ATSDR
AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY

Public Health Assessment for

Evaluation of Community Exposures Related to Coldwater Creek
St Louis Airport/Hazelwood Interim Storage Site
(HISS)/Futura Coatings NPL Site
North St Louis County, Missouri

EPA Facility ID MOD980633176
JUNE 18, 2018

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
Agency for Toxic Substances and Disease Registry

Comment Period Ends:

AUGUST 31, 2018

THE ATSDR PUBLIC HEALTH ASSESSMENT: A NOTE OF EXPLANATION

This Public Health Assessment-Public Comment Release was prepared by ATSDR pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) section 104 (i)(6) (42 U.S.C. 9604 (i)(6), and in accordance with our implementing regulations (42 C.F.R. Part 90). In preparing this document, ATSDR has collected relevant health data, environmental data, and community health concerns from the Environmental Protection Agency (EPA), state and local health and environmental agencies, the community, and potentially responsible parties, where appropriate. This document represents the agency's best efforts, based on currently available information, to fulfill the statutory criteria set out in CERCLA section 104 (i)(6) within a limited time frame. To the extent possible, it presents an assessment of potential risks to human health. Actions authorized by CERCLA section 104 (i)(11), or otherwise authorized by CERCLA, may be undertaken to prevent or mitigate human exposure or risks to human health. In addition, ATSDR will utilize this document to determine if follow-up health actions are appropriate at this time.

This document has previously been provided to EPA and the affected state in an initial release, as required by CERCLA section 104 (i) (6) (H) for their information and review. Where necessary, it has been revised in response to comments or additional relevant information provided by them to ATSDR. This revised document has now been released for a 60-day public comment period. Subsequent to the public comment period, ATSDR will address all public comments and revise or append the document as appropriate. The public health assessment will then be reissued. This will conclude the public health assessment process for this site, unless additional information is obtained by ATSDR which, in the agency's opinion, indicates a need to revise or append the conclusions previously issued.

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Prepared by:

Division of Community Health Investigations
U.S. Department of Health and Human Services
Agency for Toxic Substances and Disease Registry

Summary

Introduction

The Agency for Toxic Substances and Disease Registry (ATSDR) evaluates community exposures and makes recommendations to prevent harmful exposures to hazardous substances in the environment. This report evaluates exposures to people who play or live near Coldwater Creek in North St. Louis County, Missouri. Historical radiological waste storage sites near the St. Louis Airport released contamination into Coldwater Creek. The Army Corps of Engineers' Formerly Utilized Sites Remedial Action Program (FUSRAP) has been characterizing and cleaning up areas related to these sites since 1998.

Community members asked ATSDR to do this evaluation. They are particularly interested in exposures that occurred in the past, before storage site cleanup began.

This report uses available environmental data and information from the community to evaluate whether people playing or living near Coldwater Creek have or had harmful exposures to radiological or chemical contaminants from the creek. This report also addresses other exposure concerns which could not be fully assessed and makes recommendations for further work.

Conclusions

ATSDR reached the following four conclusions in this report.

Conclusion 1

Radiological contamination in and around Coldwater Creek, prior to remediation activities, could have increased the risk of some types of cancer in people who played or lived there.

Basis for Conclusion

- Children and adults who regularly played in or around Coldwater Creek or lived in its floodplain for many years in the past (1960s to 1990s) may have been exposed to radiological contaminants. ATSDR estimated that this exposure could increase the risk of developing bone or lung cancer, leukemia, or (to a lesser extent) skin or breast cancer.
- More recent exposures (2000s and on) increased the risk of developing bone or lung cancer from daily residential exposure.

Next Steps

- ATSDR recommends that potentially exposed residents or former residents share their potential exposure related to Coldwater Creek with their physicians as part of their medical history and consult their physicians promptly if new or unusual symptoms develop. Upon request, ATSDR can facilitate a consultation between residents' personal physicians and medical specialists in environmental health.
- ATSDR recommends that the state consider updating analyses on cancer incidence, cancer mortality, and birth defects, as feasible.
- ATSDR will provide technical support, upon request, to update cancer incidence or mortality studies in the area and identify public health actions needed.

