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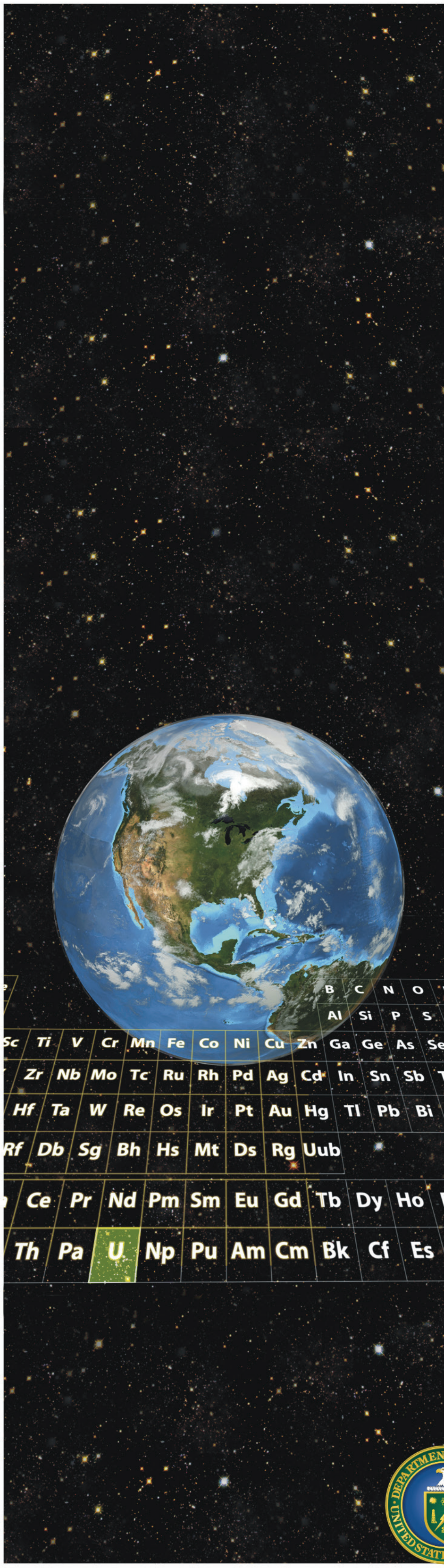

Applied Studies and Technology Persistent Secondary Contaminant Sources Data Release from Field Tracer Testing Studies at the Riverton, Wyoming, Processing Site

March 2023

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Abbreviations

AA	atomic absorption
ASTM	ASTM International
bgs	below ground surface
BTOC	below top of casing
$CaCO_3$	calcium carbonate
DFB	sodium 2,6-difluorobenzoate
DO	dissolved oxygen
ESL	Environmental Sciences Laboratory
FTA	former tailings area
IC	ion chromatography
ICP	inductively coupled plasma
ISE	ion selective electrode
L	liters
LANL	Los Alamos National Laboratory
LiBr	lithium bromide
mg	milligrams
min	minute
mL	milliliters
MS	mass spectrometry
NaI	sodium iodide
OES	optical emission spectroscopy
ORP	oxidation-reduction potential
pE	log of the electron activity
PeSCS	persistent secondary contaminant sources
PFB	potassium pentafluorobenzoate
SI	saturation index
SSMA	St. Stephens Mission Area
TOC	total organic carbon
UV	ultraviolet
UWM	University of Wisconsin–Milwaukee

Executive Summary

This report provides a data release related to aquifer tracer testing and geochemical sampling at the Riverton, Wyoming, Processing Site related to the Applied Studies and Technology Persistent Secondary Contaminant Sources Project. This report provides testing procedures and methods with well locations and resulting data in various appendixes. Procedures include well installations, aquifer testing, fluorescein dye injections, and tracer testing using multiple tracers with extensive geochemical sampling. This testing focused on two known areas with solid-phase contamination, (1) saturated zone sediments under the former tailings area (FTA), and (2) unsaturated zone sediments in an area near the Little Wind River referred to as the St. Stephens Mission Area (SSMA). Testing in 2020 at the SSMA included a traced saturated zone injection (little to no solid-phase contamination but within the uranium and molybdenum contaminant plumes) and a surface infiltration using Little Wind River water. This testing was monitored in a downgradient well gallery. Testing in 2020 at the FTA included three saturated zone injections using background groundwater (one without added sodium bicarbonate and two with added sodium bicarbonate to evaluate possible uranium mobilization). FTA testing in 2020 also included monitoring in a downgradient well gallery. Testing in 2021 at the SSMA repeated the 2020 SSMA surface infiltration test with the addition of sodium bicarbonate to the traced river water. In 2021, FTA testing was completed as single well injection drift tests, two with and two without the addition of sodium bicarbonate in wells with multilevel ports.

Major observations with the SSMA tracer testing are: (1) a significant release of uranium from the unsaturated zone, which is not seen in the saturated zone; (2) no release of molybdenum from the saturated zone, and unsaturated zone release of molybdenum is enhanced with the addition of sodium bicarbonate; and (3) the groundwater flow direction is generally aligned with the installed well gallery.

Major observations with the FTA tracer testing are: (1) significant uranium and molybdenum release from the solid phase to the water phase, in some cases at concentrations much greater than the original aquifer concentrations; (2) in one well, with the addition of sodium bicarbonate to the injection fluid directly after a test without the use of sodium bicarbonate, no additional uranium release from the solid phase is indicated; (3) heterogeneity at the FTA creates unexpected groundwater flow directions that are not in alignment with the installed well gallery; and (4) heterogeneity also creates a significant difference in geochemical conditions at one well within the well gallery.

1.0 Introduction

Persistent secondary contaminant sources (PeSCS) are defined as any residual contaminants on the solid phase that are not the primary contaminant source, in this case, uranium mill tailings. At the Riverton, Wyoming, Processing Site, PeSCS were identified (DOE 2013; DOE 2016). This led to a revised conceptual site model (Dam et al. 2015) where the ongoing persistent uranium plume is caused by the release of contaminants from the identified PeSCS. Additional reports include measurement of PeSCS release in multilevel monitoring wells after flooding events (DOE 2019) and a summary of geochemical conditions at the site (DOE 2022). The 2022 report includes column testing to determine PeSCS release rates and concentrations from various areas at the site with elevated uranium in the solid phase (DOE 2022).

Because of the availability of the prior information listed above, the Riverton site was selected by the Applied Studies and Technology PeSCS Project to test field tracer injection procedures to determine contaminant release rates. These procedures used traced field injections of background groundwater or river water with and without added alkalinity, followed by natural gradient drift, in two different areas at the Riverton site, as discussed in the original field work plan (DOE 2020). The goal of these injections was to perturb the geochemical conditions to determine field-derived PeSCS release rates and concentrations. Ultimately, reactive transport parameter values will be derived from the resulting groundwater tracer data for use in a sitewide reactive transport model. The intent of this report is to release all the information related to the groundwater tracer testing procedures along with the resulting data (in tables and in graphical form). Only limited interpretations of the results are provided, which mainly include discussions of the graphical results and PHREEQC geochemical modeling for the most apparent mineral controls. Multiple journal articles with more detailed interpretations are expected, but this report will serve as a reference for the field groundwater tracer data.

2.0 Site Details and Well Locations

The Riverton site is in central Wyoming just outside of Riverton (Figure 1). More information about the site along with multiple site documents can be found at https://www.energy.gov/lm/riverton-wyoming-processing-site. The focus of this report is data related to tracer injections and resulting geochemistry in the former tailings area (FTA) and in the St. Stephens Mission Area (SSMA) (Figure 2). In both areas, well galleries were installed as part of the tracer testing (Figure 3 and Figure 4) in areas of persistent uranium and molybdenum groundwater plumes (DOE 2022). The SSMA also had an infiltration basin (Figure 4). Details on the well installations and tracer testing procedures are discussed in the next section (Section 3.0).

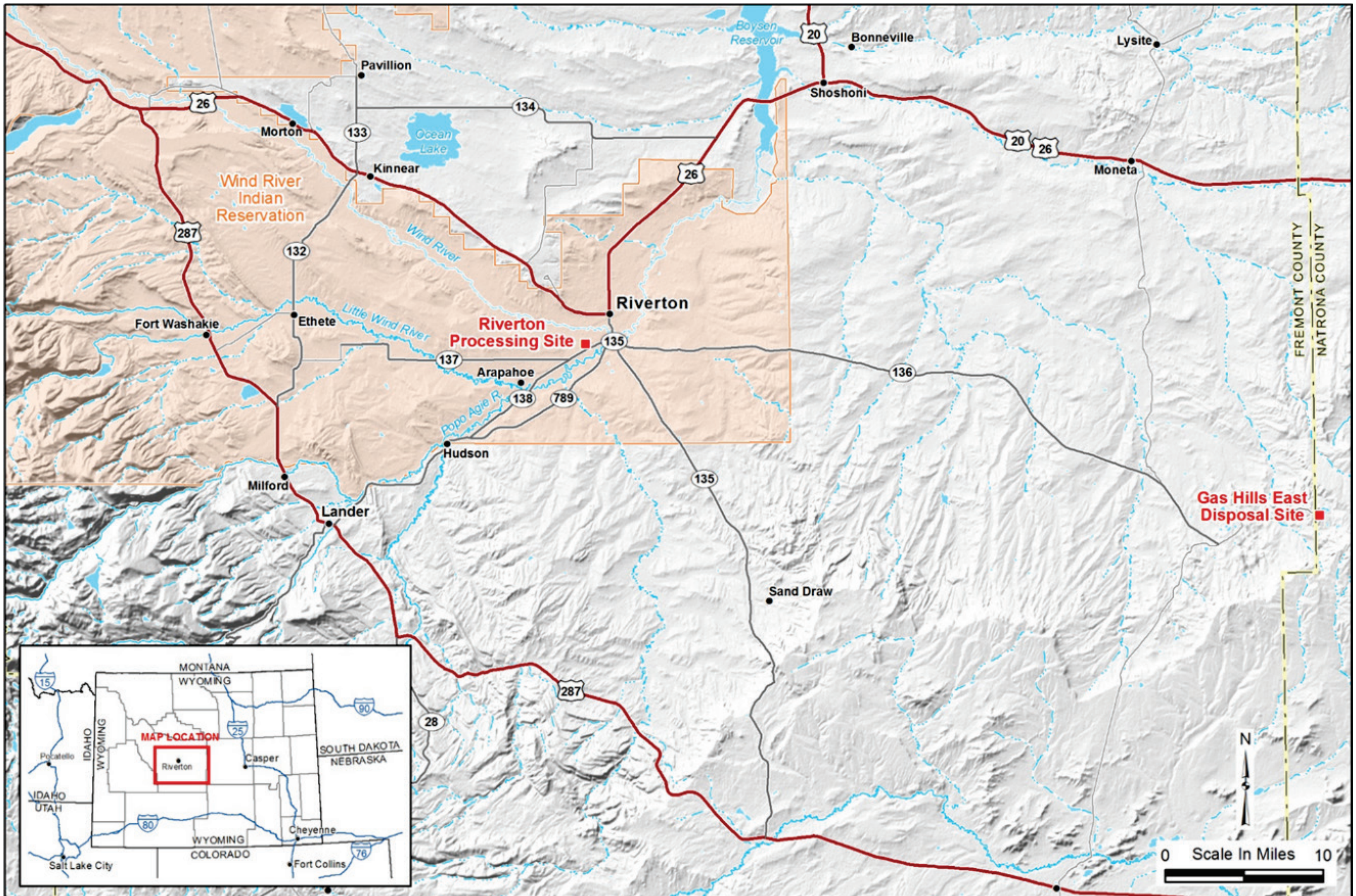

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Figure 1. Location of the Riverton, Wyoming, Processing Site

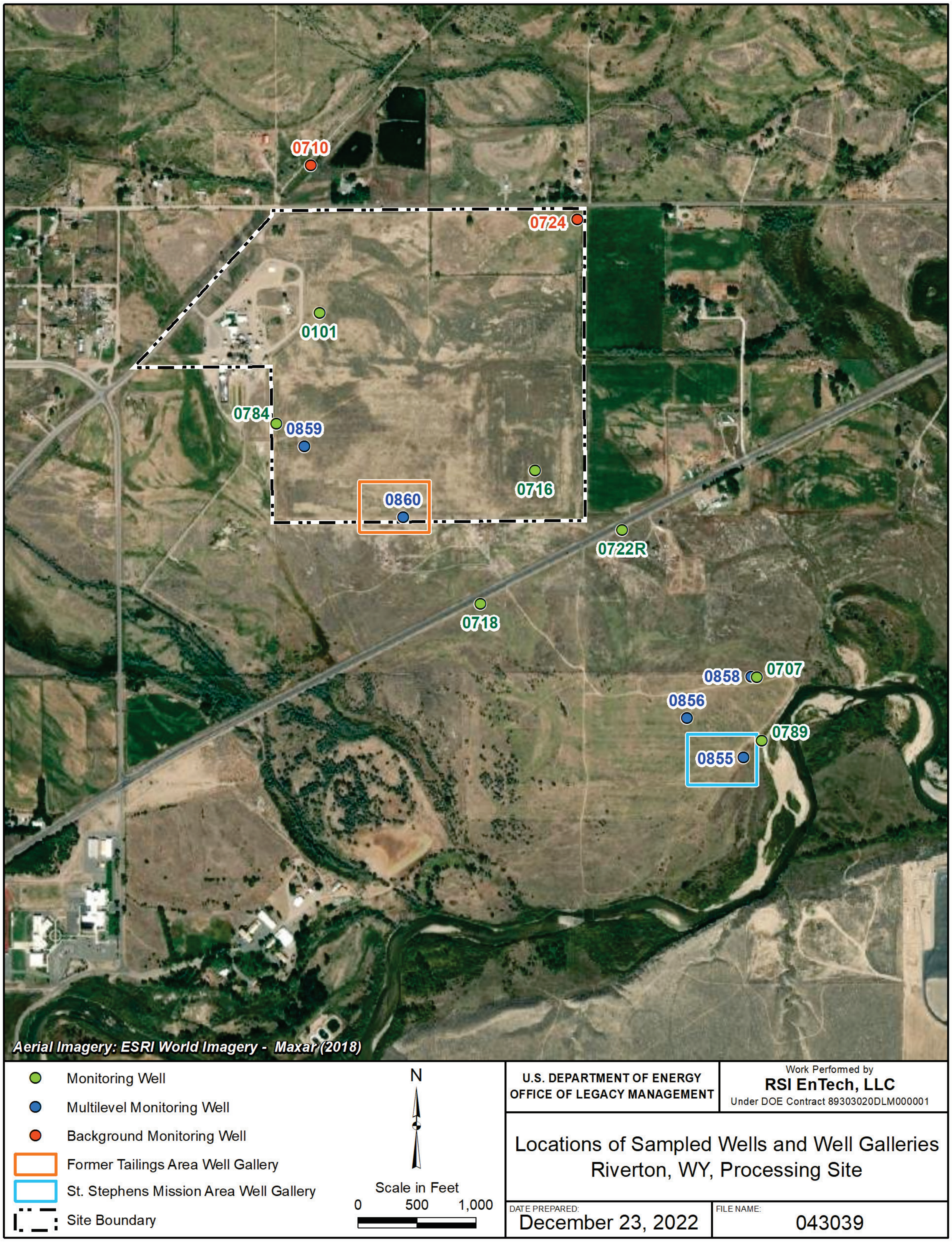


Figure 2. Location of Wells with Data in This Report and Well Gallery Locations with Details in Figure 3 and Figure 4

