Tehama

APPENDIX F

Conceptual Level Groundwater Modeling – Northwest PFAS Area
Drinking Water Protection Study
Fairchild Air Force Base, Washington

This appendix summarizes the results of conceptual level numerical groundwater modeling performed in support of the Drinking Water Protection Study (DWPS) related to per- and polyfluorinated alkyl substances (PFAS) contamination at (and in the vicinity of) Fairchild Air Force Base (FAFB). This modeling was performed as part of the evaluation of the Northwest PFAS Area, where off-Base residential wells are impacted by PFAS. This summary includes the following components:

- Objectives
- Codes utilized and numerical solution
- Model layering
- Model extent, model grid, boundary conditions, and parameter values
- Simulation results (base case and other simulations)
- References

1.0 OBJECTIVES

The objective was to perform conceptual level numerical simulations of groundwater flow to evaluate the following two potential explanations for PFAS impacts observed at residential wells in the Northwest PFAS Area (**Figure F-1**):

1. Possibility that groundwater impacted by PFAS on-Base, from an unidentified release area near IRP site SD037, could flow off-Base to the north in the Wanapum Basalt and result in PFAS impacts to residential wells screened in the Wanapum Basalt; and/or

2. Possibility that groundwater impacted by PFAS on-Base at AFFF Release Areas 3 and 5 (co-located with VOC impacts in the SS039 plume) could flow north across the northern Base boundary in alluvium within the East Deep Creek Paleochannel (which is sometimes referred to as the SS039 Paleochannel on the northern portion of FAFB), and then be pulled west from the alluvial paleochannel into the adjacent Wanapum Basalt by the extraction at residential wells screened in the Wanapum Basalt.

Figure F-1 illustrates the TCE plume associated with SD037 (Bay West, 2021) which has a “northern lobe” oriented toward the northern Base boundary and an eastern lobe that is oriented towards the East Deep Creek Paleochannel to the east-northeast (the paleochannel is also indicated on **Figure F-1**). Apparently one or more sources of TCE migrated into groundwater that flows within each of these two lobes, and direction of TCE plume migration differs between the two plume lobes.

The conceptual level modeling is a simplification of the flow system, including a porous media representation for the basalt, to evaluate the feasibility and relative likelihood of the two possible explanations for PFAS impacts in the Northwest PFAS Area listed above.

2.0 CODES UTILIZED AND NUMERICAL SOLUTION

MODFLOW-2000 was used for flow simulations and MODPATH Version 5 was used for particle tracking, as implemented in the Groundwater Vistas model interface software (Version 7.24, Build 266). MODFLOW and MODPATH are widely used codes developed by the US Geological Survey. The PCG2 package in MODFLOW was utilized to iteratively solve the finite difference equations for groundwater flow. A head convergence a criterion of 0.0001 feet (ft) was utilized, and the resulting mass balance error was sufficiently small (less than 0.01%).

3.0 MODEL LAYERING

Two model layers were used to represent the simplified flow system (from top to bottom):

- Layer 1:
  - The water table represents the top.
  - Bottom elevation is 2320 ft above mean sea level (amsl).
  - This layer represents alluvium in the East Deep Creek Paleochannel where the paleochannel is present and represents Wanapum Basalt where the paleochannel is not present.
- Layer 2:
  - Top elevation is 2320 ft amsl.
  - Bottom elevation is 2200 ft amsl.
  - This layer represents Wanapum Basalt.

The bottom elevation of layer 1 and layer 2 were assigned based on the approximate bottom of the East Deep Creek Paleochannel and the bottom of the Wanapum Basalt, respectively, near the northern Base boundary (as represented on cross-sections B-B' and I-I' developed for the DWPS). In this simplified "box geometry" the side of the paleochannel is represented as vertical; representing the sloped nature of the paleochannel sides would require many model layers which is beyond the intent of this conceptual level model.

4.0 MODEL EXTENT, MODEL GRID, PARAMETER VALUES, AND BOUNDARY CONDITIONS

The horizontal model grid is illustrated on **Figure F-2**. The model is oriented north-south and has uniform grid spacing of 100 ft. The model grid measures 20,000 ft wide divided into 200 columns, and 20,000 ft tall divided into 200 rows. The lower-left origin of the model is at easting 2,417,000 ft and northing 242,300 ft in coordinate system EPSG:2285 (Washington North, ft, NAD83).

