Prepared in cooperation the U.S. Environmental Protection Agency

Examination of Dissolved Uranium Concentrations in Regional Shallow Groundwater Relative to Operable Unit 8 of the Denver Radium Superfund Site

Scientific Investigations Report 2022–5085

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Geological Survey, Reston, Virginia: 2022

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U.S. Geological Survey [USGS], 2021, National Water Information System—Web interface USGS water data for the Nation: U.S. Geological Survey accessed October 28, 2021, at https://doi.org/10.5066/F7P55KJN.

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Contents

Figures

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
	Volume	
liter (L)	33.81402	ounce, fluid (fl. oz)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
milligram (mg)	0.0003527	ounce, avoirdupois (oz)

Datum

Horizontal coordinate information is referenced to the Web Mercator Projection World Geodetic System of 1984 (WGS 84).

Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Abbreviations

EPA	U.S. Environmental Protection Agency
MCL	maximum contaminant level
NWIS	National Water Information System
OU	Operable Unit
USGS	U.S. Geological Survey
WGS 84	World Geodetic System 1984

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Abstract

A radium industry existed between about 1914 and 1920 in Denver, Colorado, with operations located along the South Platte River. Sites associated with that industry were contaminated with radium and uranium processing residues and were incorporated into clean-up efforts as Operating Units (OUs) of the Denver Radium Superfund Site. Concentrations of uranium exceeding the U.S. Environmental Protection Agency maximum contaminant level of 0.03 milligrams per liter for drinking water are present in shallow groundwater at OU8. However, previous studies have shown concentrations of dissolved uranium can be naturally high in shallow groundwater of the South Platte River valley compared to other rivers of the world. This report compares dissolved uranium concentrations measured by the U.S. Geological Survey across the South Platte River valley to data collected at the OU8 of the Denver Radium Superfund Site. The U.S. Geological Survey data represent 5 distinct urban or agricultural geographic areas and included 230 sampling events at 114 wells during 1993 to 2013. The OU8 data represent 13 wells and groundwater discharge locations sampled during the years 2017 and 2018. Dissolved uranium concentrations were statistically significantly greater for both years of the OU8 data compared to three datasets from shallow groundwater beneath urban areas in the Denver metropolitan area. However, compared to OU8, concentrations were significantly greater in shallow groundwater from an agricultural area of the South Platte River valley distant from Denver. Additionally, each of the urban area datasets contained some individual dissolved uranium concentrations greater than the greatest concentrations from the two OU8 datasets. Thus, naturally occurring concentrations of dissolved uranium in shallow groundwater that are greater than those observed at OU8 are not uncommon in the South Platte River valley.

Introduction

Previous studies have indicated water in the South Platte River in Colorado is “anomalously rich in uranium in comparison with most other rivers of the world,” and the predominant source of uranium is weathering of Cretaceous sedimentary rocks, particularly black shales and uraniferous coal seams (Boberg and Runnells, 1971). Specifically, the Pierre Shale and coal seams in the Laramie Formation are thought to be notable sources of uranium to water in the river (Boberg and Runnells, 1971). The U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) for dissolved uranium in drinking water in public water systems is 0.03 milligrams per liter (mg/L), which provides a point of reference (EPA, 2018a). By comparison, one study measured dissolved uranium concentrations in the South Platte River up to 0.039 mg/L in Colorado and up to 0.067 mg/L in Nebraska (Boberg and Runnells, 1971). Shallow groundwater in the South Platte River valley is also enriched in dissolved uranium from natural sources (Snow and Spalding, 1994). Such uranium sources could be present in the alluvium and weathered rock hosting groundwater. The uranium may also have been transported by the river from sources upstream and entered into the adjacent groundwater by natural lateral flow (Snow and Spalding, 1994) or by diversion of river water for irrigation. Downstream, along the Platte River in Nebraska, concentrations of uranium up to 0.258 mg/L and 0.549 mg/L have been measured in shallow groundwater in bottomlands and terraces (Spalding and Druliner, 1981) The situation of anomalously high concentrations of naturally occurring uranium in groundwater in the South Platte River valley is similar to that in the Arkansas River Valley to the south, where parts of the same sequence of Cretaceous rocks are present near the surface under similar climatic and geomorphic conditions (Zielinski and others, 1995; Zielinski and others, 1997; Miller and others, 2010; Bern and others, 2020).

Such naturally occurring concentrations of dissolved uranium in shallow groundwater of the South Platte River valley provide important context for understanding how human-caused uranium contamination of groundwater within the region compares to natural concentrations. Denver, Colorado, straddles the South Platte River. Between approximately

1914 and 1920, the Denver area was a radium production center, and dozens of contaminated sites associated with that legacy were rediscovered and characterized starting in 1979 (Topolski, 1985). The Denver Radium Superfund Site was created by the EPA to address groundwater and soil contamination by radium and uranium processing residues associated with the radium industry. The Denver Radium Superfund Site has 11 Operable Units (OUs), including OU8, a property of the former S.W. Shattuck Chemical Company (EPA, 1992). Groundwater contamination associated with OU8 remains on the EPA National Priorities List (EPA, 2018b).

Purpose and Scope

The purpose of this report is to compile and present U.S. Geological Survey (USGS) data from shallow groundwater in the South Platte River valley to provide context for dissolved uranium concentrations in shallow groundwater associated with OU8 of the Denver Radium Superfund Site. Well construction information, depth-to-water data, and dissolved uranium concentrations from groundwater wells in the South Platte River valley were compiled from three USGS studies. Those data are compared to EPA data collected at OU8 using Wilcoxon rank-sum tests. Description or analysis of the site history, physical or hydrological characteristics of the study area, geochemical processes, remediation actions, or water-quality trends associated with OU8 or the broader Denver Radium Superfund Site are beyond the scope of this report.

Dissolved Uranium Concentration Data Compilation

No new data were collected for this report. The USGS data were obtained from the USGS National Water Information System (NWIS) database (USGS, 2021). The Denver Radium OU8 data were provided by the EPA (EPA, 2018b). All data discussed also are provided in appendix 1.