Conclusion 2

ATSDR does not recommend additional general disease screening for past or present residents around Coldwater Creek.

Basis for Conclusion

- The predicted increases in the number of cancer cases from exposures are small, and no method exists to link a particular cancer with this exposure.
- Not all current or former residents would have experienced exposures as high as assumed by ATSDR in this evaluation.
- Screening people who have no symptoms has risks, including false negative results, false positive results, risks from treating cancers that might never have caused a problem during a person's lifetime, and additional radiation exposure from diagnostic testing. A personal physician will use a patient's individual history, symptoms, age, and gender to determine appropriate screening and diagnostic testing.

Next Steps

- ATSDR recommends that potentially exposed residents or former residents share their potential exposure related to Coldwater Creek with their physicians as part of their medical history and consult their physicians promptly if new or unusual symptoms develop. Upon request, ATSDR can facilitate a consultation between residents' personal physicians and medical specialists in environmental health.

Conclusion 3

ATSDR supports ongoing efforts to identify and properly remediate radiological waste around Coldwater Creek.

Basis for Conclusion

- Thorium-230 (Th-230) has been found above FUSRAP remedial goals in several areas of the Coldwater Creek floodplain. Reducing Th-230 levels in accessible areas will reduce harmful exposures.
- Waste entered the creek decades ago, and detailed information about how it moved with sediment and into floodplain soil does not exist. Reports of historical use of Coldwater Creek sediment and floodplain soil in other locations indicates a possibility that contamination spread from the floodplain. Identifying and remediating contaminated areas outside the floodplain will reduce potentially harmful exposures.

Next Steps

- ATSDR recommends that the FUSRAP program continue investigating and cleaning up Coldwater Creek sediments and floodplain soils to meet regulatory goals. To increase knowledge about contaminant distribution and allay community concerns, we recommend future sampling include
  - areas reported to have received soil or sediment moved from the Coldwater Creek floodplain (such as fill used in construction)
  - areas with possible soil or sediment deposited by flooding of major residential tributaries to Coldwater Creek
  - indoor dust in homes where yards have been cleaned up or require cleanup
  - sediment or soil remaining in basements that were directly flooded by Coldwater Creek in the past
- ATSDR recommends signs to inform residents and visitors of potential exposure risks in areas around Coldwater Creek not yet investigated or cleaned up.
- ATSDR will review new data from Coldwater Creek investigations, upon request, and update conclusions if necessary.

Conclusion 4

ATSDR is unable to evaluate other exposure pathways of concern to the community.

Basis for Conclusion

- No sampling data exist that would allow ATSDR to estimate exposures from other pathways, such as inhaling dust blown from historical radiological waste storage piles.

Next Steps

- ATSDR recommends that public health agencies continue to evaluate, to the extent possible, community concerns about exposure and educate the community about radiological exposures and health.
- ATSDR is evaluating the feasibility of conducting modeling to evaluate exposure to windblown dust from historical radiological waste storage piles.
- ATSDR will remain available to provide, upon request, further technical assistance to the public, partner agencies, or other stakeholders.

NOTE

These conclusions may change following public input or availability of new environmental sampling data.

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Purpose and Health Issues

This report evaluates whether radiological contamination in and around Coldwater Creek in North St. Louis County, Missouri, has affected the health of people playing or living nearby. Historical storage and handling of uranium processing waste at distinct upstream source areas (described in the next section) released contamination into Coldwater Creek, shown in Figure 1. Coldwater Creek and its floodplain areas, the historical upstream source areas, and other nearby properties are all included on the U.S. Environmental Protection Agency's (EPA) National Priorities List (NPL) and are part of the St. Louis Airport NPL Site.

The Agency for Toxic Substances and Disease Registry (ATSDR) conducts public health activities on all sites proposed for the NPL. In 1994, ATSDR released a public health assessment evaluating radiological exposures associated with the historical source areas [1]. The 1994 report recommended dust control during remediation at the source areas and further characterization of Coldwater Creek and other offsite areas.