The following types of boundary conditions are applied in the model:

- **Specified Head.** As illustrated on **Figure F-2**, specified head boundaries were assigned along model edges. The specified head boundaries impart general control on the regional flow system so that the groundwater flow pattern (water levels and groundwater flow directions) are qualitatively similar to regional groundwater flow patterns reported for the Wanapum Basalt (Spokane County Water Resources, 2013, Figure 3.15). Key aspects of the flow system include groundwater flow to the northwest (towards the Deep Creek drainage) in locations northwest of the Base (i.e., far west of the paleochannel), and groundwater flow to the north and northeast in locations due north of the northern Base boundary. The same boundary head values were assigned in model layer 1 and 2 and are summarized below.
  - Along the southern (upgradient) edge of the model a uniform head value of 2,450 ft amsl was assigned.
  - Along the northern (downgradient) edge of the model a uniform head value of 2,340 ft amsl was assigned on the eastern portion (i.e., paleochannel), and west of the paleochannel the specified head value slowly declines to the west (see **Figure F-2**).
  - Along the northwestern edge of the model (angled), model a uniform head value of 2,320 ft amsl was assigned. This is intended to mimic the approximate orientation of water level contours expected in this area based on the available regional water level map for the Wanapum Basalt.

- Along the western edge of the model the specified head decreases from south to north (see **Figure F-2**), consistent with regional flow patterns.

- **No-Flow (assigned).** A no-flow boundary was assigned in the small northwest part of the model beyond the angled portion of the specified head boundary (see **Figure F-2**). This part of the model grid is inactive because the specified head boundary represents the edge of the active model.

- **No-Flow (implicit).** Along the eastern edge of the model there is no boundary condition assigned, and therefore the eastern model edge represents an implied no-flow boundary (i.e., the eastern model edge is simulated as a flowline). The eastern portion of the model was not the focus of this conceptual modeling exercise, and no attempt was made to accurately simulate that part of the flow system. In actuality, there is likely groundwater flow to the east in that part of the model domain, towards the Airway Heights Paleochannel that is located further east. Additionally, the bottom of the Wanapum Basalt (bottom of layer 2) is implicitly treated as a no-flow boundary in this simplified conceptual level model.

- **Net Recharge.** Net recharge was assigned to model layer 1. The assigned value for net recharge was 0.0013 feet per day (ft/d), which is equal to approximately 5.69 inches per year. This is within the range of typical values for net recharge northwest of Airway Heights (GSI et al., 2015, Figure 3) though recharge rates are likely variable by location and by time and could be locally lower or higher.

- **Wells.** Residential wells in the Northwest PFAS Area were assigned an extraction rate of 1 gallon per minute (gpm). In a recent article (KXLY, 2021) the average water use for a single person in Spokane County is around 235 gallons. A family of 4 would therefore on average use approximately 940 gallons per day, which is 0.65 gpm. A value of 1 gpm per well is therefore on the high end of what is likely. A value at the high end of the likely range was applied to assess the likelihood that residential wells might pull water into the Wanapum Basalt from the East Deep Creek Paleochannel located to the east.

Hydraulic conductivity (K) assignments are also summarized on **Figure F-2**. In model layer 1, K was assigned as 175 ft/d in the alluvial paleochannel (with a 10:1 vertical anisotropy ratio) and 3 ft/d in the Wanapum Basalt outside the paleochannel (with a 100:1 vertical anisotropy ratio). In model layer 2 (Wanapum Basalt) a K value of 3 ft/d was assigned (with a 100:1 vertical anisotropy ratio). The K value of 175 ft/d for coarse alluvium and 3 ft/d for Wanapum Basalt are within the ranges of K values reported for these units in FAFB documents and regional hydrogeology reports.

This is a simplified conceptual modeling exercise, and no formal calibration was attempted. The boundary conditions and parameter values discussed above were selected after several trial and error simulations were performed, because this combination of boundary conditions and parameter values indicated it is conceptually possible for groundwater impacted by PFAS originating on-Base near IRP site SD037 to flow to the north in the Wanapum Basalt and result in PFAS impacts to residential wells screened in the Wanapum Basalt in the northwest PFAS area. The values for boundary heads, recharge rate, and K discussed above are reasonable values, but are subject to considerable uncertainty and localized heterogeneity. Other assignments for boundary conditions and/or parameter values could result in different simulated groundwater flow patterns.