USGS Shallow Groundwater Data

Three previous USGS studies collected samples of shallow groundwater from wells in the South Platte River valley and measured dissolved uranium concentrations in those samples (Bruce and McMahon, 1998; Paschke and others, 2013; and Paschke and others, 2014). Data from those wells were compiled for this report (app. 1, table 1.1). Some of the included wells had additional samples collected with dissolved uranium concentrations measured by USGS efforts outside the scope of the three studies. Therefore, some wells have multiple measured uranium concentrations spanning multiple years for associated groundwater. Shallow groundwater was the focus of the data compiliation effort and is defined here as groundwater present at less than 50 feet below land surface. Wells were included in the data compilation if one of three criteria could establish water presence in that depth range: depth to water, sampling depth, screened interval of the well, or depth of the well (USGS, 2021).

The first study and well groupings included in the compilation were part of the USGS National Water-Quality Assessment Project of the National Water Quality Program with the goal of addressing the occurrence and distribution of water-quality conditions in the region (Bruce and McMahon, 1998). Groundwater was sampled from wells in geographically nonoverlapping agricultural and urban areas and completed in the alluvial aquifer of the South Platte River (fig. 1). Of the 30 agricultural area wells in that study area, 29 met 1 of the depth-to-water criteria. Sampling events for the wells spanned the years 1994 to 2013 with 102 individual measurements of dissolved uranium concentrations. Of the 30 urban area wells in the study area, 28 had data available in NWIS, and those data were for a single sampling event per well, all in 1993. Of the 28 samples, 1 sample had a dissolved uranium concentration less than the U.S. Geological Survey National Water Quality Laboratory (Lakewood, Colorado) reporting limit of 0.001 milligram per liter (Faires, 1993; Childress and others, 1999), leaving 27 concentrations greater than or equal to the laboratory reporting limit for 27 individual wells.

The second study and well grouping were related to water-quality conditions in Toll Gate Creek in the Denver metropolitan area, which is a tributary to the South Platte River (Paschke and others, 2013). The goal of this study was to address geologic sources and processes affecting selenium concentrations in Toll Gate Creek, but dissolved uranium concentrations were also measured in groundwater (fig. 2). Groundwater was sampled from 19 wells in generally urbanized areas. Most of the wells were completed in surficial materials, but three wells intersected material of the Denver Formation at depth. All 19 wells met the depth-to-water criteria, and some were sampled multiple times between 2003 and 2011 yielding 36 dissolved uranium concentrations in total.

The third study and associated well groupings was also related to water-quality conditions in Toll Gate Creek (Paschke and others, 2014). The goal of the report was to document selenium bearing rocks and groundwater in a broader region surrounding the Toll Gate Creek watershed. Wells in this study were divided according to land use into agricultural and urban categories (fig. 2), and the wells were completed at the water table in either alluvial materials or shallow bedrock. Of the 32 agricultural area wells, 20 did not meet any of the depth-to-water criteria and 1 was dry, resulting in usable measurements from only 11 wells (app. 1, table 1.1). All sampling occurred in 2003, but repeated sampling yielded 14 dissolved uranium concentrations in total. Of the 30 urban area wells, 2 did not meet depth-to-water criteria. Repeated sampling of the remaining 28 wells between 2003 and 2011 yielded 51 dissolved uranium concentrations in total. Altogether, the USGS data represent 230 concentrations of dissolved uranium in shallow groundwater from 114 different wells in 5 distinct geographic areas (app. 1).

