 Calculation

Details of the calculation are provided in this section with respect to the WMA-C and B-Complex potential continuing source areas.

## 5.1 Vadose Zone Flux calculation for WMA-C

As stated earlier, the mass flux calculations from Waste Management Area C (WMA C) were performed using two different approaches: (1) based on plume related information presented in groundwater annual reports and (2) using interpreted plumes based on observed groundwater concentration data and up-to-date site conceptual models.

Figure 4 shows the WMA C monitoring wells and the surrounding area. Figure 5 and Figure 6 show the technetium-99 and nitrate groundwater plumes near WMA C for years 2008, 2009, 2010, 2011, and 2012 obtained from Hanford groundwater annual reports (DOE/RL-2008-66, *Hanford Site Groundwater Monitoring Report for Fiscal Year 2008*; DOE/RL-2010-11, *Hanford Site Groundwater Monitoring and Performance Report for 2009*; DOE/RL-2011-01, *Hanford Site Groundwater Monitoring Report for 2010*; DOE/RL-2011-118, *Hanford Site Groundwater Monitoring Report for 2011*; and DOE/RL-2013-22).

According to the RPP–ENV-33418, the total technetium-99 inventory released in WMA C is 7.2 Ci. Table 2 presents the estimate of the amount of inventory released within WMA C from various locations (RPP-ENV-33418). Figure 7 shows the several unplanned releases in WMA C (designated with a UPR prefix) and suspect leaker along with the snapshot of the retrieval status of various tanks. The information related to the estimate of the waste loss, composition of the waste, and year the waste loss occurred or was determined are summarized in Figure 8.

[1] Excel and Windows are registered trademarks of Microsoft Corporation in the United States and other countries.
[2] Dell® and PowerEdge® are registered trademarks of Dell Products, Inc.

The nitrate plumes WMA C vicinity (Figure 6) do not exhibit high concentrations. The highest nitrate concentration remains typically around 45 mg/L (drinking water standard) and therefore indicates a weak source of nitrate from the vadose zone, which may be localized in nature. As a result, further nitrate calculations to evaluate vadose zone source are not undertaken for WMA C area.

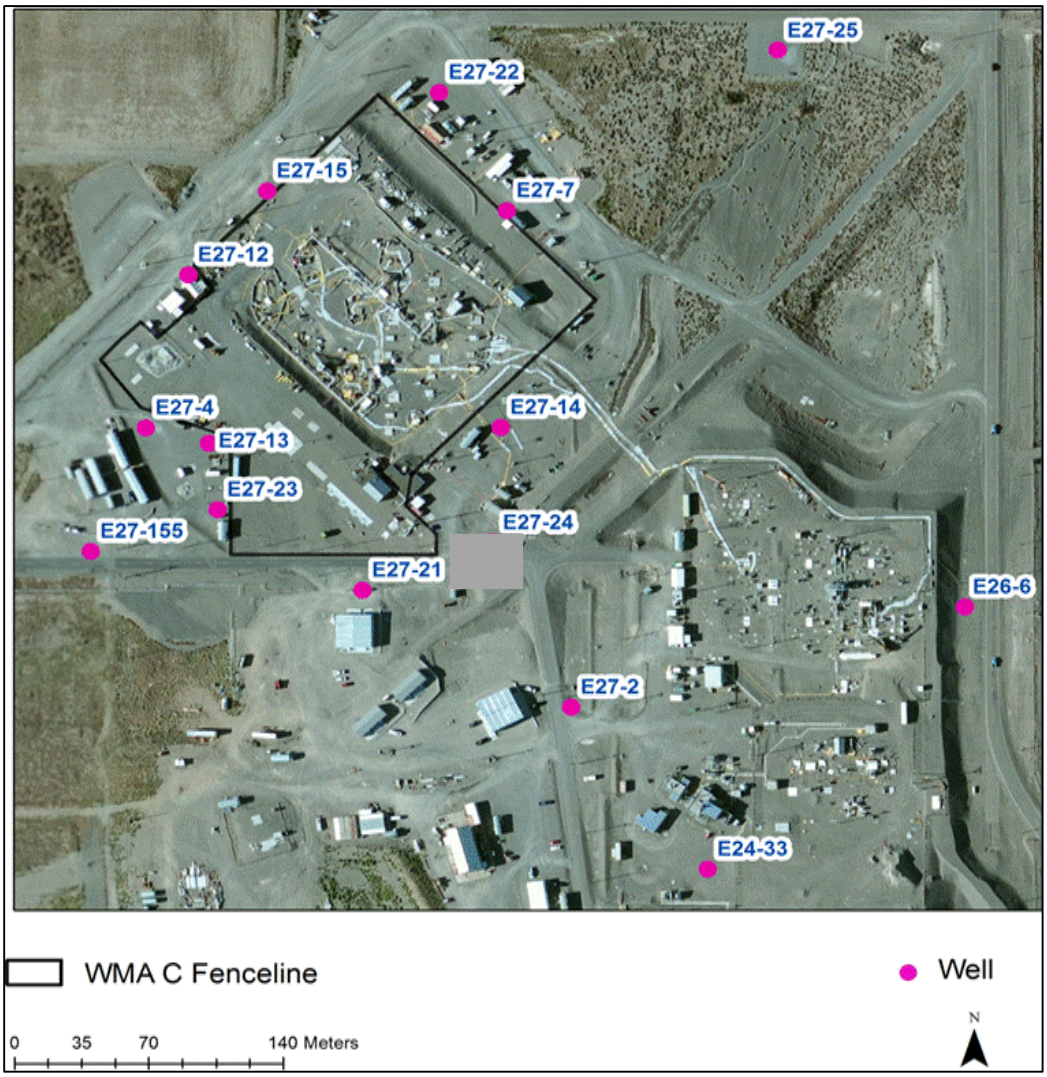



**Figure 4. WMA-C Monitoring Wells and Surrounding Area**

### 5.1.1 First Approach

The first approach uses the groundwater annual report plumes geometry to calculate activity flux for technetium-99. This approach assumes the extent of the plume is well defined based on sufficient monitoring wells and the plume has a uniform vertical concentration. Using the Groundwater annual report plumes, the activity of technetium-99 was calculated for five consecutive years (2008-2012). Following steps were used to calculate the plume mass:

- Groundwater annual report plume shape files for each year (2008, 2010, 2011 and 2012) were imported in ARCGIS

- An average saturated zone thickness of 14 m was calculated by subtracting the 2009 water table elevation surface from the top of basalt surface in ARCGIS
- The plume area was calculated using the ARCGIS Geometry calculation tool
- The total volume of the plume was calculated by multiplying the plume area with the saturated zone thickness and the porosity. Then, the total volume of the plume was multiplied with the plume concentration to get the activity for each concentration zone (different contour interval). Then the calculated activity for each concentration zone was added to get the total activity.

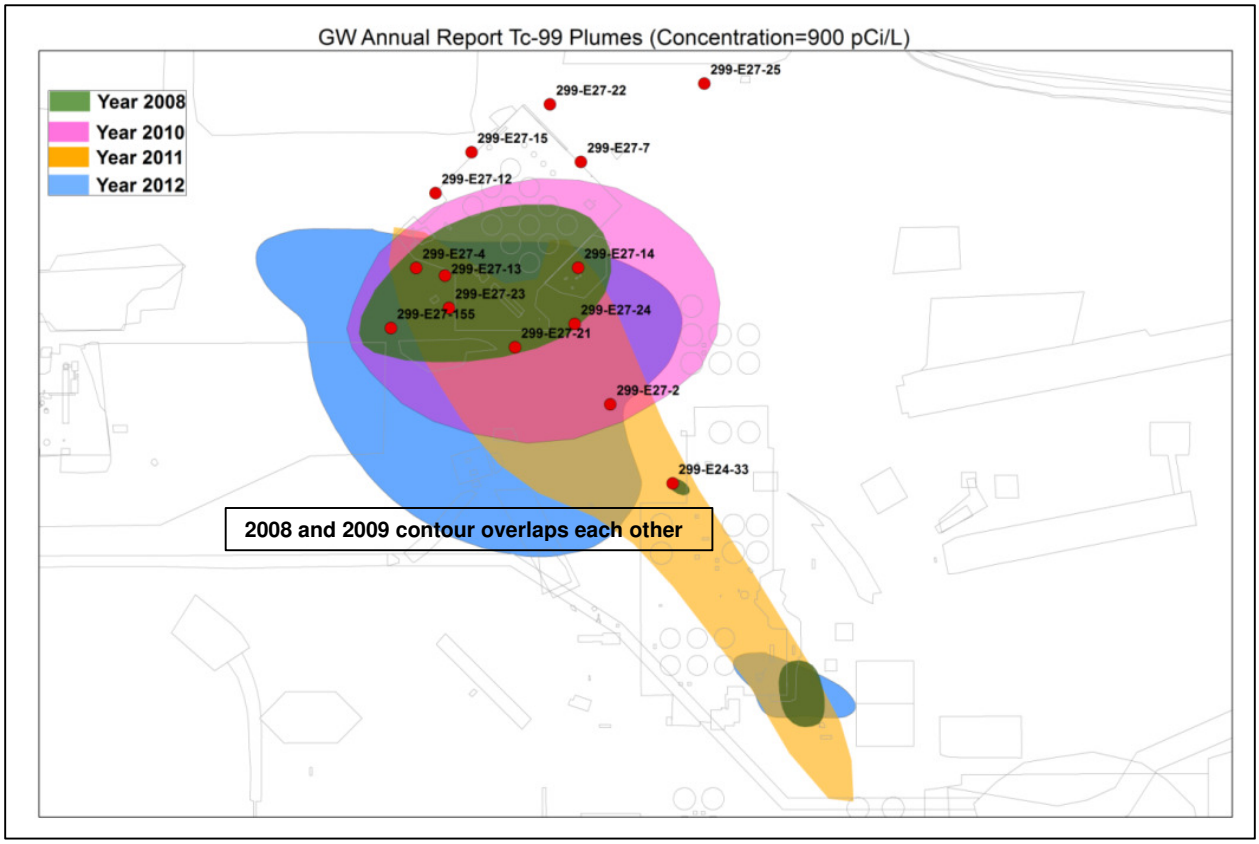



**Figure 5. Technetium-99 Groundwater Annual Report Plume for Different Years**

Table 3 presents the calculated values of total activity for technetium-99 in the saturated zone for different years based on the Annual Groundwater Monitoring Report plumes. Figure 9 shows the calculated activity for technetium-99 for different years.

It is noted in the activity flux calculation that the average increase of activity for technetium-99, from year 2008 to year 2012, is about 0.17 Ci/yr. Considering that approximately 1 Ci is already in the groundwater (based on total activity reported in 2012; see Table 3), the total amount of technetium-99 remaining in the vadose zone is estimated to be about 6 Ci (Table 2). Assuming that the average technetium-99 flux from vadose zone is 0.17 Ci/yr, it will take about 35 years to deplete the mass.

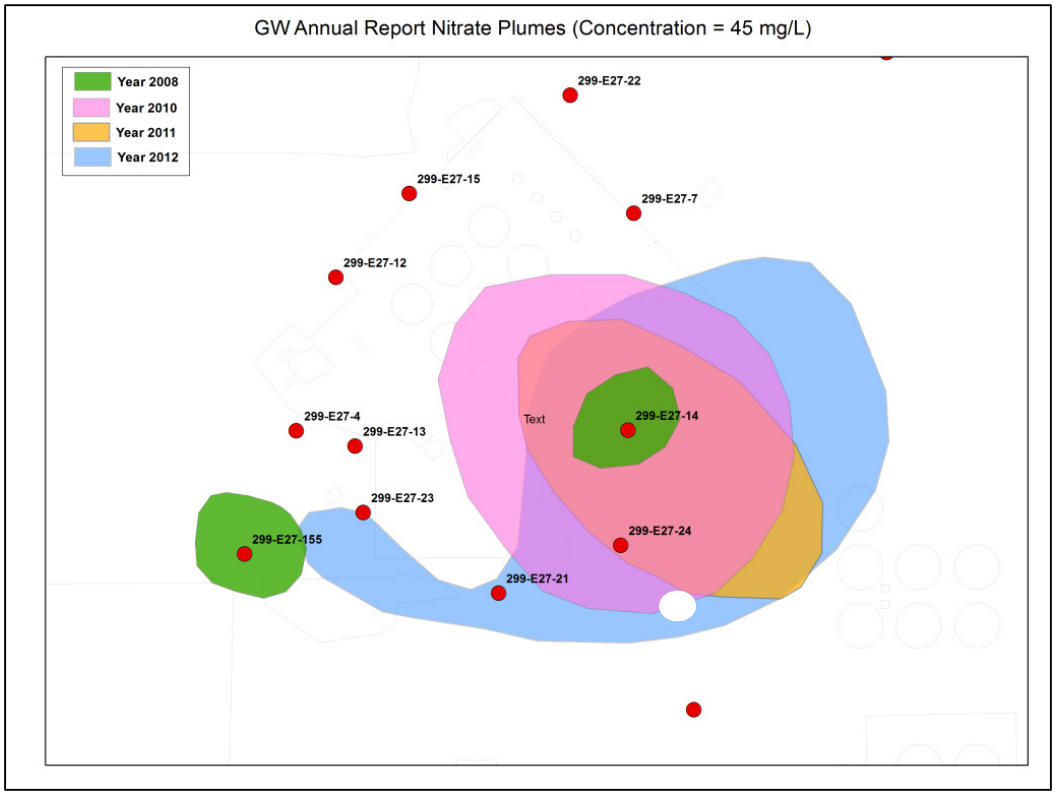



**Figure 6. Nitrate Groundwater Annual Report Plume for Different Years**

### 5.1.2 Second Approach

An alternative plume mapping approach is considered which is independent of previous interpretation. This approach is based on evaluation of about 10 years of analytical measurements, variations in aqueous chemistry spatially and temporally, and most up-to-date information on site conceptual model.
It considers documented information about past releases to the vadose zone. The conceptual model and equations used for this approach are mentioned in Section 2.The concentration trends were evaluated based on last 10 years of concentrations in groundwater monitoring wells. The focus of this approach was on large changes in concentrations for selected analytes: technetium-99, nitrate, sulfate, and chloride that provide insight into relative contribution from past leaks.

**Table 2. Inventory Released in WMA-C**

| Tank/UPR | Waste Release (gallons) | Co-60 (Ci) | Cs-137 (Ci) | Tc-99 (Ci) |
|---|---|---|---|---|
| C-101 | <37,000 (spare inlet and condensate) | 0.17 | 800 | 0.22 |
| C-104 | 28,000 (cascade line) | 1.3 | 80 | 0.03 |
| C-105 | <2,000 (cascade line; tank liner) | 0.08 | 2,500 | 0.8 |
| C-108 | 18,000 (cascade/pipeline) | 0.8 | 50 | 0.02 |
| C-110 | <2,000 (spare inlet) | 0.3 | 300 | 0.11 |
| C-111 | 0 | | | |
| C-112 | 7,000 | 0.33 | 20 | 0.0075 |
| C-201 | 0 | | | |
| C-202 | 0 | | | |
| C-203 | 0 | | | |
| C-204 | 0 | | | |
| UPR-81 | 36,000 (transfer line near 151-CR Diversion Box) | 0.36 | 350 | 0.11 |
| UPR-82 | 2,600 | 0.4 | 5,500 | 3 |
| UPR-86 | 17,000 (waste transfer line leak) | 0.7 | 11,500 | 2.9 |
| **Total** | **149,600** | **4.44** | **21100** | **7.2** |

Source: RPP–ENV-33418, *Hanford C-Farm Leak Assessments Report*

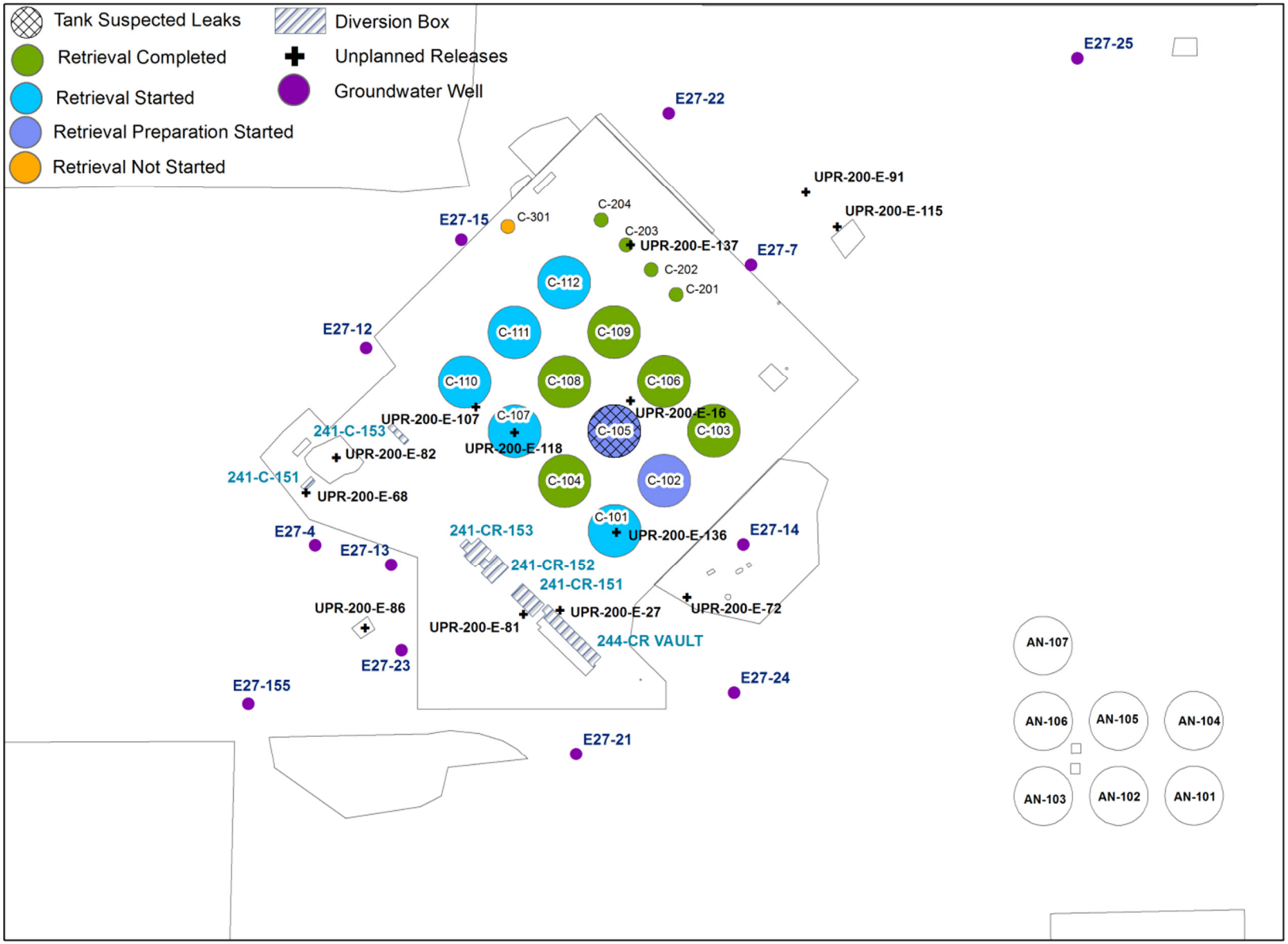



**Figure 7. WMA-C Suspected Leakers, Unplanned Releases and Tank Retrieval Status**

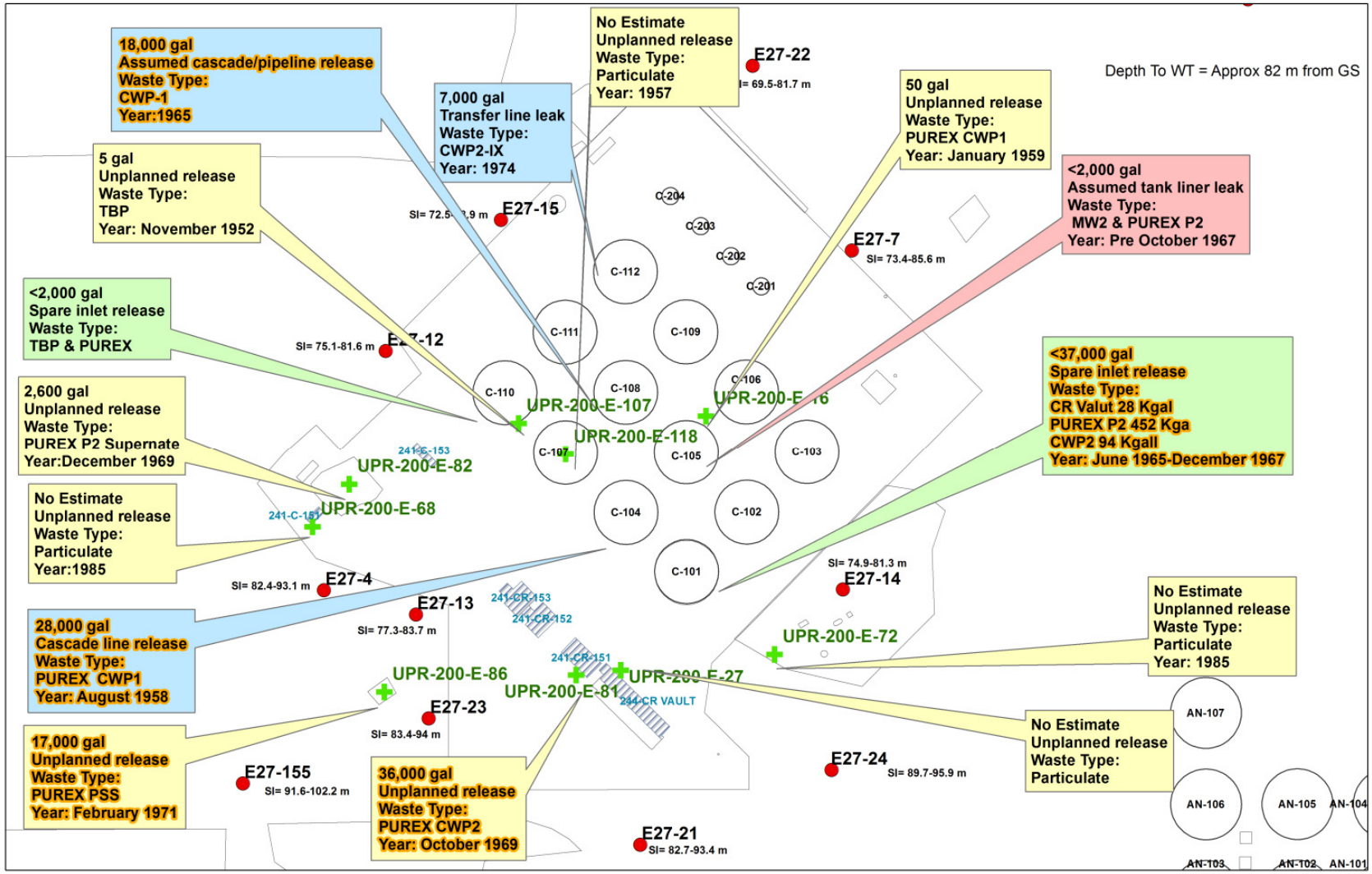



**Figure 8. Waste Amount, Composition, and Year of Waste Release from Various Locations within WMA C**

**Table 3. Technetium-99 Activity Calculation from Groundwater Annual Report Plume**

| Year | Contour value (pCi/L) | Volume ($m^3$) | Activity (pCi) | Total Volume ($m^3$) | Total Activity (pCi) |
|---|---|---|---|---|---|
| 2008 | 900 | 548076.8791 | 1.48E+11 | 6.51E+05 | 2.86E+11 |
| | 4500 | 102489.4 | 1.38E+11 | | |
| 2009 | 900 | 612933.28 | 1.65E+11 | 650566.28 | 2.67E+11 |
| | 9000 | 37633 | 1.02E+11 | | |
| 2010 | 900 | 1397371.45 | 3.77E+11 | 1472040.5 | 5.79E+11 |
| | 9000 | 74669.05 | 2.02E+11 | | |
| 2011 | 900 | 1663583 | 4.49E+11 | 1710961.63 | 5.77E+11 |
| | 9000 | 47378.63 | 1.28E+11 | | |
| 2012 | 900 | 2157401 | 5.82E+11 | 2287283.13 | 9.58E+11 |
| | 9000 | 120647.7 | 3.26E+11 | | |
| | 18000 | 9234.43 | 4.99E+10 | | |