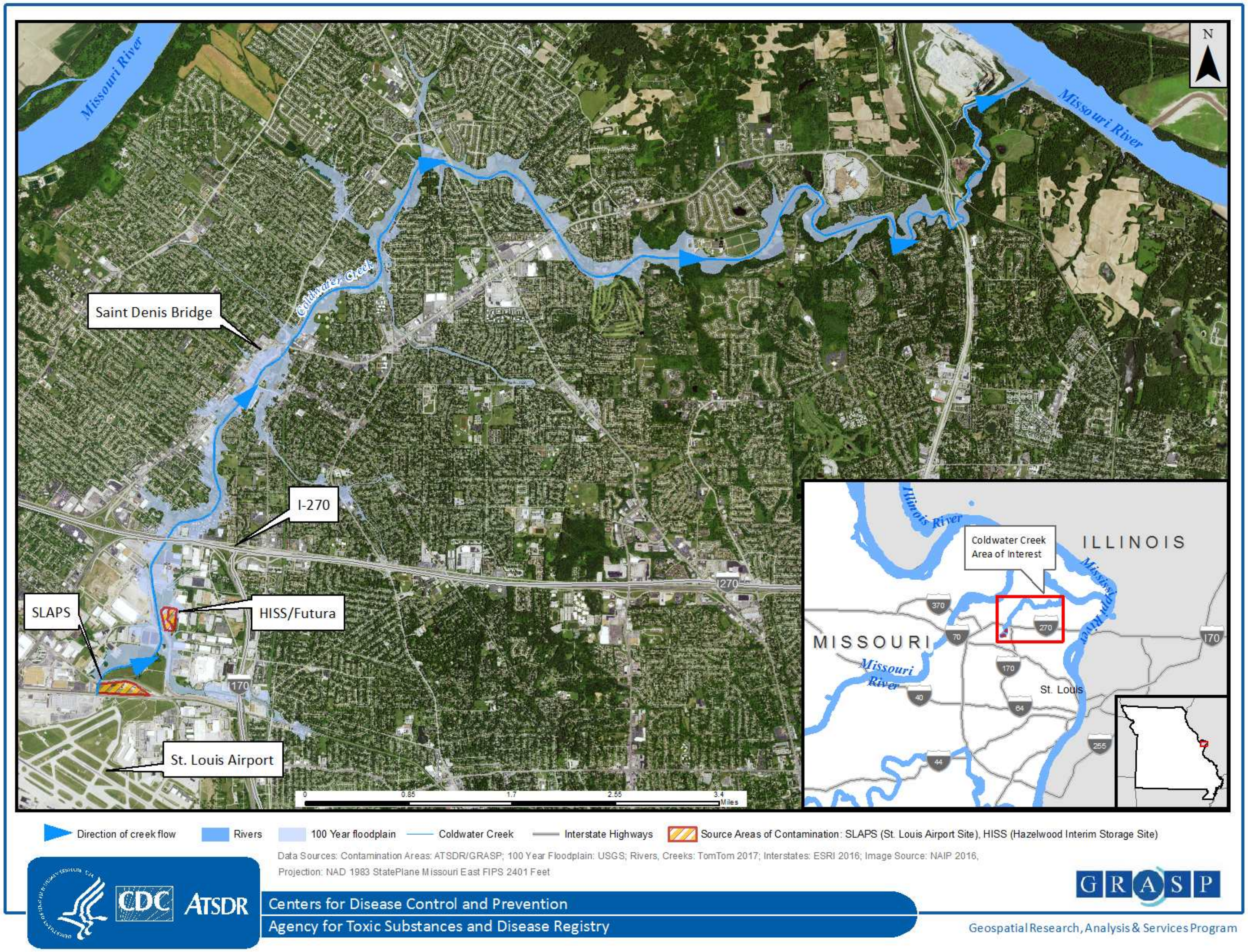
The Army Corps of Engineers' Formerly Utilized Sites Remedial Action Program (FUSRAP) has been characterizing and cleaning up source areas and other properties affected by the site since 1998. They have followed ATSDR's recommendation to perform dust control during remediation. FUSRAP began a detailed investigation of Coldwater Creek and its floodplain areas in October 2012, working downstream from the source areas. FUSRAP has identified several areas in parks and residential areas along Coldwater Creek with soil concentrations of radiological contaminants higher than remedial goals. FUSRAP was in the process of cleaning up these areas of contamination as we were preparing this report.