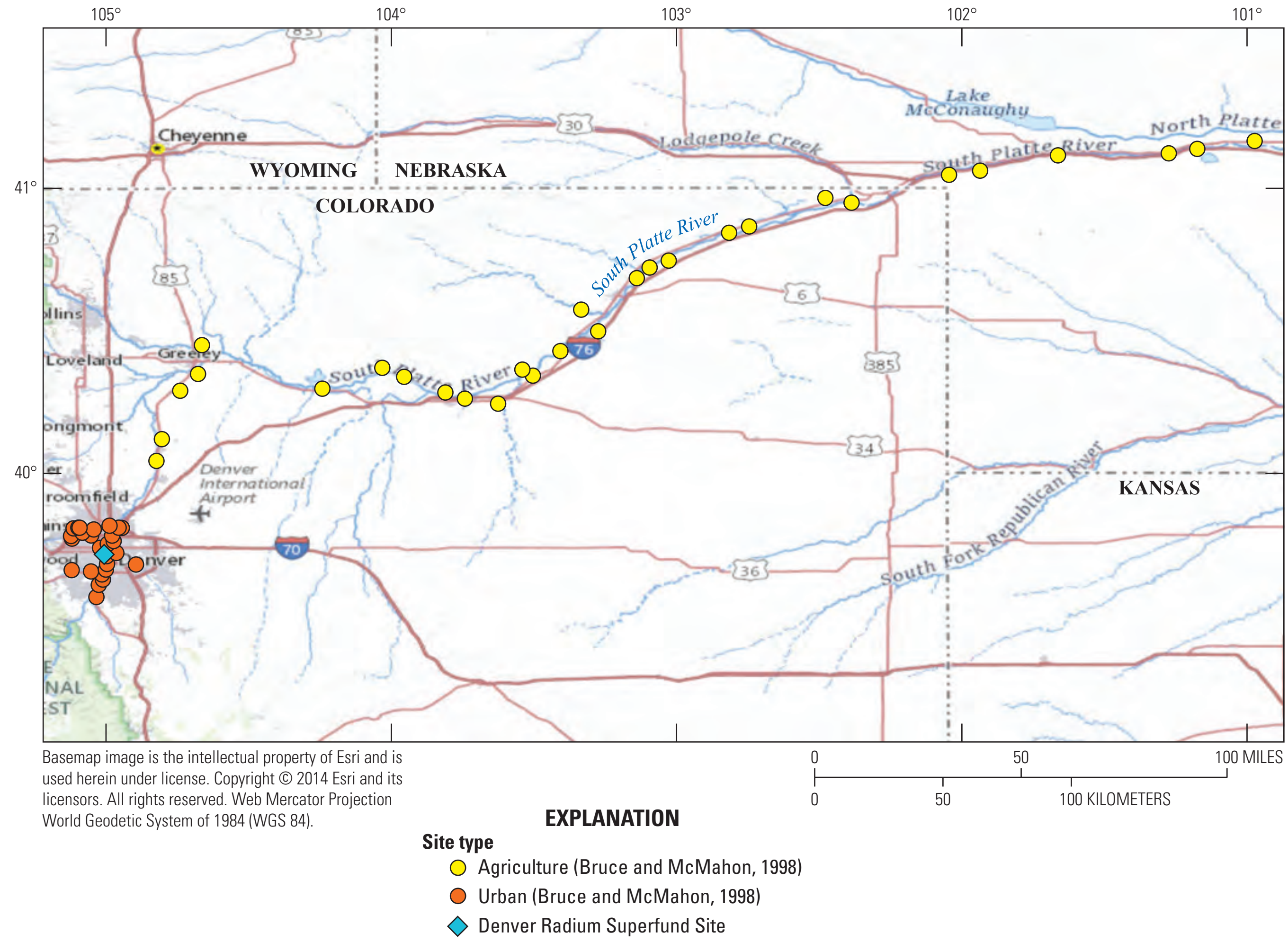


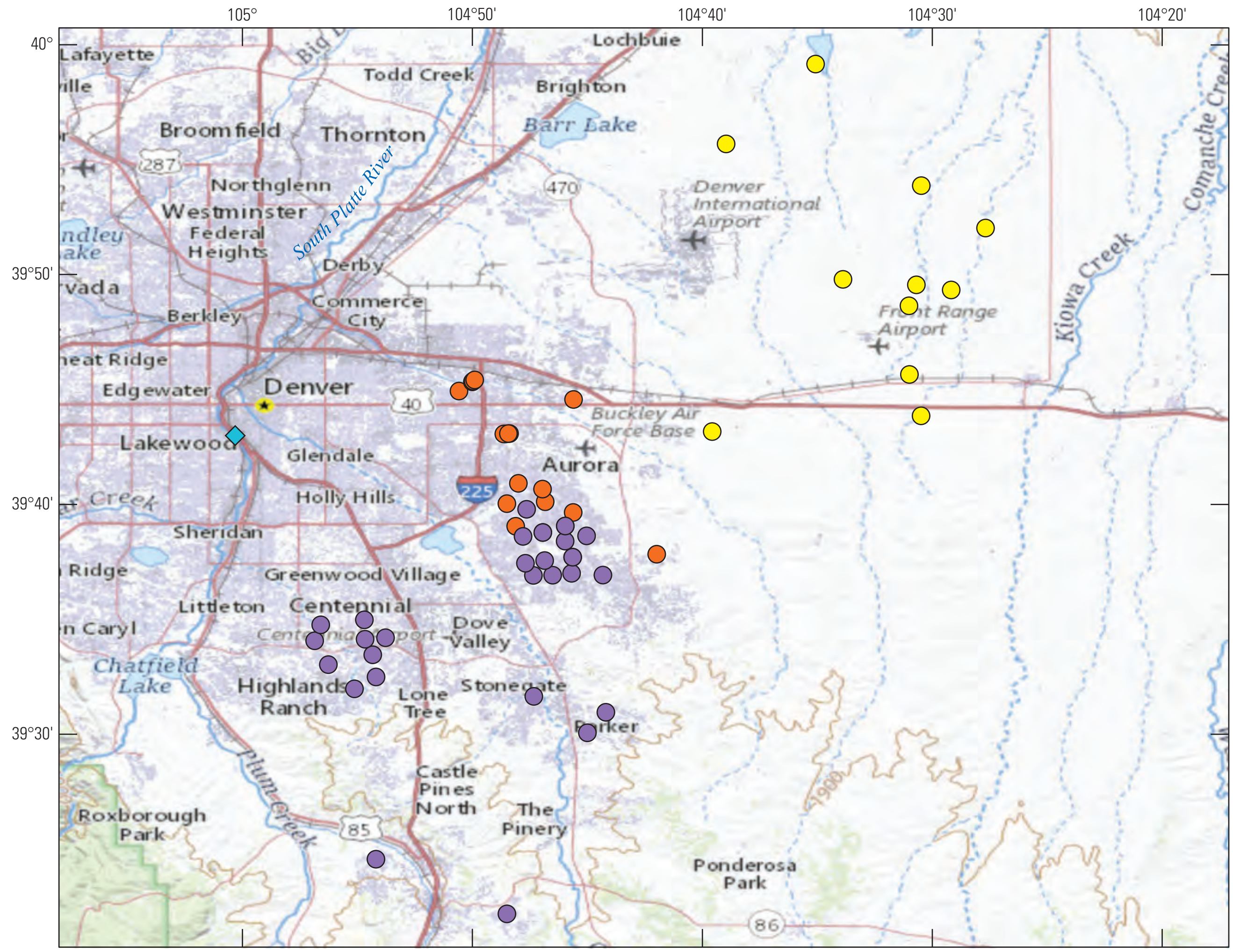
Figure 1. Agricultural and urban areas where shallow groundwater wells were sampled as part of the study by Bruce and McMahon (1998). Only wells that meet depth-to-water criteria are depicted.

Denver Radium Superfund Site, Operable Unit 8 Data

Dissolved uranium concentration data measured at the Denver Radium Superfund Site, OU8, were collected by the EPA (app. 1, table 1.2). Dissolved uranium concentrations were available for water from 10 shallow groundwater wells and 3 stormwater outfall locations. All locations were sampled on both May 11, 2017, and March 7, 2018 (EPA, 2018b; Sandor, 2018). The stormwater outfall locations were presumed to mostly reflect groundwater discharge at the times of sampling because of the absence of rain in the days prior to sampling. One stormwater outfall was dry at the time of the 2018 sampling.