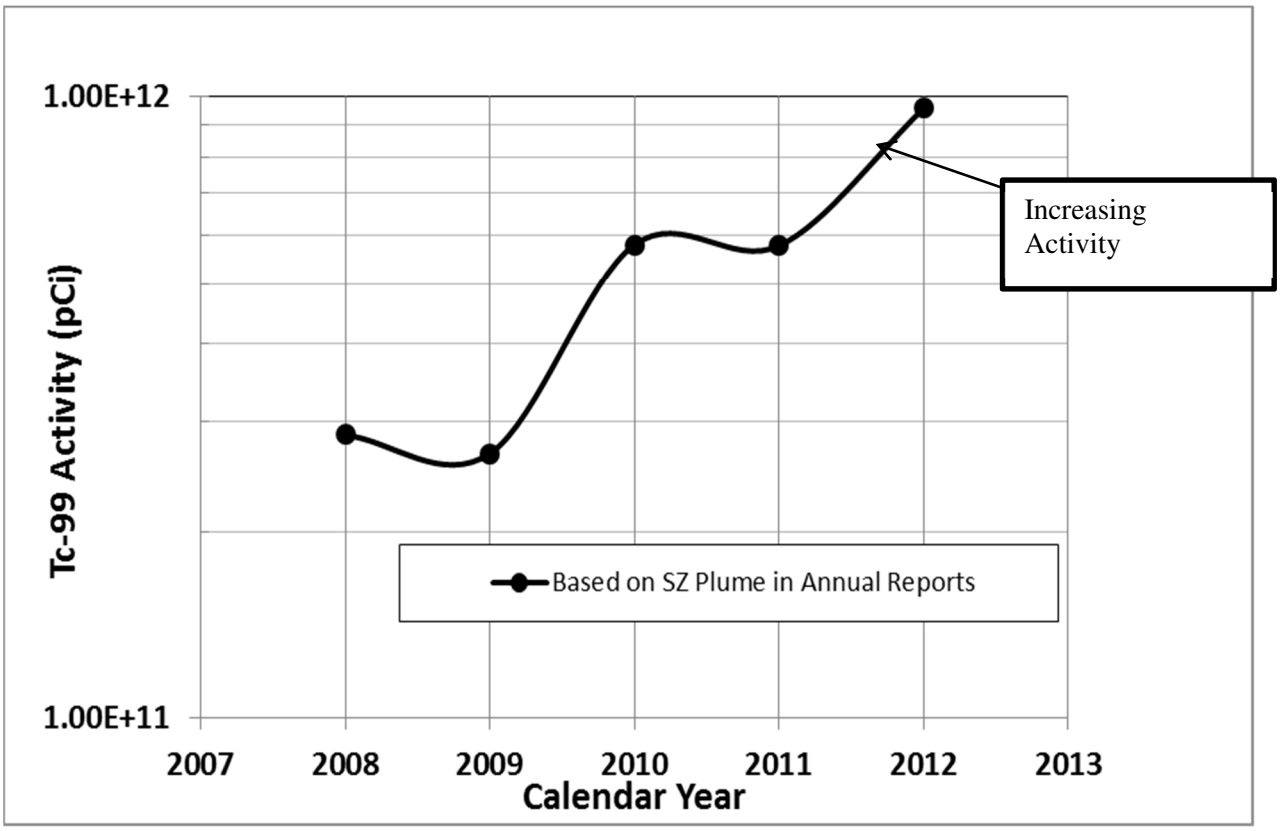



**Figure 9. Groundwater Annual Report based Technetium-99 Plume Activity Estimate**

The following steps were undertaken in this calculation approach:

- Datasets for years 2008, 2010, and 2012 were selected for this calculation. The groundwater concentrations of technetium-99, nitrate, sulfate, and chloride were analyzed for these years.
- Time histories for these analytes are presented in Figure 10.
- The median concentration values were calculated for each analyte for each year and bivariate plots were drawn for the analytes. The bivariate plots with median concentrations are presented in Figure 11, Figure 12 and Figure 13. From the bivariate plots, the end-member waters (reflecting varying sources) were identified and mixing lines were calculated between the end-member waters and the up-gradient water type. The concentrations from wells that fall along the mixing lines can be explained by dilution of the end-member water with the uncontaminated up-gradient water.
- Using information based on bivariate plots and dilution lines along with the long-term observed concentration trends, three different plume source zones have been interpreted for each year for technetium-99 (Figure 14). For comparison, the plume areas based on annual groundwater reports (shown in Figure 5) are also plotted in the background. The new interpretations indicate that there are possibly three sub-plumes of variable sizes as opposed to one big plume interpreted in the annual groundwater reports.
- Activity flux was calculated using Equation 3 for the newly interpreted plume areas shown in Figure 14 for each year. Table 4 presents the calculations used to estimate the flux from the vadose zone over the three plume areas for 2008, 2010, and 2012.

Using the vadose zone activity flux, the time to deplete the mass was calculated using the following expression:

Time to Deplete = Technetium-99 Activity in vadose zone (Ci) / Average Flux of Tc-99 from Vadose Zone (Ci/Yr) Equation 5

This calculation is applied to each of the leaked sources identified in the RPP–ENV-33418 to estimate the time to deplete the vadose zone inventory in a simplistic manner, as presented in Table 5.

Estimate of the total activity of technetium-99 for each year is calculated by adding activity for all three plumes (Table 6). Table 4 provides an estimate of the combined vadose zone flux, over all three plumes for various years; the estimate is at least 0.04 Ci/yr in a given year. This estimate is deemed to be at the lower end of the potential range because this calculation is based on activity within the highest concentration contour; it does not consider the activity (at lower concentration) that is outside the contoured area. The estimate also does not consider any plumes that are unknown due to limited well coverage area near the tanks. In order to account for this lack of information the estimate of the annual vadose zone flux is increased by a factor of two and rounded up to 0.1 Ci/yr.

Some considerations when using this approach are:

- The vadose zone activity flux was assumed equal to the observed saturated zone activity flux.
- Information from bivariate plots is used to guide plume evolution spatially and temporally, i.e. it recognizes the sub-plumes around WMA C and uses flow directions to estimate the plume shapes.
- It recognizes incomplete information regarding plume geometry and therefore uses the highest concentration regions to estimate mass flux by taking into account the conceptual site model.