5.0 SIMULATION RESULTS

5.1 Base Case

Figure F-3 illustrates simulated water levels (model layer 1) and also illustrates particle tracking results for particles released near the beginning of the SD037 TCE plume northern lobe.

The simulated groundwater flow pattern in the northern part of FAFB is consistent with expectations. Simulated groundwater levels for shallow Wanapum Basalt near Building 2447 are just below 2,428 ft amsl, which is consistent with measured water levels in that area (approximately 2,430 ft amsl, generally from monitoring wells screened in the relatively thin shallow alluvium). The simulated groundwater flow patterns are consistent with the observed orientation of both the “northern lobe” and “eastern lobe” of the SD037 TCE plume (apparently one or more sources of TCE migrated into groundwater that flows within each of these two lobes). Near the northern lobe, groundwater flow has a more northerly component. Near the eastern lobe, groundwater flow is more towards the east-northeast. This bifurcated groundwater flow pattern results from the spatial orientation of the East Deep Creek Paleochannel to the east and northeast, coupled with regional flow to the north and northwest towards the Deep Creek drainage.

Off-Base, near the impacted residential wells, the simulated flow pattern is complex due to the same bifurcation of groundwater flow direction discussed above on-Base for the SD037 TCE plume. Near the westernmost residential wells, the groundwater flow direction is to the northwest, towards the Deep Creek drainage. Near the easternmost residential wells, the groundwater flow direction transitions to the northeast, reflecting discharge from the Wanapum Basalt into the East Deep Creek Paleochannel. Under these simulated flow conditions, the residential wells could not be impacted by pulling water containing PFAS from the East Deep Creek Paleochannel into the Wanapum Basalt, because the simulated discharge is in the other direction (i.e., discharge is from the Wanapum Basalt to the East Deep Creek Paleochannel).

Groundwater velocity in the Wanapum Basalt (used for particle tracking) is based on simulated water levels, assigned K, and an assigned porosity of 0.05 which is reasonable for porous and/or fractured basalt. Particle tracking does not account for dispersion which could result in faster transport and does not account for retardation which could result in slower transport (retardation factors are site-specific and not well known). Lower porosity would result in faster transport and higher porosity would result in slower transport.

The particle traces illustrated on **Figure F-3** are terminated at elapsed time of 50 years. The particle tracks illustrate that PFAS from an AFFF release near the source of the SD037 TCE plume (if such a release occurred) could potentially reach the general area of the impacted residential wells located off-Base via groundwater migration in the Wanapum Basalt. No such PFAS release has been identified or investigated to date. The particle tracking results indicate PFAS releases to groundwater approximately in the 1970s could have reached the impacted residential wells in the Northwest PFAS Area by approximately 2017 when impacts to residential wells were first observed.

Furthermore, these results indicate that residential wells that are not yet impacted by PFAS but are located further to the north and northwest of the residential wells that are currently impacted could potentially become impacted by PFAS in the future as groundwater continues to migrate to the northwest.

5.2 Other Simulations

Figure F-4 illustrates results for Sensitivity Simulation #1, with residential well extraction rate at each well reduced from 1 gpm to 0.5 gpm. The results are similar to the base case, but the particles travel slightly further to the east towards the East Deep Creek Paleochannel with these lower extraction rates relative to the base case.

Figure F-5 illustrates results for Sensitivity Simulation #2, with RW extraction rate at each well increased from 1 gpm to 2 gpm. As noted earlier, the rate of 1 gpm per residential well is slightly higher than expected, so assuming 2 gpm per residential well is likely to be unreasonably high. The results are similar to the base case, but the particles travel slightly further to the west, and also travel further to the northwest within the 50-year period evaluated. Even at 2 gpm, groundwater flow due east of the currently impacted residential wells is towards the paleochannel, indicating those wells would not be impacted by pulling water from the paleochannel into the basalt. Further to the north (where residential wells are not impacted) the simulation suggests some potential for water to be pulled from the paleochannel into the basalt due to the higher residential well extraction rates.