Examination and Comparisons of Dissolved Uranium Datasets

Figure 3 offers a visual means of comparing dissolved uranium concentrations compiled here. Using the EPA MCL for dissolved uranium in drinking water of 0.03 mg/L (EPA, 2018a) provides a point of reference, and each dataset contains some values greater than and some values less than the MCL (fig. 3). The greatest median concentration and greatest individual concentrations of dissolved uranium were measured in agricultural area wells completed in the alluvial aquifer assessed as part of Bruce and McMahon (1998) and extending along the South Platte River valley far beyond the Denver metropolitan area (fig. 1). The median concentrations among the urban datasets were all similar and low compared to the other datasets, although the median for agricultural area wells from Paschke and others (2014) and located closer to the metropolitan area was only slightly greater (fig. 3). Interquartile ranges for those four datasets also show much overlap, and



0 10 20 MILES

0 10 20 KILOMETERS

EXPLANATION

Site type

- Agriculture (Paschke and others, 2014)
- Urban (Paschke and others, 2013)
- Urban (Paschke and others, 2014)
- Denver Radium Superfund Site

Figure 2. Urban area where shallow groundwater wells were sampled as part of the study by Paschke and others (2013) and the agricultural area and urban area where shallow groundwater wells were sampled as part of the study by Paschke and others (2014). Only wells that meet depth-to-water criteria are depicted.

thus a general similarity exists for dissolved uranium concentrations in shallow groundwater in different parts of the Denver metropolitan area (fig. 3). By comparison, the two datasets from OU8 have medians and interquartile ranges slightly greater than the three urban and one agricultural dataset from in and near the Denver metropolitan area.

The nonparametric, Wilcoxon rank-sum test was used to explore differences between the the USGS urban shallow groundwater datasets and the OU8 datasets. The test was implemented as a one-sided test of whether dissolved uranium concentrations in the OU8 2017 and OU8 2018 datasets were greater than the USGS urban datasets by using the function "wilcox.test" in the R programming language (R Core Team, 2021). In essentially all cases, the test found the differences to be significant at the 95 percent confidence level ($p \leq 0.05$). For the urban shallow groundwater results from Bruce and McMahon (1998), the p-value was 0.052, barely outside the significance threshold, when compared to the OU8 2017 dataset (EPA, 2018b), but the p-value was 0.02 when compared to the OU8 2018 dataset. For the Paschke and others (2014) dataset,

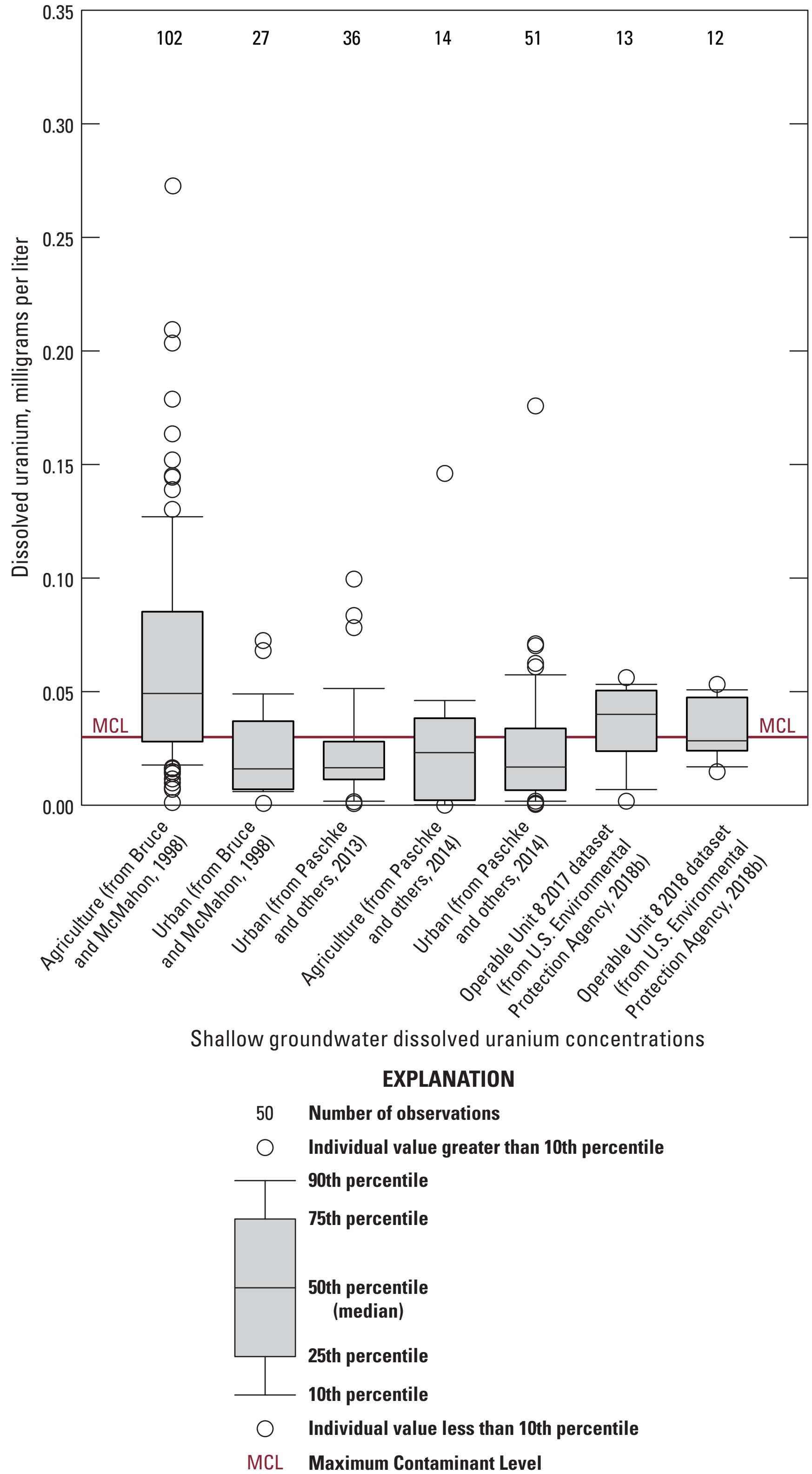


Figure 3. Shallow groundwater dissolved uranium concentration datasets from Bruce and McMahon (1998), Paschke and others (2013), Paschke and others (2014), and U.S. Environmental Protection Agency (2018b).

p-values were 0.04 and 0.01 when compared to the OU8 2017 and OU8 2018 datasets from EPA (2018b), respectively. For the Paschke and others (2013) dataset, *p*-values were 0.02 and 0.005 when compared to the OU8 2017 and OU8 2018 datasets from EPA (2018b), respectively. Thus, statistical differences between the EPA (2018b) and other urban shallow groundwater datasets can be detected. However, tests also confirmed dissolved uranium concentrations for the agricultural area wells from Bruce and McMahon (1998) were significantly greater than the OU8 2017 and OU8 2018 datasets from EPA (2018b), with *p*-values in those tests of 0.03 and 0.02, respectively. In contrast, concentrations from the Paschke and others (2014) agricultural area wells dataset were significantly lower than the OU8 2017 dataset from EPA (2018b) with a *p*-value of 0.047 but not significantly lower than the OU 2018 dataset from EPA (2018b) with a *p*-value of 0.07.