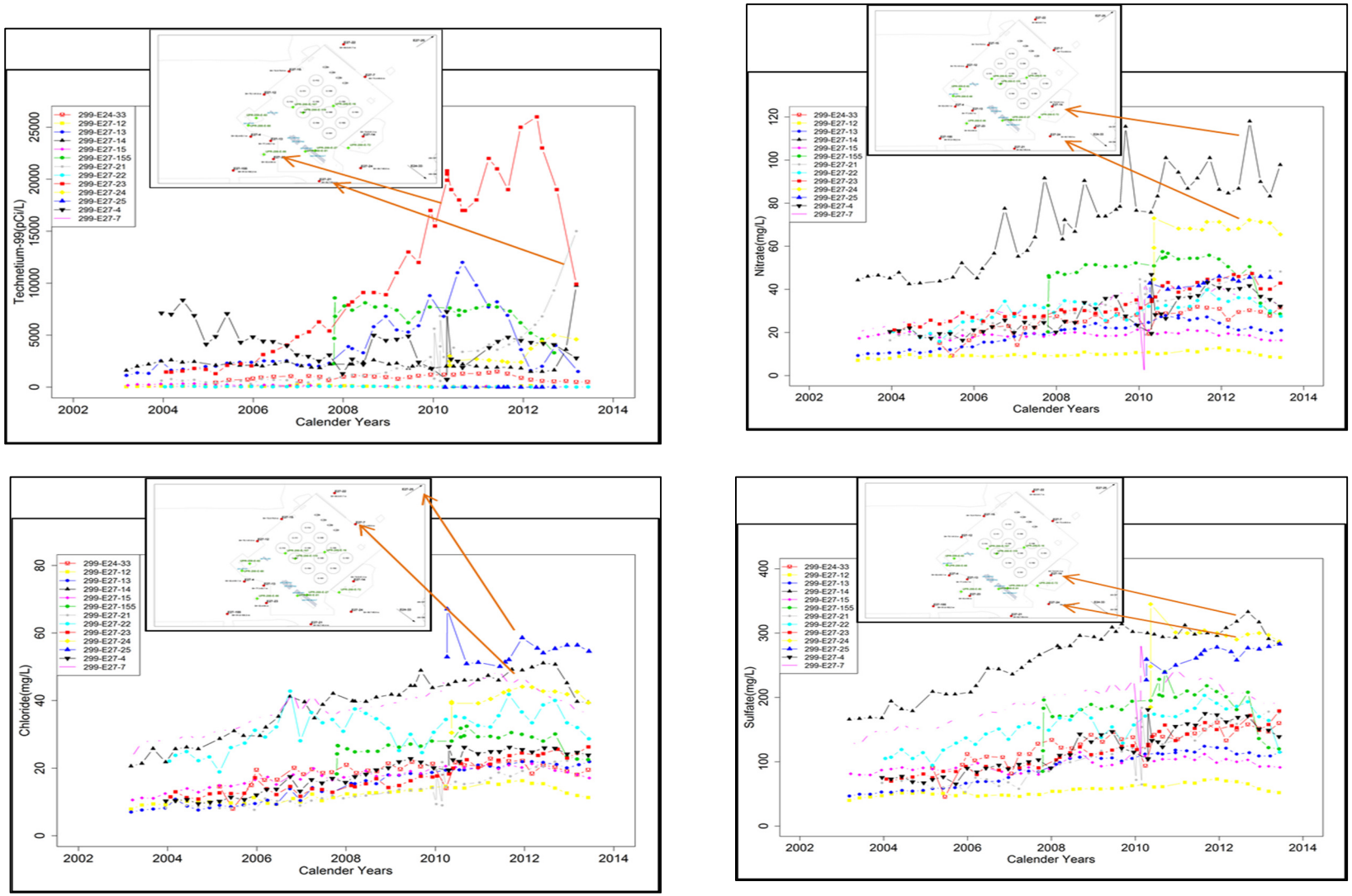



**Figure 10. Concentration Trend Analysis of Selected Analytes**

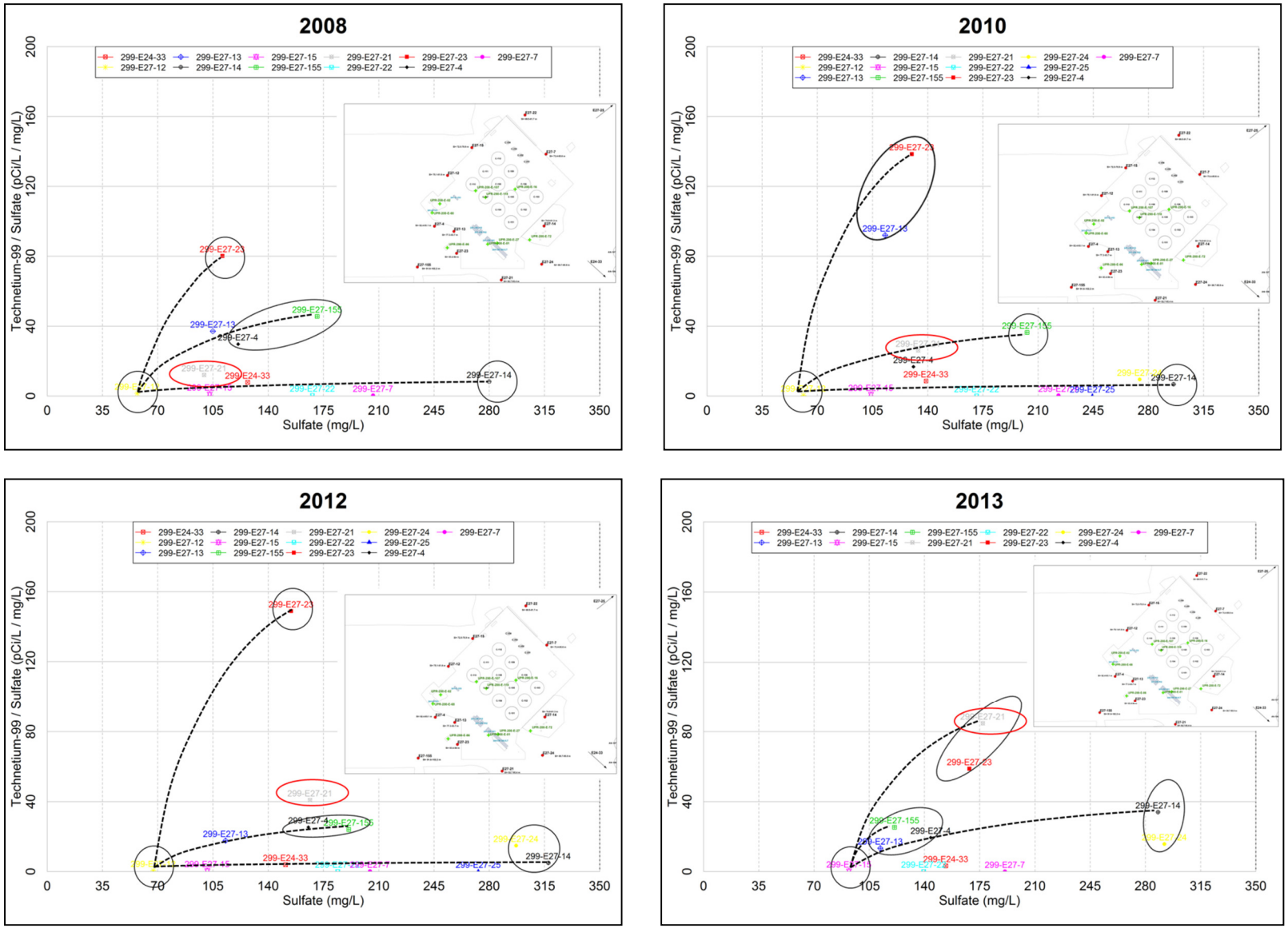



**Figure 11. Bivariate Plots of Technetium-99/Nitrate Vs Nitrate by Year**

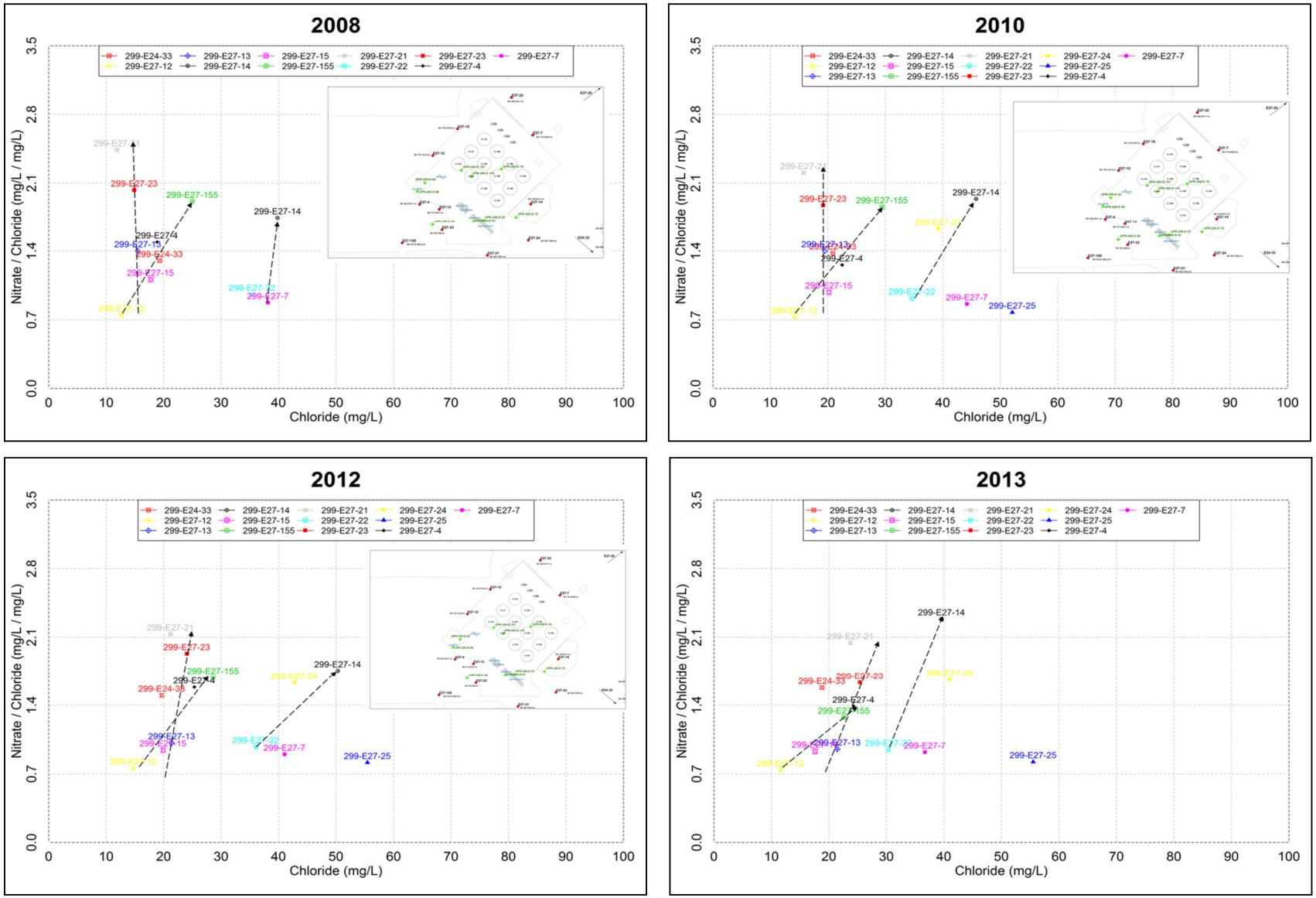



**Figure 12. Bivariate Plots of Technetium-99/Sulfate Vs Sulfate by Year**

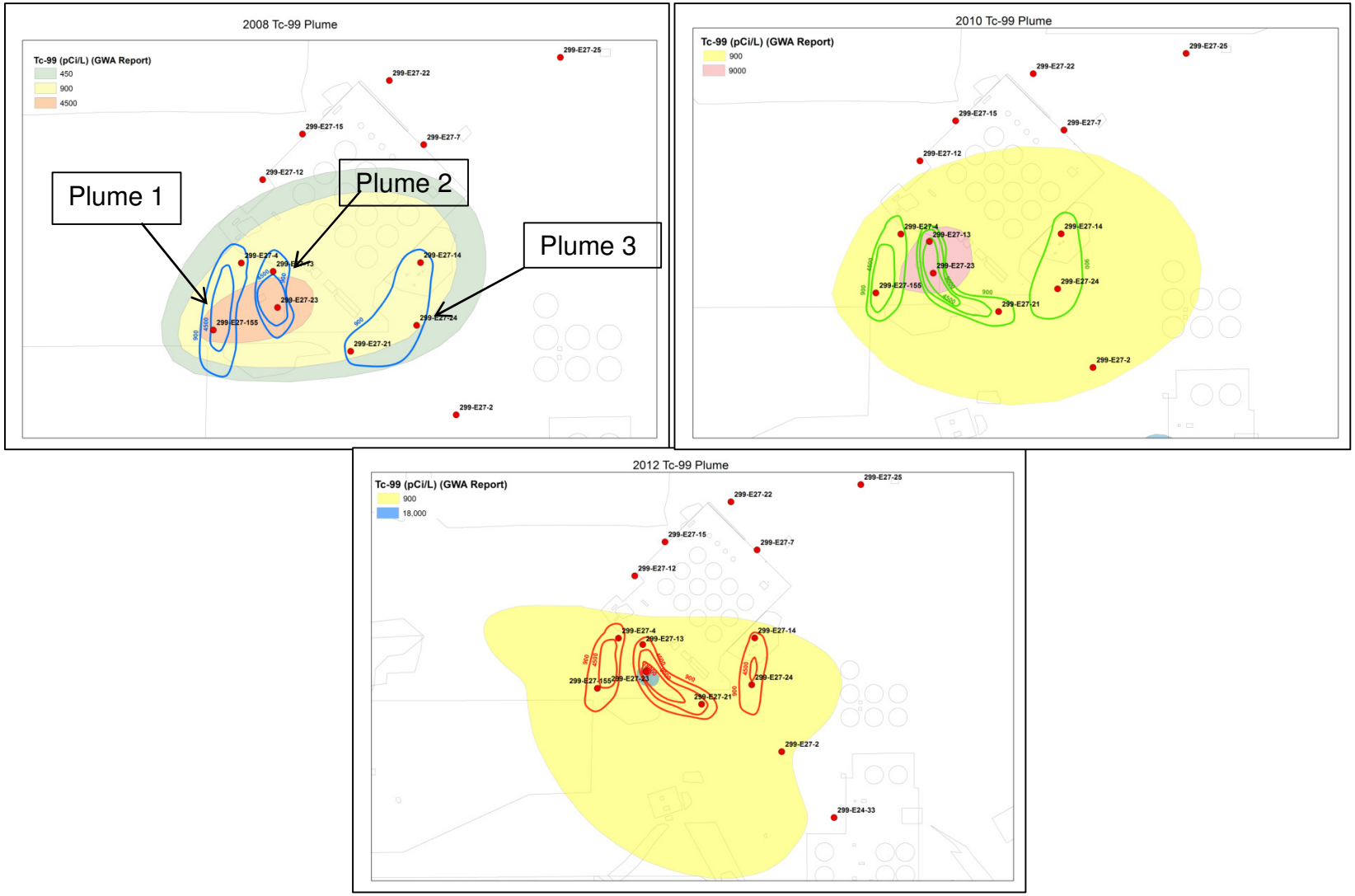



**Figure 13. Bivariate Plots of Technetium-99/Chloride ratio versus Chloride by Year**

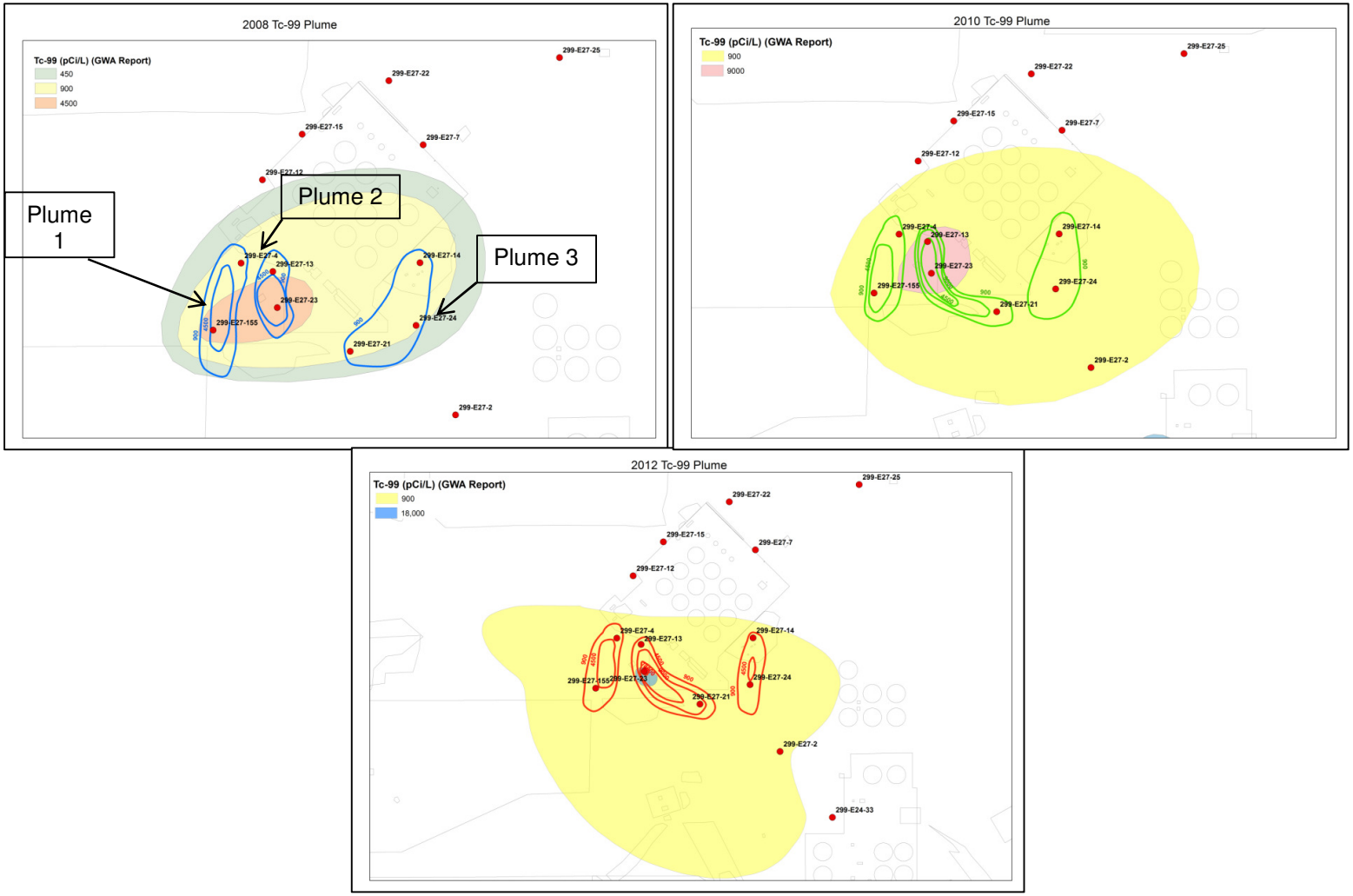



**Figure 14. Interpreted Technetium-99 Plumes in the Saturated Zone (shown as contours) with Plume Interpretations from Groundwater Annual Monitoring Reports are Also Presented for Comparison (in solid color)**

**Table 4. Vadose Zone Flux Estimate of Technetium-99 over Selected Saturated Zone Area**

| Plume | Concentration Contour (pCi/L) | Saturated zone plume Area($m^2$) | Vadose zone plume Area($m^2$) | Saturated zone Plume width (m) | Qs ($m^3$/d) | Qv ($m^3$/d) | Pore volume ($m^3$) | Residence time (day) | Saturated zone Activity (pCi) | Pore volumes flushed / yr | Vadose Zone Activity Flux over selected SZ Conc. Contour Area per year (pCi/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Plume 2008** | | | | | | | | | | | |
| Plume1 | 4500 | 1483.6 | 1637.5 | 20.0 | 8.4 | 0.4 | 6231.2 | 704.2 | 2.80E+10 | 0.52 | 1.45E+10 |
| Plume2 | 4500 | 1165.9 | 760.0 | 30.0 | 12.6 | 0.2 | 4896.7 | 382.3 | 2.20E+10 | 0.95 | 2.10E+10 |
| Plume3 | 900 | 5912.3 | 960.2 | 51.0 | 21.4 | 0.3 | 24831.7 | 1145.2 | 2.23E+10 | 0.32 | 7.12E+09 |
| **Plume 2010** | | | | | | | | | | | |
| Plume1 | 4500 | 1647.5 | 1637.5 | 25.5 | 10.7 | 0.4 | 6919.5 | 620.1 | 3.11E+10 | 0.59 | 1.83E+10 |
| Plume2 | 4500 | 1568.8 | 760.0 | 18.0 | 7.6 | 0.2 | 6589.0 | 848.2 | 2.97E+10 | 0.43 | 1.28E+10 |
| Plume3 | 900 | 5298.5 | 960.2 | 51.0 | 21.4 | 0.3 | 22253.7 | 1026.3 | 2.00E+10 | 0.36 | 7.12E+09 |
| **Plume 2012** | | | | | | | | | | | |
| Plume1 | 4500 | 1374.3 | 1637.5 | 23.0 | 9.7 | 0.4 | 5772.3 | 571.0 | 2.60E+10 | 0.64 | 1.66E+10 |
| Plume2 | 4500 | 1963.5 | 760.0 | 35.0 | 14.7 | 0.2 | 8246.6 | 553.2 | 3.71E+10 | 0.66 | 2.45E+10 |
| Plume3 | 900 | 1149.2 | 960.2 | 33.0 | 13.9 | 0.3 | 4826.5 | 341.7 | 4.34E+09 | 1.07 | 4.64E+09 |

**Table 5. Average Time Estimate for Depleting the Soil Inventory at WMA C Locations**

| Tank/UPR | Technetium-99 (Ci) | Average VZ Flux (pCi/yr) | Approximate Time to Deplete the Inventory (yr) |
|---|---|---|---|
| C-101 | 0.22 | 1.4E+10 | 16 |
| C-104 | 0.03 | | 2 |
| C-105 | 0.8 | | 60 |
| C-108 | 0.02 | | 2 |
| C-110 | 0.11 | | 8 |
| C-111 | NA | | NA |
| C-112 | 0.0075 | | 0.5 |
| C-201 | NA | | NA |
| C-202 | NA | | NA |
| C-203 | NA | | NA |
| C-204 | NA | | NA |
| UPR-81 | 0.11 | | 8 |
| UPR-82 | 3 | | 220 |
| UPR-86 | 2.9 | | 210 |

**Table 6. Total Activity of Technetium-99 in Interpreted Plumes**

| Plume | Conc. Contour (pCi/L) | SZ Plume Area ($m^2$) | Porosity | SZ Thickness (m) | Plume Volume ($m^3$) | SZ Activity (pCi) | Total Activity (pCi) |
|---|---|---|---|---|---|---|---|
| **Plume 2008** | | | | | | | |
| Plume1 | 4500 | 1483.60 | 0.30 | 14 | 6231.12 | 2.80E+10 | 8.87E+10 |
| | 900 | 2979.85 | 0.30 | 14 | 12515.36 | 1.13E+10 | |
| Plume2 | 4500 | 1165.90 | 0.30 | 14 | 4896.78 | 2.20E+10 | |
| | 900 | 1332.31 | 0.30 | 14 | 5595.70 | 5.04E+09 | |
| Plume3 | 900 | 5912.30 | 0.30 | 14 | 24831.66 | 2.23E+10 | |

**Table 6. Total Activity of Technetium-99 in Interpreted Plumes**

| Plume | Conc. Contour (pCi/L) | SZ Plume Area ($m^2$) | Porosity | SZ Thickness (m) | Plume Volume ($m^3$) | SZ Activity (pCi) | Total Activity (pCi) |
|---|---|---|---|---|---|---|---|
| **Plume 2010** | | | | | | | |
| Plume1 | 4500 | 1647.50 | 0.30 | 14 | 6919.50 | 3.11E+10 | 1.38E+11 |
| | 900 | 2419.42 | 0.30 | 14 | 10161.58 | 9.15E+09 | |
| Plume2 | 9000 | 1168.88 | 0.30 | 14 | 4909.30 | 4.42E+10 | |
| | 4500 | 1568.80 | 0.30 | 14 | 6588.96 | 2.97E+10 | |
| | 900 | 989.07 | 0.30 | 14 | 4154.09 | 3.74E+09 | |
| Plume3 | 900 | 5298.50 | 0.30 | 14 | 22253.70 | 2.00E+10 | |
| **Plume 2012** | | | | | | | |
| Plume1 | 18000 | 100.35 | 0.30 | 14 | 421.47 | 7.59E+09 | 1.41E+11 |
| | 9000 | 1156.77 | 0.30 | 14 | 4858.43 | 4.37E+10 | |
| | 4500 | 1374.30 | 0.30 | 14 | 5772.06 | 2.60E+10 | |
| | 900 | 2957.34 | 0.30 | 14 | 12420.84 | 1.12E+10 | |
| Plume2 | 4500 | 1963.50 | 0.30 | 14 | 8246.70 | 3.71E+10 | |
| | 900 | 1343.21 | 0.30 | 14 | 5641.46 | 5.08E+09 | |
| Plume3 | 4500 | 323.97 | 0.30 | 14 | 1360.67 | 6.12E+09 | |
| | 900 | 1149.20 | 0.30 | 14 | 4826.64 | 4.34E+09 | |

### 5.1.3 Comparisons of the Two Estimation Approaches

Figure 15 presents the comparison plots for the two different calculation approaches. Annual report based calculation shows increasing activity of technetium-99 in recent times while the interpreted plume based calculation exhibits fairly stable activity.

- Observations from Annual-Report-based technetium-99 activity estimate (First Approach)
  - Present total activity residing in saturated zone is estimated to be about 1 Ci but has been increasing. This appears to be an overestimate resulting from assumed plume areas.
  - Average increase from year 2008 to year 2012 is around 0.17 Ci per year (indicating technetium-99 flux). Assuming 6 Ci of technetium-99 remains in vadose zone it will take about 35 years to be released to the saturated zone

- Observations from interpreted-plume-based technetium-99 activity (Second Approach)
  - Present total activity residing in saturated zone is estimated to be about 0.14 Ci that appears to have reached a steady state. No appreciable net increase in activity is predicted in the future.
  - Vadose zone flux based on highest concentration plume areas is estimated to be 0.04 Ci per year. This estimate is increased by a factor of two in order to accommodate activity outside the highest concentration areas and in recognition of limited information on plumes elsewhere. As a result, the total vadose zone flux for WMA C is estimated to be around 0.1 Ci per year. Assuming 6 Ci of technetium-99 remains in vadose zone, it will take about 60 years to be released to the saturated zone.

Note that the nitrate plumes observed in the WMA C vicinity do not show high concentrations and, therefore, indicates a weak source of nitrate from the vadose zone that may be localized in nature.

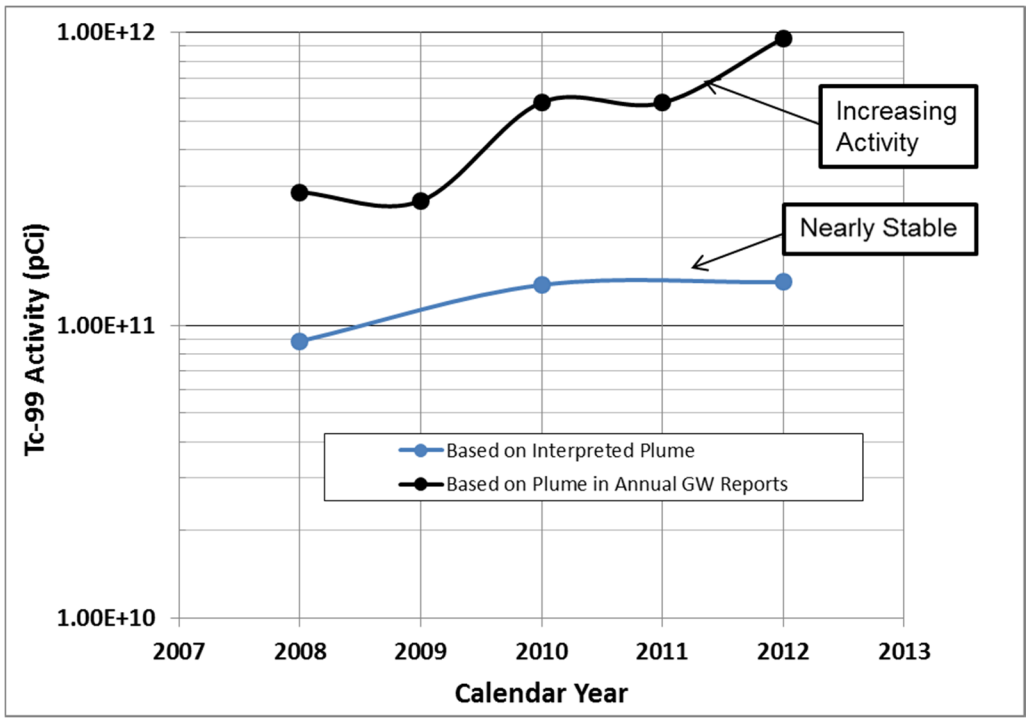



**Figure 15. Comparison of Technetium-99 Activity Estimate**

## 5.2 Vadose Zone Flux calculation for B-Complex

The approach for determining the vadose zone flux within the B-Complex is similar to the approach described earlier for WMA C. It is primarily based on utilization of readily available information from HEIS database along with information presented in PNNL-19277 and SGW-53604, *Path Forward Recommendations Report for the Uranium Contamination in the B Area*. In PNNL-19277, the total activity of technetium-99 and mass of uranium in the saturated zone was calculated based on plume interpretations from monitoring well data and therefore represents an approach that is analogous to the "First Approach" discussed in the previous section related to the WMA C. To be consistent with the methodology adopted for WMA C we have also applied the "Second Approach" to independently estimate the mass flux of technetium-99 and uranium within the B-Complex and have compared our results with the PNNL-19277 results (First Approach). Figure 16 shows the B-Complex well locations and surrounding facilities.

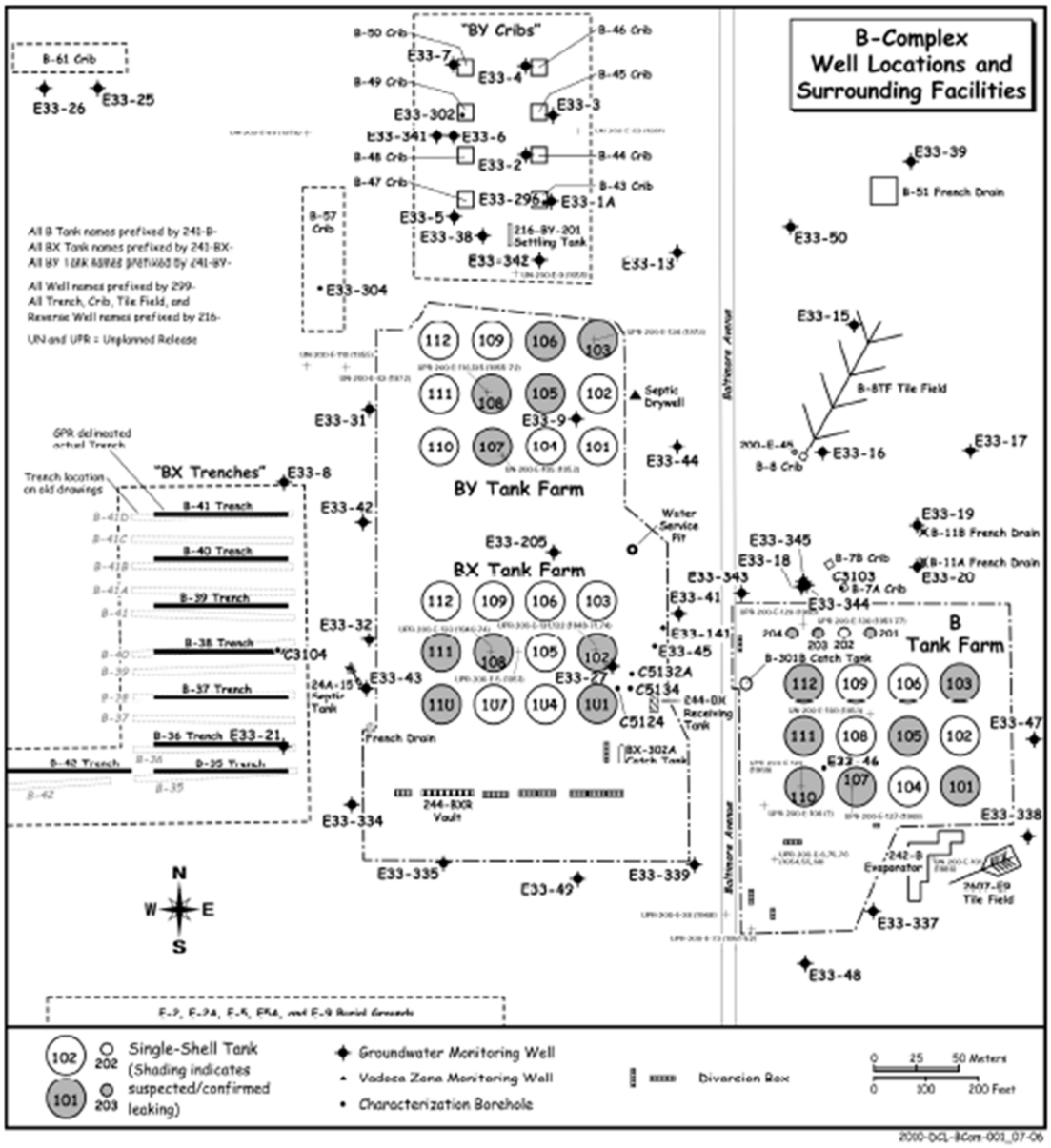



**Figure 16. B-Complex Well Locations and Surrounding Facilities**

### 5.2.1 Background of B-complex

According to PNNL-19277, technetium-99 and uranium are the two primary contaminants of concern in the future within B-Complex due to primarily large discharges of effluents in the cribs and contamination resulting from BX-102 tank overfill event. The BY Cribs received the largest volume of waste fluids among the B-Complex area: in November 1954 to December 1955 the seven BY cribs received 33.8 ML (million liters) of fairly concentrated wastes from scavenging operations related to uranium and Cs-137 out of metal wastes stored in Single Shell Tanks (SSTs); from January 1964 to January 1974 approximately 139 ML of dilute waste from in-tank stabilization process was disposed to two cribs. From September 1946 to May 1967, the B-7-A&B/B-8 Cribs region received 110 ML of wastes. In 1951, BX-102 tank overfill event led to a release of 0.35ML of highly uranium-laden fluids to the vadose zone. The contamination traveled vertically and laterally (in the northeast direction) in the vadose zone along

the natural stratigraphic dip of vadose zone sediments. It traveled laterally along the fine-grained layers in the Hanford formation (H2 unit) sediments with a vertical descent due to gravity where the fine-grained layers pinched out. High concentration of uranium resides in thick CCUz (silt) unit underlying H2 unit where a perched zone has formed in the sand lens between upper and lower CCUz silt layers, which is located about 5 m above the regional water table.