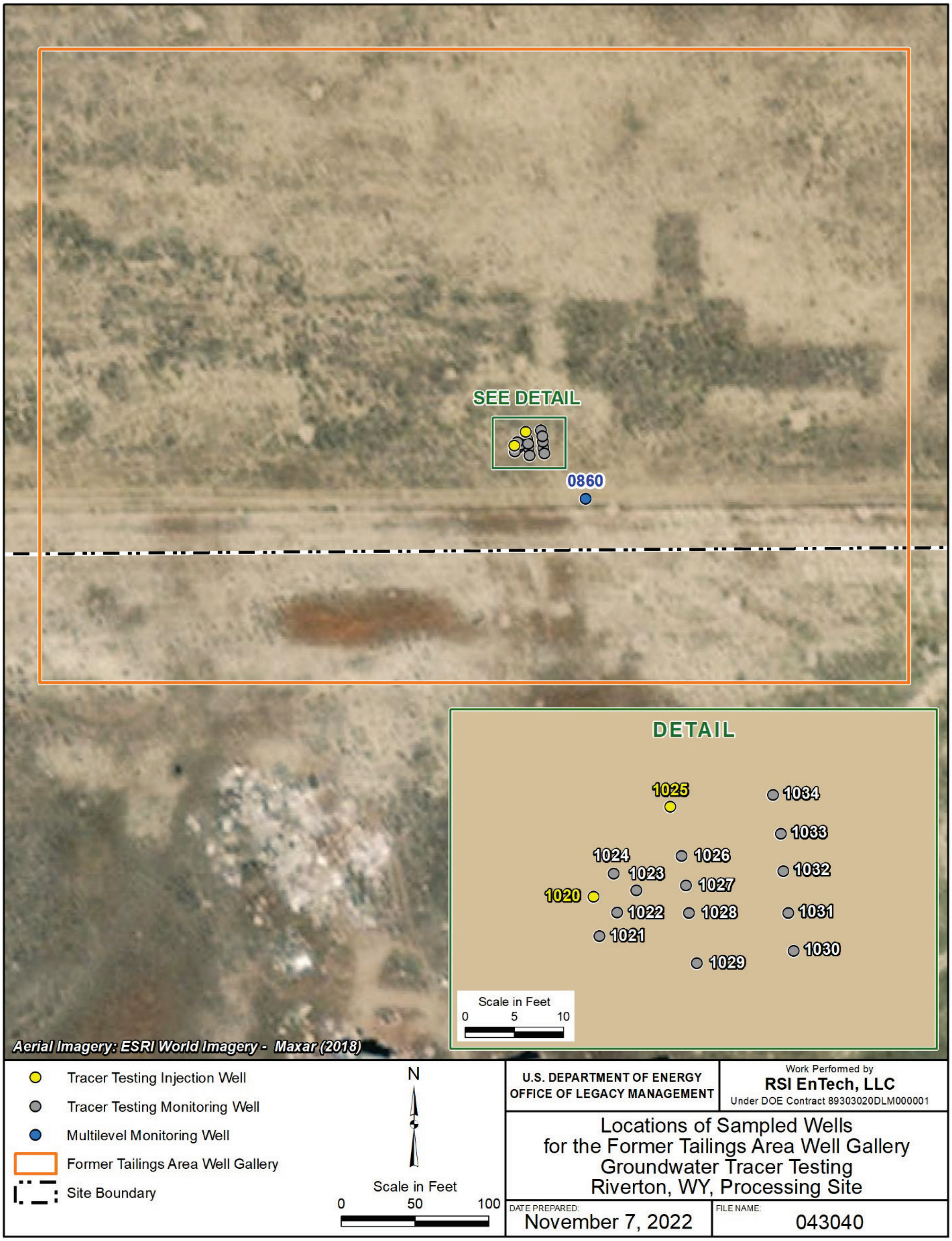


Figure 3. Location of Wells in the FTA

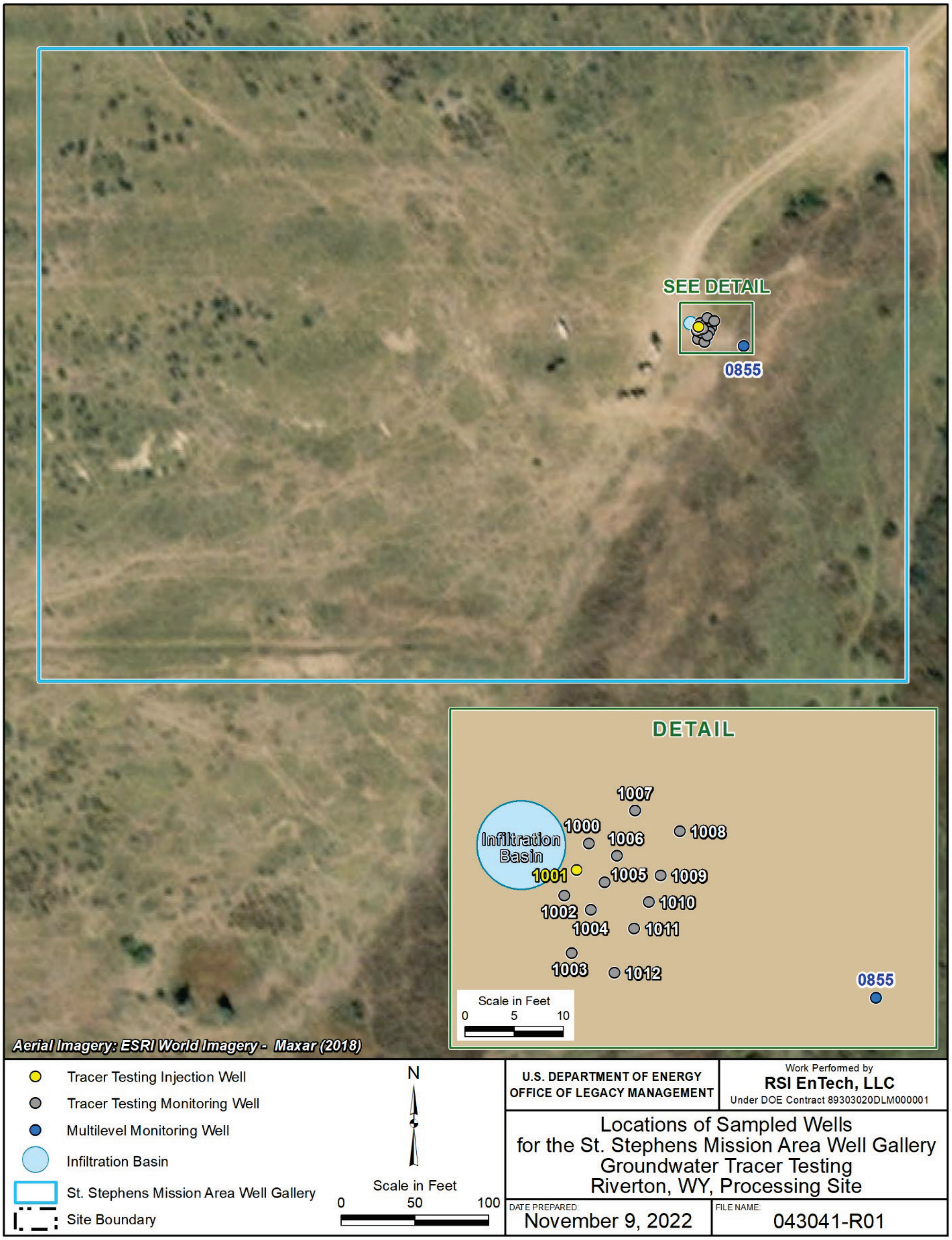


Figure 4. Location of Wells in the SSMA

3.0 Tracer Testing Procedures

Tracer testing was completed at the Riverton site during summer 2020 and 2021. This included well installation (Section 3.1), aquifer testing (Section 3.2), fluorescein dye injection (Section 3.3), saturated zone tracer testing (Section 3.4 and Section 3.5), and surface infiltrations (Section 3.4 and Section 3.6). Injection fluids were Little Wind River water or background groundwater with and without the addition of sodium bicarbonate (adds alkalinity) to potentially help mobilize uranium. All field notes and field data books have been scanned to PDF files and are available in Appendix A.

3.1 Well Installation

An initial round of four well installations at both the FTA (wells 1020 through 1023, Figure 3) and SSMA (wells 1001 and 1004 through 1006, Figure 4) was completed for use in fluorescein dye injection (Section 3.3). The results from the fluorescein dye in the three downgradient wells at each area was used for finalizing the locations of the remaining wells in the downgradient well gallery. The original design for the SSMA well gallery was used (Figure 3), but the FTA well gallery was reoriented to align with dye showing up in well 1023 (Figure 4).

Well installation (wells 1000–1012 at the SSMA and 1020–1034 at the FTA) was accomplished with a Geoprobe DT7822 direct push drilling rig utilizing the DT325 tooling system using knockout plugs. In some cases, the hole was cored beforehand and then the tooling was tripped back in for the well installation. Wells were installed with prepacked screens (Geoprobe part No. 203079) that were 5 feet long with a 1.5-inch inner diameter and 2.5-inch outer diameter and wrapped in stainless steel mesh. The wells were set at their desired location and depth, and the formation was allowed to collapse around the well. A 20/40 silica sand was added so that it extended 2 feet above the top of the screen. Granular bentonite was then added to the annulus to ground surface. The PVC well casing was extended to approximately 2 feet above ground surface.

For the SSMA, the target screen interval for the gallery wells was 7 to 12 feet below ground surface (bgs) and the water table was between 7 to 8 ft bgs during the 2020 and 2021 surface infiltration tests. Depth to bedrock in the SSMA gallery wells is unknown but is estimated at 17.5 ft bgs based on nearby well 0789 (Figure 2). Depth to bedrock in well 0855 (Figure 4) is 18.0 ft bgs, but that well has a lower surface elevation than the FTA well gallery. For the FTA, the target screen interval for the gallery wells was 11.5 to 16.5 bgs and the water table was between 8.5 to 8.9 ft bgs during the 2020 and 2021 FTA tracer testing. The depth to bedrock at the FTA in the gallery is approximately 15.5 to 16.5 ft bgs. All the wells were surveyed for horizontal location to within 0.01 feet and for elevation to within 0.05 feet.

Wells 0855, 0858, 0859, 0860, 0707, 0710, 0724, and 0789 (Figure 2) were installed before 2020. The 800-series wells are all multilevel installations with four sampling ports with depth (generally only three ports are in the saturated zone). The 700-series wells all have traditional single well screens. Boring logs, well completion diagrams, and completion elevations for all of the wells discussed in this report are provided in Appendix B.

3.2 Aquifer Testing

Borehole dilution, slug testing, and aquifer pumping tests were completed before any tracer testing to get aquifer hydraulic conductivity estimates. Borehole dilution testing was completed on planned saturated zone injection wells 1001 and 1020 and well 0789. Borehole dilution involved a circulation of deionized water within the well to remove any aquifer water. Once the recirculation was turned off, specific conductance was measured at different well screen intervals through time to monitor the rate of return of aquifer groundwater. Borehole dilution tests were conducted according to the general methodology of Pitrak et al. (2007). Slug testing was completed in wells 1020, 1021, 1022, and 1023 at the FTA and wells 0855-4, 1001, 1004, 1005, 1006 at the SSMA. Slug tests were conducted and analyzed using the general methodology of Hvorslev (Freeze and Cherry 1979). Aquifer pumping tests were completed in wells 1001 and 1020 with hydraulic head monitoring in nearby wells (SSMA 1004, 1005, and 1006 and FTA 1021 1022, and 1023, respectively). Aquifer pumping tests were analyzed according to the general methodology of the Cooper and Jacob straight-line method for transient flow to a pumping well in a confined aquifer (Freeze and Cherry 1979). Infiltration testing was completed at the SSMA outside of the actual infiltration basin to test expected infiltration rates. Infiltration testing followed the procedures of ASTM International (ASTM) D3385-18 using double-ring infiltrometers. All aquifer testing and infiltration testing data and a summary of the results are provided in Appendix C.

3.3 Fluorescein Dye Injection

To aid in the orientation of the well galleries, fluorescein dye injections were performed at the FTA and the SSMA to get approximate groundwater flow velocity and a localized groundwater flow direction. At the FTA, dye was injected into well 1020 and monitored under natural gradient conditions at wells 1021, 1022, and 1023 (Figure 3). At the SSMA, dye was injected into well 1001 and monitored under natural gradient conditions at wells 1004, 1005, and 1006 (Figure 4). Based on prior information on groundwater flow directions for each area, the injection well was intended to be upgradient, perpendicular to the transect of three downgradient wells, and in line with the center transect well. Five gallons of fluorescein dye solution (2 grams of fluorescein in 5 gallons of deionized water) was injected into the upgradient well. Samples were periodically taken at the downgradient wells to look for the presence of fluorescein. The water columns in the injection wells were continuously circulated for full mixing within the well screen. A fluorimeter (Ocean Insight) was used to measure the fluorescein concentrations. Calibration curves and data results are provided in Appendix D.

3.4 Tracer Testing Summary

Tracer testing was completed in a series of tests with a goal of quantifying contaminant release rates in different areas. A summary of the tracer testing is provided in Table 1 (mixed U.S. customary system and International System of Units are retained based on the units used for the measuring devices). Additional details are provided for the saturated zone injections in Section 3.5 and for the surface infiltrations in Section 3.6. Table 1 provides overall injection rates, and more detailed injection rates are provided in Appendix E. FTA testing in 2020 included measurements in the downgradient well gallery and testing at the FTA in 2021 was only in wells 0859 and 0860 (Figure 3). All SSMA testing included measurements in the downgradient well gallery (Figure 4). Information on solid-phase uranium concentrations can be found in the *2015 Advanced Site Investigation and Monitoring Report, Riverton, Wyoming, Processing Site* (DOE 2016). The bullets below present each general test and the associated objectives in order of chronological completion.

- 2020 SSMA Saturated Zone Injection: Test contaminant release (if any) from sediments with low solid-phase uranium concentrations below an area with higher solid-phase uranium concentrations in the unsaturated zone.
- 2020 SSMA Surface Infiltration: Test contaminant release from unsaturated zone sediments near the Little Wind River that have higher solid-phase uranium concentrations.
- 2020 FTA Saturated Zone Injections: Test release from contaminated sediments below the former tailings area in a series of injections with and without added sodium bicarbonate. Sodium bicarbonate was added to test a potential remedial strategy of increasing uranium mobilization through alkalinity addition.
- 2021 FTA Saturated Zone Injections: Same goal as 2020 FTA Saturated Zone Injections but with injection and monitoring in multilevel sampling port wells 0859 and 0860 instead of using a downgradient well gallery.
- 2021 SSMA Surface Infiltration: Same goal as the 2020 SSMA Surface Infiltration with the addition of sodium bicarbonate as a possible remedial technique.

3.5 Saturated Zone Injections

In 2020, one saturated zone injection was performed at the SSMA in well 1001, and three saturated zone injections were performed at the FTA, two in well 1020 and one in well 1025 (Figure 3 and Figure 4). In 2021, four saturated zone injections were performed at the FTA, two in port 3 of well 0859, one in port 3 of well 0860, and one in port 4 of well 0860. Sections 3.5.1 through 3.5.6 detail those injections. All wells were sampled following the procedures detailed in Section 4.0.

3.5.1 Well 1001

Injection into well 1001 at the SSMA was completed on July 18, 2020. Water in the injection well was recirculated at a rate of approximately 400 milliliters (mL)/minute (min) by pumping out of the bottom of the well and in just below the top of the water table (9 feet below top of casing [BTOC]). The injection tubing was set at 12 feet BTOC (mid-screen). Water for the injection came from the Little Wind River and was traced with sodium iodide (NaI) and potassium pentafluorobenzoate (PFB). These two tracers have different diffusion rates for use in testing dual porosity issues. For the injection, 100 gallons of traced water was added at approximately 825 mL/min for 7.6 hours. Recirculation of the injection well continued at approximately 250 mL/min for 4 days until the tracer concentration in the injection well was <5% of the initial concentration as measured by an iodide-specific ion selective electrode (ISE). The gallery wells (wells 1000–1012) were sampled daily until October 4, 2020, at the conclusion of the infiltration test. Sampling was also done at downgradient well 0855 (Figure 4) periodically.

Table 1. Tracer Testing Details

2020 SSMA									
Test	**Location**	**Source Water**	**Start Date**	**End Date**	**Overall Injection Rate**	**Injection or Infiltration Volume (gal)**	**Injection or Infiltration Duration**	**Tracers**	**Comments**
Injection	1001	Little Wind River	7/18/2020	8/6/2020	825 mL/min	100	7.63 hours 7/18/2020 10:01 to 17:39	NaI and PFB	
Infiltration with no added alkalinity	Upgradient of the well gallery	Little Wind River	8/6/2020	10/4/2020	~41 L/hour	2000	7.64 days 8/6/2020 7:41 to 8/13/2020 23:00	LiBr and DFB	End of infiltration is approximate based on infiltration rate as it finished infiltrating overnight.
2020 FTA									
Test	**Location**	**Source Water**	**Start Date**	**End Date**	**Overall Injection Rate**	**Injection Volume (gal)**	**Injection Duration**	**Tracers**	**Comments**
Injection with no added alkalinity	1020	Well 0710	9/11/2020	9/20/2020	1.7 L/min	250	9.17 hours 9/11/2020 9:15 to 18:25	NaI and PFB	
Injection with added alkalinity	1020	Well 0710	9/21/2020	10/10/2020	1.7 L/min	250	9.33 hours 9/21/2020 8:40 to 18:00	LiBr and DFB	
Injection with added alkalinity	1025	Well 0710	10/1/2020	10/10/2020	1.8 L/min	100	3.50 hours 10/1/2020 12:15 to 15:45	NaI and PFB	

Table 1. Tracer Testing Details (continued)

2021 FTA									
Test	**Location**	**Source Water**	**Start Date**	**End Date**	**Injection Rate**	**Injection Volume (gal)**	**Injection Duration**	**Tracers**	**Comments**
Injection with no added alkalinity	0859-3	Well 0724	6/29/2021	7/12/2021	1.1 L/min	210	11.7 hours 6/29/2021 6:53 to 18:35	NaI	
Injection with no added alkalinity	0860-3	Well 0724	6/29/2021	7/12/2021	1.35 L/min	205	9.55 hours 6/29/2021 8:58 to 18:31	NaI	
Injection with added alkalinity	0859-3	Well 0724	7/13/2021	8/10/2021	1.2 L/min	200	10.75 hours 7/13/2021 6:31 to 17:16	NaI	
Injection with added alkalinity	0860-4	Well 0724	7/13/2021	8/10/2021	1.25 L/min	200	10.05 hours 7/13/2021 7:57 to 18:00	NaI	
2021 SSMA									
Test	**Location**	**Source Water**	**Start Date**	**End Date**	**Injection Rate**	**Infiltration Volume (gal)**	**Infiltration Duration**	**Tracers**	**Comments**
Infiltration with added alkalinity	Upgradient of the well gallery	Little Wind River	8/2/2021	9/10/2021	~27 L/hour	2000	11.50 days 8/2/2021 10:03 to 8/13/2021 20:00	NaI	End of infiltration time is estimated; ~1 cm water left at 19:16 on 8/13/21.

Abbreviations:
cm = centimeters
DFB = sodium 2,6-difluorobenzoate
gal = gallons
L = liters
LiBr = lithium bromide
min = minute
mL = milliliters
NaI = sodium iodide
PFB = potassium pentafluorobenzoate

3.5.2 Well 1020

The first injection in well 1020 at the FTA occurred on September 11, 2020. Water in the injection well was recirculated at a rate of approximately 500 mL/min by pumping out of the bottom of the well and in just below the top of the water table (11 feet BTOC). The injection tubing was set at 17 feet BTOC (mid-screen). Water for the injection came from background well 0710 (Figure 2) and was traced with NaI and PFB. Two tracers with different diffusion rates were used to test dual porosity issues. For the injection, 250 gallons of traced water was added at approximately 1.7 liters (L)/min for 9.2 hours. Recirculation of the injection well continued at approximately 500 mL/min for 4 days until the tracer concentration in the injection well was approximately 10% of the initial concentration as measured by an iodide ISE. The gallery wells were sampled daily until October 10, 2020, at the conclusion of all of the FTA injection tests. Sampling was also done at downgradient well 0860 (Figure 3) periodically.

The second injection in well 1020 at the FTA occurred on September 21, 2020. Water in the injection well was recirculated as before. The injection tubing was set at 17 feet BTOC (mid-screen). Water for the injection came from background well 0710 (Figure 2) and was traced with LiBr (lithium bromide), sodium 2,6-difluorobenzoate (DFB), and sodium bicarbonate. Two tracers with different diffusion rates were used to test dual porosity issues. The bicarbonate acted as a tracer but was primarily added to increase the injection water alkalinity to approximately 1000 milligrams (mg)/L as calcium carbonate ($CaCO_3$). For the injection, 250 gallons of traced water was added at approximately 1.7 L/min for 9.2 hours. Recirculation of the injection well continued at approximately 500 mL/min for 4 days to match the recirculation time of the first injection. There was about 32% of the initial tracer concentration left in the well as measured by a bromide ISE. It is hypothesized that the injection of sodium bicarbonate precipitated calcite, partially clogging the well screen and slowing flow through the well. The gallery wells were sampled daily until October 10, 2020, at the conclusion of all of the FTA injection tests.

3.5.3 Well 1025

The injection in well 1025 at the FTA occurred on October 1, 2020. Water in the injection well was recirculated at a rate of approximately 500 mL/min by pumping out of the bottom of the well and in just above the top of the water table (11 feet BTOC). The injection tubing was set at 17 feet BTOC (mid-screen). Water for the injection came from background well 0710 (Figure 2) and was traced with NaI, PFB, and sodium bicarbonate. Two tracers with different diffusion rates were used to test dual porosity issues. The bicarbonate acted as a tracer but was primarily added to increase the injection water alkalinity to approximately 1100 mg/L as $CaCO_3$. For the injection, 100 gallons of traced water was added at approximately 1.8 L/min for 3.5 hours. Recirculation of the injection well continued at approximately 500 mL/min for 2 days until the tracer concentration in the injection well was <5% of the initial concentration as measured by an iodide ISE. The gallery wells were sampled daily until October 10, 2020.

3.5.4 Well 0859-3

The first injection in well 0859-3 at the FTA occurred on June 29, 2021. Water for the injection came from background well 0724 and was traced with NaI. Then, 210 gallons of traced water was injected at approximately 1.1 L/min for 11.7 hours. Ports 2, 3, and 4 of well 0859 were sampled several times a day (port 1 was dry) until August 10, 2021, at the conclusion of the second injection test at this well.

The second injection at well 0859-3 at the FTA occurred on July 13, 2021. Water for the injection came from background well 0724 and was traced with NaI and sodium bicarbonate. The bicarbonate acted as a tracer but was primarily added to increase the injection water alkalinity to approximately 1200 mg/L as $CaCO_3$. Then, 200 gallons of traced water was injected at approximately 1.2 L/min for 10.8 hours. Ports 2, 3, and 4 of well 0859 were sampled several times a day (port 1 was dry) until August 10, 2021.

3.5.5 Well 0860-3

The first injection at well 0860-3 at the FTA occurred on June 29, 2021. Water for the injection came from background well 0724 and was traced with NaI. Then, 200 gallons of traced water was injected at approximately 1.3 L/min for 9.6 hours. Ports 2, 3, and 4 of well 0860 were sampled several times a day (port 1 was dry) until August 10, 2021, at the conclusion of the injection test at well 0860-4.

3.5.6 Well 0860-4

The injection at well 0860-4 at the FTA occurred on July 13, 2021. Water for the injection came from background well 0724 and was traced with NaI and sodium bicarbonate. The bicarbonate acted as a tracer but was primarily added to increase the injection water alkalinity to approximately 1400 mg/L as $CaCO_3$. Then, 200 gallons of traced water was injected at approximately 1.25L/min for 10 hours. Ports 2, 3, and 4 of well 0860 were sampled several times a day (port 1 was dry) until August 10, 2021.

3.6 Surface Infiltrations

Two surface infiltration tests were performed at the SSMA, one in 2020 and one in 2021. In both tests, a large basin approximately 10 feet in diameter was dug into the ground to a depth of 6 inches and sealed with bentonite. The infiltration basin was immediately upgradient of the first transect of wells at the SSMA (wells 1000-1002) (see Figure 4). Water from the Little Wind River was mixed with tracer and stored in a plastic tank onsite and added to the basin periodically to maintain approximately 1 foot of water in the basin. The basin was covered to minimize evaporation. Downgradient wells were sampled following the procedures detailed in Section 4.0.

3.6.1 2020 Testing

In summer 2020, approximately 2000 gallons of water was traced with LiBr and DFB.
Two tracers with different diffusion rates were used to test dual porosity issues. The infiltration test began on August 6, 2020, and water was infiltrated over approximately 7.6 days. The downgradient wells were generally sampled daily for approximately 2 months once the infiltration started, ending on October 4, 2020.