Overall, substantial natural variability for dissolved uranium concentrations in shallow groundwater of the South Platte River valley was apparent, as demonstrated by the five USGS datasets (fig. 3). Despite variability, distinctions between geographic areas were also apparent. The statistically significant differences between the three urban area datasets and the two OU8 datasets likely reflect a human-caused effect at OU8 when compared to shallow groundwater elsewhere in the Denver metropolitan area. However, there are two factors, which provide more context for human-caused effect at OU8. First, dissolved uranium concentrations in the dataset from shallow groundwater of Bruce and McMahon (1998), which represents the distant agricultural area, were significantly greater than those at OU8. Second, each of the urban area datasets contained individual concentrations greater than the greatest concentration from the two OU8 datasets (0.0563 mg/L; app. 1, table 1.2). The urban area dataset from Bruce and McMahon (1998) contains two such values, Paschke and others (2013) contains three such values, and Paschke and others (2014) contains six such values (fig. 3; app. 1, table 1.1). Thus, some naturally occuring dissolved uranium concentrations occur in shallow groundwater in the Denver metropolitan area that are greater than the highest concentration measured at OU8 in 2017 or 2018 (EPA, 2018b).

Summary

Previous studies show concentrations of dissolved uranium can be greater in river water and shallow groundwater of the South Platte River valley compared to other rivers of the world. Weathering of sedimentary rocks and coal seams are the presumed source of that uranium. Between about 1914 and 1920, a radium industry existed in Denver, Colorado, located along the South Platte River. Dozens of contaminated sites associated with that industry were rediscovered and characterized starting in 1979 and were incorporated into clean-up efforts as Operating Units (OUs) of the Denver Radium Superfund Site. Relatively high concentrations of uranium are present in shallow groundwater beneath OU8, including some concentrations greater than the Environmental Protection Agency’s Maximum Contaminant Level for uranium in drinking water.

This report compares concentrations of dissolved uranium in shallow groundwater from across the South Platte River valley to concentrations in shallow groundwater from OU8 of the Denver Radium Superfund Site. Data representing the broader South Platte River valley come from wells sampled by the USGS over the course of three different studies covering five distinct urban or agricultural geographic areas. The data total 230 sampling events from 115 wells between the years 1993 and 2013. The OU8 data are from 10 wells and 3 stormwater outfall locations assumed to reflect groundwater discharge at the time of sampling, all sampled once each in 2017 and 2018.

Although substantial variability was observed in concentrations of dissolved uranium in shallow groundwater, distinctions between geographic areas were apparent. In all but one case, concentrations were significantly greater for both OU8 datasets compared to the three datasets from shallow groundwater beneath urban areas in the Denver metropolitan area. However, concentrations of dissolved uranium were significantly greater in shallow groundwater from an agricultural area of the South Platte River valley distant from Denver. Additionally, each of the urban area datasets contained some individual concentrations greater than the greatest concentration from the two OU8 datasets. Thus, some naturally occuring concentrations of dissolved uranium in shallow groundwater that are greater than those observed at OU8 are present in the South Platte River valley.

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Appendix 1. Dissolved Uranium Concentrations in Shallow Groundwater

Table 1.1. Well construction, groundwater-level, and sampling depth data establishing samples as meeting criteria for shallow groundwater for study and dissolved (filtered) uranium concentrations for U.S. Geological Survey (USGS) data used in the report.

[Data were compiled from Bruce and McMahon (1998), Paschke and others (2013), Paschke and others (2014), and USGS (2021). —, no data;?, indicates some uncertainty regarding the upper limit of the screened interval]

USGS site identifier	Sample date (month/day/year)	Screened interval or hole depth (feet below land surface)	Depth to water level (feet below land surface)	Sampling depth (feet below land surface)	Uranium, water, filtered (milligrams per liter)
Agricultural land use dataset from Bruce and McMahon (1998)					
400237104500301	6/8/1994	7.5–12.5	—	—	0.028
	7/18/2002	7.5–12.5	7.9	—	0.0192
	6/24/2013	7.5–12.5	7.7	9.5	0.00089
400711104481801	6/8/1994	21–31	—	—	0.018
	7/24/2002	21–31	20.5	24	0.0207
	8/26/2013	21–31	13.8	19.5	0.0106
401440103373201	7/20/1994	13–23	—	—	0.063
	7/31/2002	13–23	13.2	20	0.0203
401544103443101	7/21/1994	37–47	—	—	0.04
	7/30/2002	37–47	36.7	39	0.0217
	7/14/2004	37–47	36.1	42	0.034
	8/30/2006	37–47	35.8	35.8	0.039
	8/11/2010	37–47	32.4	39	0.0163
	9/4/2012	37–47	34.1	—	0.0323
	7/30/2013	37–47	35.8	39	0.0369
401702103483901	7/21/1994	21–31	—	—	0.051
	7/30/2002	21–31	23.7	28	0.0435
401726104442201	6/9/1994	16–26	—	—	0.016
401750104143101	7/26/1994	28–38	—	—	0.024
	7/25/2002	28–38	29.5	33	0.0675
	8/1/2013	28–38	28.5	31.8	0.11
402018103571801	7/25/1994	7–12	—	—	0.06
	7/29/2002	7–12	2.1	6	0.0538
	7/31/2013	7–12	3.7	5.5	0.0551
402034103301001	7/19/1994	13–23	—	—	0.051
	8/1/2002	13–23	20.7	22	0.0684
	7/18/2013	13–23	18.4	18.9	0.0641

Table 1.1. Well construction, groundwater-level, and sampling depth data establishing samples as meeting criteria for shallow groundwater for study and dissolved (filtered) uranium concentrations for U.S. Geological Survey (USGS) data used in the report.—Continued