High concentrations of nitrate have been observed in the groundwater in the BY cribs vicinity. This is related to the large effluent discharges. Origin of nitrate and techenetium-99 in the BY cribs appears to be from the same effluent discharge. Because of high nitrate concentrations in and around the BY cribs, it is also being considered as a primary contaminant in the B-Complex. Figure 17 shows the probable source location of technetium-99 (and nitrate) and uranium in the B-complex area. Table 7 presents the relative estimate of contaminant mass distribution within various subregions located in B-Complex area (PNNL-19277). The subregions where substantial mass of technetium-99, nitrate, and uranium is believed to reside in the vadose zone are highlighted with a green circle.

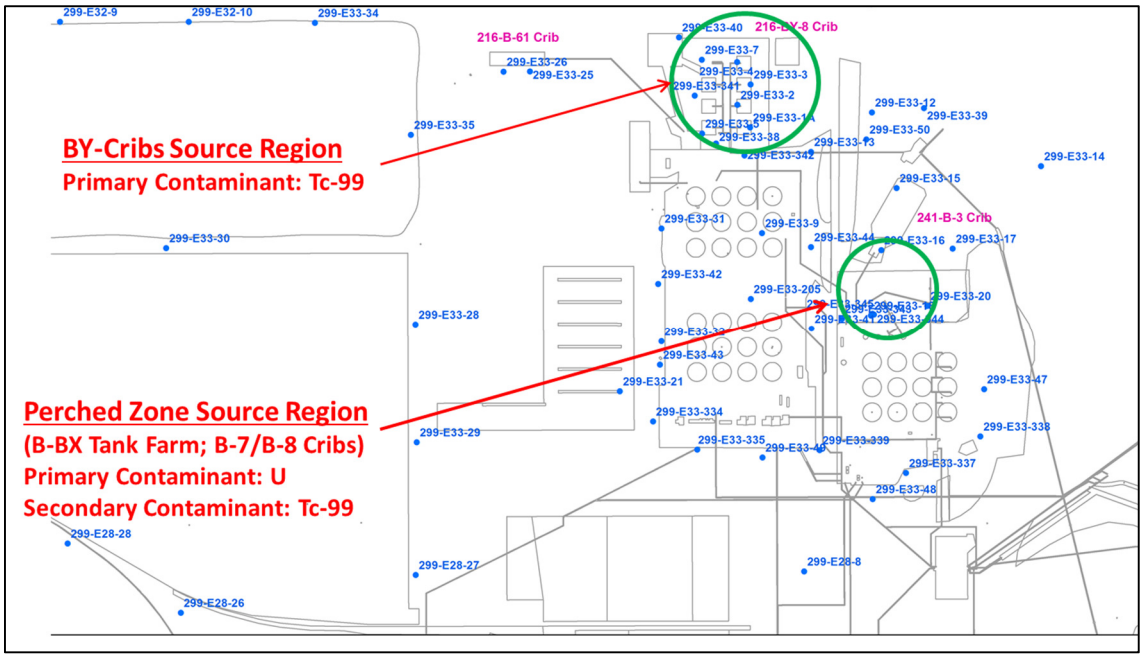



**Figure 17. Probable Source Location of Tecnetium-99 and Uranium in B-Complex Area**

**Table 7. Contaminant Mass Distribution in B-Complex (PNNL-19277)**

| Sub-region | Vol Disposed (%) | $NO_3$ (%) | F (%) | $Fe(CN)_6$ (%) | U (%) | Cr (%) | Co-60 (%) | I-129 (%) | Tc-99 (%) | H-3 (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| BY Cribs (TBP) | 11.30% | **50%** | **30%** | **100%** | **9%** | **20%** | **50%** | **80%** | **90%** | **30%** |
| BY Cribs Vicinity (ITS) | 46.70% | 0% | 0% | 0% | 0% | 0.1% | 0.2% | 0.2% | 0.2% | **50%** |
| B-7-A&B/B-8 Cribs Farm | 36.70% | **36%** | **58%** | 0.% | 3% | **62%** | 3.4% | 0.3% | 0.1% | 2.4% |
| BX Trenches | 5.00% | **13%** | **12%** | 0% | 4.2% | **18%** | **35%** | **15%** | **6%** | **14%** |
| BX Tank Farm | 0.15% | 0% | 0% | 0% | **84%** | 0.3% | 3% | 1% | 3% | 1% |
| BY Tank Farm | 0.05% | 0 % | 0% | 0% | 0% | 0.1% | 1.4% | 1% | 1.0% | 0.1% |
| B Tank Farm | 0.08% | 0% | 0% | 0% | 0% | 0.1% | **8.3%** | 4% | 1% | 1.1% |

Red type delineates the major contributor for each constituent, and bold type delineates other significant contributors.

As part of the uranium characterization from BX-102 overfill event and its extent of contamination (Figure 18), the solid phase testing of the highly contaminated sediments indicated that uranium is predominantly present as calcium uranyl silicate (uranophane). Uranium bearing mineral phases precipitate within small pores in the sediments resulting in larger concentrations in finer grained layers. As a result, a significant fraction of uranium is not readily leachable. Pore waters in CCUz obtained by ultracentrifugation have yielded 110,000 to 435,000 µg/L of uranium.

### 5.2.2 Flux Calculation Procedure

The last 10 years of contaminant concentration trends were evaluated based on the monitoring well records in HEIS. Figure 19 through

Figure 22, inclusive, show the technetium-99, uranium, and nitrate plume history in the B-complex area. These plume geometries are used in the calculations.

Technetium-99 and uranium plume extents were obtained from PNNL-19277 while the nitrate plumes were based on information presented in the Groundwater Annual Reports and HEIS database. To better understand the relative source strength of nitrate within the BY crib area and in the perched zone area, time history of nitrate for three different wells representing the two areas are compared (

Figure 22). From the plot it is evident that concentration of nitrate has been exceeding the drinking water standards (45 mg/L), however, the well located in the BY crib area shows much higher concentration which supports the presence of significant nitrate source in that area. The nitrate concentration for the wells located in the perched zone indicates relatively weak (diffuse) source locally or perhaps influence of migration of contamination from the BY cribs area that got diluted along the flow path. Because there is no clear evidence of separate nitrate source in the perched area, one contiguous nitrate plume for the whole area is considered to estimate the nitrate flux.

Figure 23 and Figure 24 show the bivariate plots of technetium-99/uranium vs. uranium based on median concentration values from various monitoring wells sampled during Year 2009 and 2010. Three end-member water compositions are observed: well waters defined with the green circle have very low technetium-99/uranium ratio as well as low uranium concentrations; waters defined with the blue circle have low technetium-99/uranium ratio but have very high uranium concentration; waters indicated with purple circle are considered upgradient waters that have not been contaminated. Using these three end member compositions, and by simple mixing of the end-member waters (as shown by the mixing lines), all other well water compositions in this area can be explained. The spatial location of end-member waters is presented in the inset figures.

Based on these plots, two sources of contamination are identified and designated as Group 1 waters (characterized by low technetium-99/uranium ratio but high uranium concentration) and Group 2 waters (characterized by low technetium-99/uranium ratio and low uranium concentration). Figure 25 shows the grouping of the wells spatially while Figure 26 shows the time history plots for technetium-99 and uranium for selected wells in a given group. Observations based on nitrate/chloride vs. chloride ratio (Figure 27) and technetium-99/uranium ratio vs. nitrate/chloride ratio (Figure 28) for year 2009 also indicate two different end-member source waters with all other water types being explained through mixing. The Group 1 waters are characterized as being low in nitrate and low in technetium-99/uranium ratio while the Group 2 waters are characterized as being high in nitrate and high in technetium-99/uranium ratio.

Following calculation steps were undertaken:

- Groundwater technetium-99 and uranium plume configurations, as reported in PNNL-19277 for year 2006 and 2009, are considered (see Figure 29 and Figure 30). The Plume figures were imported in ARCGIS and geo-referenced.
- For nitrate the plume geometry was interpreted based on information taken from Groundwater Annual Reports and HEIS for year 2006 and 2009 (see Figure 31 and Figure 32)
- For technatium-99 plumes the high concentration zone was divided into two spatial regions: one to represent the contamination derived from BY Cribs (20,000 pCi/L concentration contour was used in the calculations) and other to represent the contamination derived from the perched zone area (10,000 pCi/L concentration contour was used in the calculations). The plume width for these two concentration zones were calculated using the ArcGIS measuring tool.
- For uranium plumes, there is only one high concentration zone. However, for year 2006, the high concentration was 300 µg/L; and for year 2009, it was 600 µg/L. The width of the plumes was calculated using the ARCGIS measuring tool.
- For nitrate in year 2006, the concentration of the selected zone of the plume was 500 mg/L and for year 2009, the concentration of the selected zone of the plume was 450 mg/L. The plume widths for the zones were calculated using the ARCGIS measuring tool.
- Figure 29, Figure 30, Figure 31 and Figure 32 show the selected plume zone for each contaminants and their respective plume width.
- An average saturated zone thickness of 2 m was calculated by subtracting the 2009 water table elevation from the top of basalt surface.
- The saturated zone activity/mass flux was calculated by using Equation 3 (See section 2).
- Results of the calculations are presented in Table 8, Table 9, and Table 10.