3.6.2 2021 Testing

In summer 2021, approximately 2000 gallons of water was traced with NaI and sodium bicarbonate. The bicarbonate acted as a tracer but was primarily added to increase the infiltration water alkalinity to approximately 1600 mg/L as $CaCO_3$. The infiltration test began on August 2, 2021, and water was infiltrated over approximately 11.5 days. The downgradient wells were generally sampled daily for a little over 1 month once the infiltration started, ending on September 10, 2021.

4.0 Methods

4.1 Field Methods

4.1.1 Sample Collection

Samples were collected via peristaltic pumps at 100 mL/min. Dedicated down well tubing was set to have the intake at the middle of each 5-foot screen unless there was a specific need for a sample higher or lower in the water column. Before each sample, 100 mL of water was purged from the tubing. Once purged, 50 mL was collected for field parameters (temperature, specific conductance, pH, and oxidation-reduction potential [ORP]), 25 to 100 mL was collected for alkalinity (depending on the expected alkalinity range), sufficient volume was collected for dissolved oxygen (DO) AccuVac ampules, and 25 mL was collected for ferrous iron. These tests were measured immediately on unfiltered samples. Then, a 0.45 micrometer filter was put in line on the tubing and two 125mL bottles were filled with filtered water. One bottle was immediately put on ice and the other was acidified with nitric acid to a pH less than 2. The sample bottles were then shipped to the Environmental Sciences Laboratory (ESL) in Grand Junction, Colorado, for analysis or further processing.

4.1.2 Field Analysis

Samples were measured for temperature, specific conductance, pH, and ORP immediately on samples using a YSI 556MPS (Yellow Springs, Ohio). Samples were also analyzed immediately upon collection for DO, ferrous iron, and alkalinity following procedures from Hach (Loveland, Colorado). DO was measured using AccuVac ampules and a DR890 handheld colorimeter following Hach procedure 8166. Ferrous iron was measured using a DR890 following Hach procedure 8146. Alkalinity was done by titration of the sample with 1.6 Normal sulfuric acid to an endpoint of approximately 4.3 (pH) using Bromcresol Green-Methyl Red indicator as prescribed by Hach procedure 8203. All resulting data are provided in Appendix F.

4.1.3 Laboratory Analysis

Laboratory analysis was completed at the ESL, Los Alamos National Laboratory (LANL), and the University of Wisconsin–Milwaukee (UWM). All resulting data are provided in Appendix F.

A variety of methods were employed to analyze cations and metals in the filtered, acidified samples, including inductively coupled plasma (ICP)-optical emission spectroscopy (OES), ICP-mass spectrometry (MS), ion chromatography (IC), and flame atomic absorption (AA).

ICP-OES analysis was performed at LANL (PerkinElmer NexION), ICP-MS analysis was performed at the ESL and UWM (Agilent 7850 and Thermo Element 2, respectively), and flame AA analysis was performed at UWM (Thermo iCE 3000). Some uranium analysis was also performed at the ESL by kinetic phosphorescence analysis (KPA-11, Chemchek Instruments, Inc.). The laboratory and the methods used for cations and metals analyses are indicated with the data in Appendix F.

Anions were analyzed at the ESL on the filtered, unacidified sample by IC using a Dionex Aquion (Thermo Fisher Scientific Inc.) utilizing suppressed conductivity detection. Dissolved organic carbon was analyzed at the ESL on the filtered, unacidified sample using the combustion-oxidation, infrared detection technique employed by the TOC-L (Shimadzu). Analysis of iodide and bromide was done at the ESL on the filtered, unacidified sample by IC using a Dionex Aquion (Thermo Fisher Scientific Inc.). Bromide used suppressed conductivity detection and iodide used ultraviolet (UV) detection. Analysis of iodide, PFB, and DFB was done on the filtered, unacidified sample by high-performance liquid chromatography using a Thermo Fisher Ultimate 3000 with UV detection.

4.1.4 Down Well Instruments

A select set of wells in each well gallery had down well electrical conductivity probes (CS547A-L, Campbell Scientific, Inc.) measuring specific conductance and temperature in the wells every hour. Some of these probes remained in the selected well between the 2020 and 2021 tracer testing. Probes were set about 6 inches below mid-screen in the wells. All resulting data are provided in Appendix G.

Water levels on all gallery wells and some surrounding wells were collected frequently using a Heron Skinny Dipper (Heron Instruments Inc.). All resulting data are provided in Appendix H in the file "Static Water Levels During Tracer Testing.xlsx." In addition, Riverton site monitoring includes continuous transducer measurements in some wells. Transducer data in nearby wells (wells 0101, 0710, 0722R, and 0724 near the FTA and 0707, 0789, 0855, and 0856 for the SSMA) for 2020 and 2021 are included in Appendix H. These transducers are non-vented and, as such, are subject to variations due to barometric pressure changes. Locations for all monitoring wells are provided in Figure 2.

4.2 Geochemical Modeling

Geochemical modeling was completed for the evaluation of mineral saturation indexes (SIs) using PHREEQC (Parkhurst and Appelo 2013) and the minteq.v4.dat database (provided with software download). An SI near zero indicates that a specified mineral is near equilibrium with the mineral dissolution products in solution. An SI greater than 0 indicates the possibility of mineral precipitation (referred to as supersaturation) and an SI less than 0 indicates that mineral dissolution is a possibility (referred to as undersaturation), if that mineral is present. Given data from multiple laboratories and with sample rerun data (Appendix F), PHREEQC was run on the different datasets independently to allow for SI comparisons from multiple datasets. PHREEQC input files are provided in Appendix I, and the SI output has been copied into the associated data files (Appendix I). If any of these PHREEQC files are run on another computer, the system path to the minteq.v4.dat database may need to be reset. Redox conditions in the PHREEQC SI calculations used the ORP measurement with 200 millivolts added to adjust for the standard hydrogen reference electrode for conversion to pE (log of the electron activity). The PHREEQC files were created with ferrous iron (Fe^{2+}) and ferric ion (Fe^{3+}) columns to allow for the use of the iron pairs to calculate redox conditions in any future analyses.

5.0 Results

Appendixes B through D have information collected before the main tracer work and are not discussed further.

Appendix E has the detailed tracer injection flow rate as Table 1 only has the overall average flow rates. Appendix F has the main geochemistry data files. Some analytes from the same samples were analyzed at multiple laboratories, which are indicated in multiple data columns in Appendix F. Additional sample reruns are also provided in separate data columns in Appendix F. Results were generally comparable within about 10% between laboratories, with the major exception being low calcium concentrations for some analyses at the ESL due to strontium interference on the ICP-MS. An interference adjustment was applied to all ESL calcium data. That compensation worked well for 2021 ESL calcium data, but 2020 ESL calcium concentrations are consistently lower than the LANL calcium concentrations. Appendixes G and H have the specific conductance probes and water level data, respectively. All these data will be useful for future modeling efforts, but only the geochemistry data are discussed in detail in this report.

Appendix I has all the geochemical modeling SI results, with copies of the input data organized for easy input into PHREEQC. The iodide and bromide columns in the PHREEQC input data Excel files are highlighted in yellow, as some of the detection limit data were adjusted in the final master geochemistry data files (Appendix F). PHREEQC was not rerun with any iodide and bromide detection limit updates since they are not part of any mineral reactions. Additional spreadsheet tabs and PHREEQC files are provided for analyzing LANL versus ESL data along with separate rerun files and tabs.

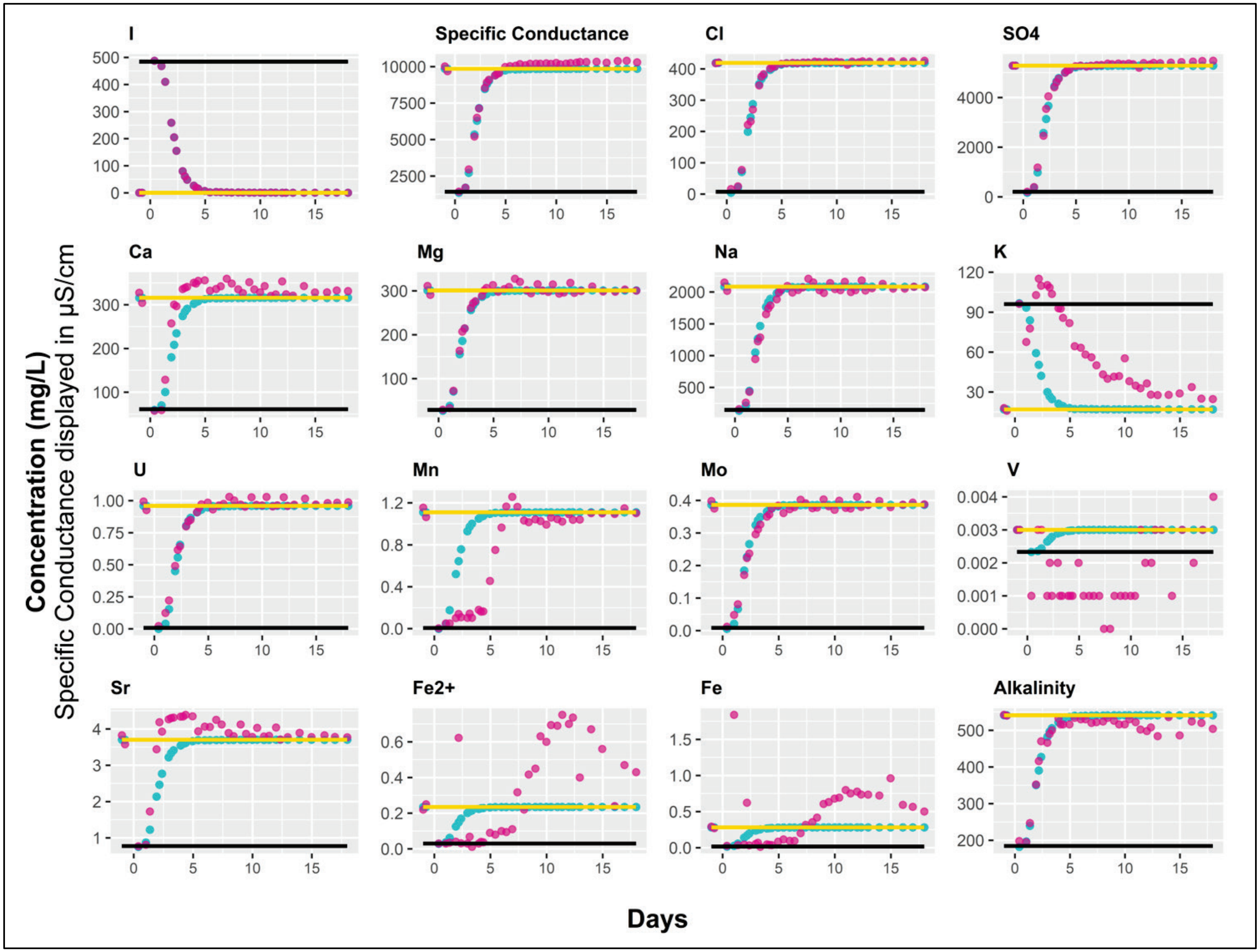
The PHREEQC formatted files in Appendix I were used to create the graphical results presented in Appendix J. Appendix J has plots of all the geochemistry data along with SIs for selected minerals at all wells. The graphs in Appendix J generally use the ESL data. For comparison, additional graphs using the LANL data are provided only for selected wells in Appendix J. Concentration trends are the same, regardless of the laboratory used for analyses. The main difference is slightly lower calcium values for the ESL compared to LANL for 2020 data, as discussed above. For Appendix J, results were plotted using scripts based on the R programming language. The injected tracers, iodide and bromide, are considered nonreactive; thus, equation 1 provided in Paradis et al. (2020) was used to calculate expected concentrations of the measured analytes. This expected concentration scales each analyte to a concentration based on the tracer data, which assumes no reactions. The R scripts used to create the graphs in Appendix J are available upon request.

The graphical results in Appendix J are organized as follows: (1) analytical results with measured and expected concentrations for all detected constituents except silicon (minimal trends and not always measured); (2) selected mineral saturation indices; (3) measured and expected concentrations for pH, pE, and DO; (4) analytical results with measured concentrations consistently compared to iodide concentrations for all detected constituents (except silicon); and (5) measured concentrations consistently compared to iodide concentrations for pH, pE, and DO. All Appendix J graphs show the two or three pretest samples; thus, time zero is the start of any injection or infiltration. If later samples were collected after the end of each tracer testing period, items 4 and 5 are repeated with a longer time scale on the x-axis. On selected wells, the graphical results for item 1 from Appendix J are shown in Sections 5.1 through 5.5, which all have a common legend (Figure 5) that is not repeated for the subsequent figures. In Appendix J, all items (originally separate R output files) for each well have been inserted into one file for each tracer test. Plotting in Appendix J was not done for any rerun data and was only done for LANL data on select wells.

Figure 5. Common Legend for All Figures in Section 5.0

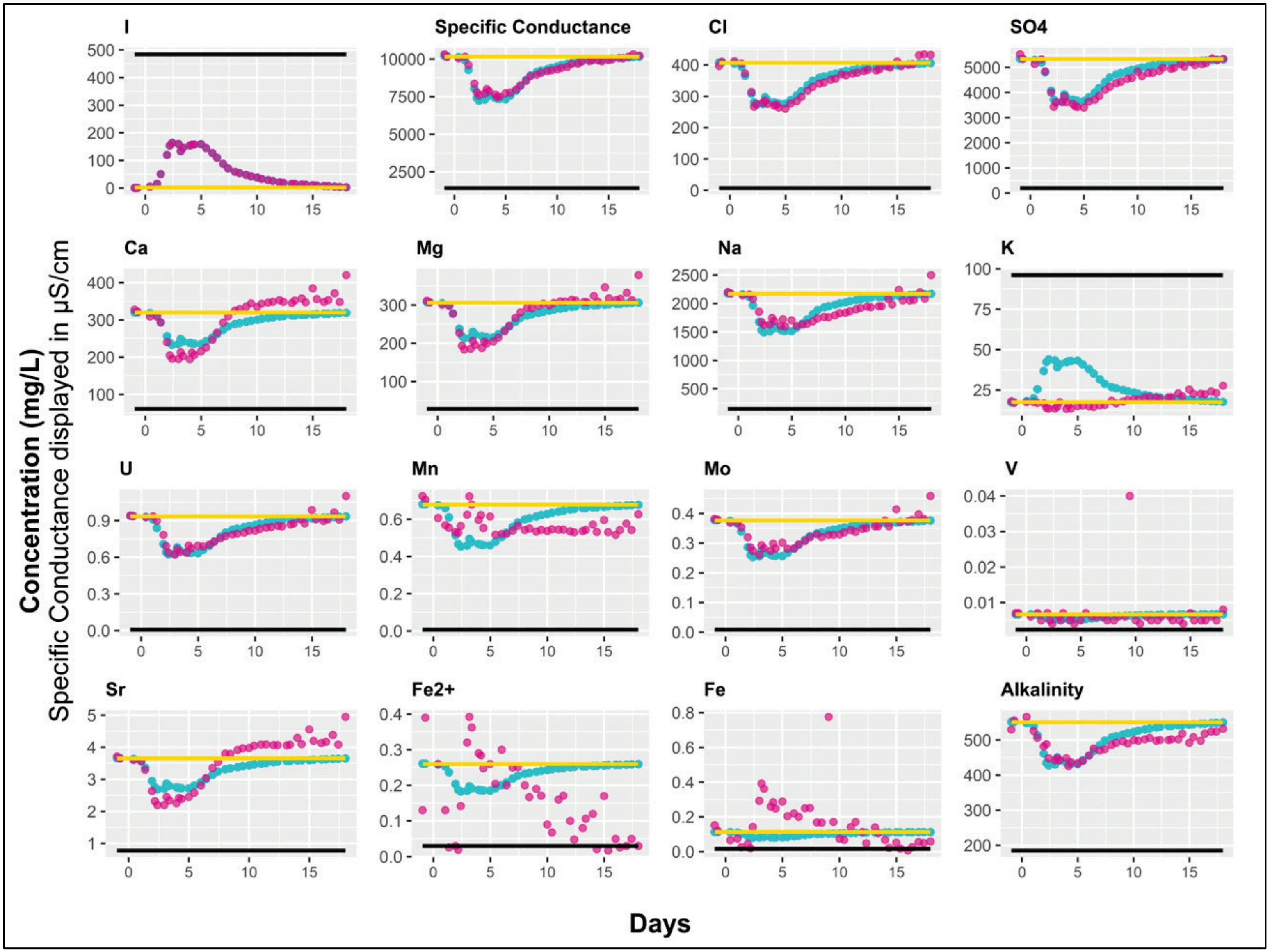
5.1 2020 SSMA Saturated Zone Injection with Well Gallery

The first 2020 SSMA tracer test was an injection in well 1001 (Figure 4 and Table 1) to test whether reactions occur on the saturated zone sediments in this area after the injection of river water. Analyses of this test have been published in Paradis et al. (2022). Based on tracer concentrations (Appendix F), the in-line groundwater flow direction was from well 1001 to 1005 to well 1011 (one well off-center). Results from those wells are shown below in Figure 6, Figure 7, and Figure 8, respectively. Results from all other wells are provided in Appendix J with files labeled as injection 1.



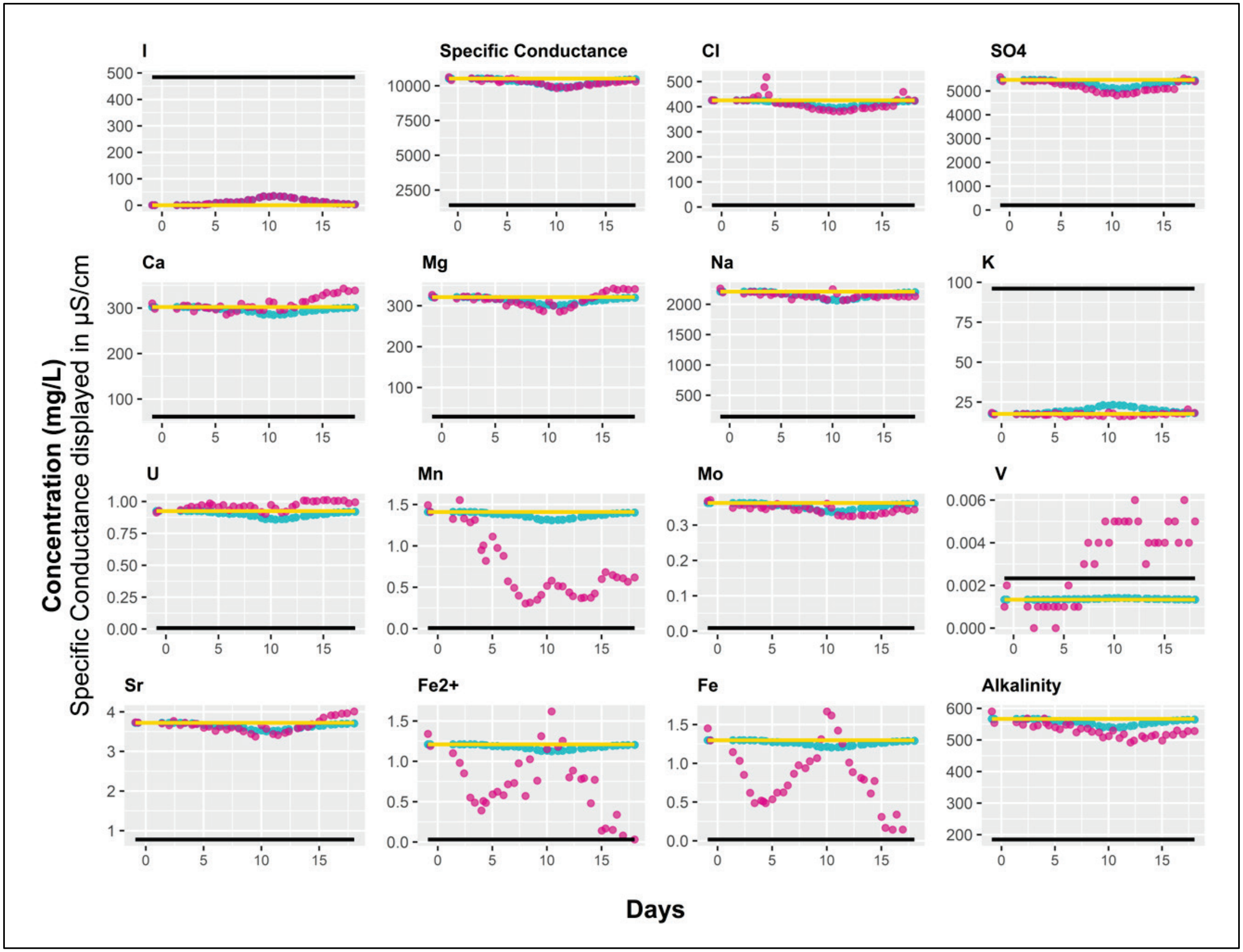
Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium, V = vanadium