Community members asked ATSDR to evaluate past and present exposures of those who played, lived, or worked near Coldwater Creek. They were particularly interested in exposures that occurred in the past before cleanup began at the sites. In response to community concerns, this public health assessment focuses on Coldwater Creek to help determine potential public health effects of past, present, or future exposures to hazardous substances in or near Coldwater Creek.

In this report, ATSDR uses available environmental sampling data to estimate and evaluate exposure of children and adults to contaminants in Coldwater Creek and floodplain areas for two scenarios:

- Playing in and around the creek, its banks, and floodplain soils and riding bicycles or dirt bikes near the creek
- Playing, gardening, or landscaping in residential yards near the creek

Figure 1. Coldwater Creek area, North St. Louis County, Missouri



This report also includes a section listing and addressing other community exposure and health concerns that ATSDR did not directly evaluate. We provide information about these concerns, indicating any further work that we recommend or that may be in progress to help address them.

Background

Historical Activities and Source of Contamination

The following is a brief overview of the activities and sources that led to contamination of Coldwater Creek. See site documents for a detailed history [1–9].

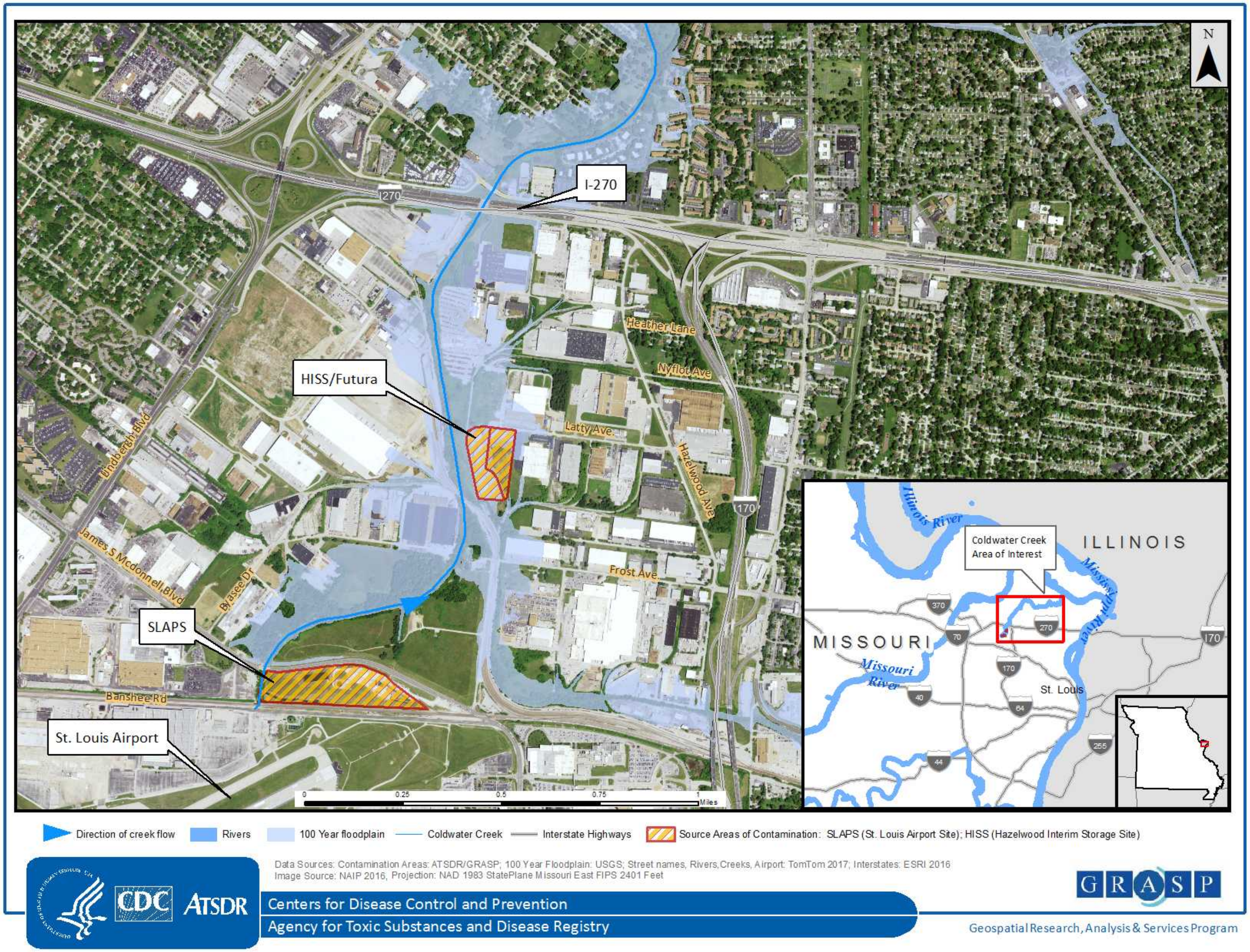
During World War II, the Mallinckrodt Chemical Works in downtown St. Louis developed technology for extracting uranium from ore. The extracted uranium was shipped elsewhere to be purified, enriched, and used in the early nuclear weapons program known as the Manhattan Project. After Mallinckrodt extracted the uranium, the remaining wastes contained residual uranium and other radioactive elements.