Figure F-6 illustrates results for Sensitivity Simulation #3, which is intended to demonstrate that similar results to the base case can be obtained for an alternate set of reasonable model parameters. This simulation includes the following changes from the base case:

- K in paleochannel reduced from 175 ft/d to 125 ft/d.
- K in Wanapum Basalt reduced from 3 ft/d to 2 ft/d.
- Net recharge rate reduced from 0.0013 ft/d to 0.00085 ft/d.

- Basalt porosity reduced from 0.05 to 0.04.

The simulated water levels and particle traces are very similar to the base case for this simulation, except that the particles do not travel quite as far after 50 years relative to the base case.

6.0 CONCLUSIONS

Based on the simplified conceptual level modeling results, it seems possible that groundwater impacted by PFAS on-Base, from an unidentified release area near IRP site SD037, could flow off-Base to the north in the Wanapum Basalt and result in PFAS impacts to residential wells screened in the Wanapum Basalt. This possibility is consistent with the observed concentrations of PFAS at residential wells northwest of the Base. The highest RW concentrations are located in the southern part of the Northwest PFAS Area, whereas RW concentrations furthest east near the East Deep Creek paleochannel are relatively low. Based on simulated groundwater flow patterns it seems less likely that the Residential wells in the Northwest PFAS Area are impacted by PFAS due to the residential wells pulling groundwater impacted by PFAS into the Wanapum Basalt from the alluvial paleochannel to the east, consistent with the PFAS impacts noted above. Additional field work is merited to help confirm these conclusions, as recommended in the DWPS report.

7.0 REFERENCES

Bay West, 2021. Draft SD037 In Situ Chemical Oxidation Pilot Study Work Plan. Performance-Based Remediation. Fairchild Air Force Base, Washington. January.

GSI Water Solutions, Inc., INTERA, Inc., GeoEngineers, Inc., and Carlstad Consulting, 2015. Hydrogeologic Framework and Conceptual Groundwater Flow Model, Review of Groundwater Conditions in the West Plains Area, Spokane County, Washington. June.

KXLY, 2021. Spokane County Ranks in 98th Percentile for Water Usage; City Council Eager to Change Trend. January 25. https://www.kxly.com/spokane-county-ranks-in-98th-percentile-for-water-usage-city-council-eager-to-change-trend/#:~:text=%E2%80%94%20According%20to%20data%20from%20the,County%20is%20around%20235%20gallons.

Spokane County Water Resources, 2013. West Plains Hydrogeology. West Plains Groundwater Elevation Monitoring and Mapping. June 30.

(b) (6)

Figure F-1 provides information about the type and location of off-base private sampling sources. It contains personal privacy information that is not publicly releasable under the Freedom of Information Act, 5 U.S.C. § 552, and is maintained in a separate portion of the Administrative Record that is not accessible to the public.

[redacted]

Legend

Groundwater PFOS + PFOA (ppt)

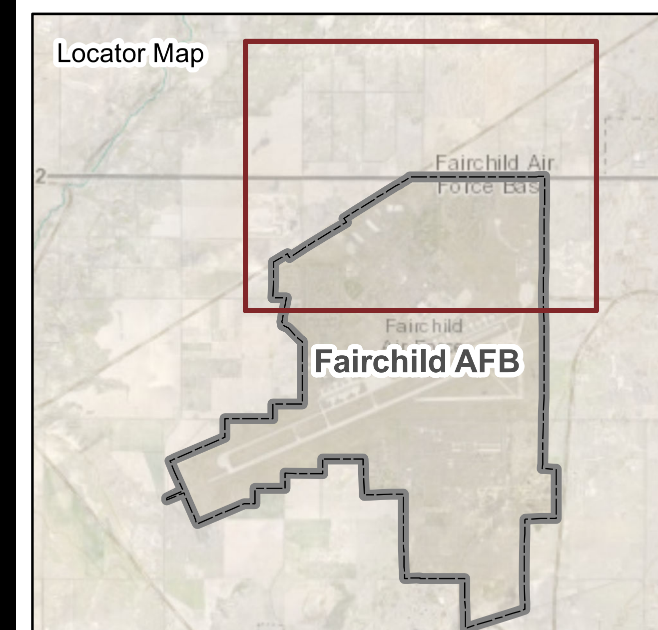
- Not Detected
- Detected Below LHA
- 70ppt - 1,000ppt
- 1,000ppt-100,000ppt
- >100,000ppt
- Paleochannel Contours