Figure 6. Data from Well 1001 for 2020 SSMA Saturated Zone (Injection 1)



Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum,Na = sodium, SO_4 = sulfate, U = uranium, V = vanadium

Figure 7. Data from Well 1005 for 2020 SSMA Saturated Zone (Injection 1)

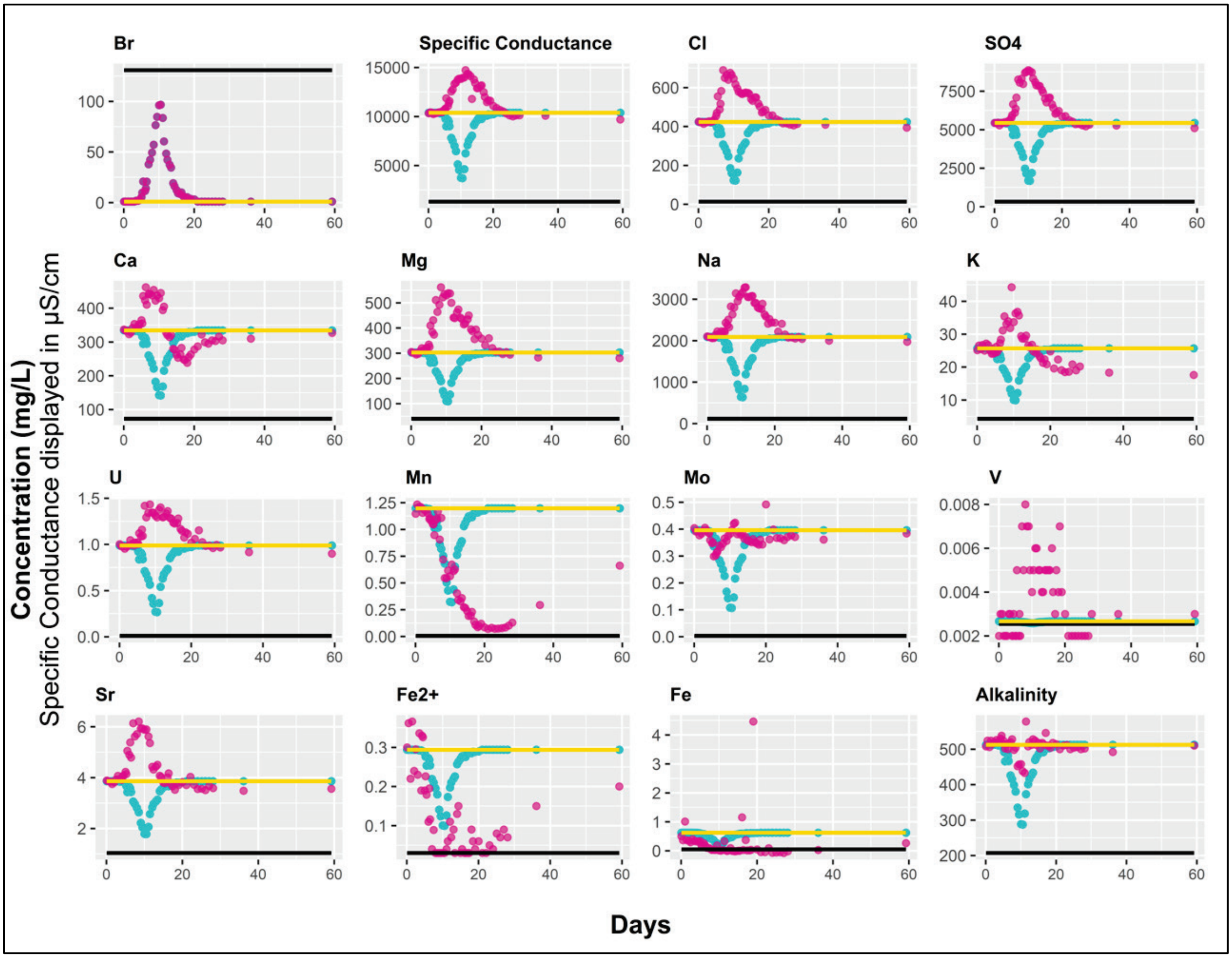


Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum,Na = sodium, SO_4 = sulfate, U = uranium, V = vanadium

Figure 8. Data from Well 1011 for 2020 SSMA Saturated Zone (Injection 1)

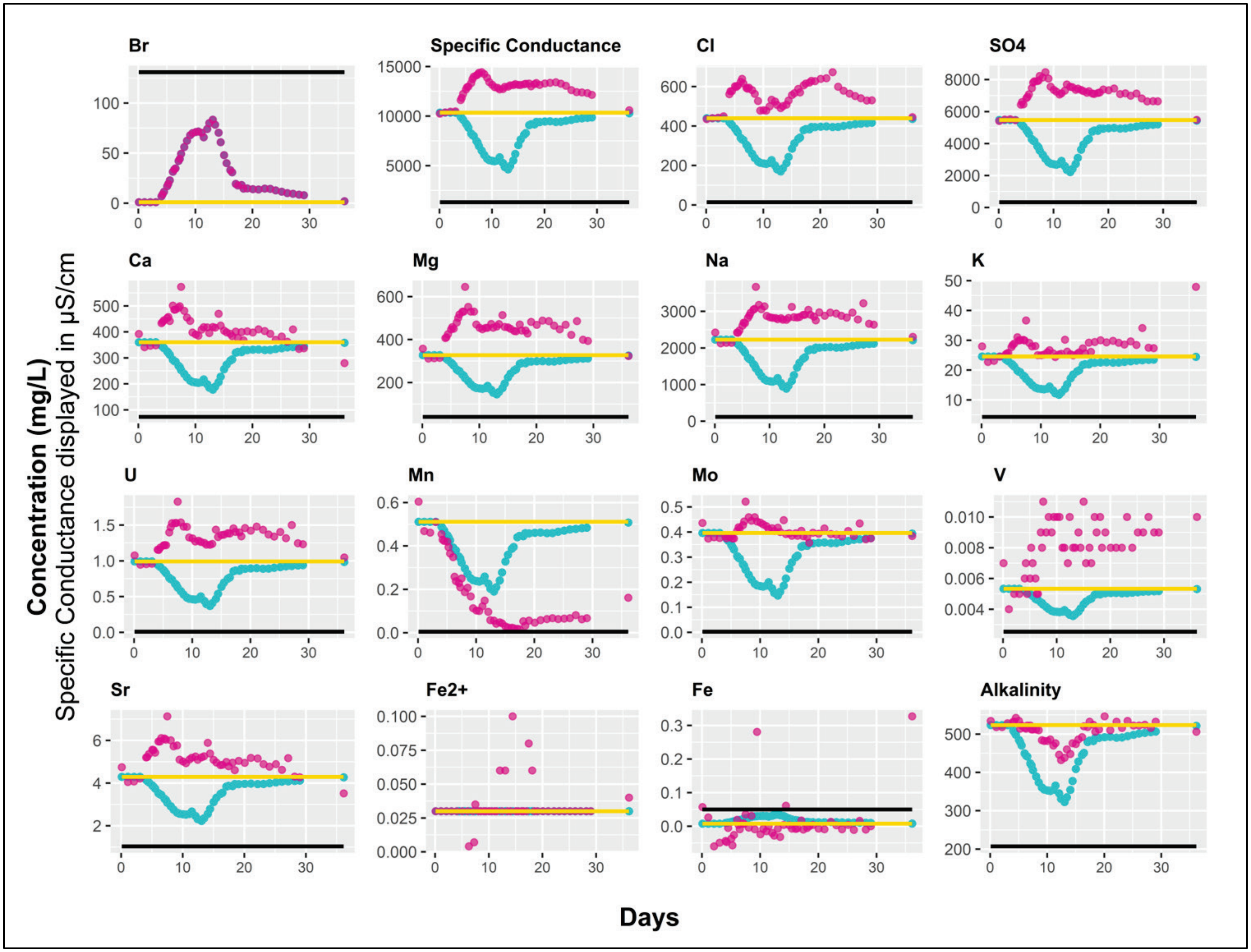
5.2 2020 SSMA Surface Infiltration without Added Sodium Bicarbonate

The second 2020 SSMA tracer test was surface infiltration of river water (Figure 4 and Table 1) to test whether reactions occur on the unsaturated zone sediments in this area. Based on tracer concentrations (Appendix F), the in-line groundwater flow direction was from well 1001 to 1005 to well 1011 (one well off-center). Results from those wells are shown below in Figure 9, Figure 10, and Figure 11, respectively. Results from all other wells are provided in Appendix J with files labeled as injection 2.



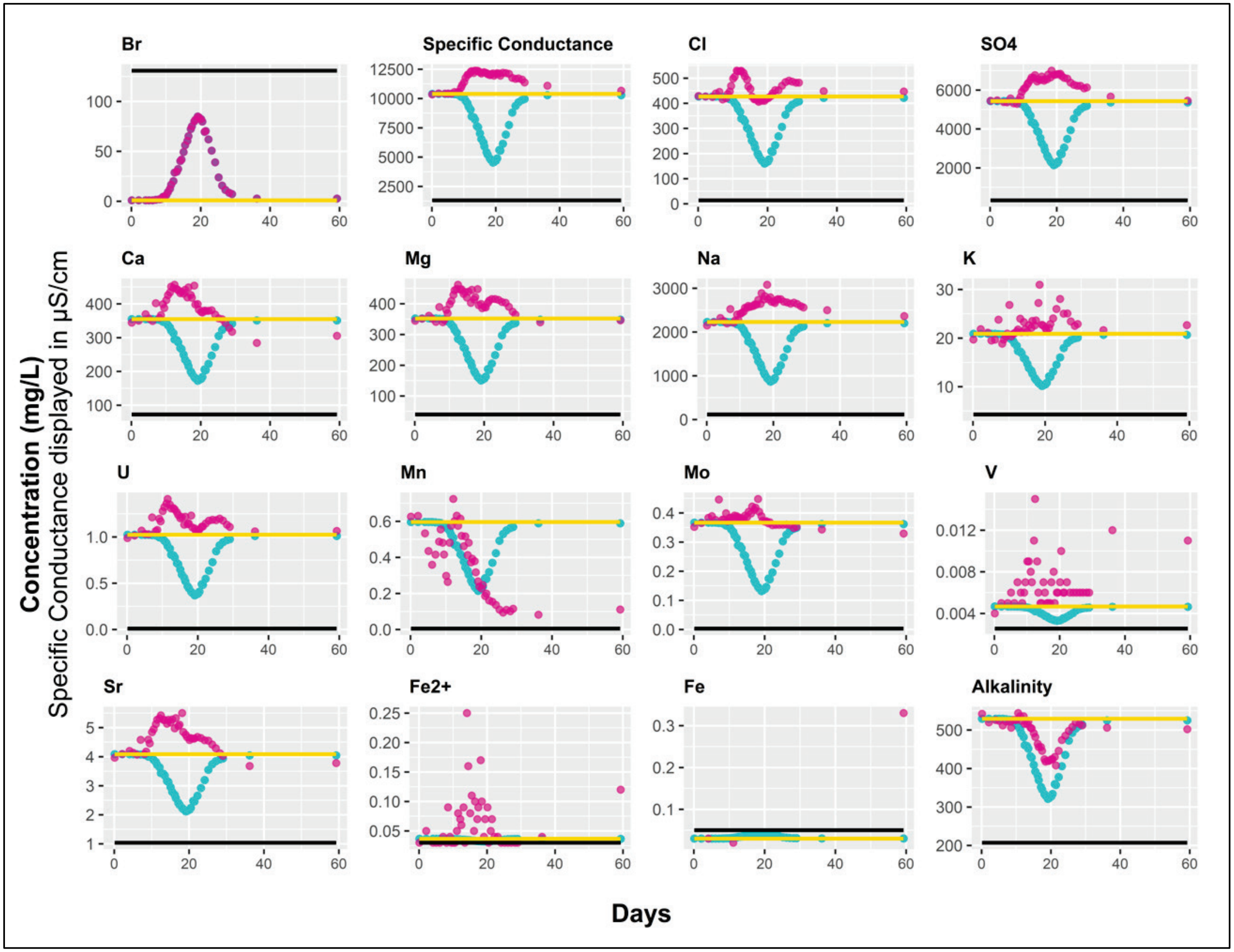
Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium, V = vanadium

Figure 9. Data from Well 1001 for 2020 SSMA Surface Infiltration (Injection 2)



Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum,Na = sodium, SO_4 = sulfate, U = uranium, V = vanadium

Figure 10. Data from Well 1005 for 2020 SSMA Surface Infiltration (Injection 2)



Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum,Na = sodium, SO_4 = sulfate, U = uranium, V = vanadium

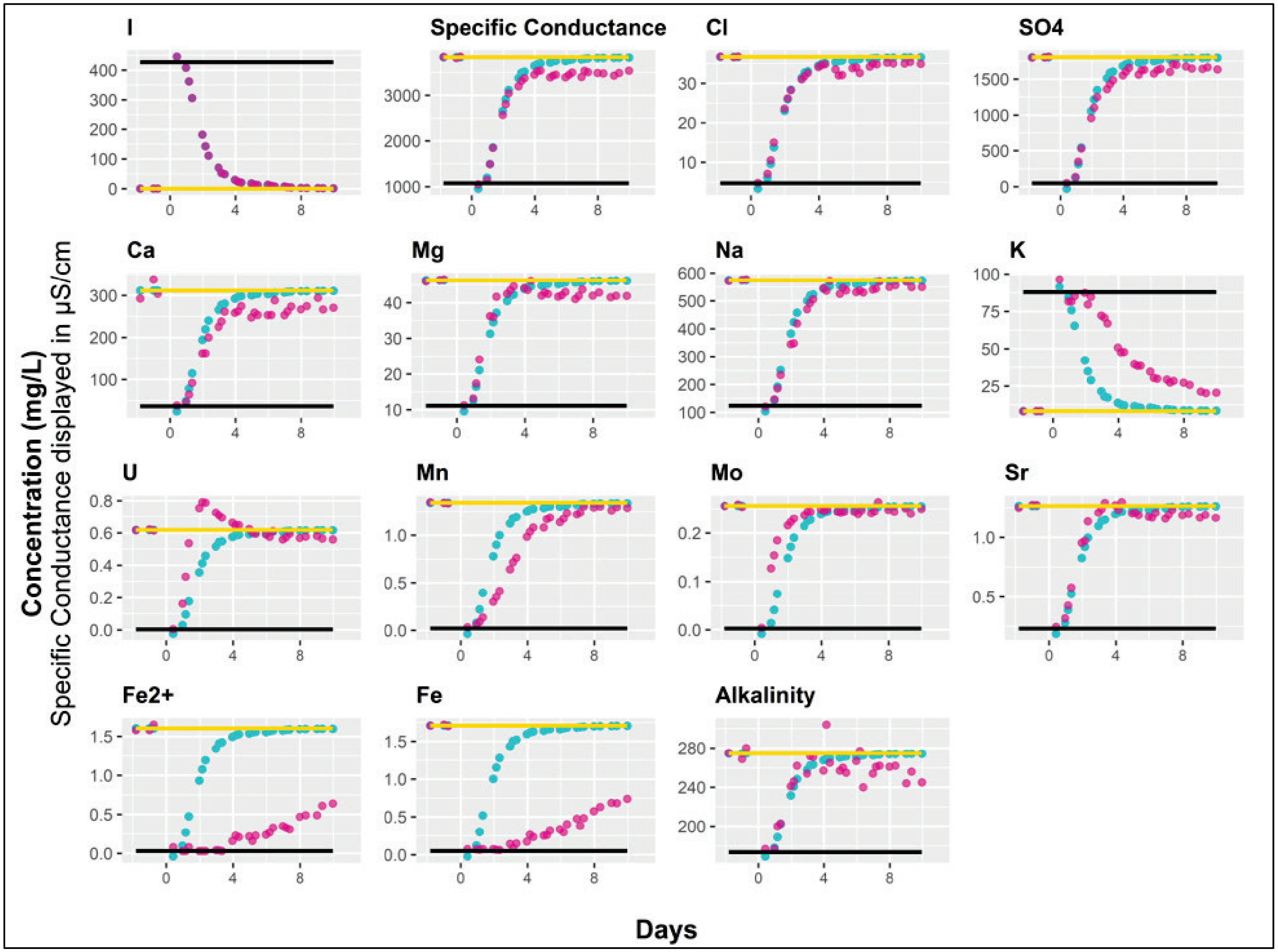
Figure 11. Data from Well 1011 for 2020 SSMA Surface Infiltration (Injection 2)

5.3 2020 FTA Saturated Zone Injections with Well Gallery

The 2020 FTA tracer testing was a series of saturated zone injections with two injections in well 1020 and one injection in well 1025 using background groundwater (Figure 3 and Table 1). These tests were completed using background groundwater from well 0710 with and without the addition of sodium bicarbonate (Table 1) to test water and rock reactions on the contaminated saturated zone sediments in this area. The injections in well 1020 were in series, first just background groundwater and then, with the addition of sodium bicarbonate. The injection in well 1025 was done directly with the addition of sodium bicarbonate to background groundwater. Based on tracer concentrations in the gallery wells (Appendix F), the in-line groundwater flow directions are not as straightforward as the 2020 SSMA gallery. Thus, the results from injection well 1020 and the two nearest downgradient wells (wells 1022 and 1023) are provided below in Figure 12, Figure 13, and Figure 14 for the first well 1020 injection (Section 5.3.1) and Figure 15, Figure 16, and Figure 17 for the second well 1020 injection with added sodium bicarbonate (Section 5.3.2). Results from all other wells are provided in Appendix J and are labeled as injection 1 and injection 2, respectively.