[Data were compiled from Bruce and McMahon (1998), Paschke and others (2013), Paschke and others (2014), and USGS (2021). —, no data;?, indicates some uncertainty regarding the upper limit of the screened interval]

USGS site identifier	Sample date (month/day/year)	Screened interval or hole depth (feet below land surface)	Depth to water level (feet below land surface)	Sampling depth (feet below land surface)	Uranium, water, filtered (milligrams per liter)
Agricultural land use dataset from Bruce and McMahon (1998)—Continued					
402104104404501	6/9/1994	5.5–19	—	—	0.009
	7/25/2002	5.5–19	11	15	0.00986
	7/15/2004	5.5–19	9.5	13	0.0097
	8/28/2006	5.5–19	3	4.33	0.0143
	8/12/2010	5.5–19	7.1	8	0.0127
	8/28/2012	5.5–19	5.5	—	0.0177
	8/27/2013	5.5–19	4.1	4.95	0.0133
402150103322801	7/20/1994	17–27	—	—	0.044
	8/1/2002	17–27	21.1	24	0.0484
	7/18/2013	17–27	18.3	23	0.0469
402213104015501	7/25/1994	5–12	—	—	0.081
	7/29/2002	5–12	2.3	5	0.0767
	7/14/2004	5–12	2.6	8	0.0977
	8/30/2006	5–12	5.6	3.83	0.106
	8/11/2010	5–12	3.6	8	0.0821
	9/6/2012	5–12	3.4	—	0.0965
	7/31/2013	5–12	3.5	5.8	0.0852
402538103242001	7/19/1994	10–20	—	—	0.106
	8/6/2002	10–20	9.1	11	0.0415
	7/17/2013	10–20	8.7	12.4	0.0329
402658104400001	6/10/1994	18–33	—	—	0.063
	7/24/2002	18–33	26.6	30	0.0392
	8/28/2013	18–33	—	31.5	0.04
402955103163501	7/18/1994	26–36	—	—	0.065
	9/11/2002	26–36	21.6	—	0.0344
	6/25/2013	26–36	19	24.7	0.086
403426103200401	7/18/1994	21–31	—	—	0.047
	8/7/2002	21–31	17.4	20	0.044
	7/17/2013	21–31	29.7	30.8	0.0505
404106103082201	8/4/1994	8–18	—	—	0.109
	8/7/2002	8–18	5.1	7	0.13
	7/16/2013	8–18	5.3	9	0.0725

Table 1.1. Well construction, groundwater-level, and sampling depth data establishing samples as meeting criteria for shallow groundwater for study and dissolved (filtered) uranium concentrations for U.S. Geological Survey (USGS) data used in the report.—Continued

[Data were compiled from Bruce and McMahon (1998), Paschke and others (2013), Paschke and others (2014), and USGS (2021). —, no data;?, indicates some uncertainty regarding the upper limit of the screened interval]

USGS site identifier	Sample date (month/day/year)	Screened interval or hole depth (feet below land surface)	Depth to water level (feet below land surface)	Sampling depth (feet below land surface)	Uranium, water, filtered (milligrams per liter)
Agricultural land use dataset from Bruce and McMahon (1998)—Continued					
404320103053801	8/3/1994	7–17	—	—	0.075
	8/8/2002	7–17	8.9	11	0.139
	6/27/2013	7–17	5.8	8	0.1
404450103013501	8/3/1994	37–47	—	—	0.021
	8/8/2002	37–47	40	42	0.0223
	7/16/2013	37–47	37.7	43	0.0212
405039102485601	8/2/1994	5–15	—	—	0.04
	8/12/2002	5–15	6.7	8	0.0375
	6/27/2013	5–15	6.7	8	0.0379
405159102444201	8/2/1994	5–15	—	—	0.092
	8/13/2002	5–15	8.3	—	0.113
	7/13/2004	5–15	5.4	12	0.105
	8/29/2006	5–15	6.2	3.83	0.146
	8/10/2010	5–15	5.9	8	0.0835
	8/30/2012	5–15	8.6	12	0.0908
	6/26/2013	5–15	9.1	10	0.0734
	8/1/1994	6–16	—	—	0.034
	8/15/2002	6–16	6.2	7	0.0514
	7/8/2013	6–16	8.2	10	0.0567
405801102284501	8/1/1994	20–30	—	—	0.036
	8/13/2002	20–30	21.1	—	0.024
	6/26/2013	20–30	16.2	18.8	0.0243
410251102024201	6/16/1994	12–22	—	—	0.146
	8/14/2002	12–22	19.4	20	0.152
	7/13/2004	12–22	18.1	19.7	0.164
	8/10/2010	12–22	17.1	18	0.209
	8/29/2012	12–22	20.4	21	0.204
	7/9/2013	12–22	20.2	21	0.179
410344101560901	6/16/1994	23–33	—	—	0.039
	8/14/2002	23–33	26.8	28	0.0864
	7/11/2013	23–33	30.4	31.5	0.0451
410657101394501	6/15/1994	7–17	—	—	0.087
	8/20/2002	7–17	13	14	0.273
	7/9/2013	7–17	12	14.2	0.127

Table 1.1. Well construction, groundwater-level, and sampling depth data establishing samples as meeting criteria for shallow groundwater for study and dissolved (filtered) uranium concentrations for U.S. Geological Survey (USGS) data used in the report.—Continued

[Data were compiled from Bruce and McMahon (1998), Paschke and others (2013), Paschke and others (2014), and USGS (2021). —, no data;?, indicates some uncertainty regarding the upper limit of the screened interval]