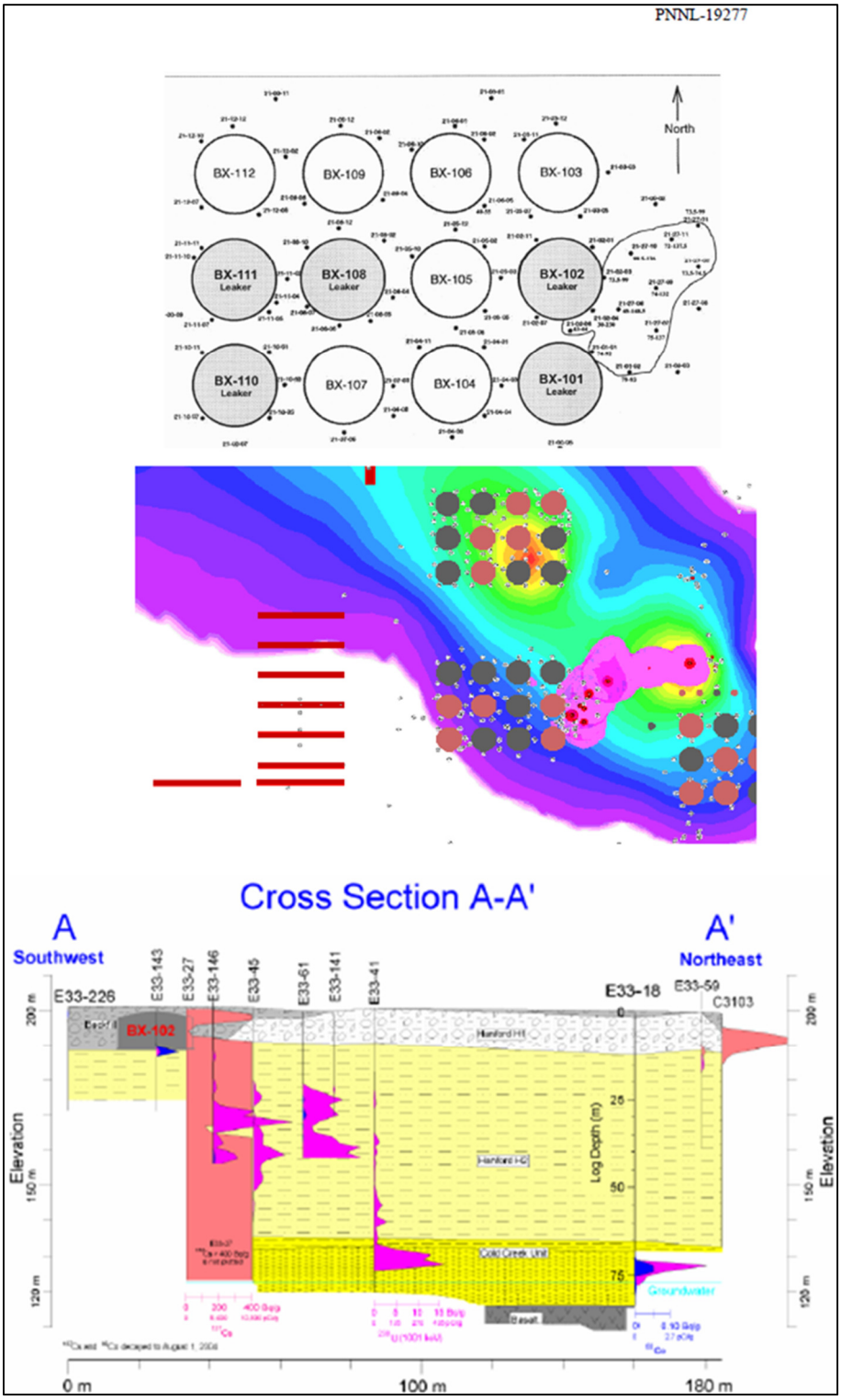



**Figure 18. BX-102 Overfill Event Extent (PNNL-19277)**

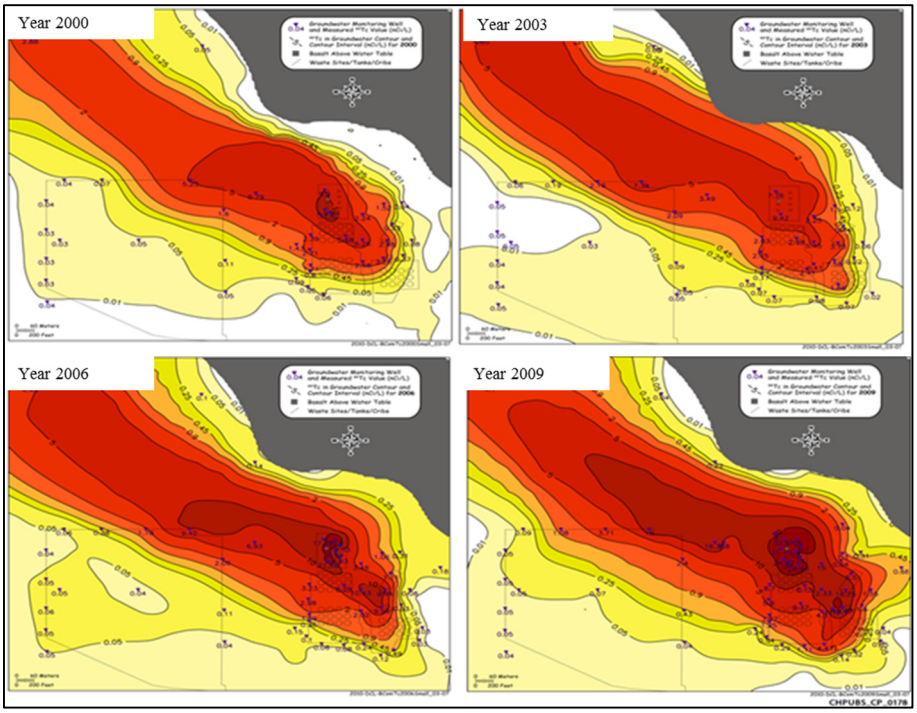



**Figure 19. Technetium-99 Plume Maps (PNNL-19277)**

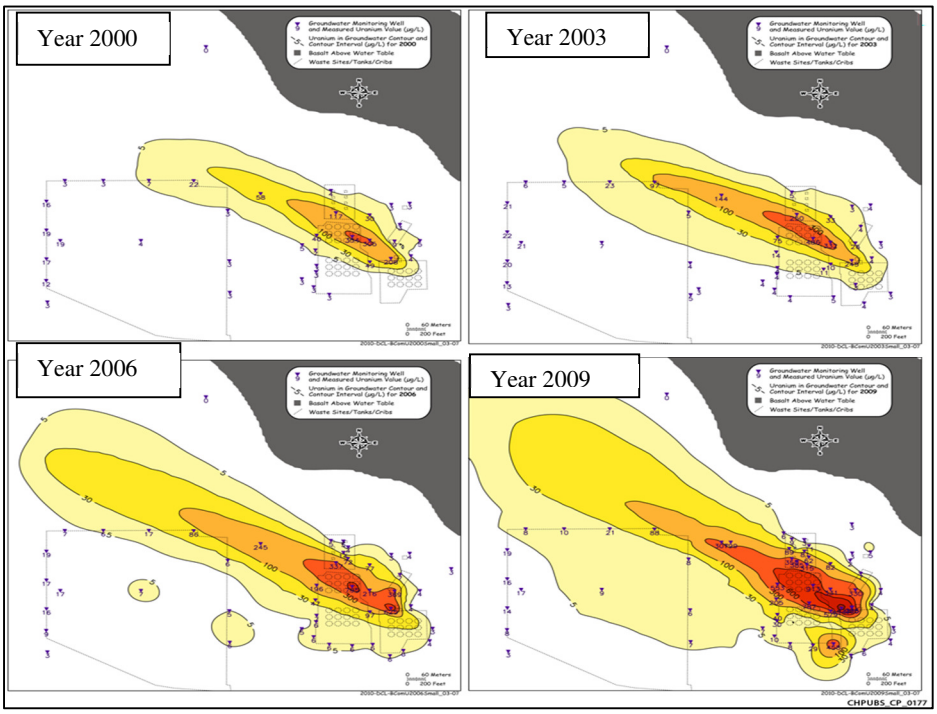



**Figure 20. Uranium Plume Maps (PNNL-19277)**

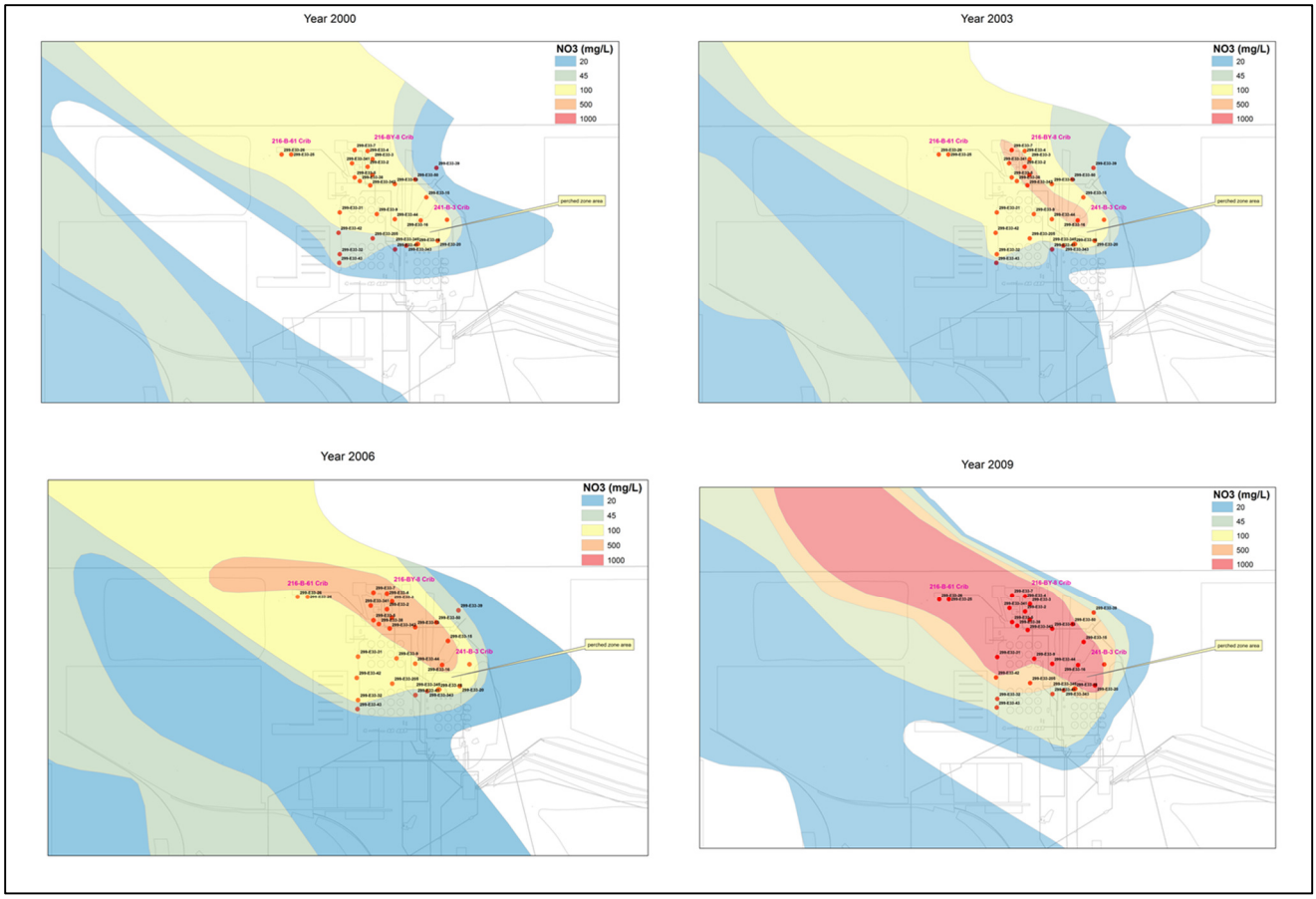



**Figure 21. Nitrate Plume Maps**

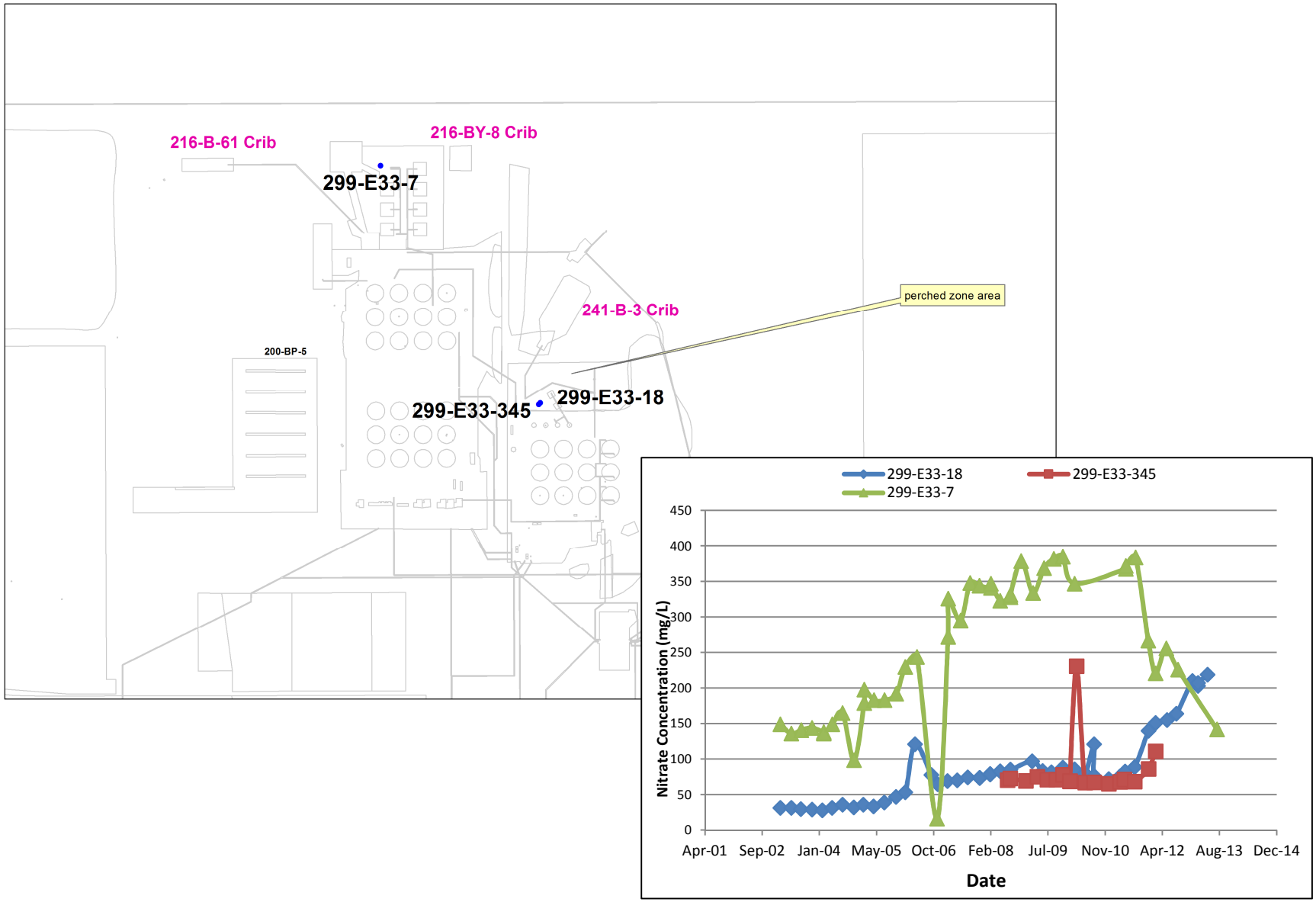



**Figure 22. Nitrate Concentration Plot for Selected Wells**

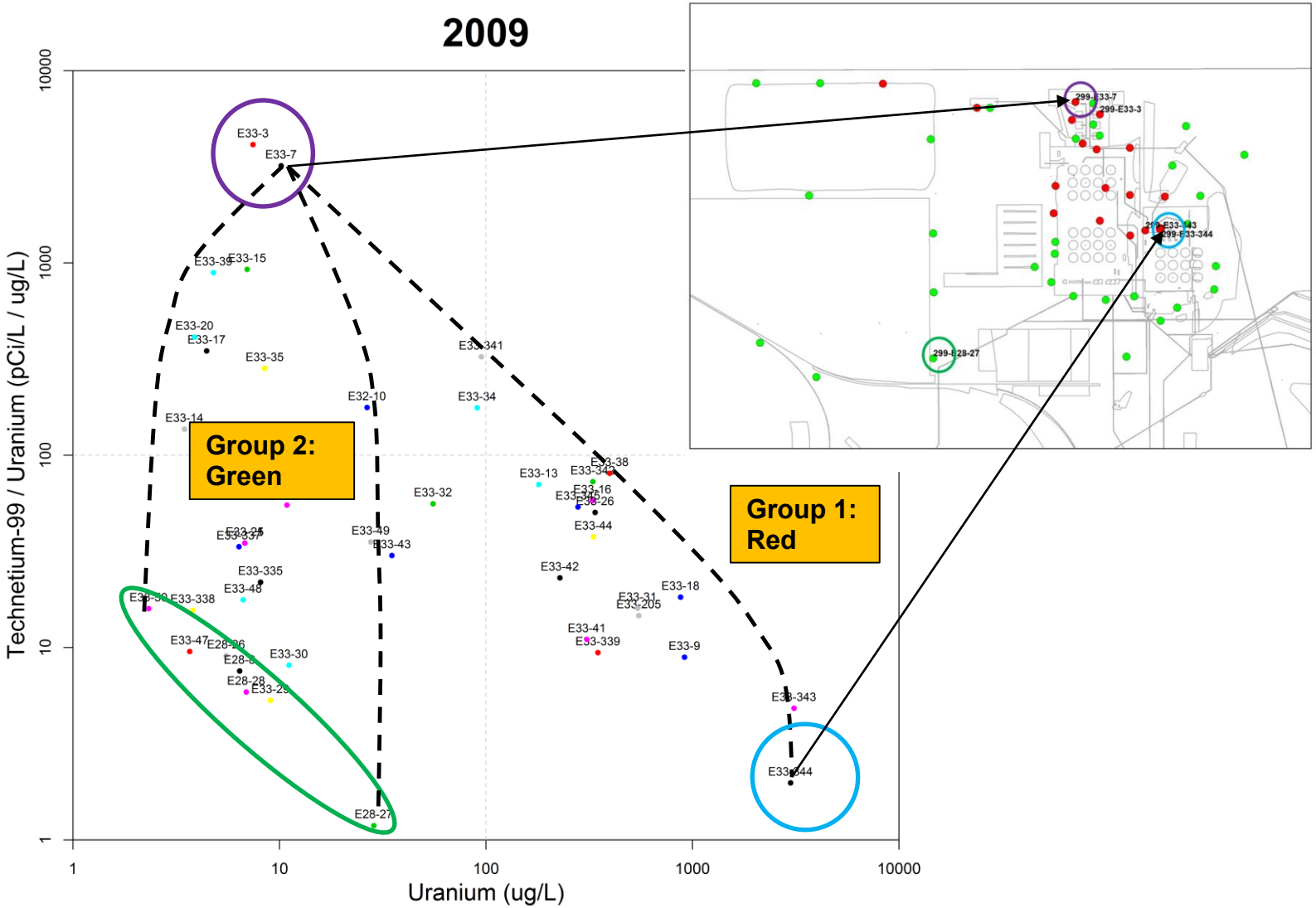



Figure 23. Technetium/Uranium versus Uranium Plot for Year 2009

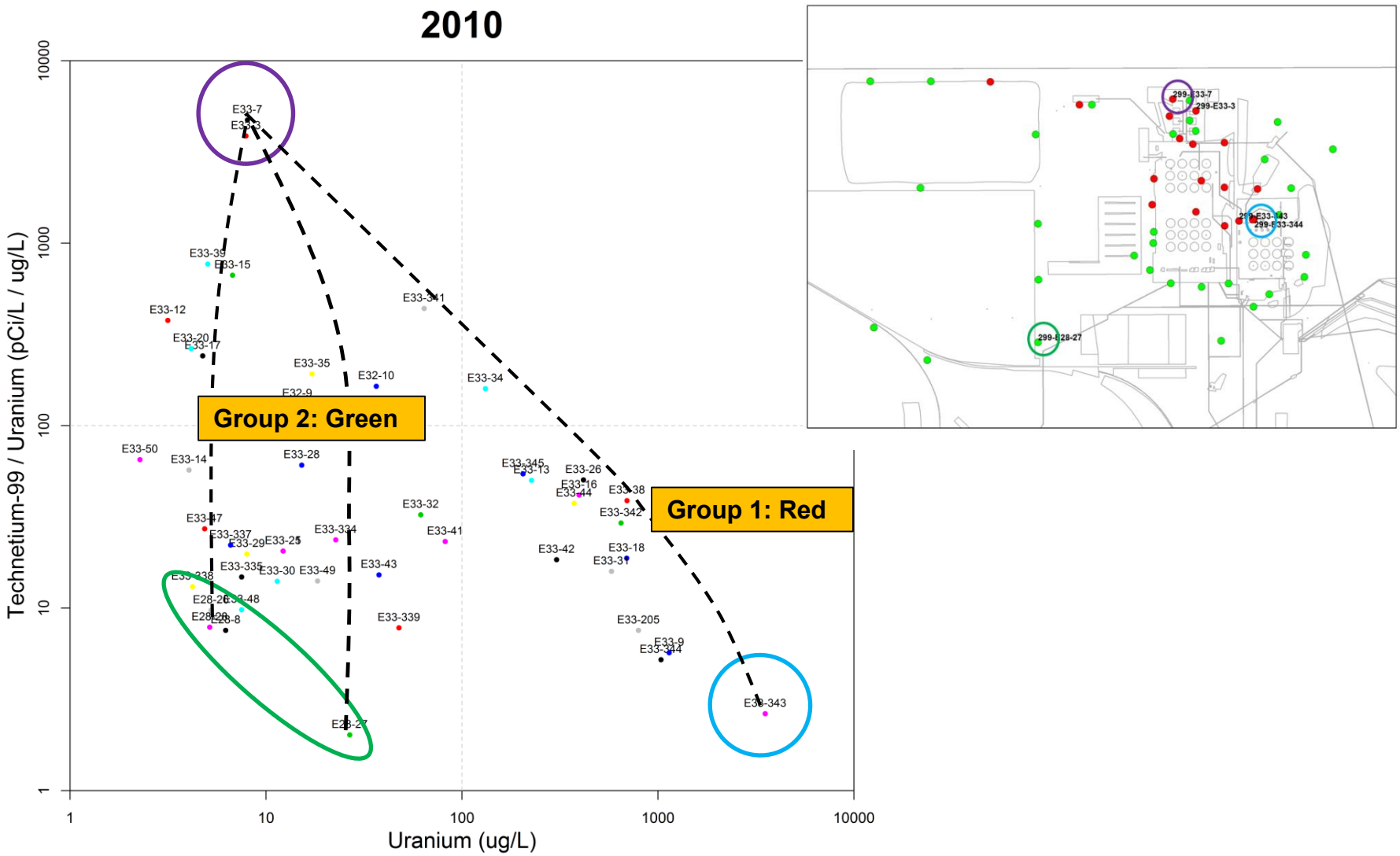



Figure 24. Technetium/Uranium versus Uranium Plot for Year 2010

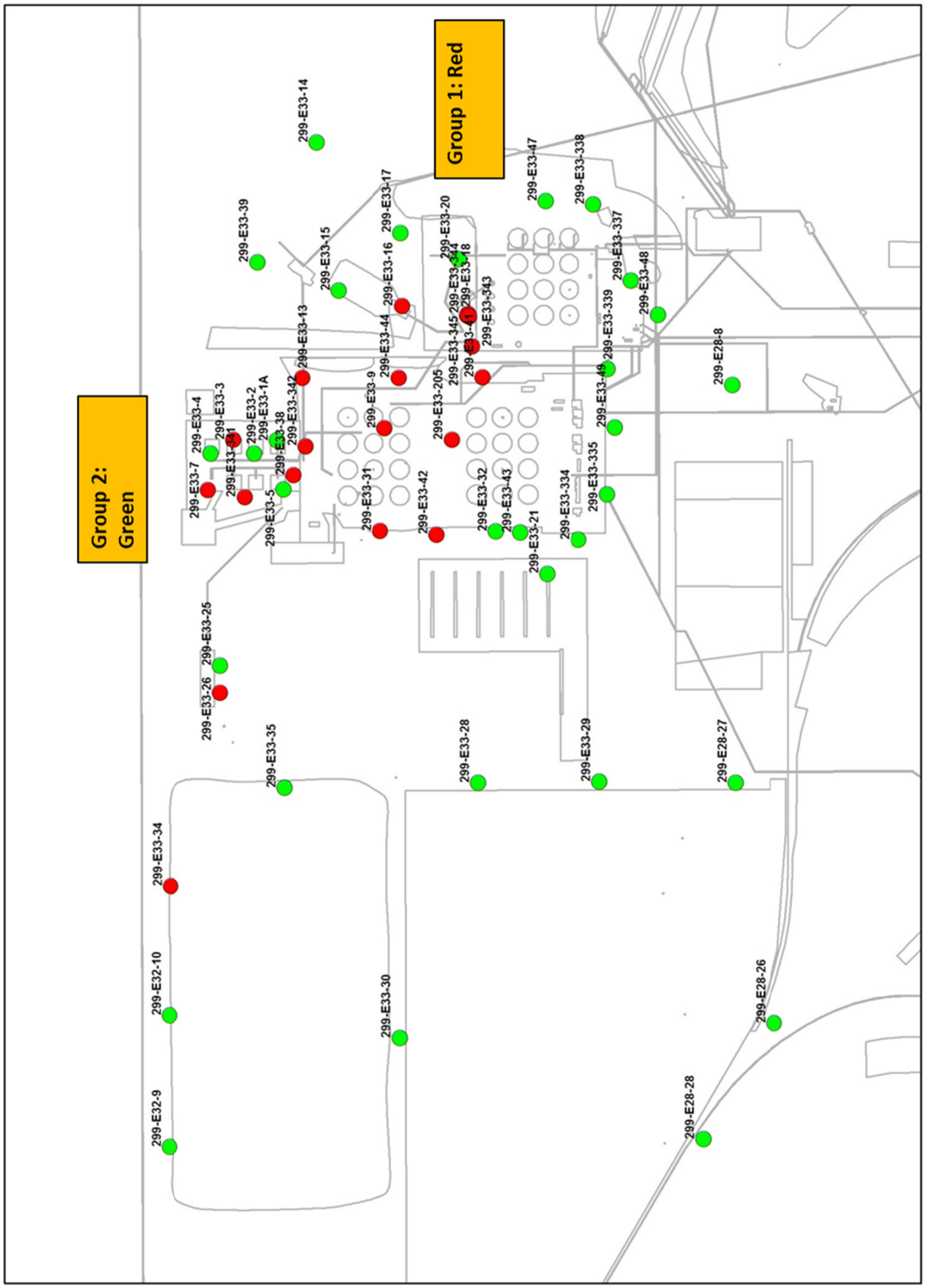



**Figure 25. B-Complex Wells**

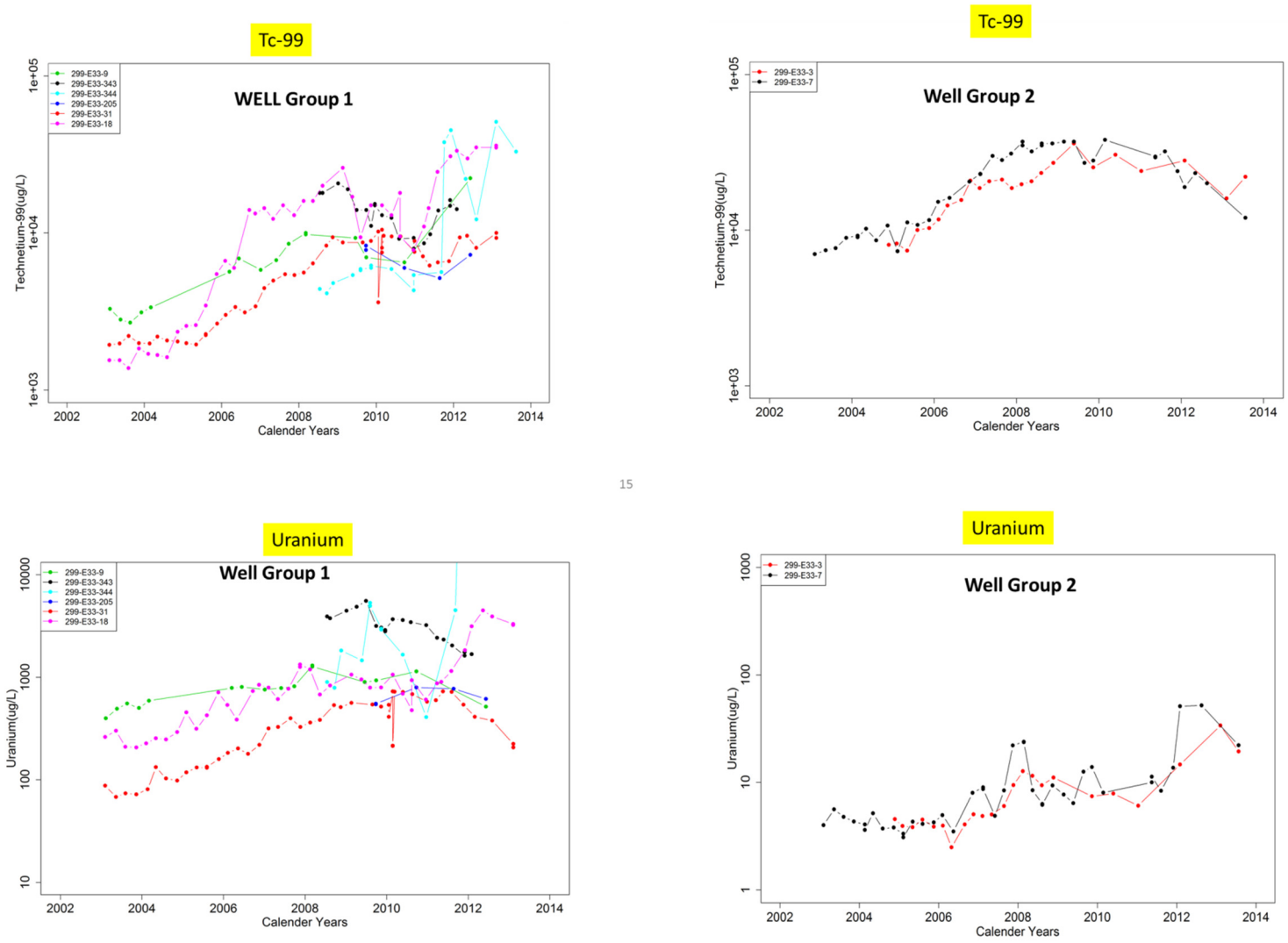



**Figure 26. Time History Plots for Selected Wells**

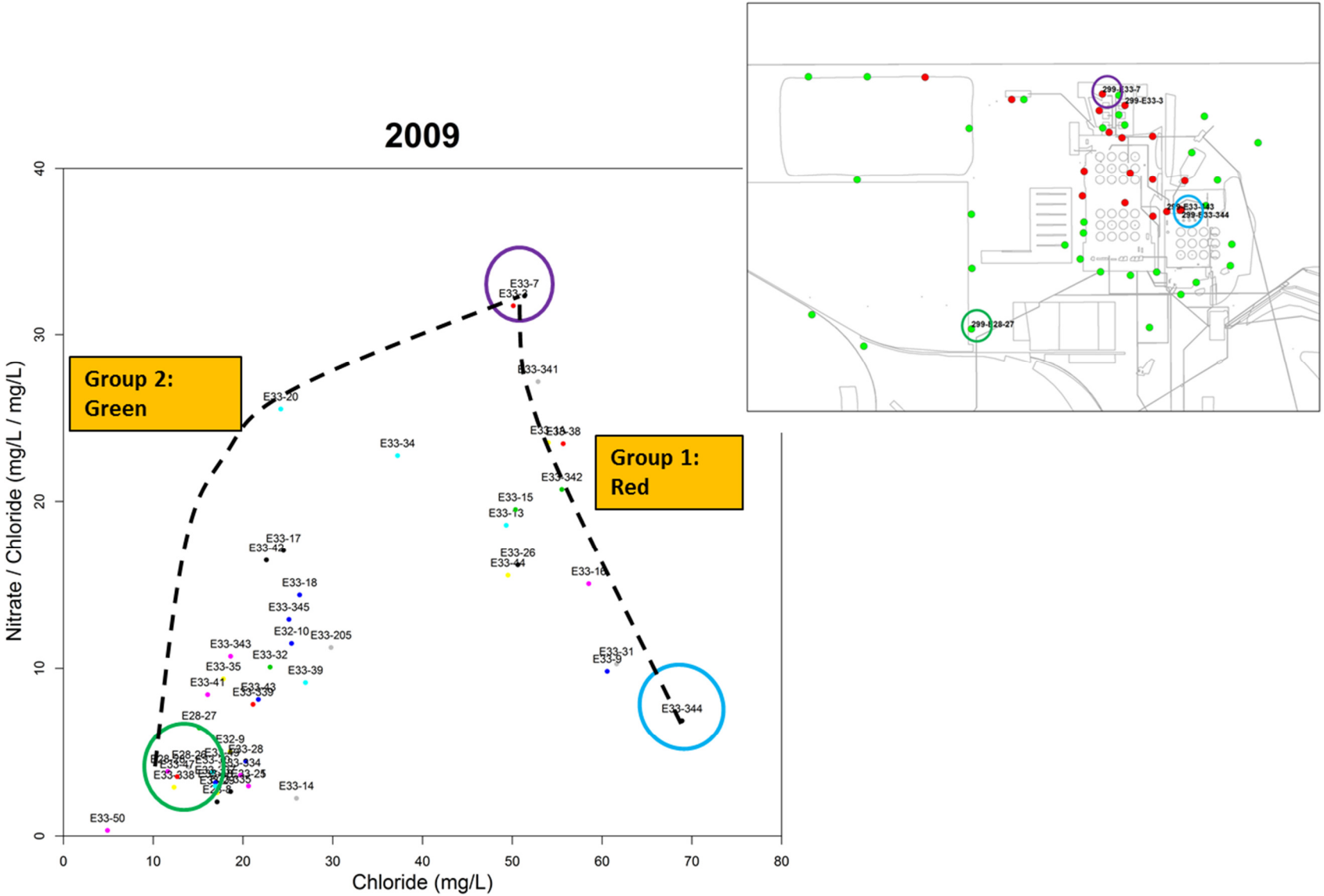



Figure 27. Nitrate/Chloride vs Chloride for Year 2009

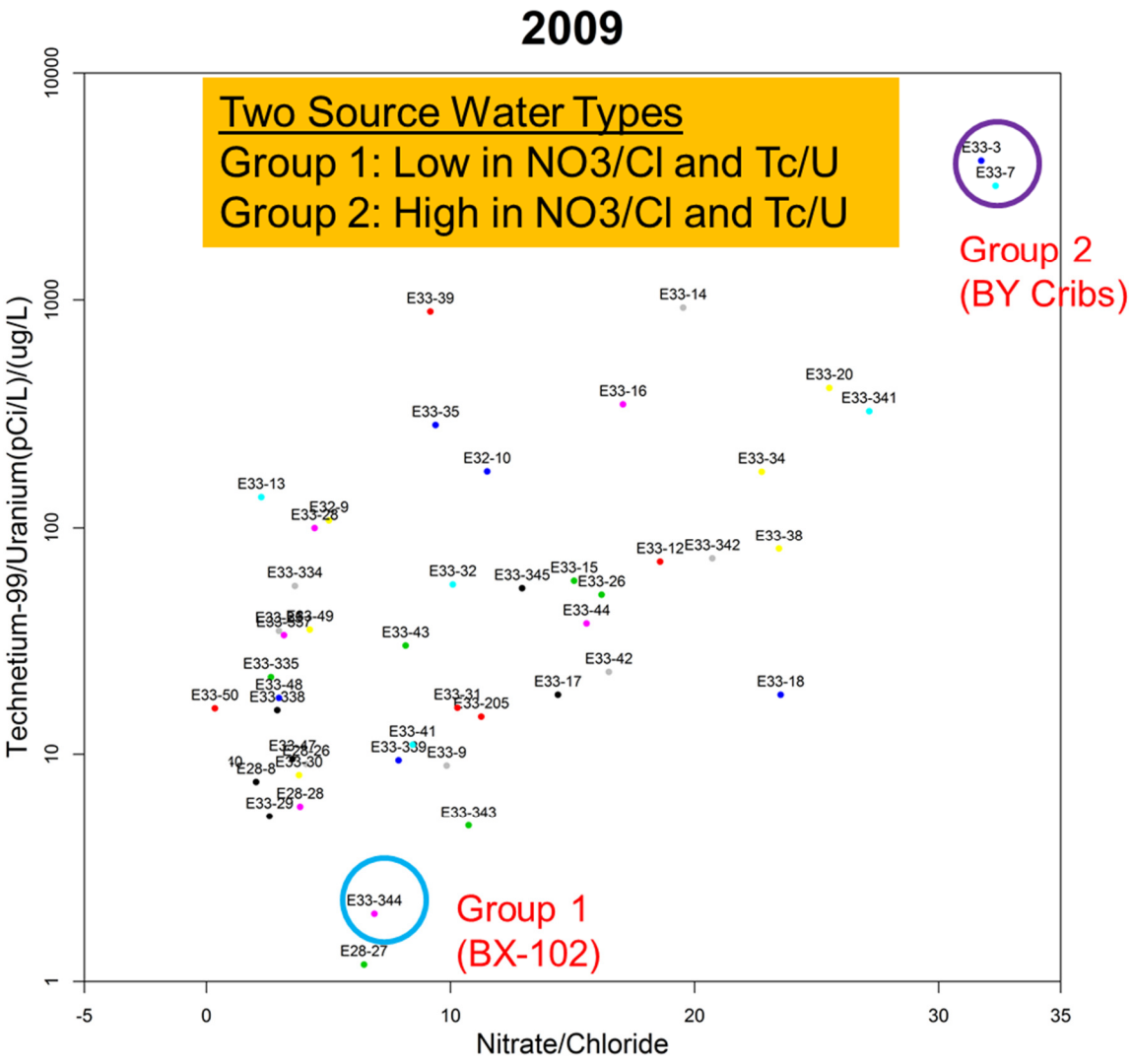



**Figure 28. Technetium-99/Uranium Ratio vs Nitrate/Chloride Ratio Plot for Year 2009**

## 2006 Tc-99 B-Complex

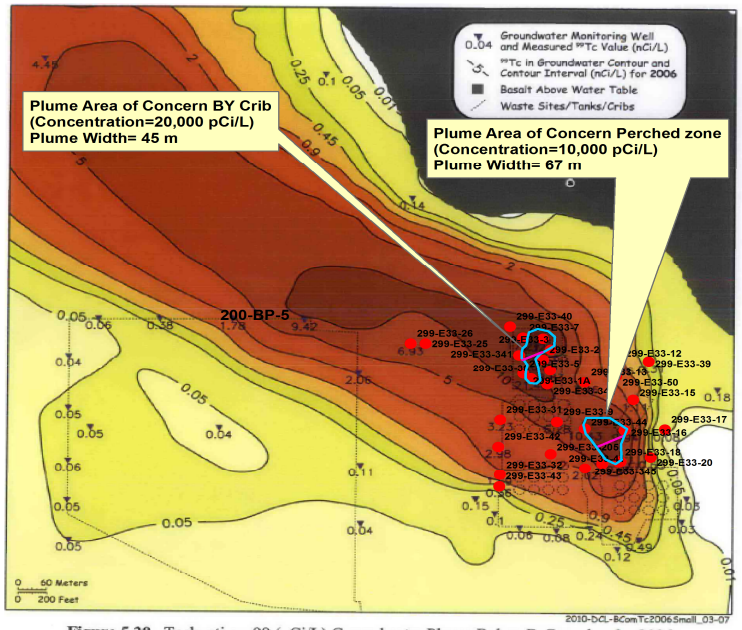



**Figure 5.20.** Technetium-99 (nCi/L) Groundwater Plume Below B-Complex for 2006

## 2009 Tc-99 B-Complex

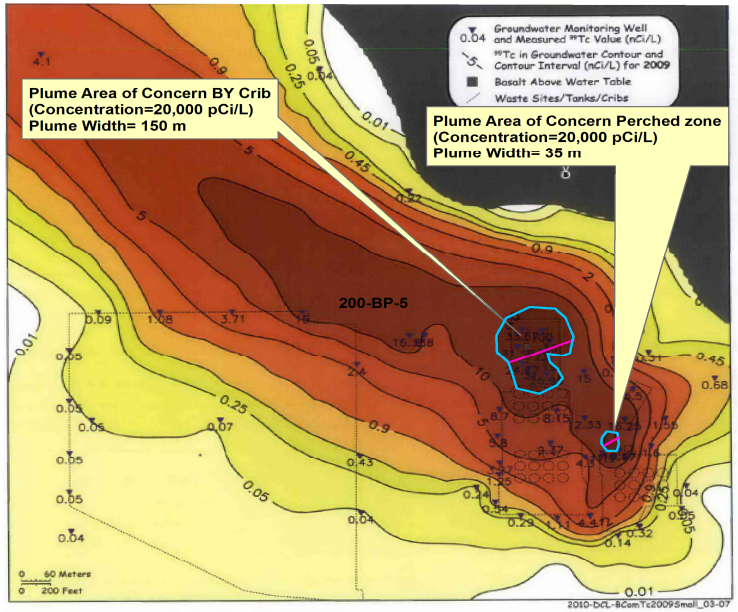



**Figure 5.21.** Technetium-99 (nCi/L) Groundwater Plume Below B-Complex for 2009

**Figure 29. Technetium Plumes in 2006 and 2009 (as presented in PNNL-19277)**

## 2006 Uranium Plume

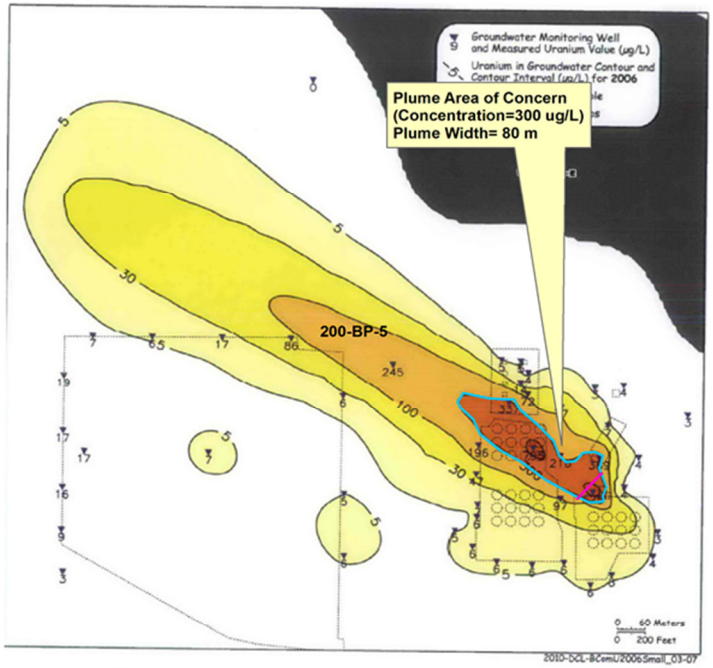



**Figure 5.43.** Groundwater Uranium (µg/L ) Plume Map for Year 2006

## 2009 Uranium Plume

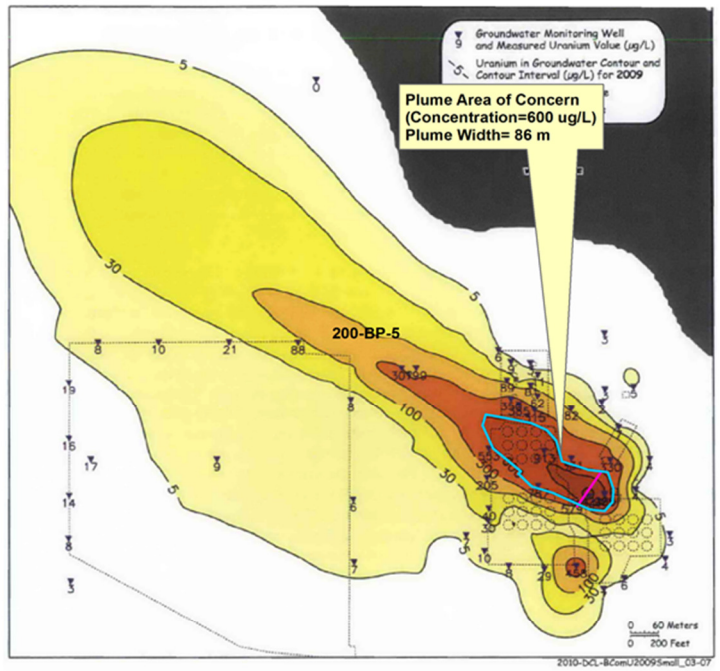



**Figure 5.44.** Groundwater Uranium (µg/L ) Plume Map for Year 2009

**Figure 30. Uranium Plumes in 2006 and 2009 (as presented in PNNL-19277)**

Year 2006

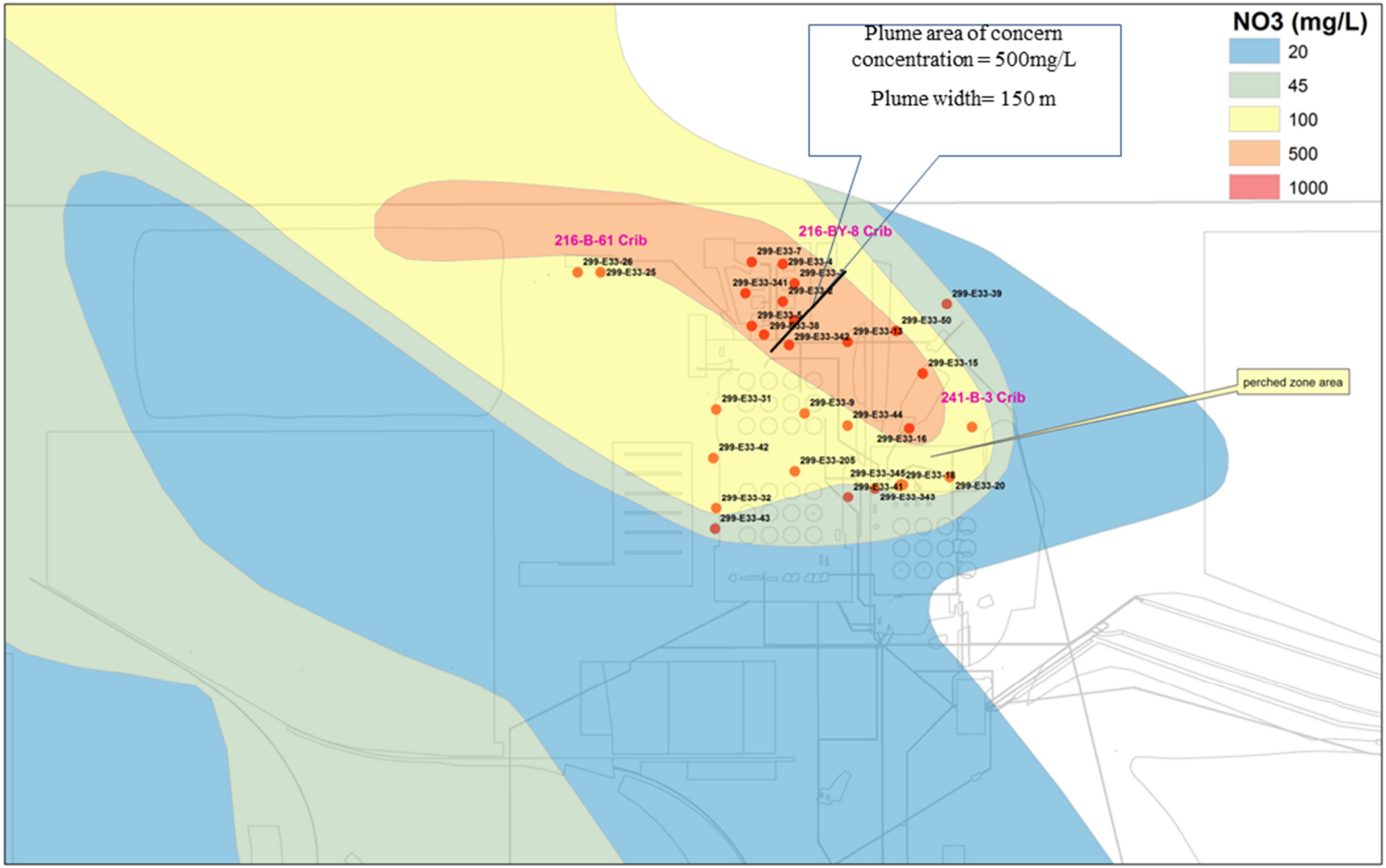



**Figure 31. Nitrate Plume for Year 2006**

Year 2009