TCE Contour (Based on June 2017 Results)

- 1 µg/L
- 5 µg/L
- 100 µg/L
- 1000 µg/L
- Installation Boundary

PII - Do Not Release

CONTROLLED



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Locations of Impacted Residential Wells (RWs) in Northwest PFAS Area, SD037 TCE Plume, Building 2447, and SS039 Paleochannel

Drinking Water Protection Study
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DATE	FIGURE
8/10/2021	**F-1**

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Figure F-2 provides information about the type and location of off-base private sampling sources. It contains personal privacy information that is not publicly releasable under the Freedom of Information Act, 5 U.S.C. § 552, and is maintained in a separate portion of the Administrative Record that is not accessible to the public.

[redacted]

Legend

Groundwater PFOS + PFOA (ppt)

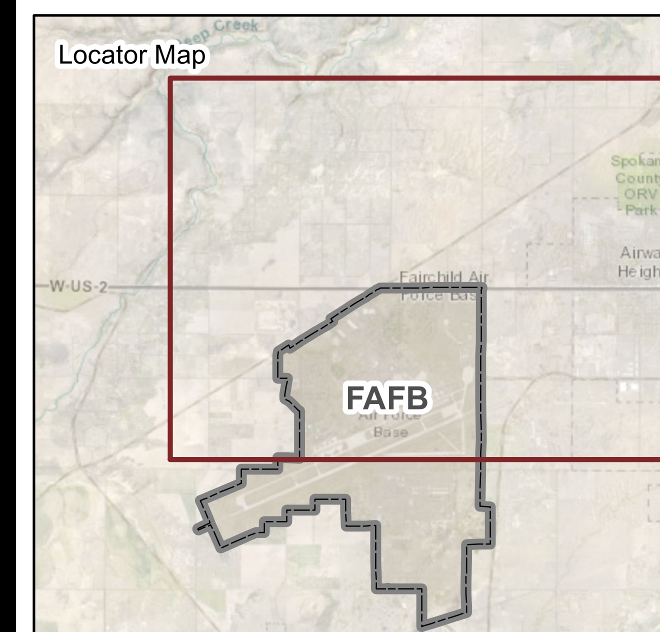
- Not Detected
- Detected Below LHA
- 70ppt - 1,000ppt
- 1,000ppt-100,000ppt
- >100,000ppt
- Paleochannel Contours
- Paleochannel K-zone

TCE Contour (Based on June 2017 Results)

- 1 µg/L
- 5 µg/L
- 100 µg/L
- 1000 µg/L
- Installation Boundary

PII - Do Not Release

CONTROLLED



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Model Grid, Specified Head Boundaires, and Hydraulic Conductivity Zones

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Fairchild Air Force Base

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DATE	FIGURE
8/10/2021	**F-2**

(b) (6)

Figure F-3 provides information about the type and location of off-base private sampling sources. It contains personal privacy information that is not publicly releasable under the Freedom of Information Act, 5 U.S.C. § 552, and is maintained in a separate portion of the Administrative Record that is not accessible to the public.

[redacted]

Legend

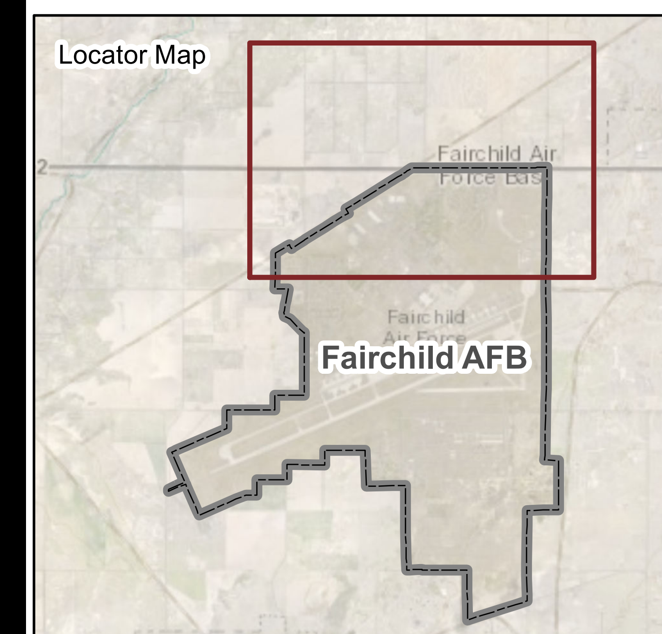
Groundwater PFOS + PFOA (ppt)