USGS site identifier	Sample date (month/day/year)	Screened interval or hole depth (feet below land surface)	Depth to water level (feet below land surface)	Sampling depth (feet below land surface)	Uranium, water, filtered (milligrams per liter)
Agricultural land use dataset from Bruce and McMahon (1998)—Continued					
410722101162901	6/15/1994	12–22	—	—	0.05
	8/21/2002	12–22	12.3	13	0.0299
	7/10/2013	12–22	12.3	14	0.036
410819101102801	6/14/1994	7–17	—	—	0.046
	8/21/2002	7–17	6.6	7	0.0526
	7/10/2013	7–17	5.9	8	0.0389
410959100582401	6/14/1994	13–23	—	—	0.02
	8/22/2002	13–23	4.1	12	0.024
	7/11/2013	13–23	5.3	11	0.018
Urban land use dataset from Bruce and McMahon (1998)					
393357105020201	7/15/1993	15–25	18	—	0.014
	8/4/1993	21–41	9.7	—	0.007
393736105004001	7/29/1993	10–20	15.5	—	0.006
393843105005201	8/4/1993	4–19	8.4	—	0.006
	8/11/1993	9–24	14.9	—	0.037
393938105071401	7/15/1993	9–14	8.8	—	0.007
393944105000201	7/29/1993	8–23	15.1	—	0.037
394044104533901	8/3/1993	10.5–37	11.4	—	0.018
394056104594801	8/19/1993	25–45	9	—	0.034
394234104595301	8/5/1993	10–30	12.6	—	0.008
394314104575001	8/19/1993	20–30	15.1	—	0.016
394326105003901	8/5/1993	12.5–27.5	—	—	0.013
394418105011501	7/22/1993	10–30.25	16.8	—	0.014
394508104593801	7/21/1993	12–22	14	—	0.007
394545104582301	7/21/1993	26–46	37.1	—	0.046
394612105071001	8/18/1993	20?–40	—	—	0.018
394648105072301	7/14/1993	4.5–19.5	4.5	—	0.014
394654104584301	7/20/1993	9.5–34.5	14.5	—	0.027
394655105030901	7/20/1993	3–12	5.2	—	0.049
394728105045801	7/14/1993	4–19	6.6	—	0.006
394811105023201	7/13/1993	5–15	9.2	—	0.018
394824105065001	8/12/1993	10–51	19.4	—	0.048
394830104564001	8/13/1993	14–24	22.1	—	0.001

Table 1.1. Well construction, groundwater-level, and sampling depth data establishing samples as meeting criteria for shallow groundwater for study and dissolved (filtered) uranium concentrations for U.S. Geological Survey (USGS) data used in the report.—Continued

[Data were compiled from Bruce and McMahon (1998), Paschke and others (2013), Paschke and others (2014), and USGS (2021). —, no data;?, indicates some uncertainty regarding the upper limit of the screened interval]

USGS site identifier	Sample date (month/day/year)	Screened interval or hole depth (feet below land surface)	Depth to water level (feet below land surface)	Sampling depth (feet below land surface)	Uranium, water, filtered (milligrams per liter)
Urban land use dataset from Bruce and McMahon (1998)—Continued					
394833104572201	7/23/1993	15–20	15	—	0.013
394834105055001	9/9/1993	18–30	19.5	—	0.031
394835105053301	9/9/1993	20–65	19.3	—	0.072
394858104591701	7/30/1993	6.5–31.5	9.2	—	0.068
393903104455701	6/3/2003	28–37.5	—	—	0.00177
	11/21/2003	28–37.5	16.8	34	0.0168
	8/6/2007	28–37.5	16.2	27	0.03
393742104453801	11/19/2003	18.3–28.1	11.5	20	0.0114
	10/20/2005	18.3–28.1	10.7	—	0.0113
	7/12/2007	18.3–28.1	11.4	21	0.0101
	10/16/2007	18.3–28.1	11	17	0.012
	10/14/2009	18.3–28.1	11	17	0.0109
	11/1/2011	18.3–28.1	11.5	16.5	0.0132
393846104465601	12/8/2003	28.4–38.2	23.2	27	0.0157
	10/20/2005	28.4–38.2	20.8	—	0.0199
	7/17/2007	28.4–38.2	21.8	22	0.0174
	10/23/2007	28.4–38.2	21.6	—	0.0162
	10/14/2009	28.4–38.2	20.2	26	0.0181
	11/1/2011	28.4–38.2	21.9	25	0.0156
	7/18/2007	28.4–38.2	15.5	30	0.0249
394456104503501	7/31/2007	43.0–48.0	44.3	46	0.0783
394305104482601	6/21/2006	14.0–24.0	—	—	0.000282
	6/21/2006	14.0–24.0	—	—	0.000307
	6/21/2006	14.0–24.0	—	—	0.00238
	6/21/2006	14.0–24.0	—	—	0.000215
	6/21/2006	14.0–24.0	—	—	0.0128
	7/30/2007	14.0–24.0	13.2	15	0.00966
394305104482301	7/16/2007	17.0–27.0	10.9	12	0.0173
394520104500001	7/20/2007	14.0–24.0	18.9	22	0.0405
394002104483001	7/19/2007	25.0–40.0	16.3	24	0.015
394304104483801	7/16/2007	10.0–15.0	4.3	8	0.0386
393903104480701	7/19/2007	7.0–17.0	8.9	13	0.0232

Table 1.1. Well construction, groundwater-level, and sampling depth data establishing samples as meeting criteria for shallow groundwater for study and dissolved (filtered) uranium concentrations for U.S. Geological Survey (USGS) data used in the report.—Continued

[Data were compiled from Bruce and McMahon (1998), Paschke and others (2013), Paschke and others (2014), and USGS (2021). —, no data;?, indicates some uncertainty regarding the upper limit of the screened interval]