Beginning in 1946 until the downtown facility stopped operating in 1957, this waste was transported to a storage site in a relatively undeveloped industrial area near the St. Louis Airport. See Figure 2 for a map of the historical source areas and surroundings. This original storage location is the St. Louis Airport Site (SLAPS). The waste at SLAPS included storage drums, scrap metal, and large covered and uncovered piles stored on open ground. In 1966, much of the waste at SLAPS was moved to another location about half a mile to the northeast, where it was processed, dried in open uncovered piles, and shipped offsite, mostly to Colorado companies. This second processing and storage area includes the Hazelwood Interim Storage Site (HISS) and Futura Coatings Site. HISS and Futura are both part of the NPL site along with SLAPS; they are considered historical sources of contamination of Coldwater Creek for the purposes of this report.

While waste piles were uncovered, rain and wind moved particles containing radiological contaminants to surrounding soil and nearby properties. Some of the waste eventually ran off into Coldwater Creek, which flowed past the sites, where it contaminated creek sediments. Contaminated sediments could flow downstream, settle out in certain locations, or end up in soils next to the creek after floods.

In October 1989, EPA placed SLAPS and Futura/HISS on the NPL. Associated vicinity properties, including Coldwater Creek, have been considered part of the site for characterization and cleanup. Site cleanup is currently the responsibility of FUSRAP and is directed by the September 2005 Record of Decision (ROD) for the North St. Louis County Sites [2]. Cleanup focused initially on controlling historical source areas and then on cleaning up properties nearest them. As of 2017, the historical source areas at SLAPS and HISS/Futura have been cleaned up, and more than half of the 148 vicinity properties have been released for beneficial use.

Figure 2. Coldwater Creek historical source areas, North St. Louis County, Missouri



FUSRAP began extensive characterization of Coldwater Creek in 2012, working downstream (north) from the source areas. Sampling focuses on the ten-year floodplain of the creek; if contaminants found are above remedial goals, sampling may extend past the ten-year floodplain to delineate the edge of contamination. Pre-design investigation sampling has been completed for the stretch of the creek from McDonnell Boulevard (within the industrial area, near SLAPS) to the St. Denis Bridge, about three and a half miles downstream from SLAPS. As FUSRAP works its way down the creek, it is cleaning up soils identified with contaminants above remedial goals.

Activities by ATSDR and its Public Health Partners

- In 1988 and 1989, the Missouri Department of Health (MDOH, now known as the Missouri Department of Health and Senior Services [MDHSS]) reviewed cancer incidence and mortality data from August 1984 to September 1988 around several sites, including SLAPS and HISS. At that time, MDOH could not calculate the observed and expected cancer rates, because about 15% of hospitals were not yet in compliance with new cancer reporting laws [10]. Graphic plots of cancer cases and deaths around SLAPS and HISS showed no obvious clustering. The review noted one case of leukemia in a child living on Nyflot Avenue, the residential street closest to HISS (See Figure 2).