- Not Detected
- Detected Below LHA
- 70ppt - 1,000ppt
- 1,000ppt-100,000ppt
- >100,000ppt
- Simulated Particle Tracks
- Paleochannel Contours

TCE Contour (Based on June 2017 Results)

- 1 µg/L
- 5 µg/L
- 100 µg/L
- 1000 µg/L
- Installation Boundary

Note:
Water levels likely simulated too high East of SS039 Paleochannel due to implied no-flow boundary at Eastern model edge which does not account for flow to the East towards Airway Heights Paleochannel



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Simulation Results for Base Case Simulation

Drinking Water Protection Study
Fairchild Air Force Base

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DATE	FIGURE
8/10/2021	F-3

(b) (6)

Figure F-4 provides information about the type and location of off-base private sampling sources. It contains personal privacy information that is not publicly releasable under the Freedom of Information Act, 5 U.S.C. § 552, and is maintained in a separate portion of the Administrative Record that is not accessible to the public.

[redacted]

Legend

Groundwater PFOS + PFOA (ppt)

- Not Detected
- Detected Below LHA
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- 1,000ppt-100,000ppt
- >100,000ppt
- Simulated Particle Tracks
- Paleochannel Contours

TCE Contour (Based on June 2017 Results)

- 1 µg/L
- 5 µg/L
- 100 µg/L
- 1000 µg/L
- Installation Boundary

Note:
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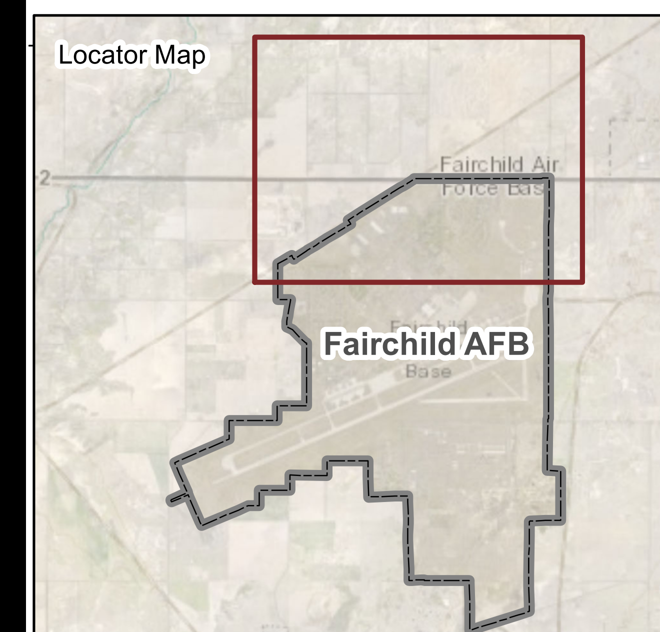

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Simulation Results for Sensitivity Simulation #1 - RW Extraction at Each RW Reduced (from 1 gpm to 0.5 gpm)
Drinking Water Protection Study
Fairchild Air Force Base

Tehama / Burns McDonnell / HGL	DATE	FIGURE
	8/10/2021	F-4

(b) (6)

Figure F-5 provides information about the type and location of off-base private sampling sources. It contains personal privacy information that is not publicly releasable under the Freedom of Information Act, 5 U.S.C. § 552, and is maintained in a separate portion of the Administrative Record that is not accessible to the public.