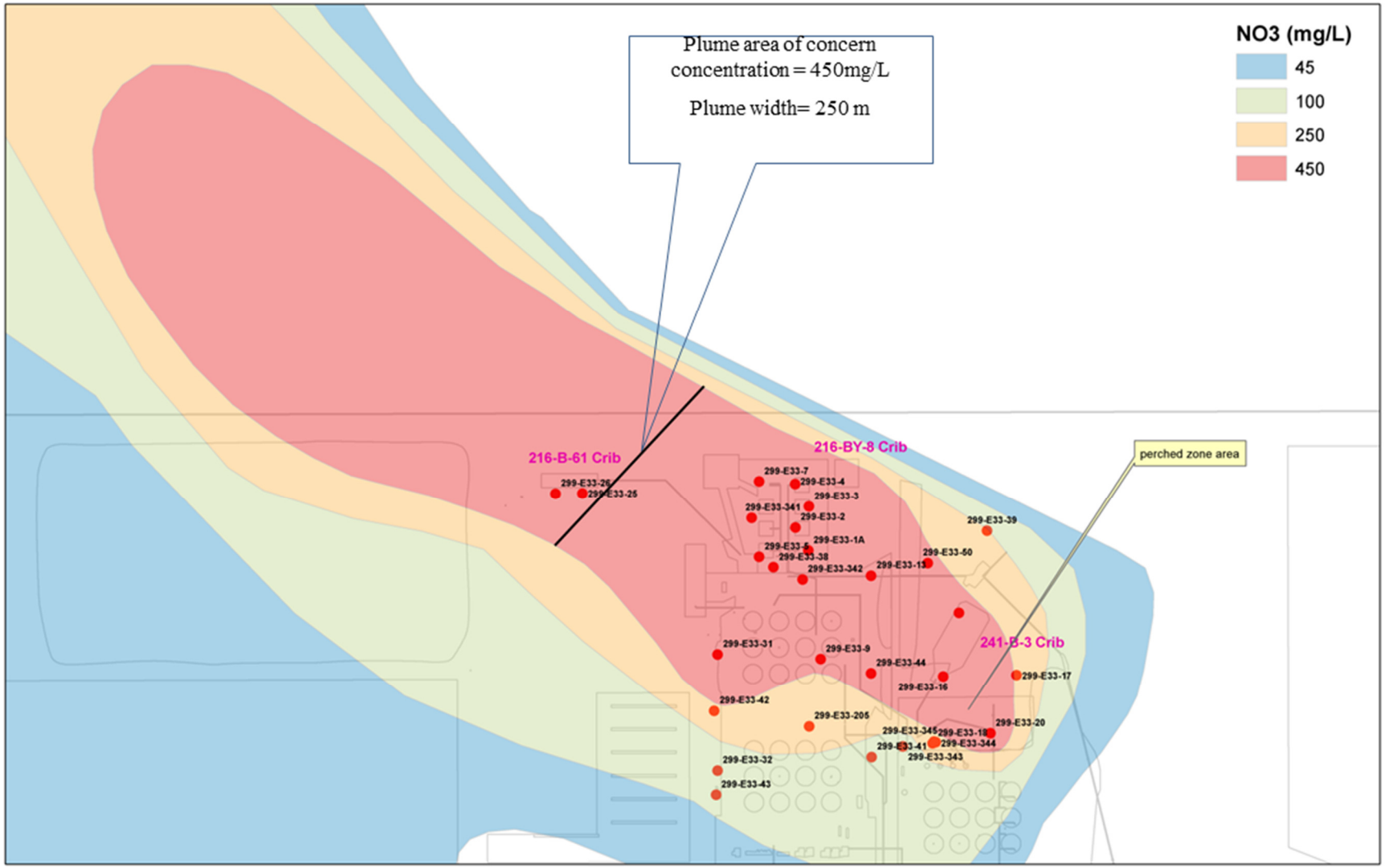



**Figure 32. Nitrate Plume for Year 2009**

**Table 8. Technetium-99 Activity Flux Calculation from Vadose Zone to Saturated Zone for B-Complex**

| Year | Highest Concentration: Under BY Crib (pCi/L) | Highest Concentration: Under B-BX-B-7 (pCi/L) | Flux BY Crib (Ci/yr) | Flux B-BX-B-7 (Ci/yr) | Total Flux to SZ Calculated in This Study (Ci/yr) | Average Flux Calculated From PNNL-19277 (Ci/yr) |
|---|---|---|---|---|---|---|
| 2006 | 20,000 | 10,000 | 0.07 | 0.05 | 0.12 | 0.21 |
| 2009 | 20,000 | 20,000 | 0.22 | 0.05 | 0.27 | 0.19 |

**Table 9. Uranium Mass Flux calculation from Vadose Zone to Saturated Zone for B-Complex**

| Year | Concentration (µg/L) | Mass Flux to SZ Calculated in This Study (kg/yr) | Average Mass Flux From PNNL-19277 (kg/yr) |
|---|---|---|---|
| 2006 | 300 | 1.8 | 1.9 |
| 2009 | 600 | 3.8 | 3.6 |

**Table 10. Nitrate Mass Flux Calculation from Vadose Zone to Saturated Zone for B-Complex**

| Year | Concentration (mg/L) | Mass Flux Calculated in this Study (kg/yr) |
|---|---|---|
| 2006 | 500 | 5475.0 |
| 2009 | 450 | 8212.50 |

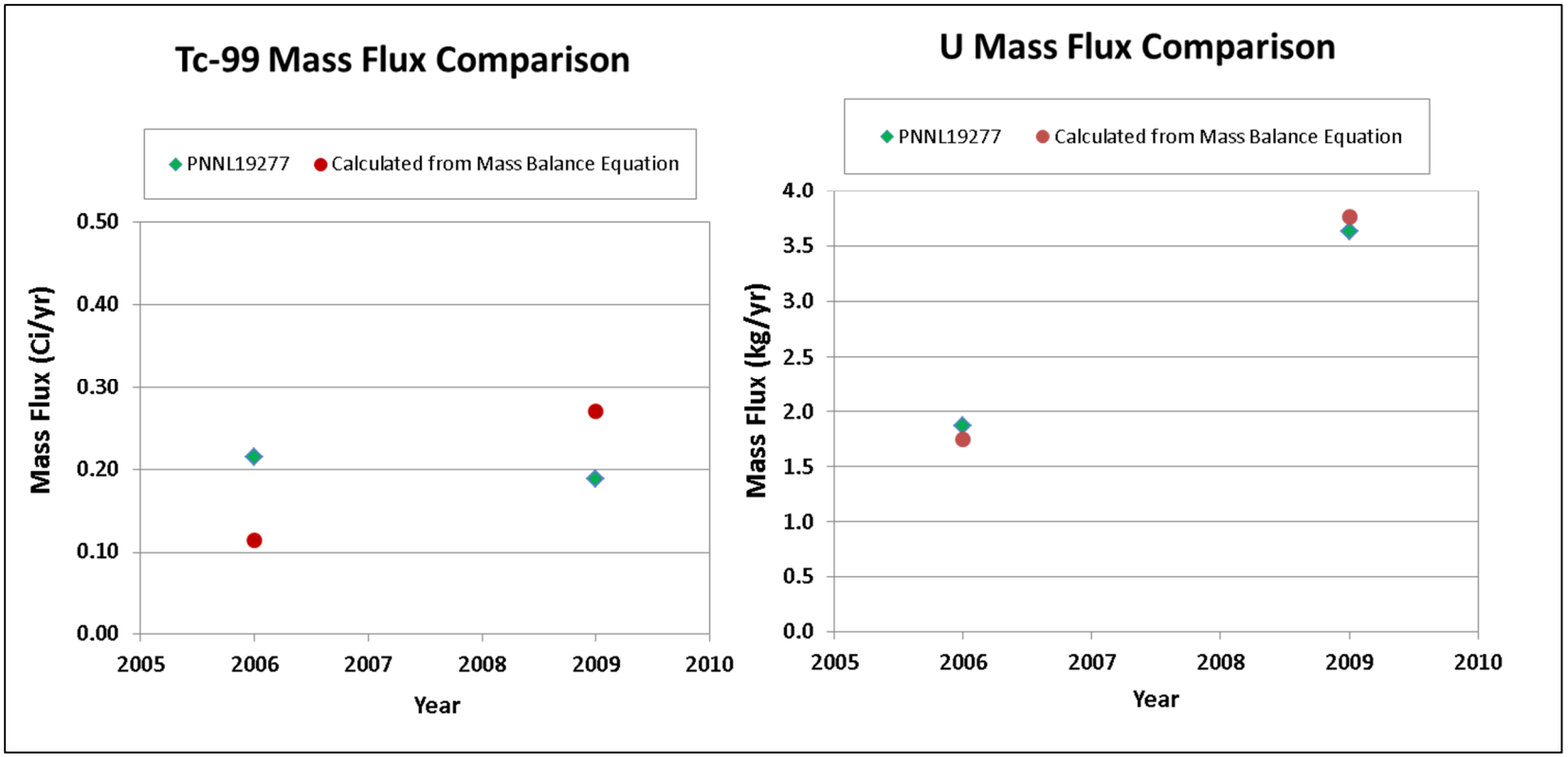



**Figure 33. Technetium-99 & Uranium Flux Comparison (B-Complex)**

In PNNL-19277, the total activity of technetium-99 and uranium activity/mass residing within the entire plume volume was calculated for years 2003, 2006 and 2009. The average activity/mass flux for a particular year was calculated by using the following expression:

> *Average Saturated zone (SZ) Activity or Mass flux For a given Year = (Activity or Mass estimated for that Year in SZ based on Plume Area –Activity or Mass estimated for Year 2003 in SZ based on Plume Area)/(Number of years elapsed since 2003).*

Figure 33 shows the comparison of the mass flux estimates between PNNL-19277 and those based on calculations performed in this ECF. A comparatively good agreement is observed between the two different approaches.