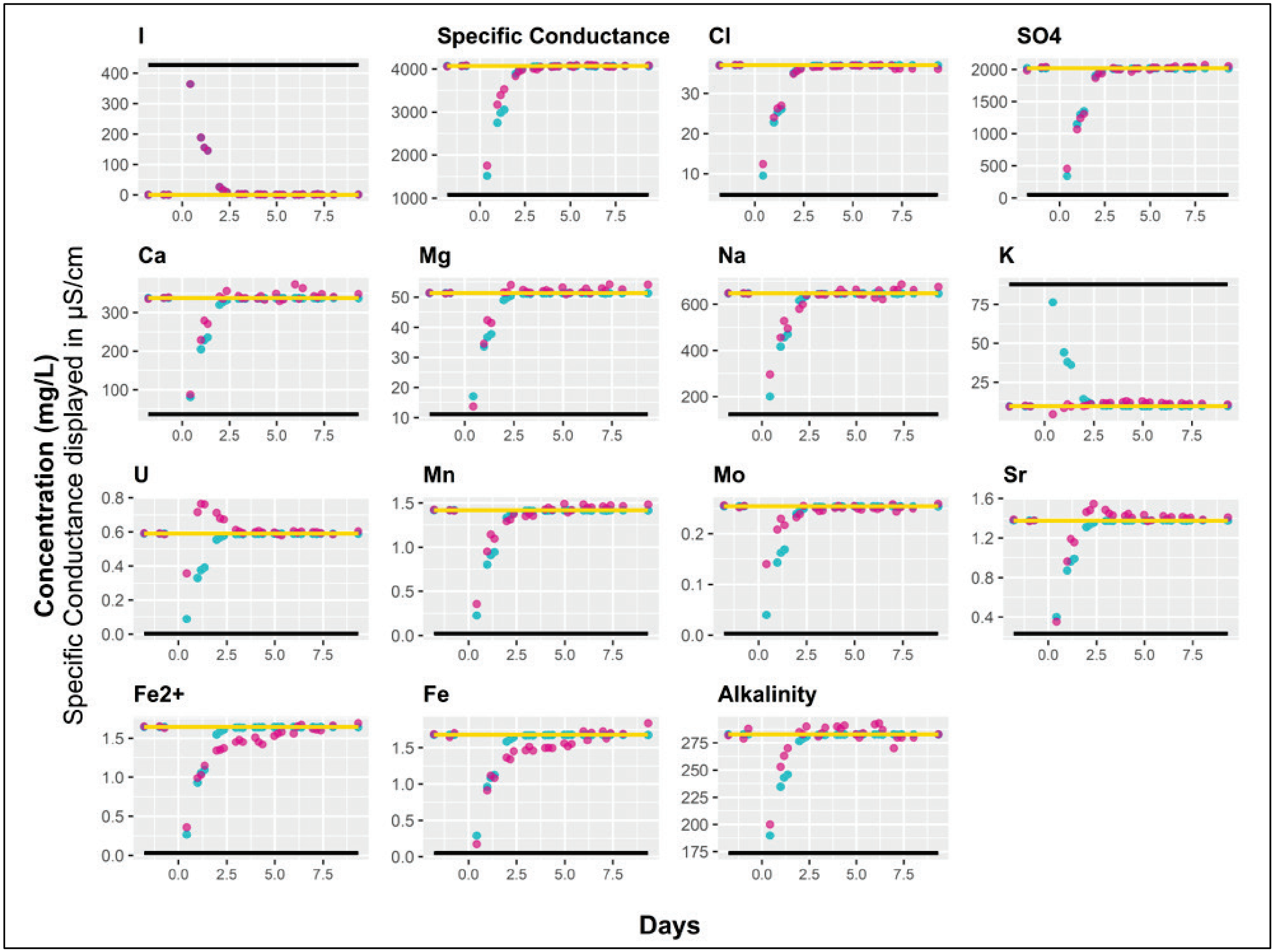
For the injection in well 1025, it appears likely that most of the injected tracer (Appendix F) went between the two well transects (wells 1025–1029 and 1030–1034, Figure 3). Thus, only well 1025 data are shown in Figure 18 (Section 5.3.3). Results from all other wells are provided in Appendix J and are labeled as injection 3.

5.3.1 Injection in Well 1020 With Background Groundwater Only



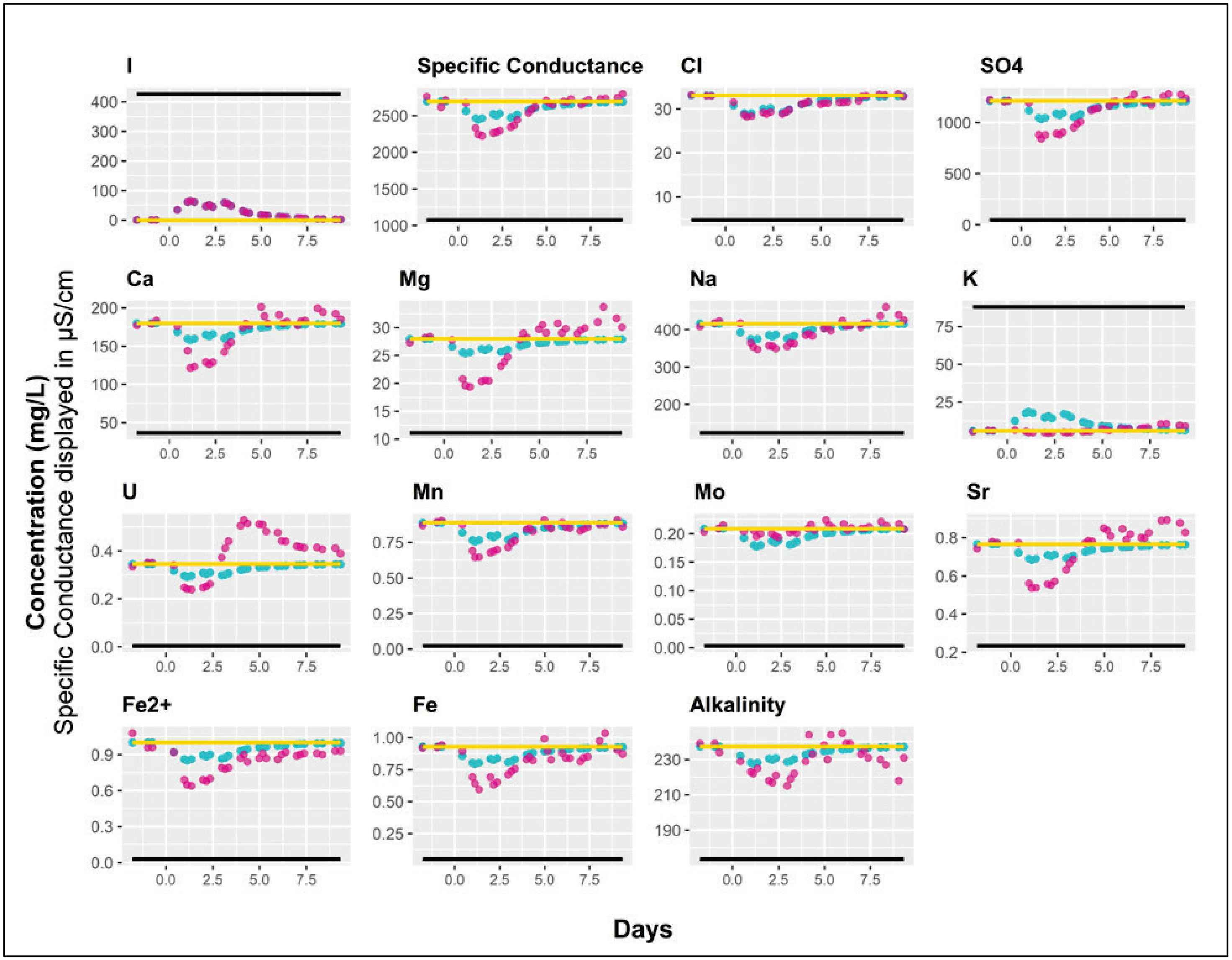
Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium

Figure 12. Data from Well 1020 for 2020 FTA (Injection 1)



Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum,Na = sodium, SO_4 = sulfate, U = uranium

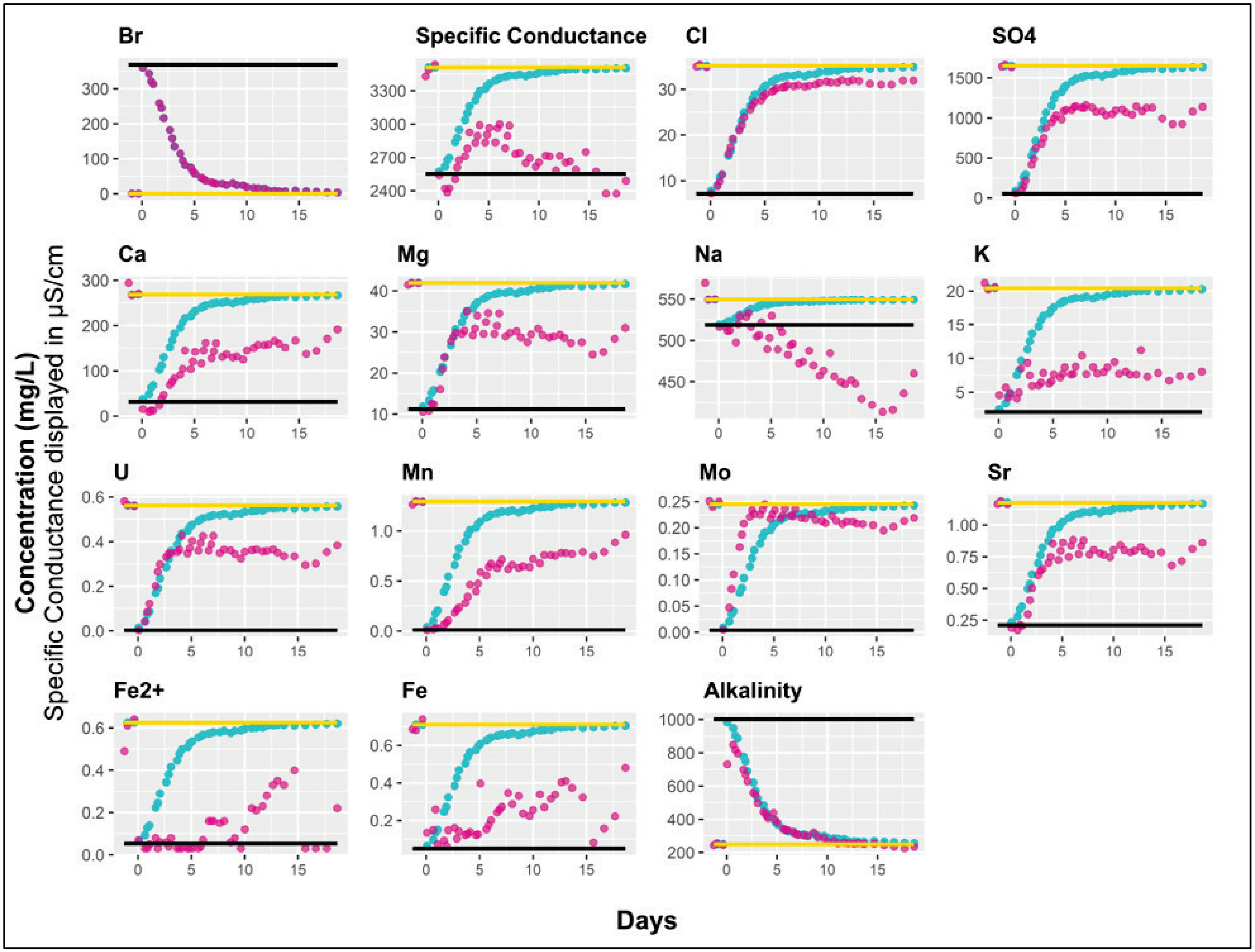
Figure 13. Data from Well 1022 for 2020 FTA (Injection 1)



Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium

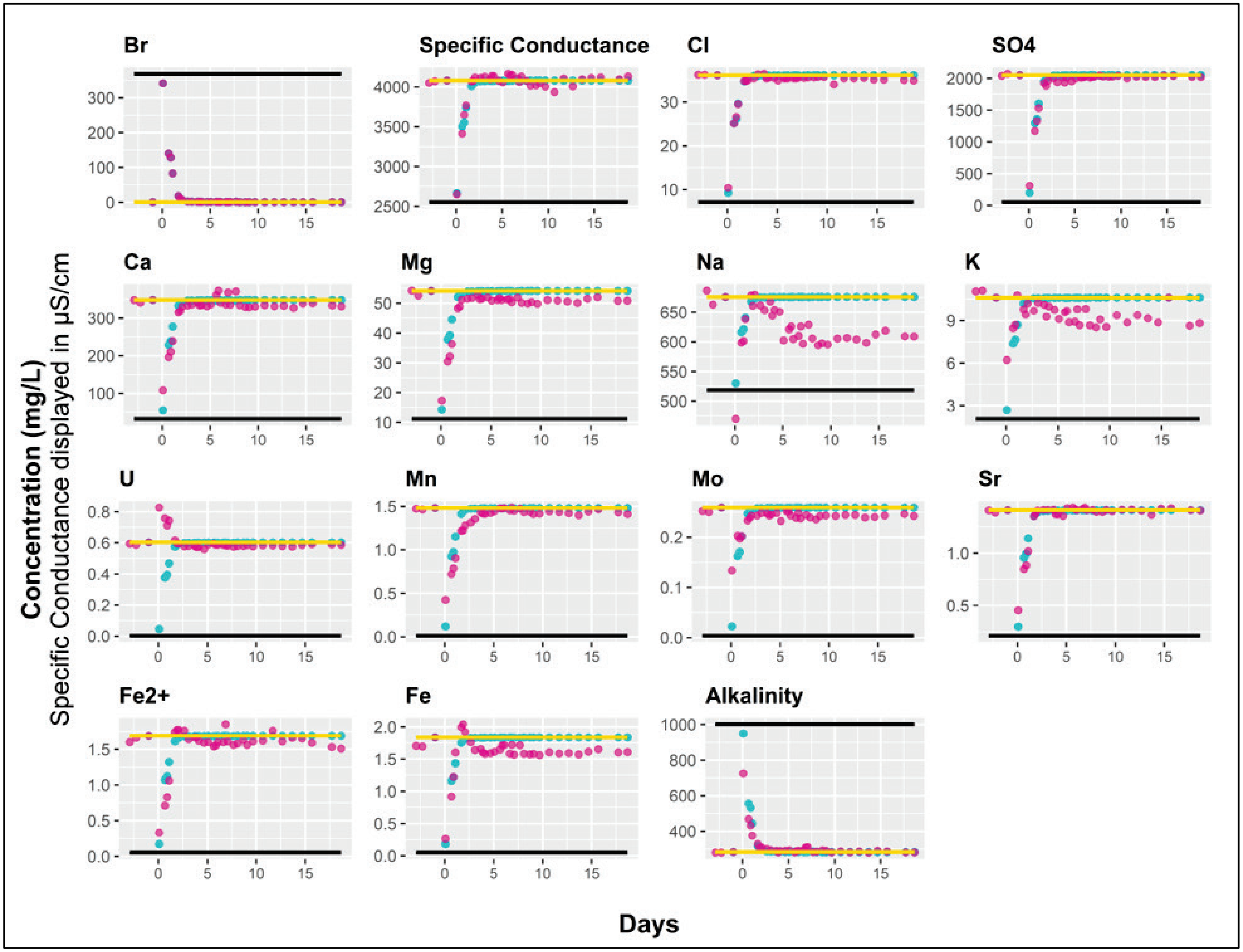
Figure 14. Data from Well 1023 for 2020 FTA (Injection 1)

5.3.2 Injection in Well 1020 With Background Groundwater and Added Sodium Bicarbonate



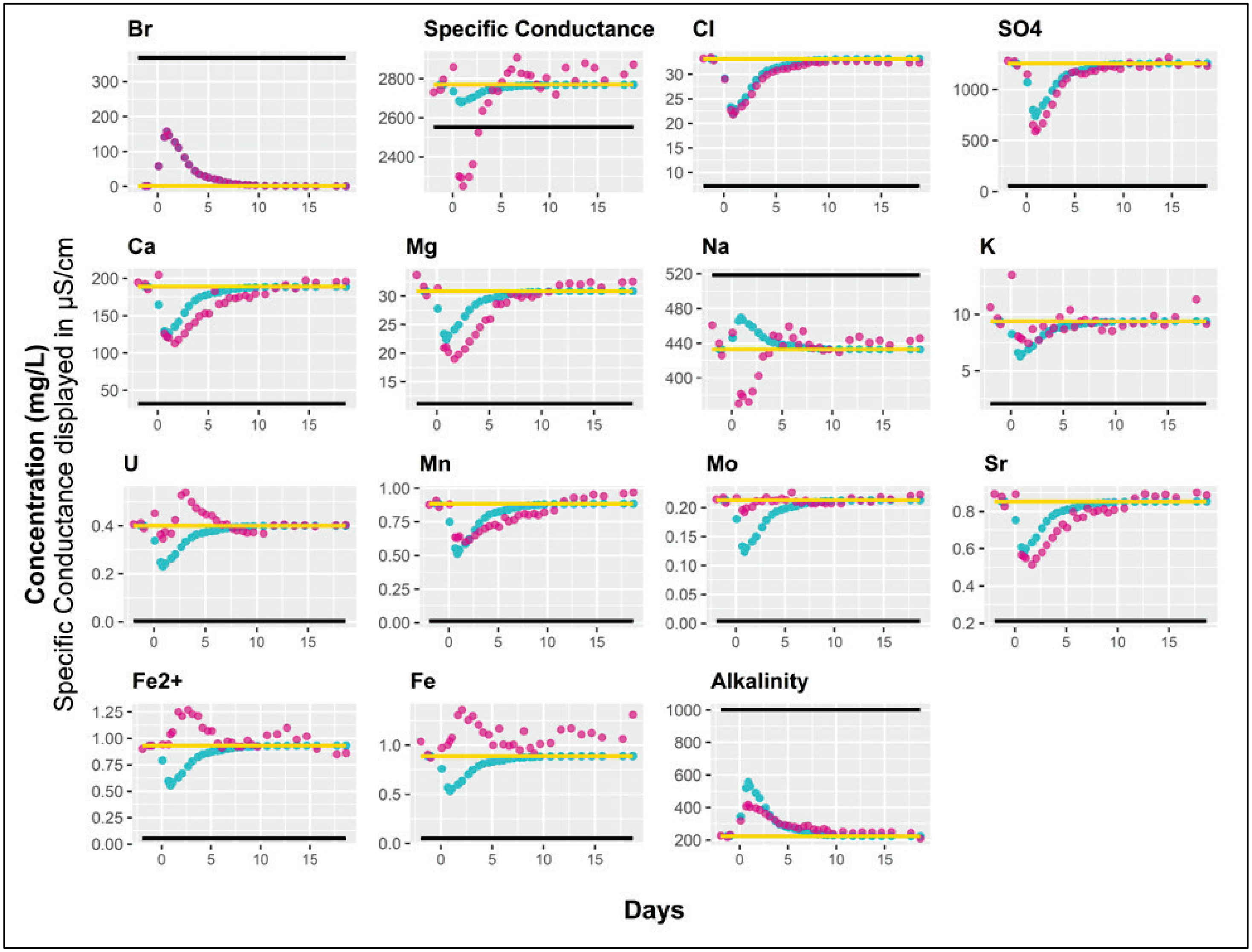
Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum,Na = sodium, SO_4 = sulfate, U = uranium

Figure 15. Data from Well 1020 for 2020 FTA (Injection 2)



Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum,Na = sodium, SO_4 = sulfate, U = uranium

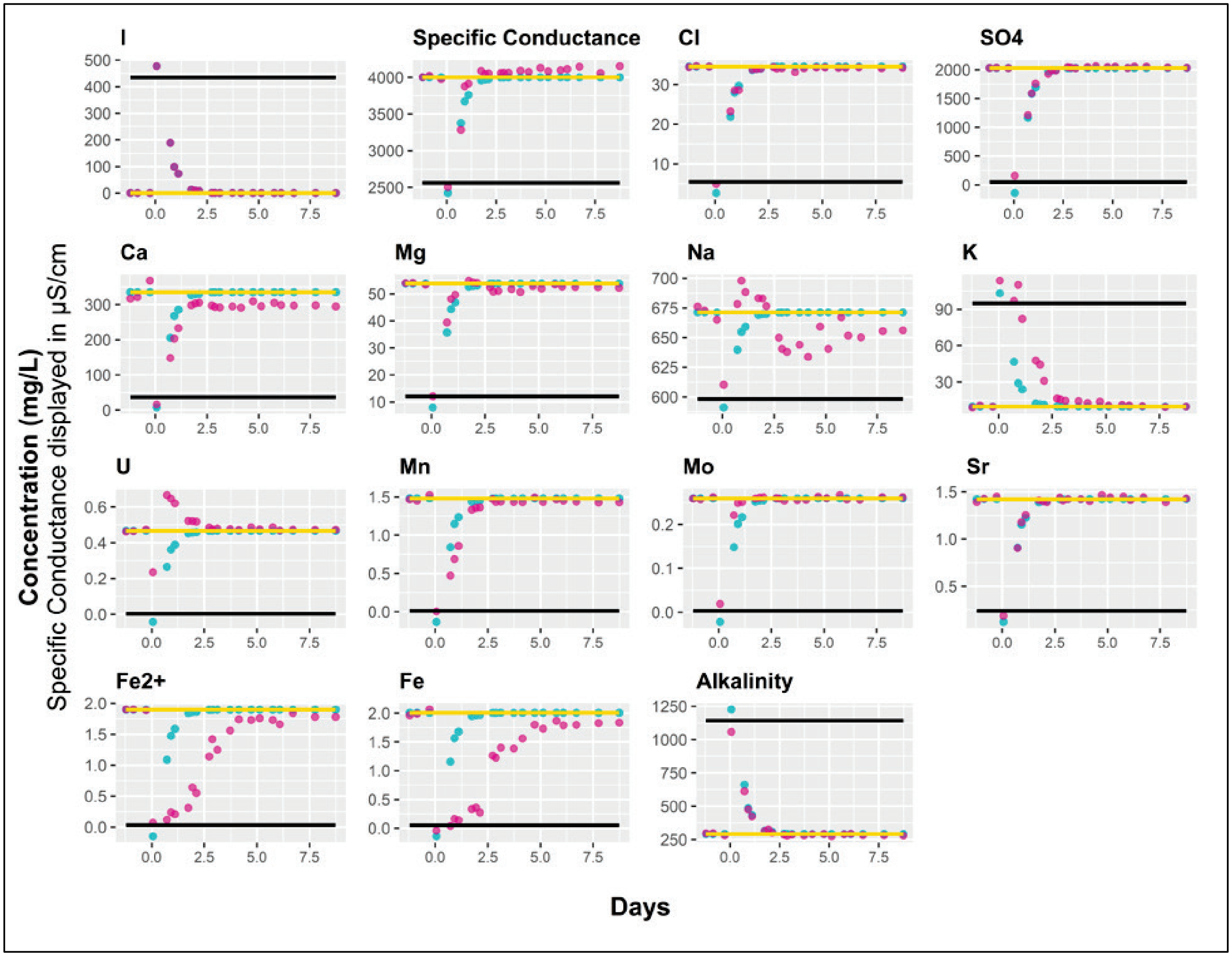
Figure 16. Data from Well 1022 for 2020 FTA (Injection 2)



Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum,Na = sodium, SO_4 = sulfate, U = uranium

Figure 17. Data from Well 1023 for 2020 FTA (Injection 2)

5.3.3 Injection in Well 1025 With Background Groundwater and Added Sodium Bicarbonate

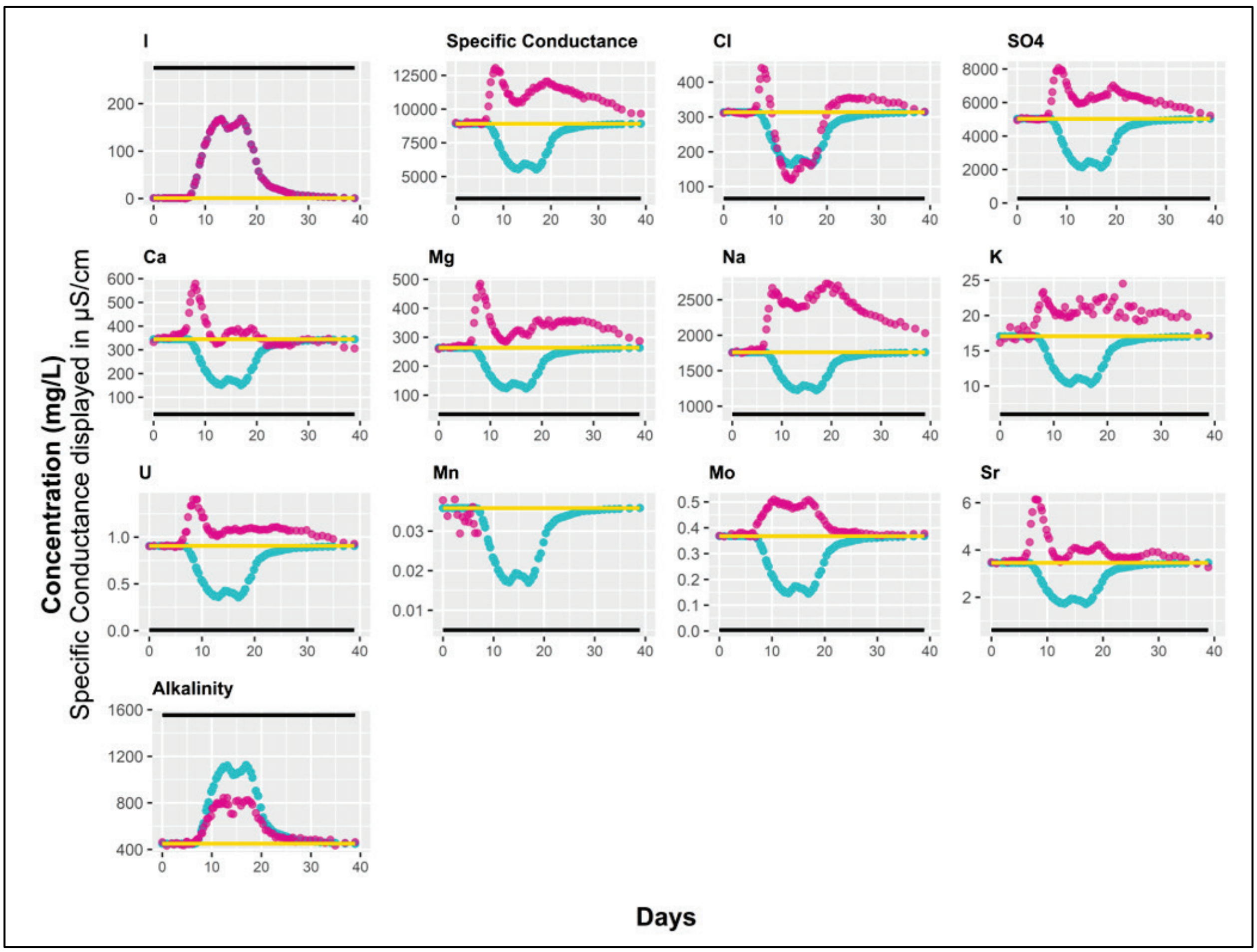


Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum,Na = sodium, SO_4 = sulfate, U = uranium

Figure 18. Data from Well 1025 for 2020 FTA (Injection 3)

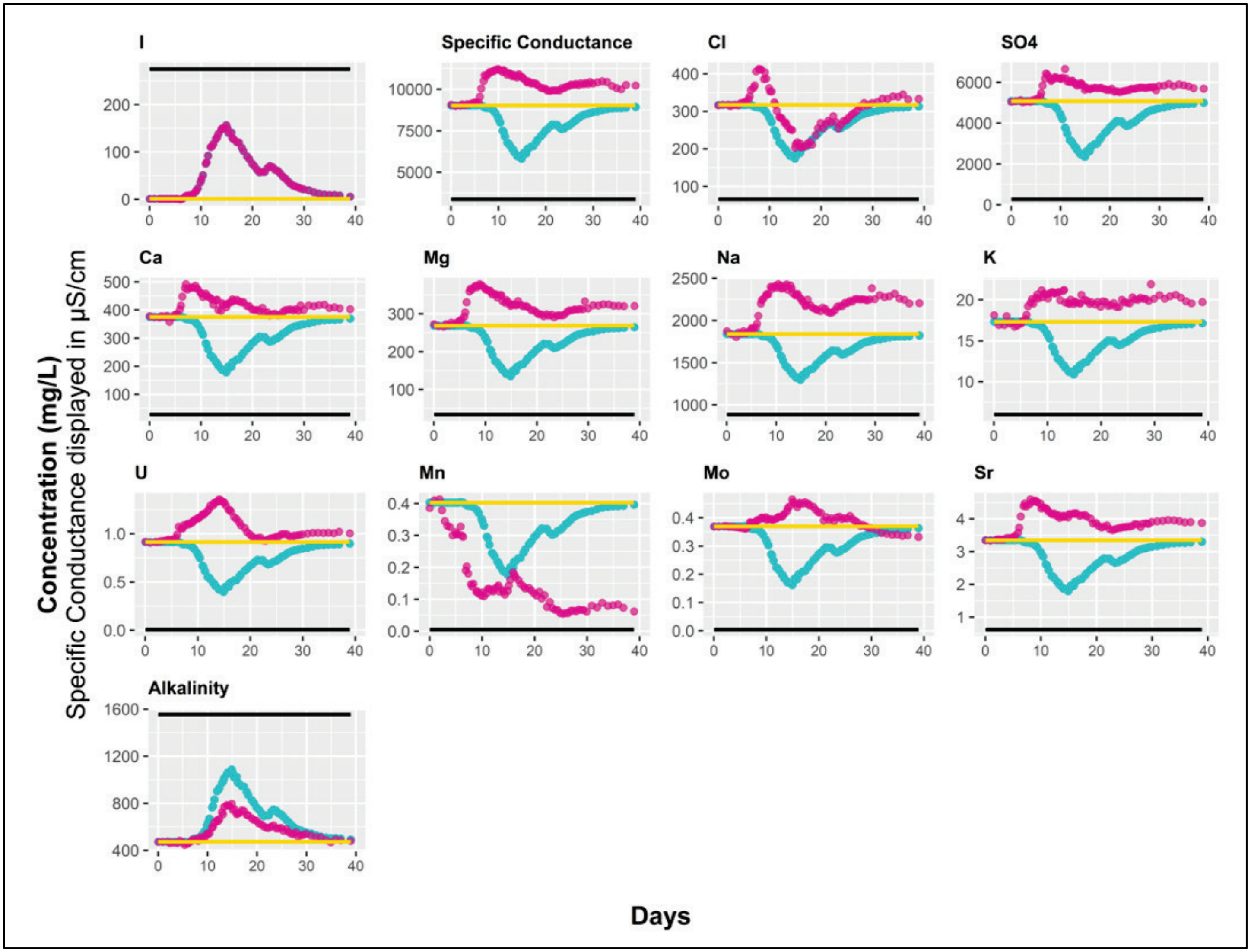
5.4 2021 SSMA Surface Infiltration with Added Sodium Bicarbonate

The 2020 SSMA tracer test with surface infiltration of river water was repeated in 2021 with the addition of sodium bicarbonate (Figure 4 and Table 1). The goal of this second tracer test was to see if added alkalinity would mobilize more uranium from the unsaturated zone sediments in this area. Based on tracer concentrations (Appendix F), the in-line groundwater flow direction was from well 1000 to 1005 to well 1010 (on the gallery center line, except for the first well). In the 2020 SSMA surface infiltration, the highest tracer concentration in the third well transect (Figure 4) was in well 1011. Results from wells 1000, 1005, and 1010 are shown below in Figure 19, Figure 20, and Figure 21, respectively. In addition, tracer from the 2021 SSMA surface infiltration was seen in downgradient well 0855. Of the three ports in 0855, the top saturated zone port (well 0855-2) did not show any tracer (Figure 22), and in the bottom two ports, tracer arrived earlier in well 0855-3 (Figure 23) than the deeper port 0855-4 (Figure 24). Similar results were seen in the 2020 SSMA surface infiltration testing (Appendix F and Appendix J) for well 0855, though fewer samples were taken that year, so only the 2021 results are shown here. Results from all other wells are provided in Appendix J.



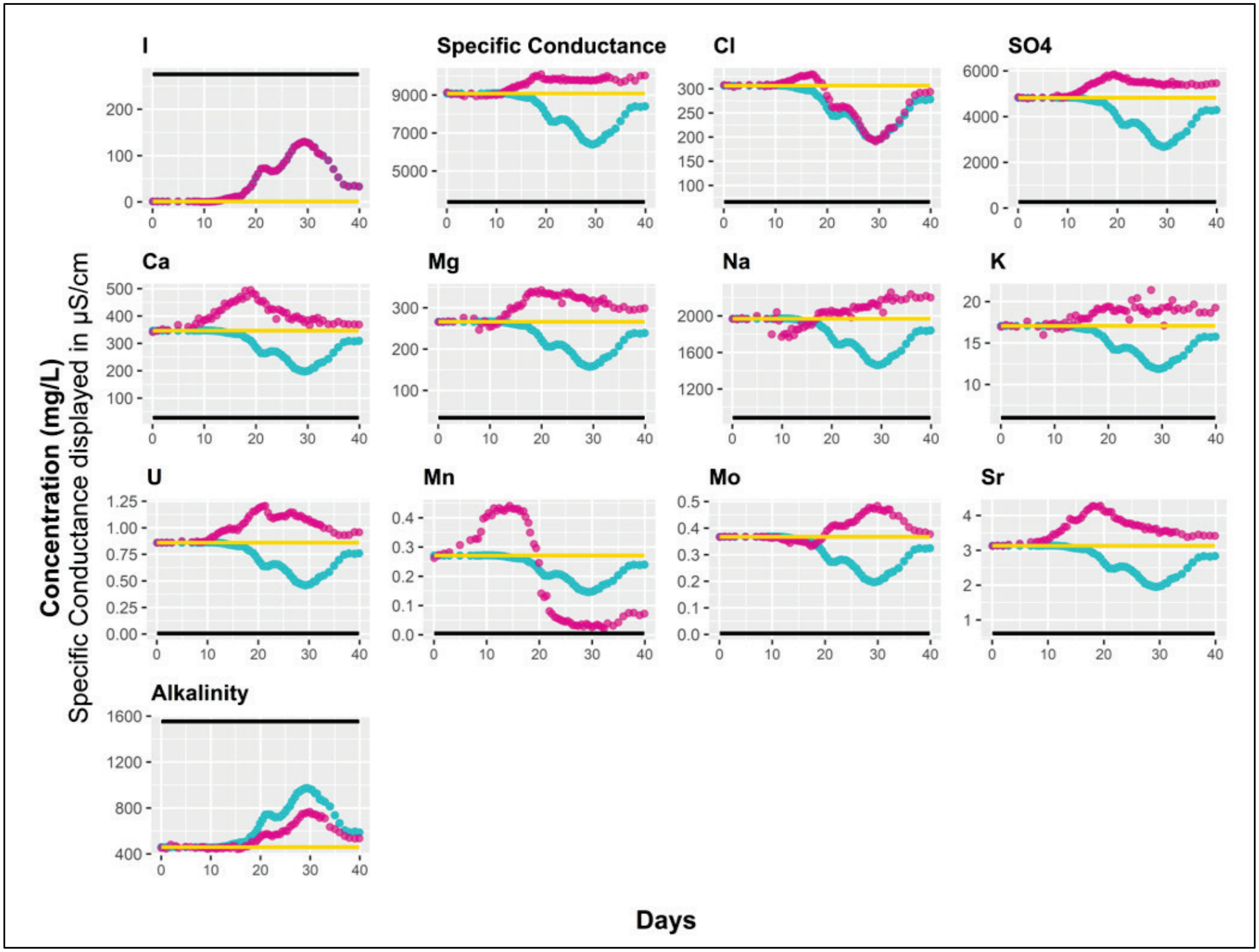
Abbreviations: Ca = calcium, Cl = chloride, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium

Figure 19. Data from Well 1000 for 2021 SSMA Surface Infiltration



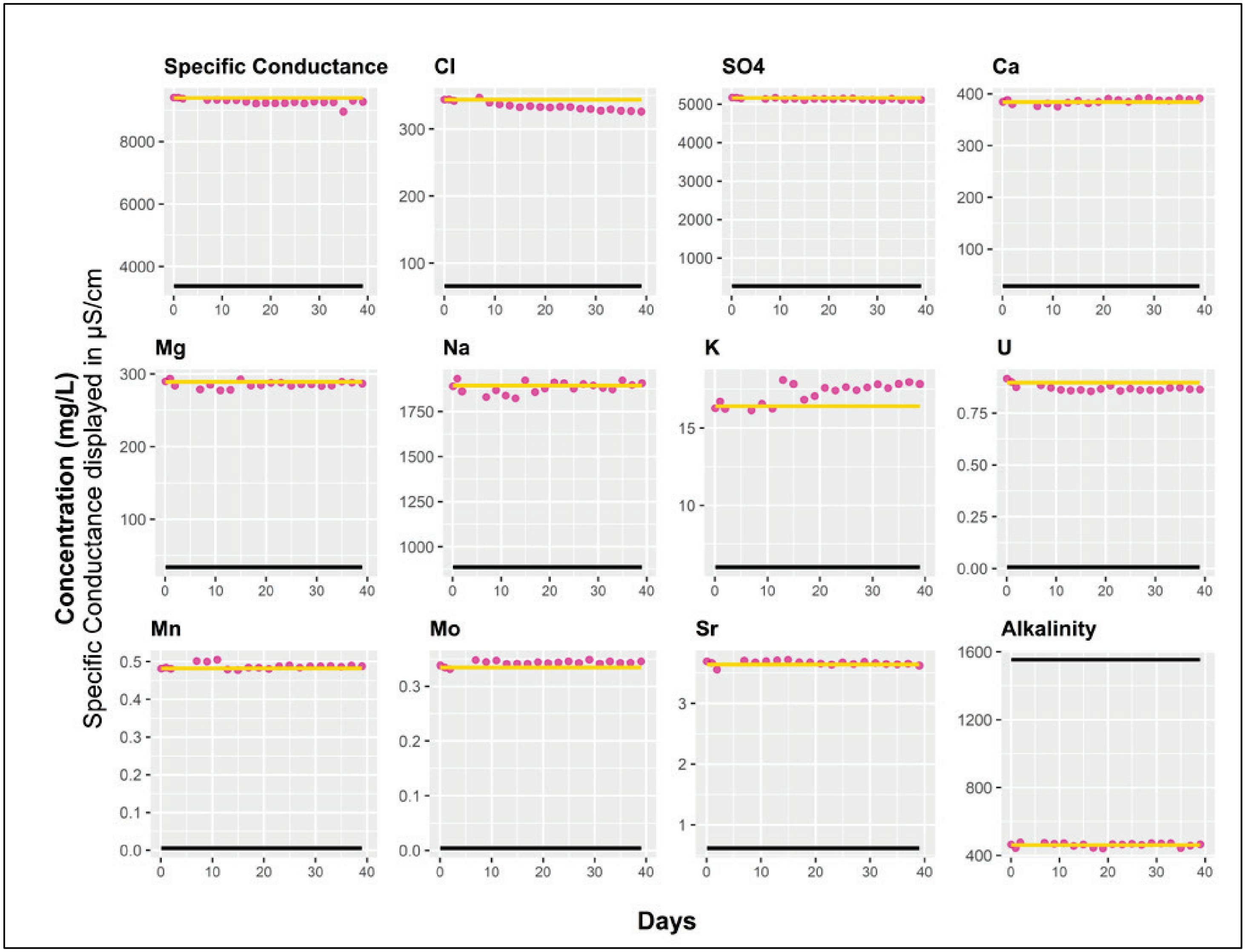
Abbreviations: Ca = calcium, Cl = chloride, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium

Figure 20. Data from Well 1005 for 2021 SSMA Surface Infiltration



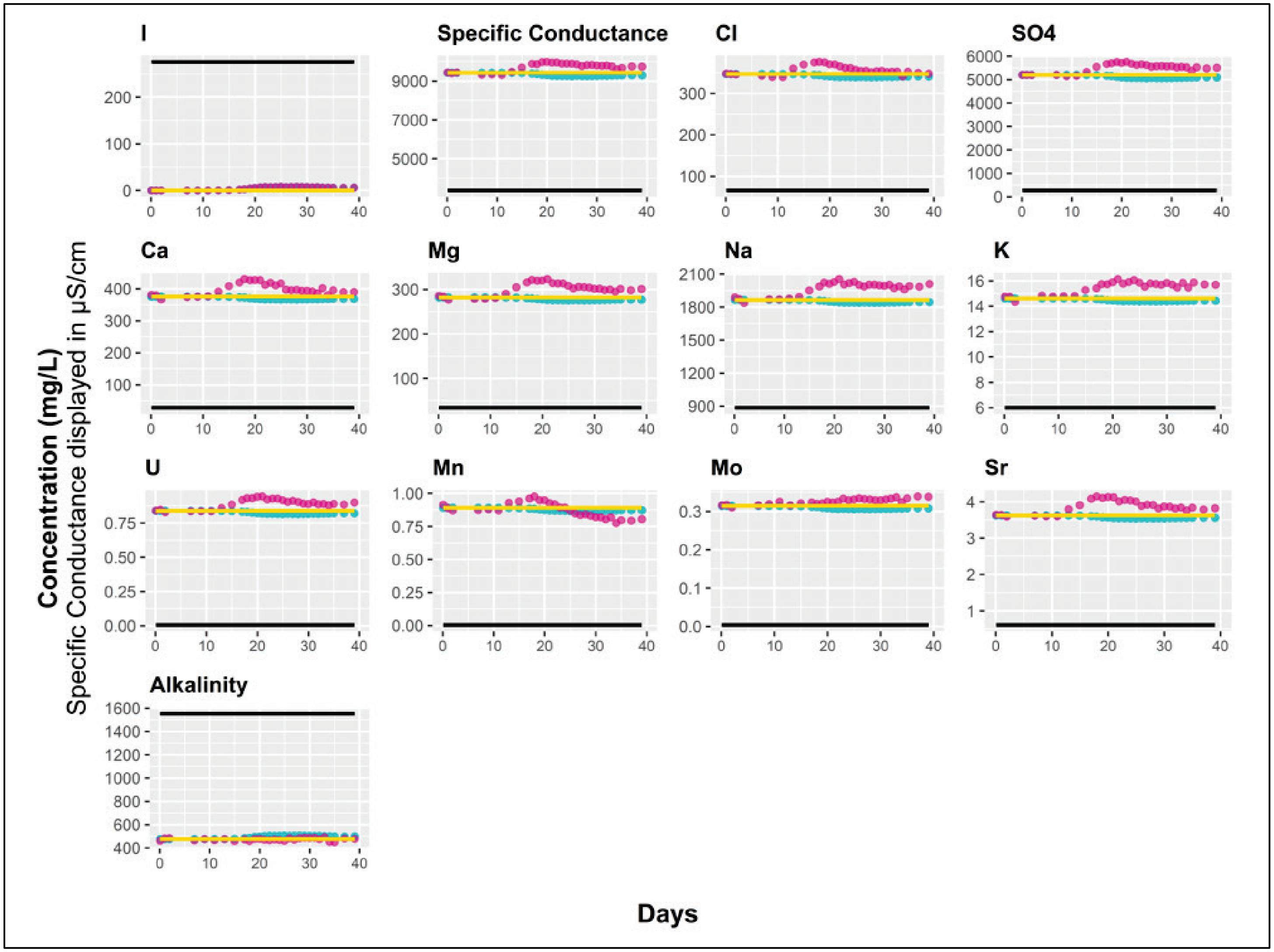
Abbreviations: Ca = calcium, Cl = chloride, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium

Figure 21. Data from Well 1010 for 2021 SSMA Surface Infiltration



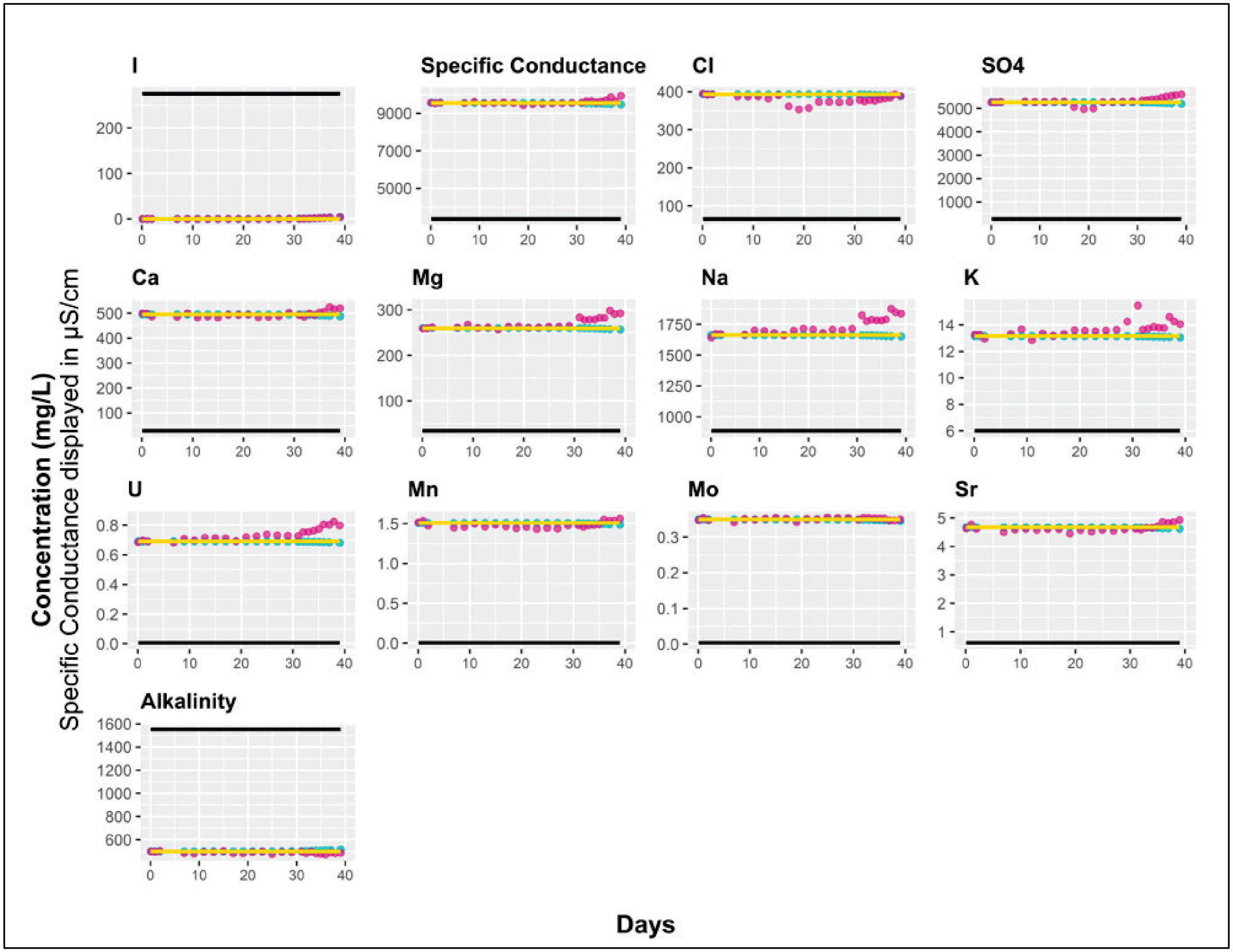
Abbreviations: Ca = calcium, Cl = chloride, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium

Figure 22. Data from Well 0855-2 for 2021 SSMA Surface Infiltration



Abbreviations: Ca = calcium, Cl = chloride, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium

Figure 23. Data from Well 0855-3 for 2021 SSMA Surface Infiltration

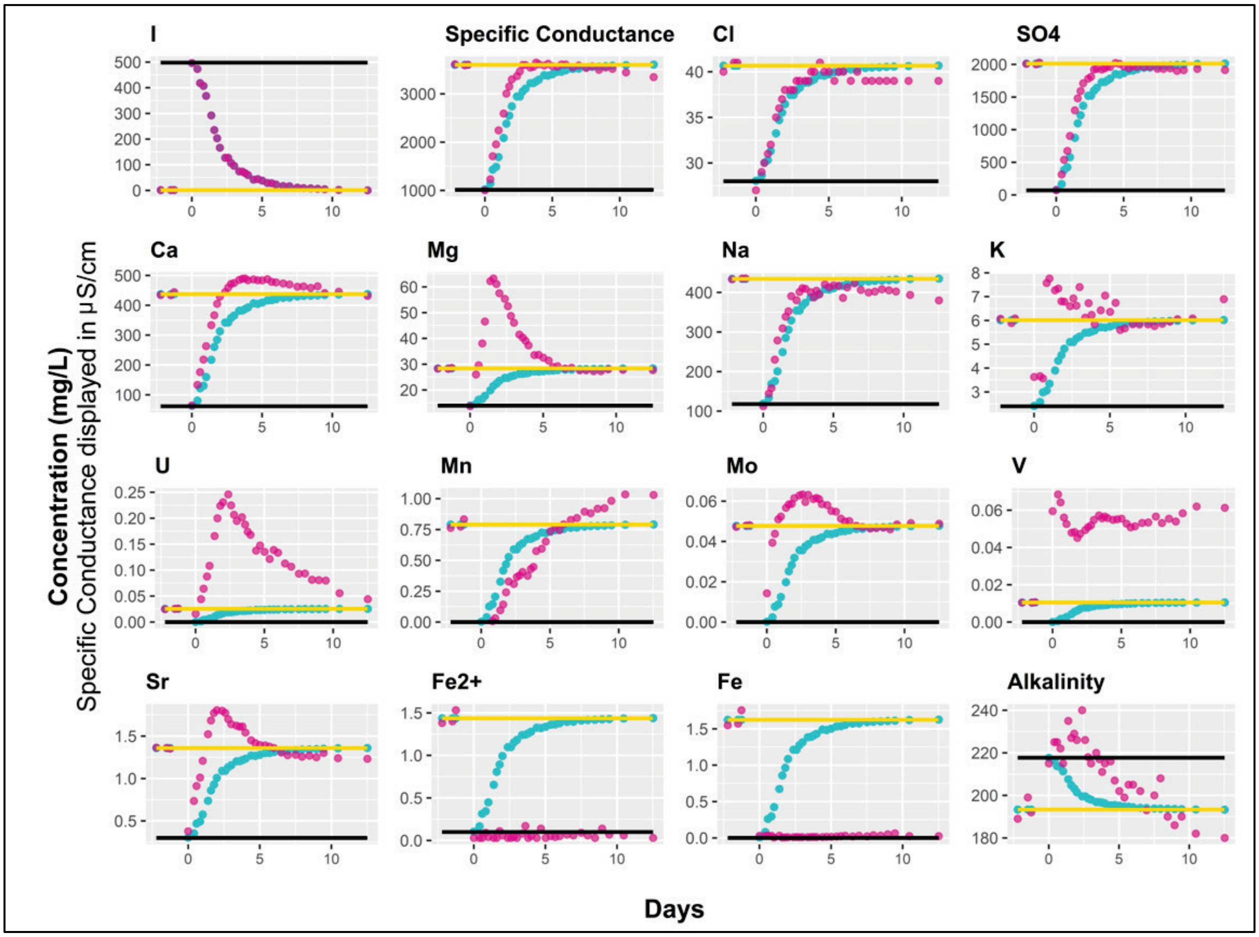


Abbreviations: Ca = calcium, Cl = chloride, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum,Na = sodium, SO_4 = sulfate, U = uranium

Figure 24. Data from Well 0855-4 for 2021 SSMA Surface Infiltration

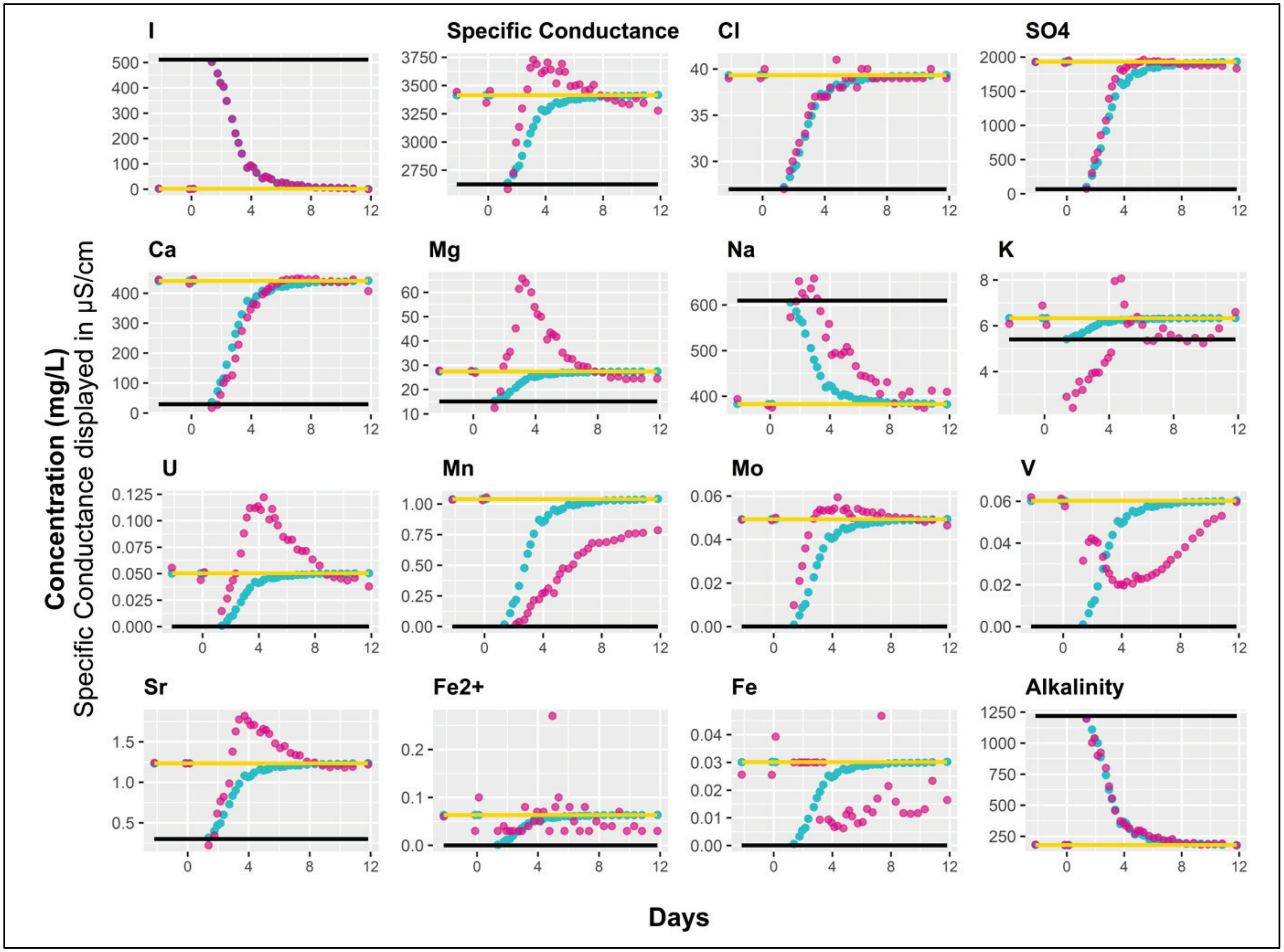
5.5 2021 FTA Saturated Zone Injections in Wells 0859 and 0860

Saturated zone tracer testing was completed again in the FTA in 2021 but not in the gallery area. These injections used background groundwater from well 0724, since well 0710, which was used in 2020, was not accessible (Figure 2). Two injections each were completed in wells 0859 and 0860 (Figure 3). The first injections were in wells 0859-3 and 0860-3 with background groundwater only, and the second injections were in wells 0859-3 and 0860-4 with background groundwater that had an addition of sodium bicarbonate. Results from these four tests for well 0859-3 without added alkalinity (well 0859 injection 1), well 0859-3 with added alkalinity (well 0859 injection 2), well 0860-3 without added alkalinity (well 0860 injection 1), and well 0860-4 with added alkalinity (well 0860 injection 2) are shown in Figure 25, Figure 26, Figure 27, and Figure 28, respectively. Results from the other ports in these wells are provided in Appendix J.



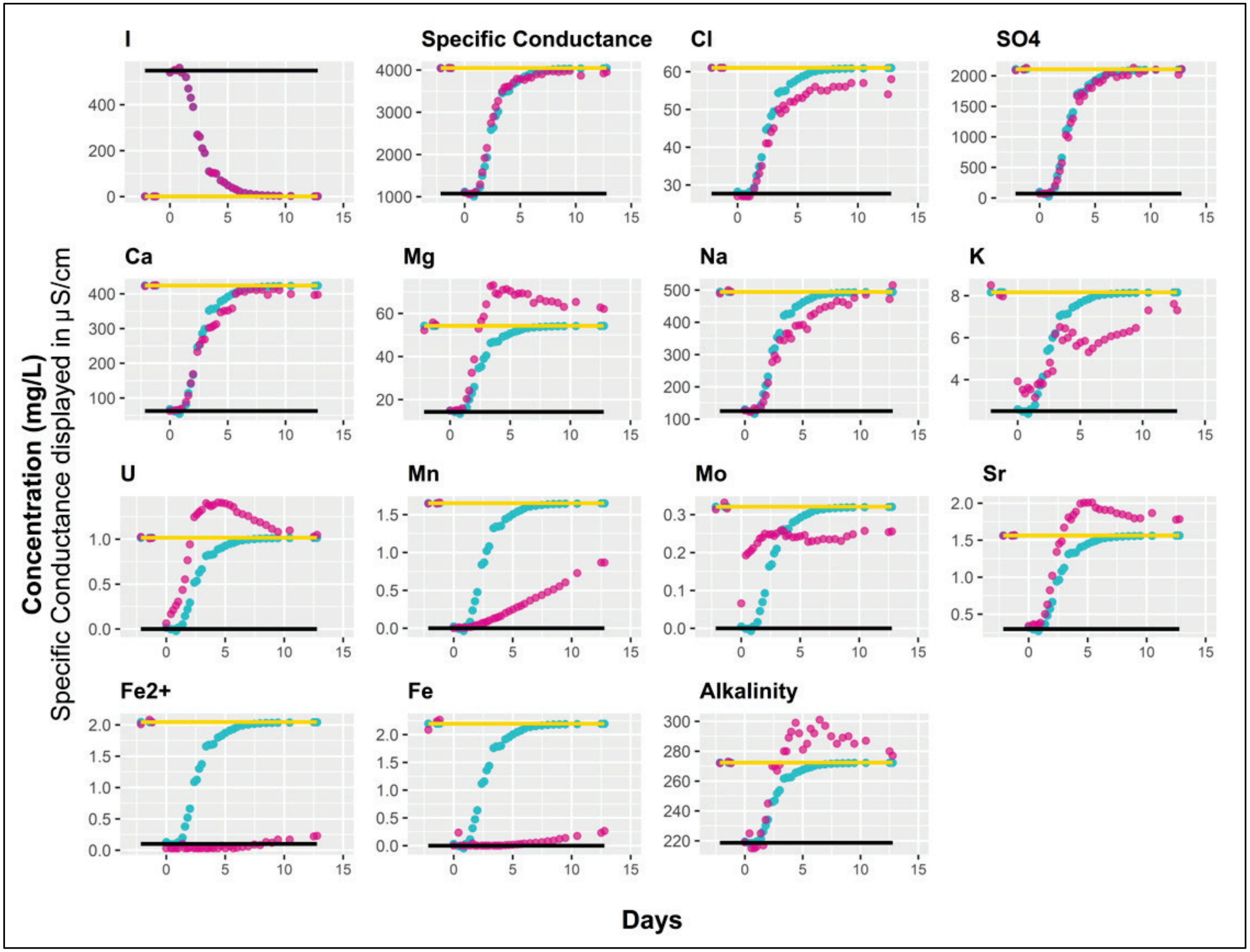
Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium, V = vanadium

Figure 25. Data from Well 0859-3 for 2021 FTA (Well 0859 Injection 1)



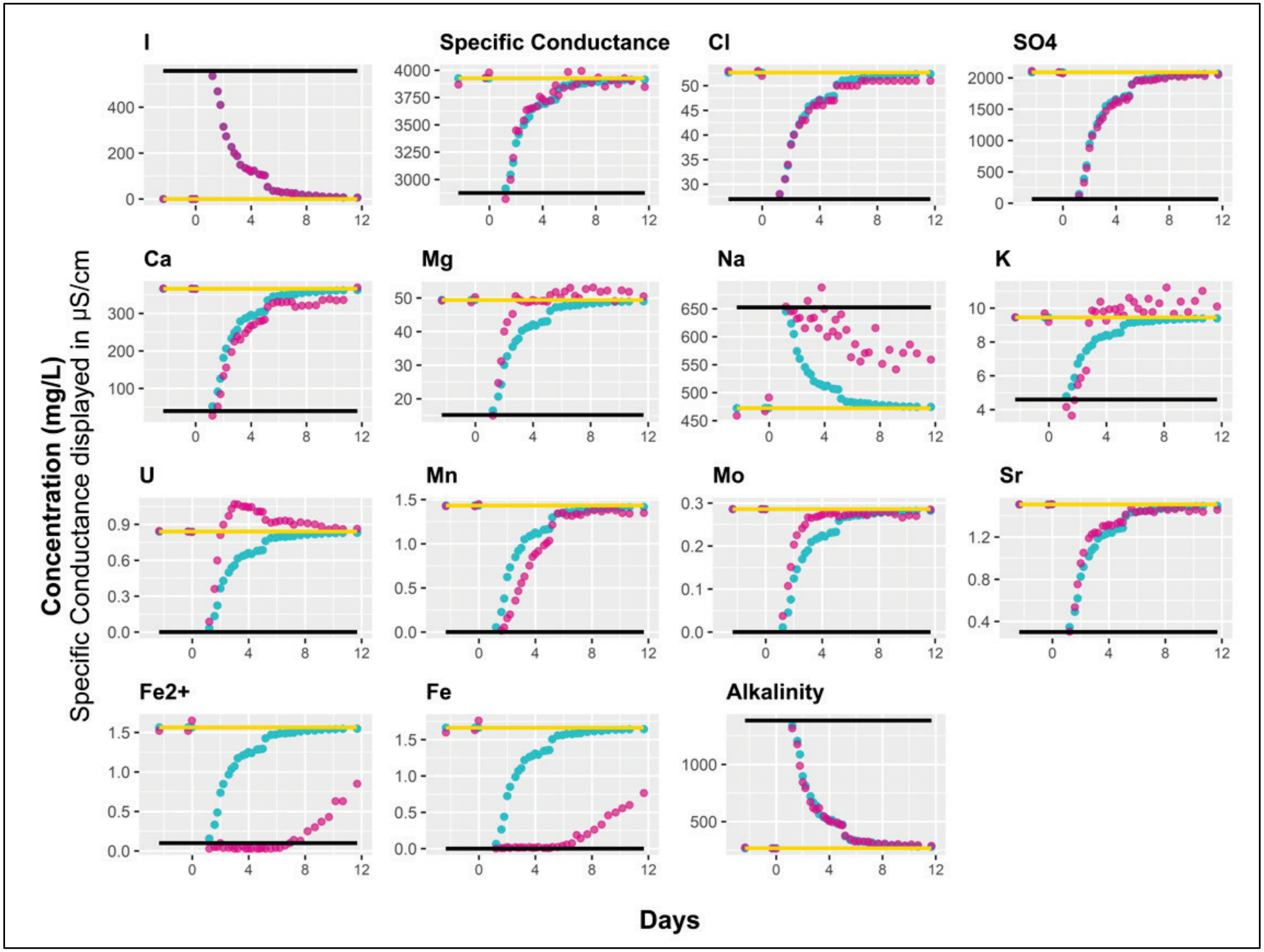
Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium, V = vanadium

Figure 26. Data from Well 0859-3 for 2021 FTA (Well 0859 Injection 2)



Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium

Figure 27. Data from Well 0860-3 for 2021 FTA (Well 0860 Injection 1)



Abbreviations: Ca = calcium, Cl = chloride, Fe = iron, I = iodide, K = potassium, Mg = magnesium, µS/cm = microsiemens per centimeter, Mn = manganese, Mo = molybdenum, Na = sodium, SO_4 = sulfate, U = uranium, V = vanadium

Figure 28. Data from Well 0860-4 for 2021 FTA (Well 0860 Injection 2)

6.0 Major Observations Summary

These observations are considered preliminary and are an initial summary of conditions observed with the tracer testing. The discussions below are focused on measured uranium and molybdenum compared to expected concentrations calculated from the tracer concentrations (conservative transport with no reactions). Any measured concentrations that are greater than expected must be a release from the solid phase to the water phase and vice versa.