[redacted]

Legend

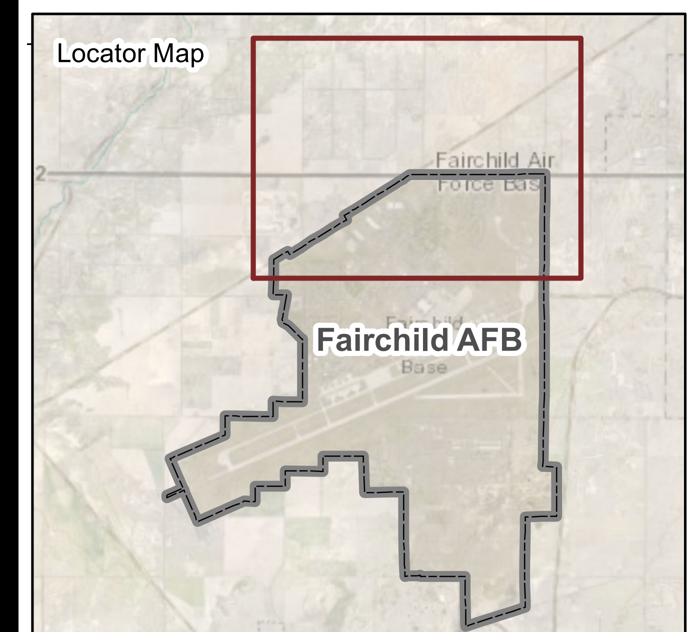
Groundwater PFOS + PFOA (ppt)

- Not Detected
- Detected Below LHA
- 70ppt - 1,000ppt
- 1,000ppt-100,000ppt
- >100,000ppt
- Simulated Particle Tracks
- Paleochannel Contours

TCE Contour (Based on June 2017 Results)

- 1 µg/L
- 5 µg/L
- 100 µg/L
- 1000 µg/L
- Installation Boundary

Note:
Water levels likely simulated too high East of SS039 Paleochannel due to implied no-flow boundary at Eastern model edge which does not account for flow to the East towards Airway Heights Paleochannel



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Simulation Results for Sensitivity Simulation #2 - RW Extraction at Each RW Increased (from 1 gpm to 2 gpm)

Drinking Water Protection Study
Fairchild Air Force Base

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DATE	FIGURE
8/10/2021	F-5

(b) (6)

Figure F-6 provides information about the type and location of off-base private sampling sources. It contains personal privacy information that is not publicly releasable under the Freedom of Information Act, 5 U.S.C. § 552, and is maintained in a separate portion of the Administrative Record that is not accessible to the public.

[redacted]

Legend

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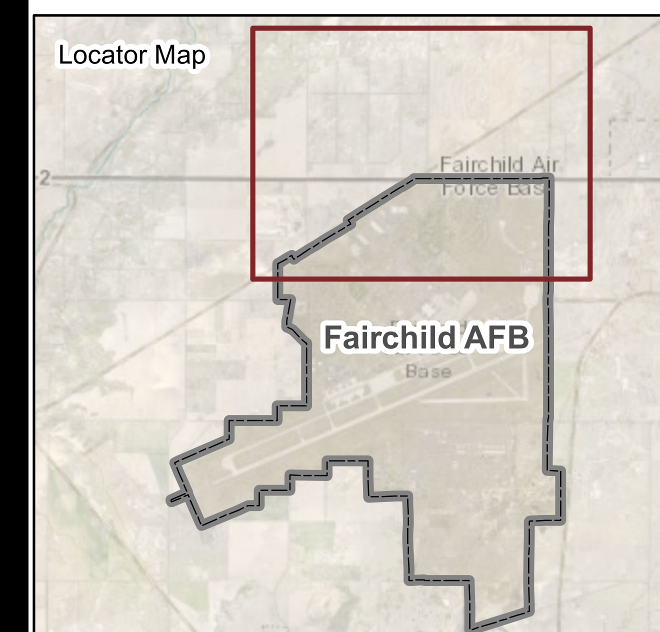
- 1,000ppt-100,000ppt
- >100,000ppt
- Simulated Particle Tracks
- Paleochannel Contours

TCE Contour (Based on June 2017 Results)

- 1 µg/L
- 5 µg/L
- 100 µg/L
- 1000 µg/L
- Installation Boundary

Note:
Water levels likely simulated too high East of SS039 Paleochannel due to implied no-flow boundary at Eastern model edge which does not account for flow to the East towards Airway Heights Paleochannel



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Simulation Results for Sensitivity Simulation #3 - Alternate Set of Parameter Values With Similar Results as Best Case

Drinking Water Protection Study
Fairchild Air Force Base

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DATE	FIGURE
8/10/2021	**F-6**