SGW-53604 identifies the perched zone of the B-Complex area. The approximate extent of the perched water zone as identified in SGW-53604 is presented on Figure 34. Extent of the Cold Creek lower silt unit is presented in Figure 35 and the two cross-sections through this area are shown in Figure 36 and Figure 37 along with the extent of uranium contamination in the perched zone. The estimated areal extent of uranium contamination in the vadose zone is shown in Figure 38 based on evaluation of information presented in Figures 34 through 37.

The probable uranium source area is judged as approximately 10,000 $m^2$, as calculated in ARCGIS. Figure 39 shows the dissolved concentration profile of uranium and technetium-99 in the perched zone wells. The concentrations show a sharp increase between year 2011 and 2012 resulting from the perched water extractions pumping which began in September 2011. Prior to this time, the concentration variations were relatively small. For the purpose of mass flux calculations for years 2009-2010, an average concentration in the perched zone *before* the start of extraction is estimated in order to represent near-equilibrium conditions that existed before the pumping started. The average concentration of uranium is estimated to be 2500 µg/L while that for technetium-99 is estimated to be about 5000 pCi/L. These concentrations are deemed representative for years 2009-2010.

Using the mass balance approach, where the contaminant mass in the saturated zone is deemed to be derived from the vadose zone, the approximate leakage rate from the perched zone can be calculated by considering the uranium mass flux in the saturated zone (derived in Table 9) and considering the extent of source area in the perched zone (Figure 38) and average concentration (Figure 39):

<u>Leakage Rate in Year 2009 (prior to Extraction):</u>

$$SZ\ Uranium\ Mass\ Flux = VZ\ Leakage\ rate \times VZ\ Plume\ Area \times C_{VZ\ for\ Uranium}$$

$$3.8\ (kg/yr) \times 1000000000\ (ug/kg) = VZ\ Leakage\ Rate\ (m/yr) \times 10{,}000(m^2) \times 2500\ (\mu g/L)$$

$$Approx.\ Leakage\ Rate\ from\ Perched\ Zone = 150\ (mm/yr)$$

PNNL-22499, *Perched-Water Evaluation for the Deep Vadose Zone beneath the B, BX, and BY Tank Farms Area of the Hanford Site,* estimated a leakance rate of 120 mm/yr, which is very close to the calculated rate of 150 mm/yr value from this study.

Using this leakage rate, technetium-99 vadose zone flux in the perched zone can be estimated using the average concentration prior to the extraction, with the following equation:

$$VZ\ Flux\ from\ Perched\ Zone = 150(mm/yr) \times 10{,}000(m^2) \times 5000\ (pCi/L) = 0.008\ (Ci/yr)$$

Table 11 presents the vadose zone flux estimation of uranium and technetium-99 for the perched zone with respect to the total vadose zone flux. The uranium vadose zone flux estimation from the perched zone is almost 100% of the total vadose zone flux in the B-complex, whereas for technetium-99 it is

only 3-4 % (negligible). PNNL-19277-based estimates are very similar that are derived from information presented in Table 12 regarding the mass residing in the deep vadose zone (highlighted in red circle). Figure 40 presents the activity/mass of technetium-99 and uranium in the saturated zone over the past several years based on information presented in PNNL-19277 (in Table 5.2 and Table 5.4 of that report). It indicates increasing mass of uranium and relatively stable activity of technetium-99 in the saturated zone thereby reflecting increasing influence of leakance from the perched zone.

Table 13 provides a summary of the flux estimates for three major contaminants of concern for the two source areas located in the B-complex (technetium-99, uranium, and nitrate). This estimate is based on review of available data prior to any extraction pumping in the perched zone. As extraction operations continue in the perched zone the contaminant mass will reduce, which may influence the long-term flux of uranium and technetium-99. Because the extraction pumping remedy is still being implemented, it is not possible to estimate the overall impact on the perched zone mass removal. For the purpose of this calculation, it is assumed that after the perched zone pumping is completed, the uranium concentration in the perched zone will decline but are likely to go back to 2009-2010 (pre-pumping) concentrations reflecting equilibrium conditions with uranium bearing solid mineral phases. As a result, the uranium flux due to leakage from the perched zone may not reduce appreciably; however, because the total mass available for release will be reduced (due to extraction pumping), the clean-up times will be less compared to the no-action scenario.