Uranium and molybdenum are the two compliance constituents for the Riverton site with the current regulatory requirements of being below 0.044 mg/L and 0.10 mg/L, respectively, by 2098 (DOE 1998, 100-year natural flushing). The following discussion is based on data from wells with the highest tracer concentrations, either the injection wells or downgradient wells from the surface infiltration basin. Italics are used to highlight the major observations. More detailed analyses are expected to follow in subsequent reports and publications.

6.1 SSMA

6.1.1 Saturated Zone Injection

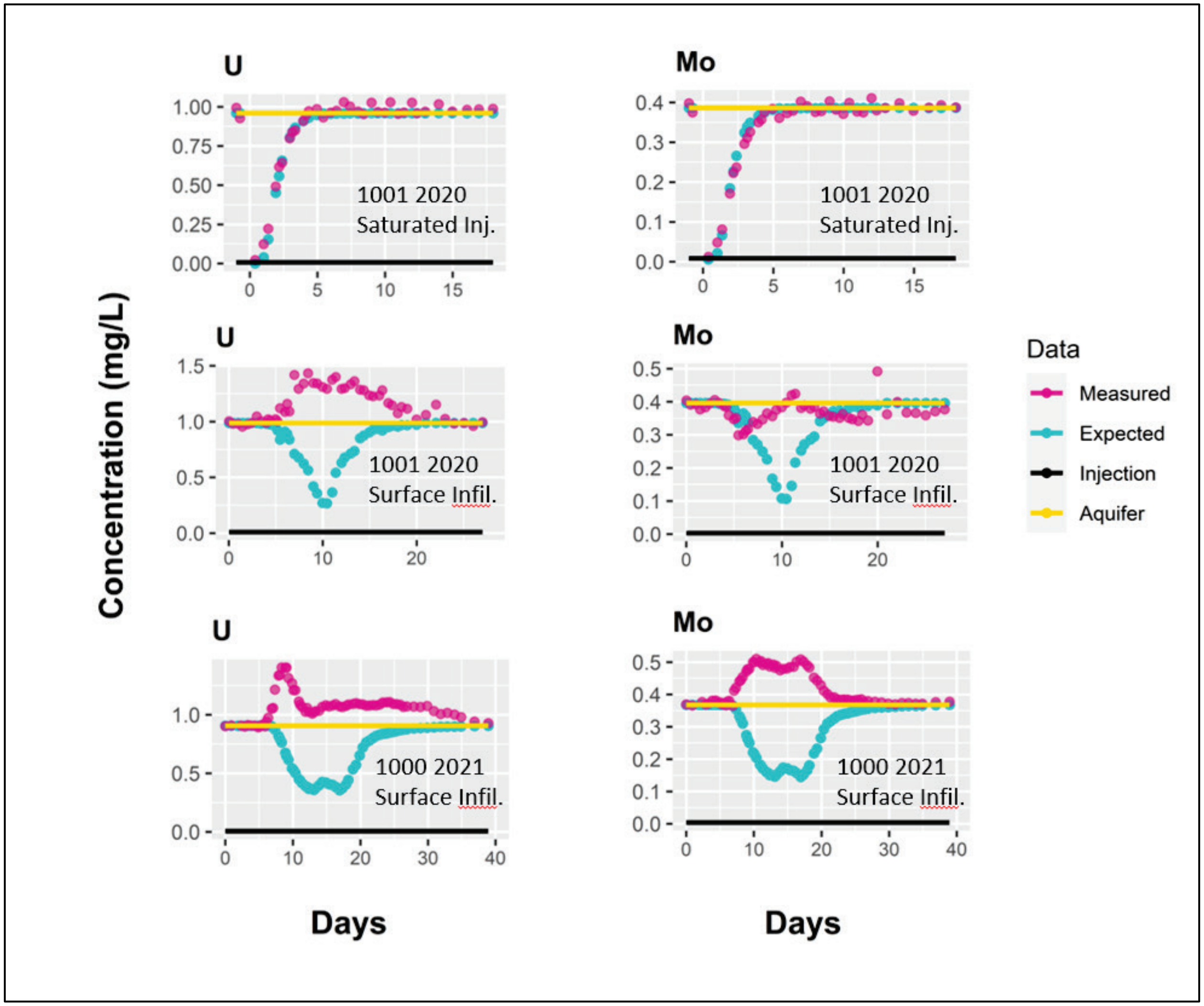
A major observation for the 2020 SSMA saturated zone injection is the *general lack of any reactions compared to the other tracer tests*. Thus, uranium and molybdenum behave conservatively (Figure 29) with no apparent transfer from the solid phase to the water phase. This observation is also noted in Paradis et al. (2022) based on the same data.

6.1.2 Surface Infiltrations

In contrast to the 2020 SSMA saturated zone injection, significant reactions occur as river water is infiltrated through the unsaturated zone. This occurs in 2020 without added alkalinity (sodium bicarbonate) and in 2021 with added alkalinity. Changes in uranium mobility with the addition of sodium bicarbonate are not evaluated for this report.

Major observations at the SSMA that are applicable to the surface infiltration tracer testing include:

- In 2020, *without any alkalinity addition, there is a significant release of uranium without an associated molybdenum release* (Figure 29) from the unsaturated zone. This uranium release is likely related to the mill-related contaminants in the unsaturated zone (evaporite-type minerals) that are released during recharge events (DOE 2022; Dam et al. 2015).
- In 2021, *with alkalinity addition, there is significant release of uranium and molybdenum* (Figure 29) from the unsaturated zone. Uranium release occurs early in the infiltration test and may be associated with unsaturated zone pore water. Molybdenum release appears to be directly associated with the infiltration water as more infiltration fluid (lower expected molybdenum concentrations) correlates with more measured molybdenum (Figure 29).
- Based on the highest tracer concentrations, *groundwater flow is generally aligned with the centerline of the gallery wells*, though not a perfect alignment, going from wells 1000/1001 to 1005 to 1010/1011 (data are in Appendix F and well locations are in Figure 4).



Notes: Samples were taken from wells with the highest measured tracer concentrations during each test. Testing from 2021 included the addition of sodium bicarbonate for the surface infiltration, whereas 2020 testing did not include any sodium bicarbonate addition.

Abbreviations: infil. = infiltration, inj. = injection, Mo = molybdenum, U = uranium

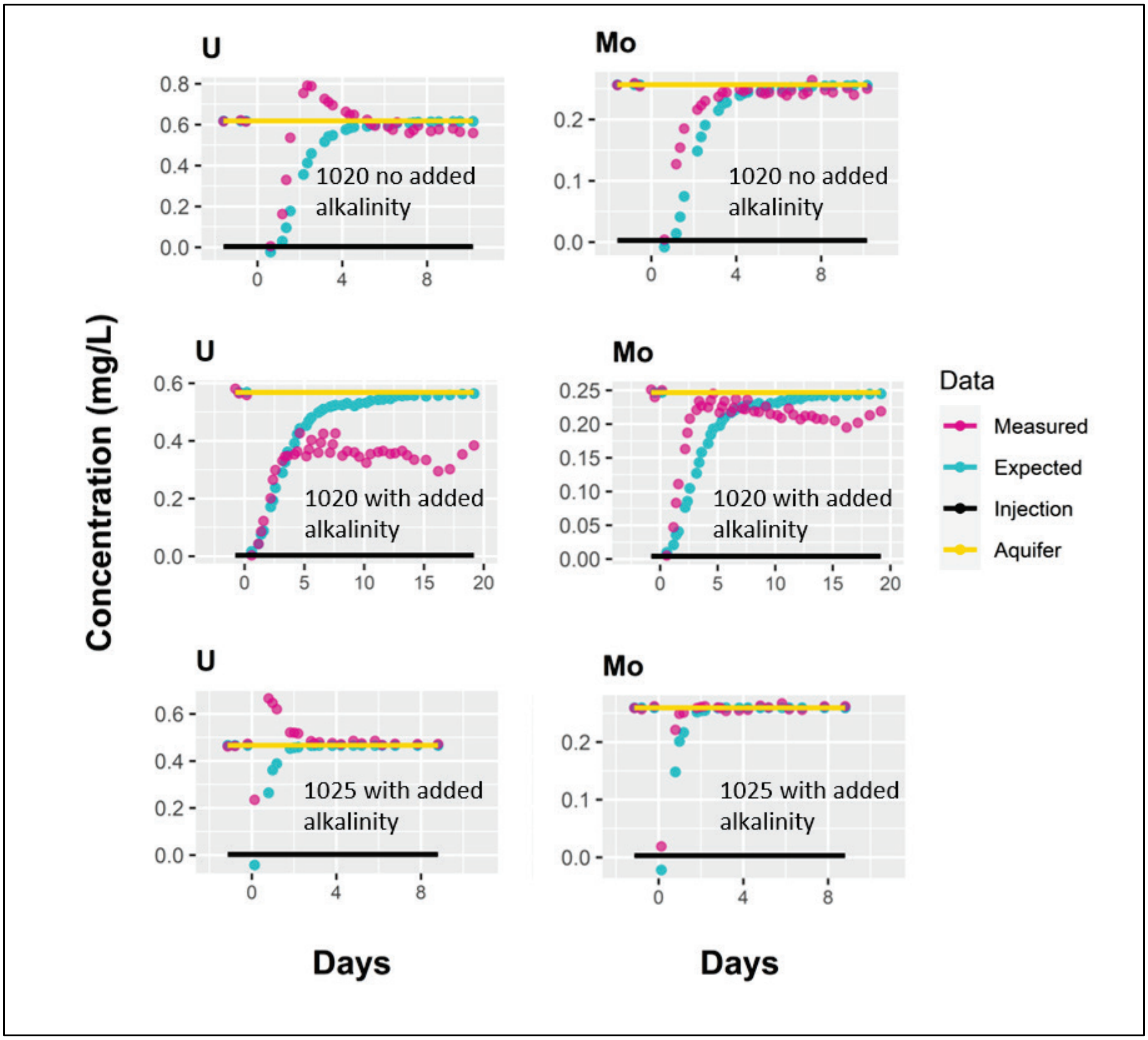
Figure 29. Uranium and Molybdenum Concentrations, Measured Versus Expected at the SSMA

6.2 FTA

6.2.1 2020 Testing

Major observations at the FTA that are applicable to 2020 saturated zone injections in the FTA well gallery include:

- In the well *1020 injection without added alkalinity, both uranium and molybdenum are released from the solid phase* (measured concentrations are greater than expected, Figure 30) with uranium concentrations exceeding the initial aquifer concentrations.
- In the well *1020 injection with added alkalinity (done right after the no alkalinity injection), no additional uranium release is indicated*, and uranium concentrations remain below the initial aquifer concentrations, indicating a loss of uranium to the solid phase. *Molybdenum release from the solid phase is again indicated* at early times (Figure 30), but concentrations at the end of the test are less than the initial aquifer concentrations.
- For the injection in well *1025 with added alkalinity*, the fast groundwater flow rates make for a *limited monitoring period*, but the *results from this injection are like the well 1020 injection without added alkalinity, though with less time for any observed concentration changes*. Thus, uranium is released from the solid phase (measured concentrations are greater than expected, Figure 30) with uranium concentrations exceeding the initial aquifer concentrations.
- *Strong heterogeneity* is confirmed by the different geochemistry in well 1023 (Appendix F). Groundwater flow appeared to be aligned with wells 1020 to 1023 with a west to east flow direction based on fluorescein dye detection. This led to a realignment of the well gallery. However, a strong tracer signal from the injection into well 1020 was not observed in the next aligned transect (wells 1025 through 1029, Figure 3, Appendix F), likely due to a north-south trending high hydraulic conductivity channel in this area. Because of this, the additional injection in well 1025 was completed.

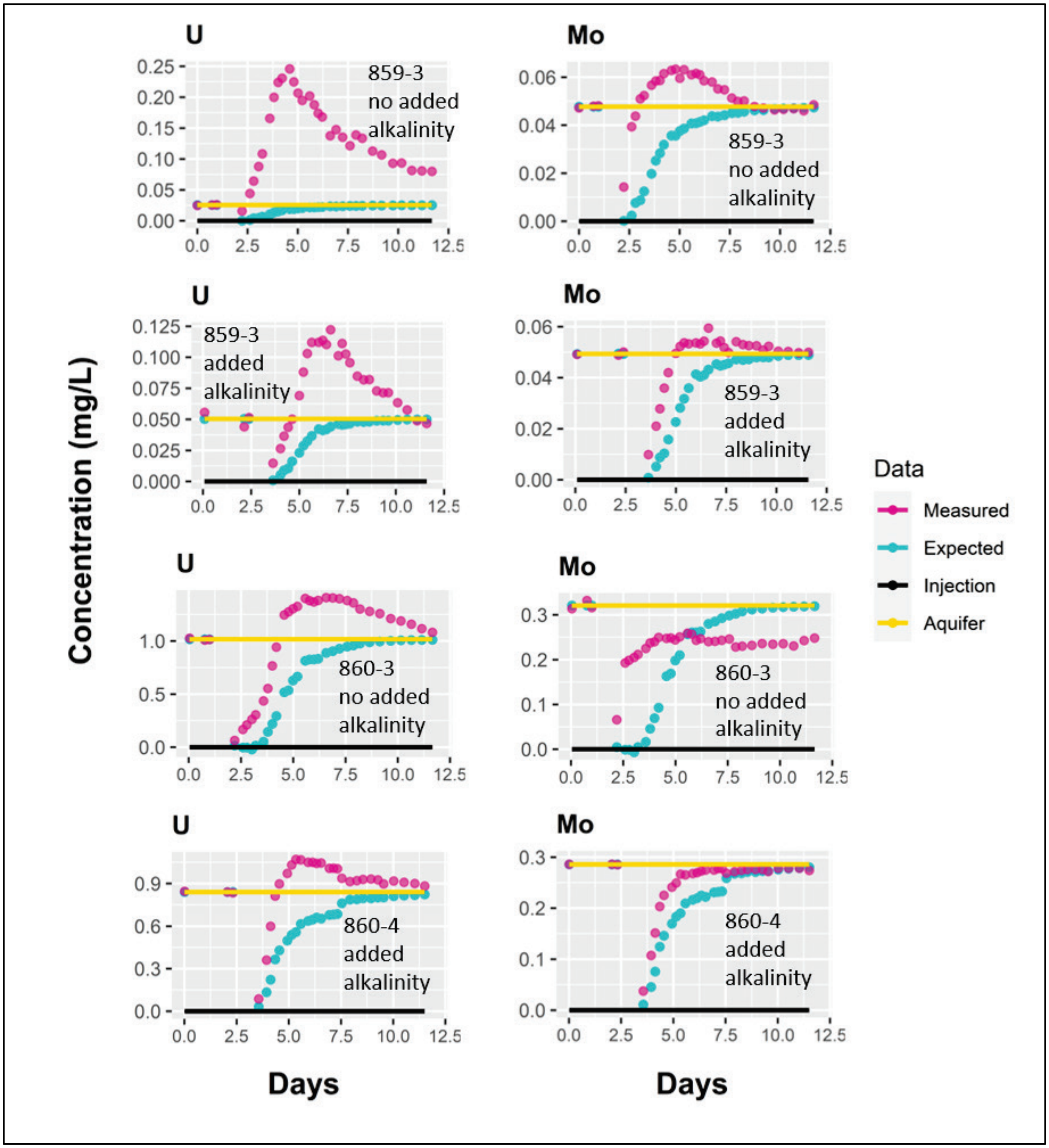


Abbreviations: Mo = molybdenum, U = uranium

Figure 30. Uranium and Molybdenum Concentrations in the Injection Wells at the FTA in 2020

6.2.2 2021 Testing

For the FTA 2021 saturated zone injections, *both uranium and molybdenum are released from the solid phase to the water phase in early time periods for all tests* (measured exceeds expected concentrations, Figure 31). This release creates uranium concentrations during the tracer testing that are greater than the original aquifer concentrations, especially for the well 0859-3 injection with no added alkalinity (Figure 31). Molybdenum concentrations exceed the aquifer concentrations only for the two injections in well 0859-3. However, the starting aquifer concentrations for molybdenum in well 0859 are much lower than in well 0860 (Figure 31). The well 0860-3 injection with no added alkalinity is the only test where molybdenum concentrations return to values less than the original aquifer concentrations.



Abbreviations: Mo = molybdenum, U = uranium

Figure 31. Uranium and Molybdenum Concentrations at the Injection Wells at the FTA in 2021

7.0 References

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Appendix A

Field Notes and Data Books Scans

Please see separate .zip file for data.
(*Appendix A Field Notes and Data Books Scans.zip*)

Appendix B

Boring Logs and Well Construction

Please see separate .zip file for data.
(Appendixes B through I.zip)

Appendix C

Aquifer Test Data

Please see separate .zip file for data.
(*Appendix B through I.zip*)

Appendix D

Fluorescein Dye Injection Data

Please see separate .zip file for data.
(*Appendix B through I.zip*)

Appendix E

Injection Flow Rates

Please see separate .zip file for data.
(*Appendix B through I.zip*)

Appendix F

Geochemistry Master Data Files

Please see separate .zip file for data.
(*Appendix B through I.zip*)

Appendix G

Specific Conductance Probe Data

Please see separate .zip file for data.
(*Appendix B through I.zip*)

Appendix H

Water Levels

Please see separate .zip file for data.
(*Appendix B through I.zip*)

Appendix I

Data Files with PHREEQC Sis

Please see separate .zip file for data.
(*Appendix B through I.zip*)

Appendix J

Graphical Results

Please see separate .zip file for data.
(*Appendix J Graphical Results.zip*)