USGS site identifier	Sample date (month/day/year)	Screened interval or hole depth (feet below land surface)	Depth to water level (feet below land surface)	Sampling depth (feet below land surface)	Uranium, water, filtered (milligrams per liter)
Urban land use dataset from Paschke and others (2013)—Continued					
394522104495801	7/20/2007	17.0–27.0	20.8	2.6	0.0514
394525104495401	7/18/2007	25.0–35.0	20.1	30	0.0127
394040104465701	7/31/2007	8.0–13.0	5.5	10	0.0998
394304104483301	7/30/2007	10.0–20.0	12.3	15	0.0223
394055104480001	7/23/2007	22.0–32.0	5.1	18	0.0833
393939104453701	7/23/2007	8.5–18.5	4.9	12	0.0316
394007104465001	7/24/2007	16.0–26.0	8.2	14	0.0307
393750104415901	7/17/2007	7.0–12.0	5.3	8	0.026
Agricultural land use dataset from Paschke and others (2014)					
395352104302801	1/12/2003	46.2	—	—	0.00935
	7/31/2003	46.2	38.7	45	0.0241
394310104393401	7/29/2003	20	11.4	16.5	0.0383
395201104274001	9/6/2012	73.3	54.1	—	0.00102
394838104310001	7/21/2003	28.3	18.7	21	0.0222
394539104305901	8/4/2003	44.4	30.9	38.5	0.146
394947104335201	7/31/2003	33.4	19.9	32	0.0309
394933104304101	8/13/2003	43.7	30	38	0.00232
394919104291001	8/4/2003	29.1	24.4	28.5	0.0461
395909104350401	7/28/2003	42.4	23.8	32	0.0305
395541104385701	7/28/2003	18.7	9.2	16	0.0384
394351104302901	3/1/2003	46.1	—	—	0.0022
	3/1/2003	46.1	—	—	0.00012
	7/30/2003	46.1	20.6	42.5	0.000144
Urban land use dataset from Paschke and others (2014)					
393700104454101	12/2/2003	42.3	24.1	36	0.0288
	11/19/2003	23.7	9.9	18	0.0708
393903104455701	6/3/2003	38.5	—	—	0.00177
	11/21/2003	38.5	16.8	34	0.0168
	8/6/2007	38.5	16.2	27	0.03
393003104450001	11/25/2003	58.6	43.6	54	0.0458
	10/19/2005	58.6	42.3	—	0.0228
	10/15/2007	58.6	41.3	54	0.0393
	10/16/2009	58.6	40.4	—	0.0177
	10/28/2011	58.6	42	48	0.0407
393654104472001	12/1/2003	18.9	4.1	10	0.0198

Table 1.1. Well construction, groundwater-level, and sampling depth data establishing samples as meeting criteria for shallow groundwater for study and dissolved (filtered) uranium concentrations for U.S. Geological Survey (USGS) data used in the report.—Continued

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USGS site identifier	Sample date (month/day/year)	Screened interval or hole depth (feet below land surface)	Depth to water level (feet below land surface)	Sampling depth (feet below land surface)	Uranium, water, filtered (milligrams per liter)
Urban land use dataset from Paschke and others (2014)—Continued					
393655104441901	12/2/2003	23.6	12.2	20	0.00312
393655104463001	12/1/2003	48.9	23.6	40	0.0274
393742104453801	11/19/2003	28.6	11.5	20	0.0114
	10/20/2005	28.6	10.7	—	0.0113
	7/12/2007	28.6	11.4	21	0.0101
	10/16/2007	28.6	11	17	0.012
	10/14/2009	28.6	11	17	0.0109
	11/1/2011	28.6	11.5	16.5	0.0132
393158104550701	10/29/2003	77.5	39	74	0.00698
393301104561601	10/28/2003	62.9	45.6	47	0.176
393327104542001	10/27/2003	57.6	31.4	35.5	0.00421
392210104482901	11/18/2003	54.2	38.4	43	0.0531
	10/18/2005	54.2	35.4	—	0.0559
	10/11/2007	54.2	33.8	39	0.0574
	10/15/2009	54.2	38.1	42	0.0631
	10/25/2011	54.2	38.1	—	0.0703
392433104541101	11/17/2003	39.1	23.9	32	0.0338
393138104471901	11/14/2003	77.1	28.8	60	0.000139
393726104474101	11/13/2003	29.2	16.8	25	0.0416
393057104441101	11/25/2003	24.9	10.1	16	0.0237
	10/29/2003	24.9	39.4	60	0.000578
393404104565101	11/12/2003	54	19.3	37	0.000105
393408104544001	11/20/2003	49.6	35.8	40	0.00662
	10/19/2005	49.6	33.5	—	0.0011
	10/10/2007	49.6	34.4	37	0.00359
	10/15/2009	49.6	—	40	0.00574
	10/28/2011	49.6	34.8	41	0.00546
393412104534601	11/13/2003	42.2	17.8	30	0.000209
393458104544101	11/20/2003	28.6	15.3	21	0.0617
393445104563501	11/12/2003	48.8	20.4	37	0.00342
393836104474701	11/18/2003	23.8	8.4	13	0.0105
393823104455801	12/10/2003	43.1	17.6	29	0.00997

Table 1.1. Well construction, groundwater-level, and sampling depth data establishing samples as meeting criteria for shallow groundwater for study and dissolved (filtered) uranium concentrations for U.S. Geological Survey (USGS) data used in the report.—Continued

[Data were compiled from Bruce and McMahon (1998), Paschke and others (2013), Paschke and others (2014), and USGS (2021). —, no data;?, indicates some uncertainty regarding the upper limit of the screened interval]

USGS site identifier	Sample date (month/day/year)	Screened interval or hole depth (feet below land surface)	Depth to water level (feet below land surface)	Sampling depth (feet below land surface)	Uranium, water, filtered (milligrams per liter)
Urban land use dataset from Paschke and others (2014)—Continued					
393846104465601	12/8/2003	38.7	23.2	27	0.0157
	10/20/2005	38.7	20.8	—	0.0199
	7/17/2007	38.7	21.8	22	0.0174
	10/23/2007	38.7	21.6	—	0.0162
	10/14/2009	38.7	20.2	26	0.0181
	11/1/2011	38.7	21.9	25	0.0156
393733104465101	12/10/2003	28.7	13.8	18	0.0224
393947104473801	12/8/2003	25.7	10.8	14	0.0337

Table 1.2. Dissolved uranium concentrations from shallow groundwater samples and stormwater outfalls from Operating Unit 8 (OU8) of the Denver Radium Superfund Site.

[From U.S. Environmental Protection Agency (2018) and Sandor (2018)]

Site identifier	Site type	Dissolved uranium, in milligrams per liter	
		5/11/2017	3/7/2018
APM-3	Well	0.0505	0.0526
APM-4	Well	0.0332	0.0237
APM-6	Well	0.0238	0.0243
BH-3	Well	0.051	0.0483
MW-1	Well	0.0301	0.0293
MW-3	Well	0.0532	0.0274
MW-6	Well	0.0439	0.0352
VMW-03	Well	0.0563	0.0508
VMW-04	Well	0.0448	0.0466
VMW-06	Well	0.04	0.0258
S-133-E	Stormwater outfall	0.0016	dry
SPR-1	Stormwater outfall	0.0069	0.0152
SPR-2	Stormwater outfall	0.0076	0.0169

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