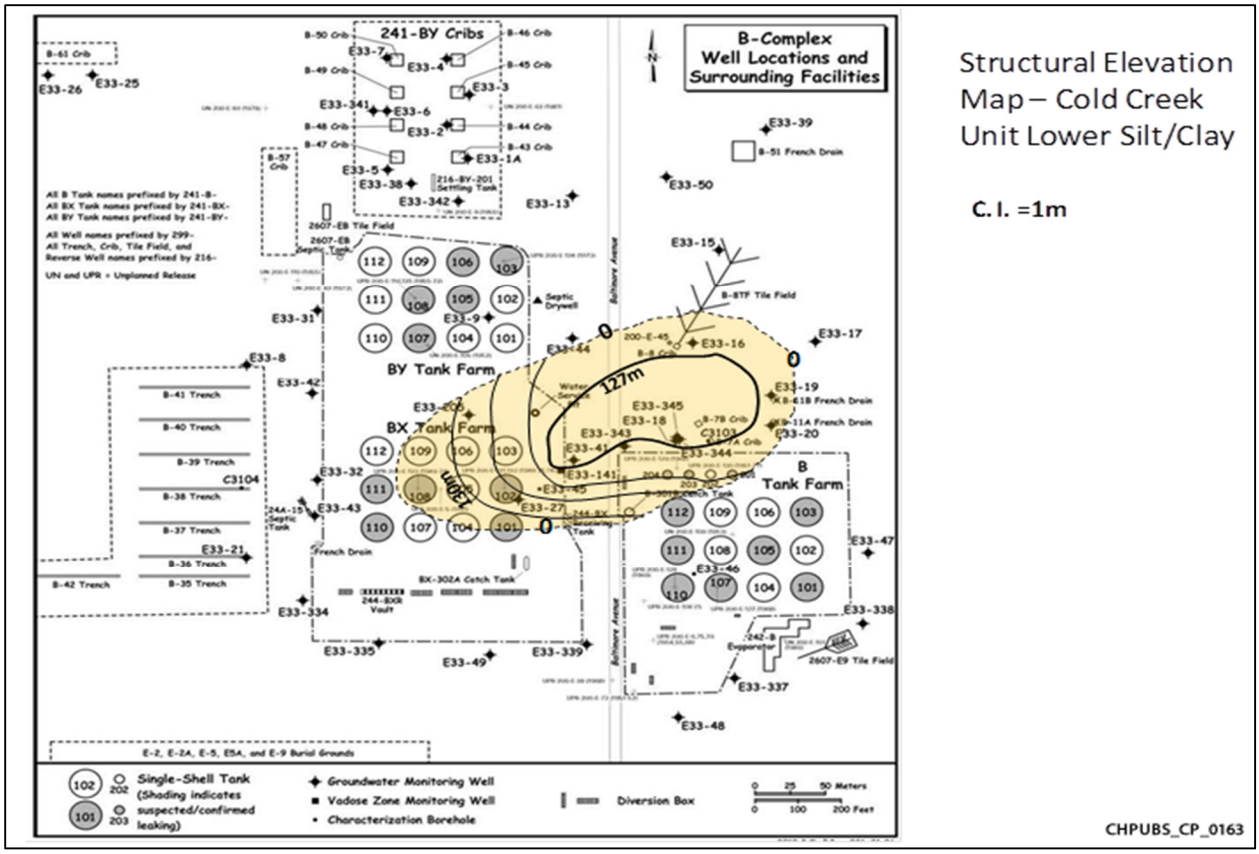



**Figure 34. Approximate Extent of the Perched Water Zone in the B-Complex Area (SGW-53604)**

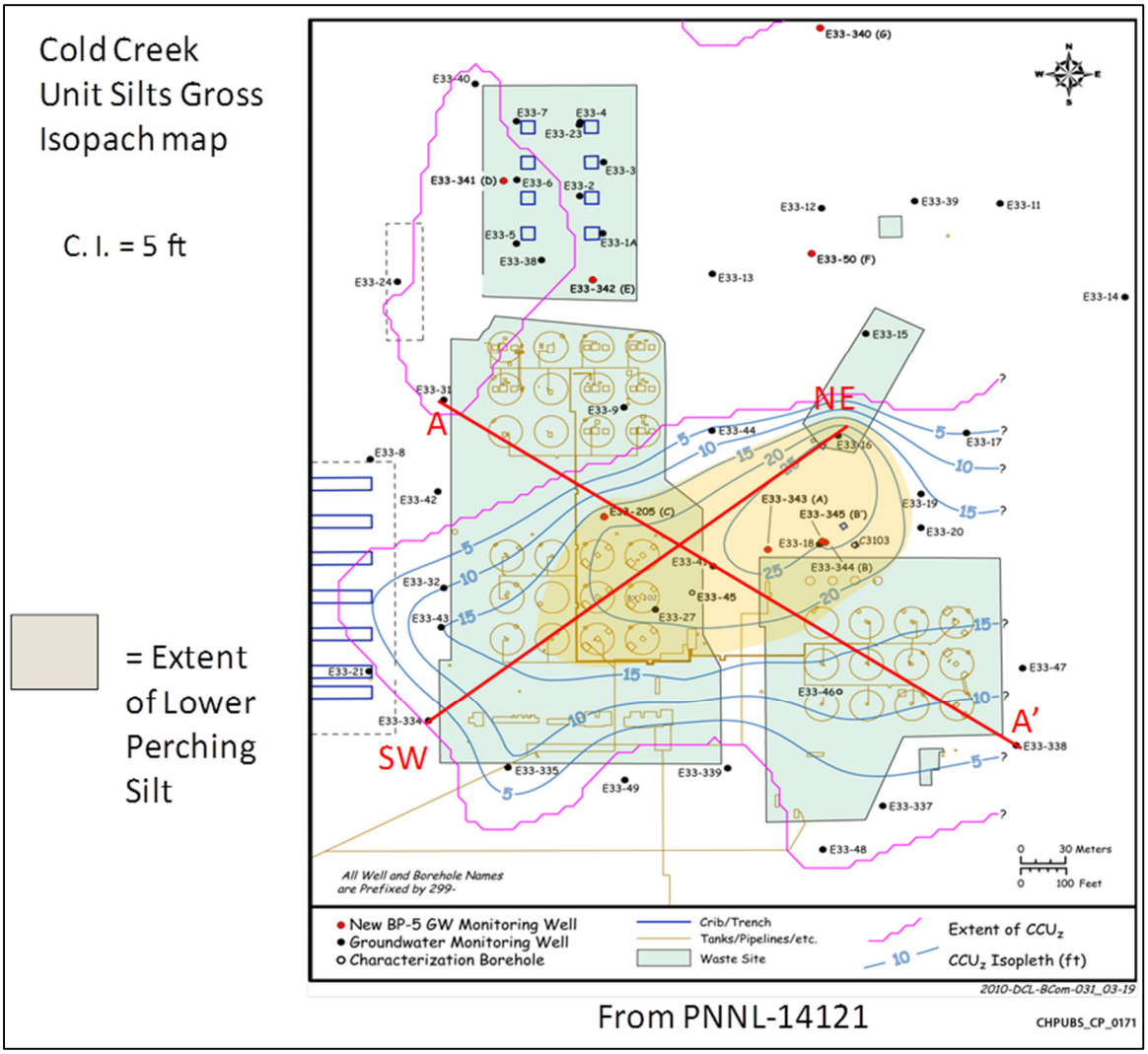



**Figure 35. Extent of Cold Creek Unit Lower Silt Layer**

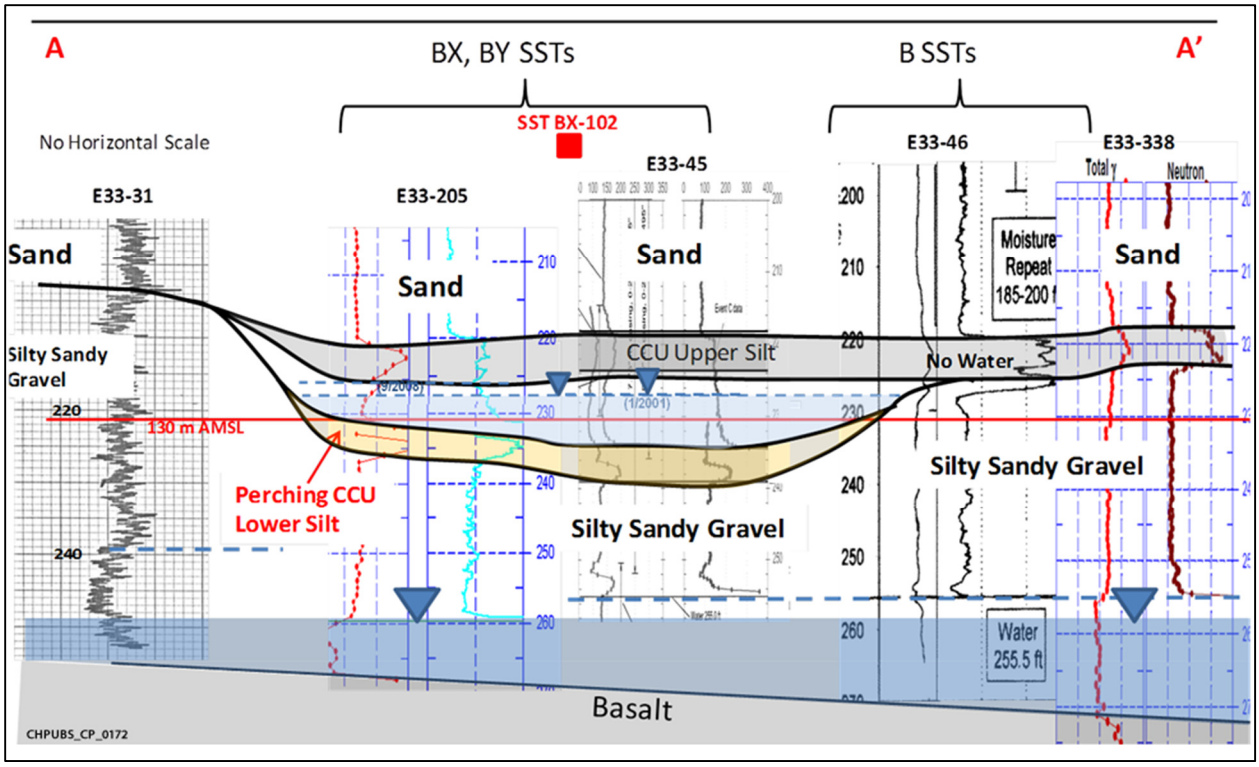



**Figure 36. Hydrogeologic Cross Section Illustrating Upper and Lower Cold Creek Unit Silt Layers**

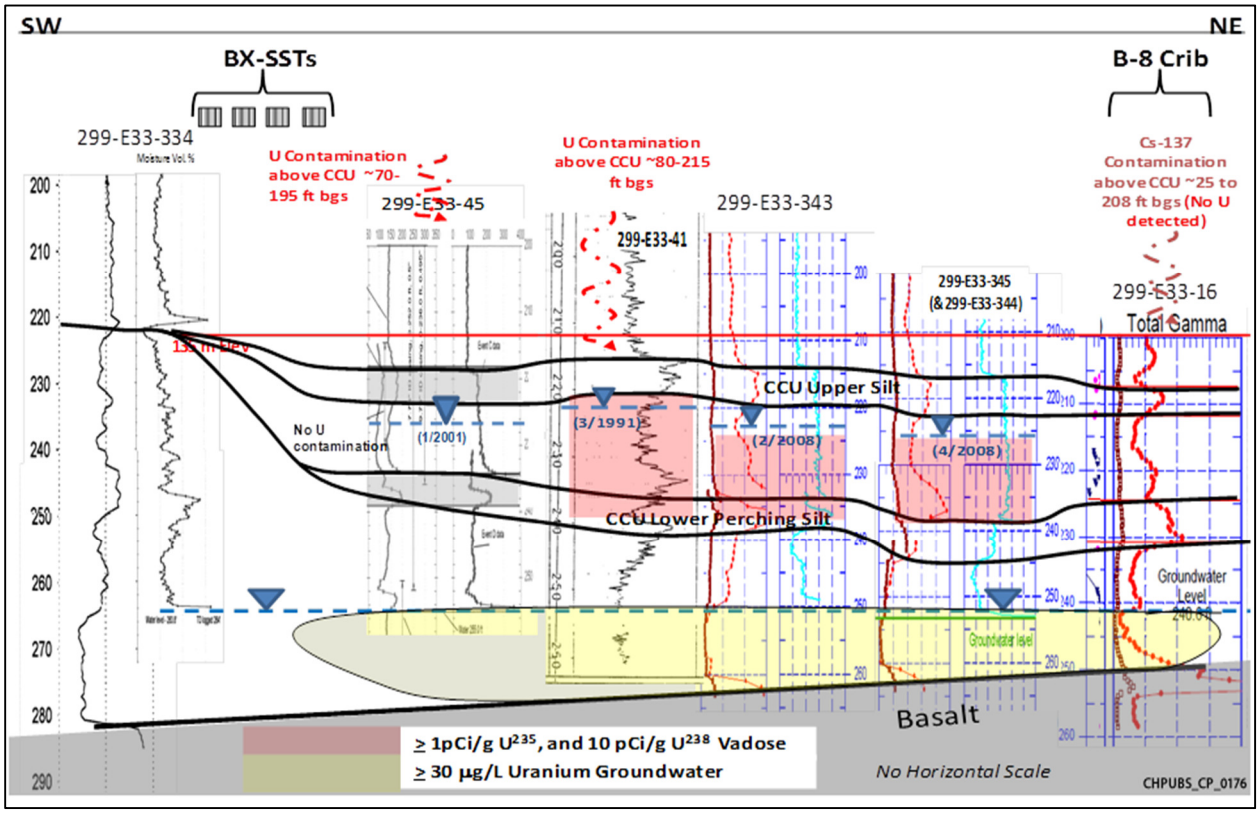



**Figure 37. Extent of Contamination – Perched Zone**

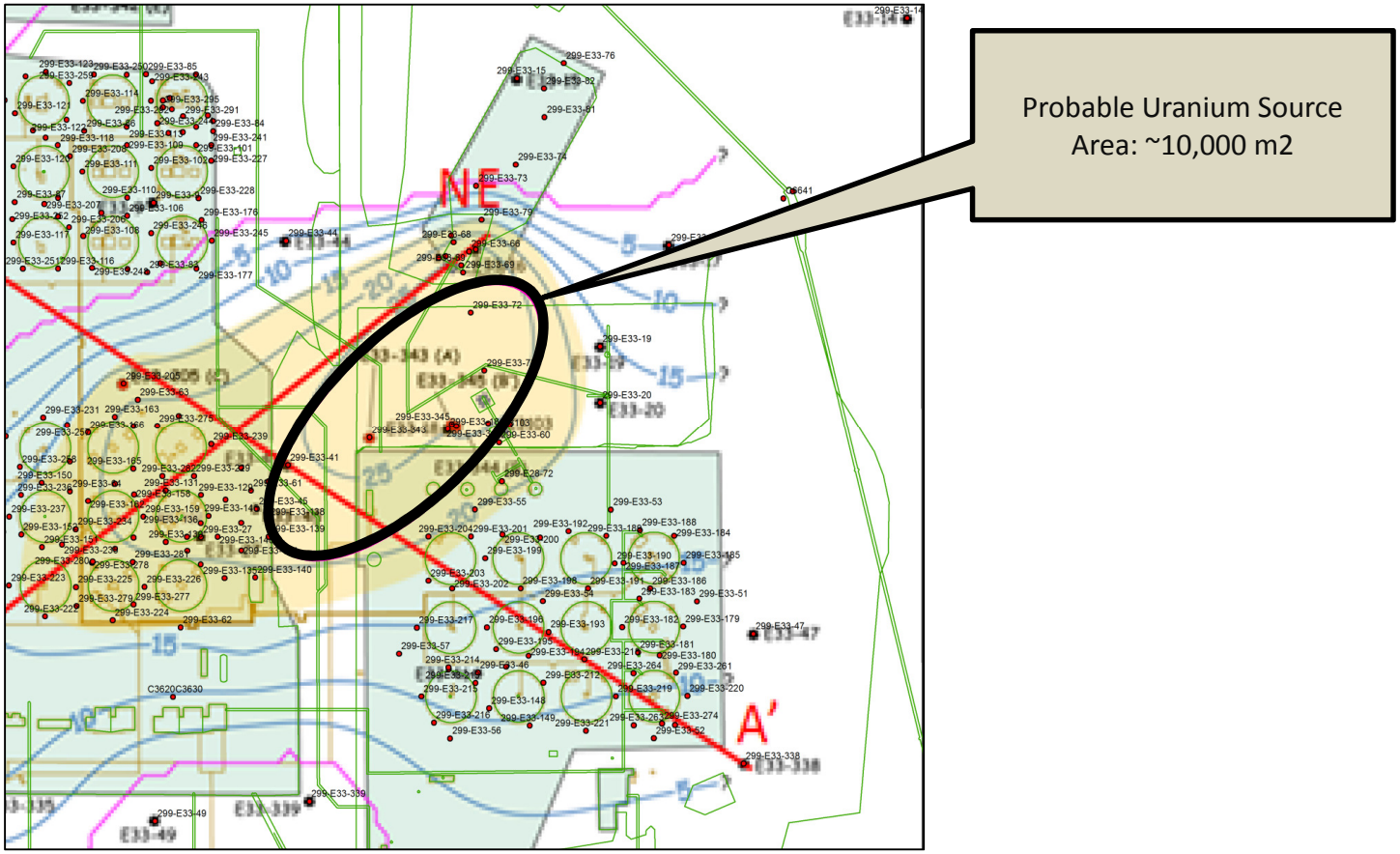



**Figure 38. Uranium Source Area Determination**

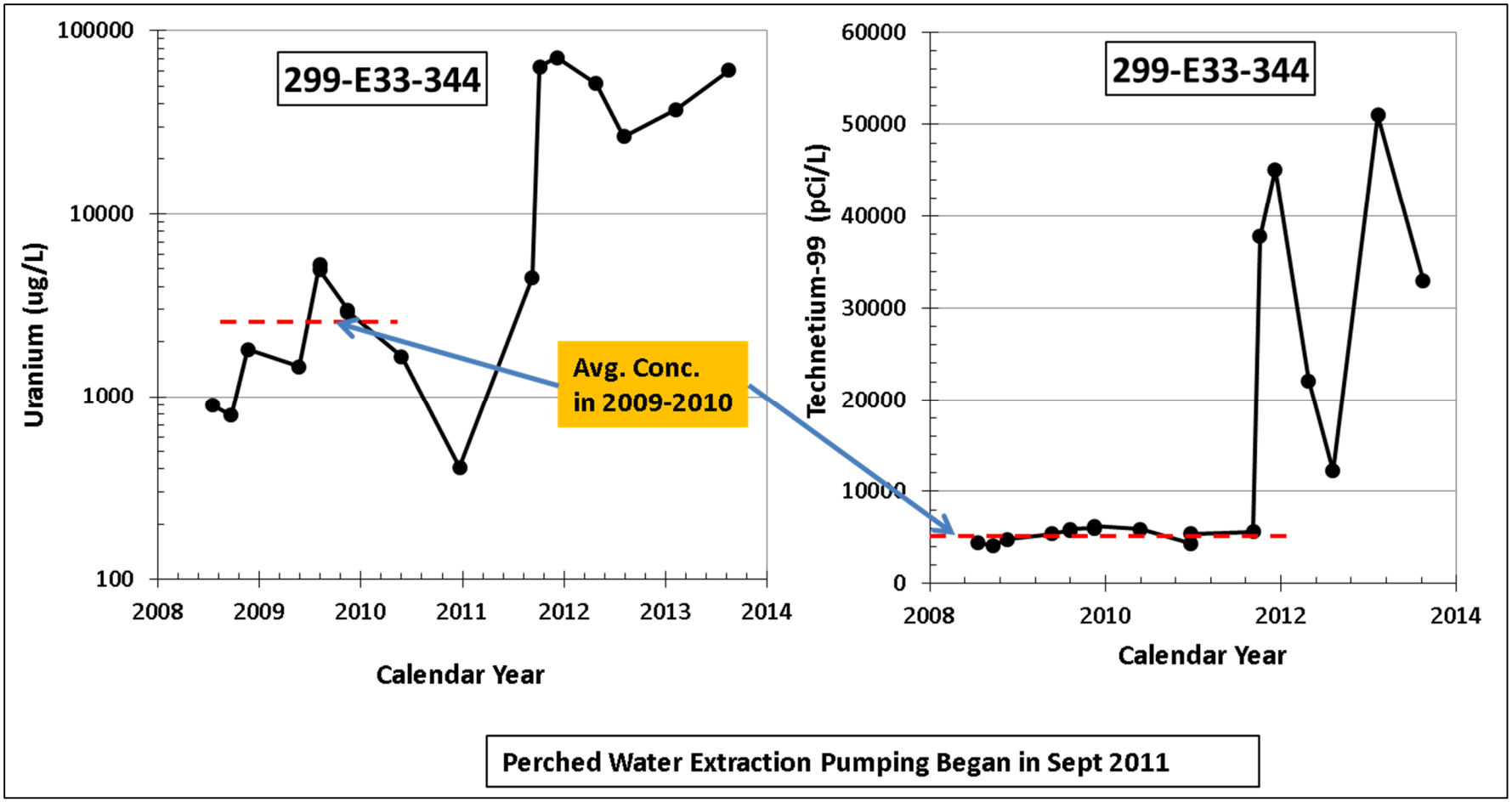



Figure 39. Concentration Changes in Perched Water from Well 299-E33-344

**Table 11. Evaluation of Technetium-99 and Uranium in GW near Perched Zone (B-BX Tank Farm & B-7/B-8 Cribs)**

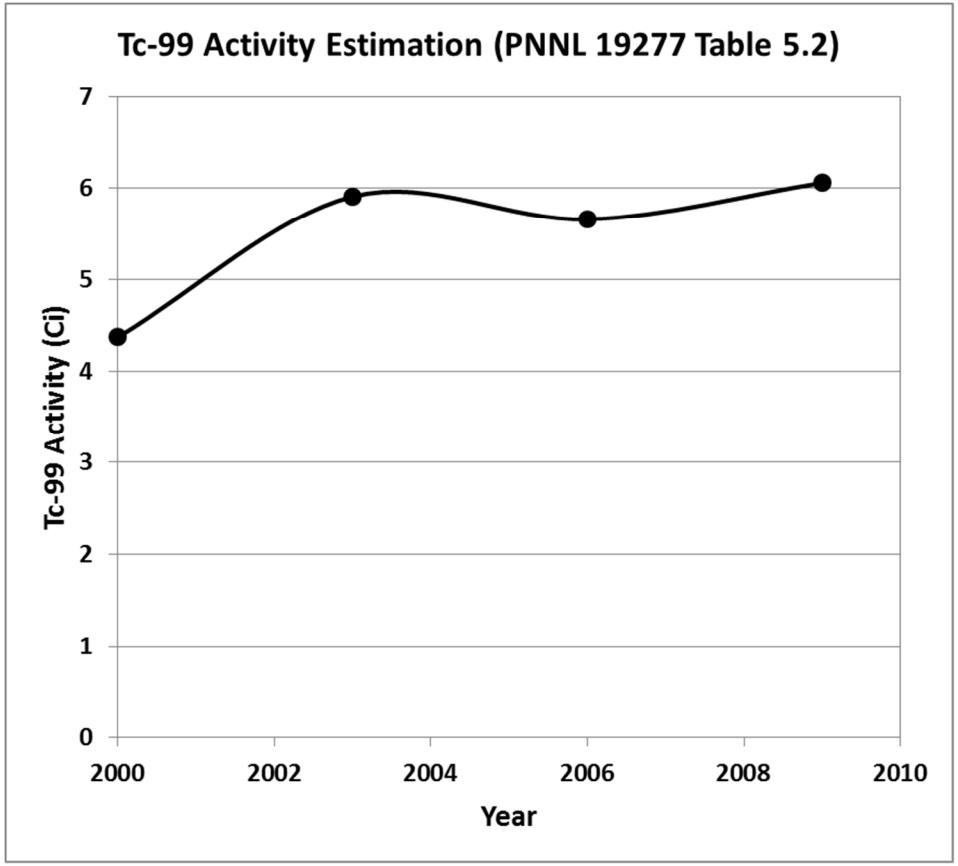
| COC | VZ plume Area ($m^2$) | Total SZ Mass Flux For Year 2009 (Tables 8 and 9) | Concentration in Perched Zone | VZ Flux From Perched Zone (calculated) | Ratio of VZ Mass Flux From Perched Zone To Total SZ Mass Flux | PNNL-19277 (Table 9-2) Based Mass Discharged Relative To Total Discharged in B-Complex |
|---|---|---|---|---|---|---|
| Uranium | 10,000 | 3.8 kg/yr | 2,500 µg/L | 3.8 kg/yr | 100% | 90-100% |
| Technetium-99 | 10,000 | 0.27 Ci/yr | 5,000 pCi/L | 0.008 Ci/yr | 3% | 3-4% |

**Table 12. PNNL-19277 (Table 9.2): Mass Estimates in Deep VZ**

**Table 9.2.** Summary Estimates of Mass in Vadose Zone, Deep Vadose, and groundwater by Subregion for Most Realistic Conceptual Models and Comparison to Entire B-Complex Masses Released

| Subregion | Tc-99 (Ci) Entire VZ | Tc-99 (Ci) Deep VZ | Tc-99 (Ci) groundwater | Tc-99 Disposed of (Ci) | Total U (kg) Entire VZ | Total U (kg) Deep VZ | Mobile U (kg) Entire VZ | Mobile U (kg) Deep VZ | Mobile U (kg) groundwater | U Disposed of (kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| BY Cribs | 30 to 55.53 | 3.4 to 20.9 | | 129 | 1009 | 202 | 6.5 | 0.23 | | 1063 |
| B-7-A&B/B-8 Cribs | 0.02 to 1.64 | 0.01 to 1.6 | | 0.018 | 583 | 59.8 | 4.3 | 2.6 | | 388 |
| BX-102 Overfill | 3.3 to 4.0 | 3.0 to 3.6 | | 3.7 | 6360 to 7220 | 3050 to 3910 | 2380 to 2460 | 1520 to 1600 | | 10,100 |
| Sum of these 3 | 33.3 to 58.9 | 6.5 to 24.4 | | 133 | 7950 to 8810 | 3310 to 4170 | 2390 to 2470 | 1520 to 1600 | | 11,550 |
| B-Complex (All) | | | 6.06 (0.76 below B-Complex) | 145 | | | | | 22.3 | 12,000 |

Realistic BY cribs conceptual model for uranium is Model #2 (Table 3.8).
Realistic B-7-A&B/B-8 cribs conceptual model for total uranium is Model #2 and for mobile uranium is Model #1 (Table 3.14), respectively.



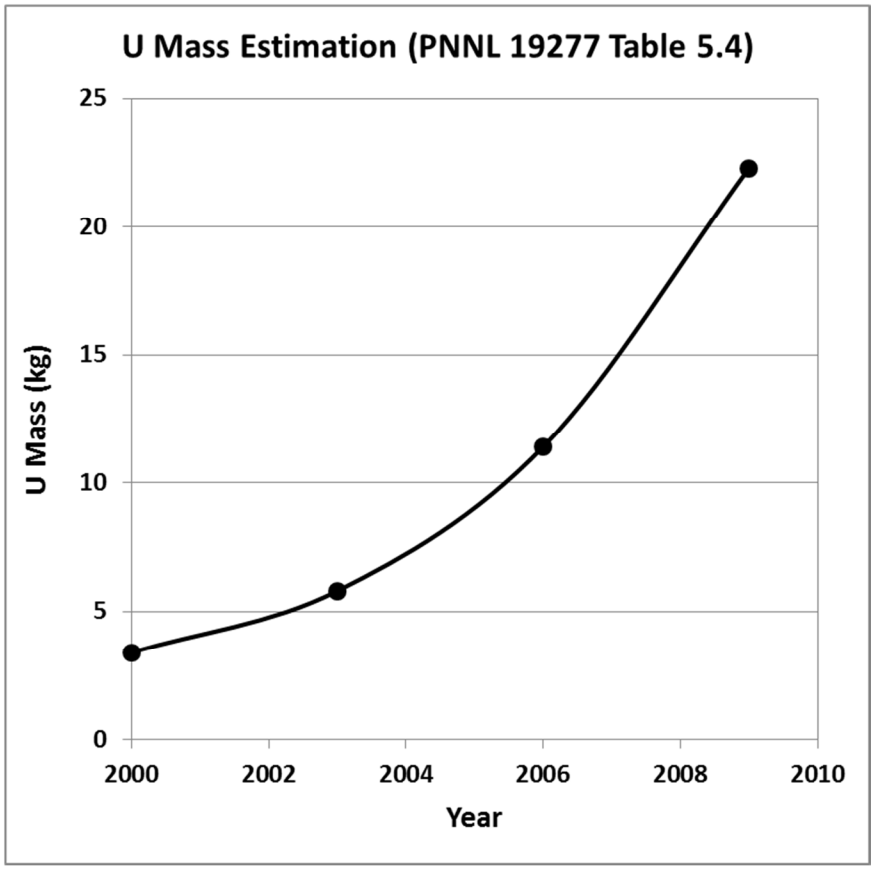




**Figure 40. Technetium-99 and Uranium Mass Estimated in the Saturated Zone Using Information Presented in PNNL-19277**

**Table 13. Estimated Vadose Zone Flux in the B-Complex**

| Contaminant | BY Crib Source | B-BX-B-7/B-8 (Perched Zone) |
|---|---|---|
| Technetium-99 | 0.22 Ci/yr | 0.008 Ci/yr |
| Uranium | ~0 kg/yr | 3.8 kg/yr |
| Nitrate | 8212.50 kg/yr | ~0 kg/yr |

# 6 Results/Conclusions

Conclusions drawn from the vadose zone contaminant flux estimate calculation are presented in this section for WMA C and B-Complex source areas separately. Both the best estimate and uncertainty in the estimated values are discussed.

## 6.1 Flux Estimate for WMA C

Two independent methods have been used for estimating technetium-99 flux from the vadose zone to the saturated zone in the WMA C vicinity. Table 6 provides the final calculations.

In the first approach, using information from the Groundwater Annual Reports, the calculated total activity residing in the saturated zone is estimated to be about 1 Ci, which shows an increasing trend. This appears to be an overestimate and influenced by the assumed plume area where information is not available. Average increase in technetium-99 activity from year 2008 to year 2012 is calculated to be around 0.17 Ci per year, which reflects average annual technetium-99 flux. Assuming 6 Ci of technetium-99 remains in vadose zone (based on estimate given in the WMA C leak assessment report), it will take about 35 years to be released to the saturated zone assuming uniform flux.

In the second approach, combining the site-specific conceptual models and evaluating the spatial and temporal trends in concentrations over the last ten years the technetium-99 plumes have been redrawn for the highest concentration regions. Present total activity residing in saturated zone is estimated to be about 0.14 Ci that appears to have reached a steady state. No appreciable net increase in activity is predicted in the future. Vadose zone flux based on highest concentration plume areas is estimated to be 0.04 Ci per year. This estimate is increased by a factor of two in order to accommodate activity outside the highest concentration areas and in recognition of limited information on plumes elsewhere. As a result, the total vadose zone flux for WMA C is estimated to be around 0.1 Ci per year. Assuming 6 Ci of technetium-99 remains in vadose zone, it will take about 60 years to be released to the saturated zone. This should be considered a best estimate. Because of simplifying assumptions used in the calculation and inherent uncertainty in estimating the technetium-99 leaked from the WMA C area, a factor-of-two uncertainty in mass flux (and corresponding effect on timing) can be considered to evaluate impact on groundwater.

The nitrate plumes observed in the WMA C vicinity do not show high concentrations and therefore indicate a weak source of nitrate from the vadose zone that may be localized in nature.

## 6.2 Flux Estimate for B-Complex

Two independent approaches have been used for estimating flux of technetium-99, uranium, and nitrate from the vadose zone to the saturated zone in the B-Complex vicinity. Two areas within the B-complex

have been identified which can act as continuing source of contaminants from the vadose zone to the saturated zone. The two areas: (a) in and around the BY cribs and (b) around B-BX-B-7/B-8 area that includes the perched zone. Table 13 provides the calculated estimates.

The technetium-99 flux from vadose zone to the saturated zone for the BY Crib area is estimated to be around 0.22 Ci/yr and approximately 20 Ci of technetium-99 is estimated to reside in the deep vadose zone. Based on this information and assuming uniform flux in the future, it will take approximately 90 years to deplete the total activity. On the other hand, in the B-BX-B-7/B-8 (perched zone) area, the vadose zone flux is estimated to be around 0.008 Ci/yr and the total activity of technetium-99 in deep vadose zone is estimated to be about 3.5 Ci. Based on this information and assuming uniform flux in the future, it will take approximately 440 years to deplete the total activity. A similar calculation for uranium based on 3.8 kg/yr flux from vadose zone to the saturated zone and using estimate of 1,600 kg present in the deep vadose zone, a 420-year timeframe is calculated for the mass to deplete the available inventory (ignoring extraction from any future pumping). However, since some of the mass is likely to be removed from the currently ongoing (and planned) extraction remedy, the total time to deplete the inventory in B-BX-B-7/B-8 (perched zone) area is conservatively assumed to be 300 years.

The calculated mass flux for nitrate to the saturated zone is estimated to be 8212.50 kg/yr for the B-Complex area that is almost entirely from BY cribs source. As a result, and to be consistent with the depletion times calculated for technetium-99 for the BY cribs source, a total timeframe of 90 years of uniform flux of nitrate is recommended.

Considerable uncertainty exists in estimating the mass flux and clean-up times. Furthermore, the impact of currently planned remedy on extracting the contaminants from the perched zone and reducing the long-term mass flux to the saturated zone is not clear. To account for this uncertainty on future groundwater concentrations, some sensitivity cases may be considered, such as by assuming 50 percent to 75 percent mass removal from the perched zone that will also impact the total time to deplete the remaining inventory.

Table 14 summarizes the best estimate of the contaminant flux from the vadose zone to the saturated zone for WMA C and B-complex source areas along with their estimated durations. Impact of uncertainties in these estimates should be evaluated prior to making remediation related decisions.

**Table 14. Estimated Vadose Zone Flux and Duration**

| Source Area | Contaminant | Rate | Duration (years) |
|---|---|---|---|
| WMA C | Technetium-99 | 0.1 Ci/yr | 60 |
| BY CRIB | Technetium-99 | 0.22 Ci/yr | 90 |
| BY CRIB | Nitrate | 8212.5 kg/yr | 90 |
| B-BX-B-7/B-8 (perched zone) | Technetium-99 | 0.008 Ci/yr | 300 |
| B-BX-B-7/B-8 (perched zone) | Uranium | 3.8 kg/yr | 300 |

# 7 References

DOE/RL-2008-66, 2009, *Hanford Site Groundwater Monitoring Report for Fiscal Year 2008*. Rev 0, Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www.hanford.gov/c.cfm/sgrp/GWRep08/html/start08.htm

DOE/RL-2009-127, 2009, *Remedial Investigation Report for the 200-BP-5 Groundwater Operable Unit*, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2010-11, 2010, *Hanford Site Groundwater Monitoring and Performance Report for 2009*, Rev. 1, Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www.hanford.gov/c.cfm/sgrp/GWRep09/html/start09.htm

DOE/RL-2011-01, 2011, *Hanford Site Groundwater Monitoring Report for 2010*, Rev. 0, Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www.hanford.gov/c.cfm/sgrp/GWRep10/html/start10.htm

DOE/RL-2011-118, 2012, *Hanford Site Groundwater Monitoring Report for 2011*, Rev. 0, Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www.hanford.gov/c.cfm/sgrp/GWRep11/html/start11.htm

DOE/RL-2013-22, 2013, *Hanford Site Groundwater Monitoring Report for 2012*, Rev. 0, Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www.hanford.gov/c.cfm/sgrp/GWRep12/html/gw12_Start-PDF.htm

PNNL-19277, 2010, *Conceptual Models for Migration of Key Groundwater Contaminants through the Vadose Zone and Into the Unconfined Aquifer below the B-Complex*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19277.pdf

PNNL-22499, *Perched-Water Evaluation for the Deep Vadose Zone beneath the B, BX, and BY Tank Farms Area of the Hanford Site*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22499.pdf.

RPP–ENV-33418, 2012, *Hanford C-Farm Leak Assessments Report*, Rev. 2, Washington River Protection Solutions, LLC, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0091702.

RPP-RPT-46088, *Flow and Transport in the Natural System at Waste Management Area C*, Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

SGW-53604, 2013, *Path Forward Recommendations Report for the Uranium Contamination in the B Area*, Rev. 1, CH2M Hill Plateau Remediation Company, Richland. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0086487.

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