  Subsequently, MDOH received reports of additional cancer cases on Nyflot Avenue and investigated. They confirmed nine cases of cancer, including lymphoma, thyroid, prostate, colon, breast, melanoma, and three different types of leukemia, in residents of the street from 1963 to 1989. MDOH's review of medical records concluded that radiation induction could not be ruled out for any of the cases except melanoma [10,11].
- In 1994, ATSDR released a preliminary public health assessment of the SLAPS/HISS sites [1].
  - The report concluded that exposure at the site posed an indeterminate public health hazard, but limited data suggested that possible past exposures may have been at levels of health concern.
  - Environmental data from Coldwater Creek-associated residential, recreational, or other floodplain sites were not available at the time of the evaluation.
  - ATSDR recommended additional on-site and off-site sampling, characterization of site contaminants, and implementation of dust control actions during remedial activities at the sites.
  - ATSDR's assessment concluded that follow-up public health actions or studies were appropriate for the site.
- In March 2013, MDHSS reviewed 1996–2004 cancer incidence data from six ZIP codes adjacent to Coldwater Creek [12].
  - Incidence of several types of cancer, including female breast, colon, prostate and kidney, was statistically significantly elevated compared to the Missouri state rates.
- In September 2014, MDHSS released an update to the 2013 report that included more recent incidence data up to 2011. MDHSS added two ZIP codes to the review to account for people

who may have moved to nearby areas and refined the analysis to obtain more details about child cancers, leukemia, and rare cancers [13]. The updated analysis found that
  - Incidence of childhood brain and other nervous system cancers was statistically significantly elevated compared to the Missouri state rates.
  - Incidence of leukemia, female breast, colon, prostate, kidney, and bladder cancers was statistically significantly elevated compared to the Missouri state rates.

  Later, empirical Bayesian modeling confirmed these findings.
- In January 2015, ATSDR participated in a meeting with MDHSS and other stakeholders to discuss next steps for Coldwater Creek. The meeting resulted in three key recommendations:
  - Evaluate potential exposures to contaminants along Coldwater Creek.
  - Perform advanced statistical modeling.
  - Engage the community.

This report fulfills the first recommendation from the January 2015 meeting to the extent possible, given the data and science available at this time. In completing this report, ATSDR engaged with the community during multiple ATSDR open houses, community meetings, and FUSRAP public meetings. ATSDR also toured the site with members of a local community group to learn how they currently use areas near the creek and how they used them in the past. We thank the community for sharing this valuable local knowledge. We also thank the FUSRAP program for providing the extensive site-related data used in this assessment and describing that data in both its current and historical context.

Characteristics of Coldwater Creek and Its Surroundings

Land Use and Demographics

Originally, the area between the St. Louis Airport and current I-270 was used for agricultural purposes; the very few residential dwellings present were several hundred feet away from Coldwater Creek. Industrial development of this area began in the early 1950s. From the early 1970s through the 1980s, an area immediately north of SLAPS and east of Coldwater Creek was used as baseball fields [9]. ATSDR's 1994 public health assessment discussed potential exposures at these fields and recommended further characterization of contamination there [1]. The ball fields are closed, and the area south of I-270 remains mostly industrial. Two streets, Nyflot Avenue and Heather Lane, are about ¼ mile northeast of the HISS/Futura source area and include residential homes pre-dating the sites. These homes are about ½ mile from Coldwater Creek. Industrial businesses obstruct direct access to the creek from these homes.

The stretch of Coldwater Creek from I-270 and Pershall Road to the St. Denis Bridge (evaluated in this report) was used primarily for agricultural purposes through the 1950s, with a few residential dwellings located several hundred feet from the creek [9]. By 1966, the area was highly developed (residentially and commercially), with recreational parks located within 100 feet of Coldwater Creek [9]. This stretch of the creek remains residential, recreational, and commercial today. Figure 3 illustrates how the demographic profile of the area has changed over the years.

Topography, Geology, and Soil

The source areas and Coldwater Creek are located on land slightly elevated above the Missouri River floodplain [2–4]. Bedrock consists of Pennsylvanian shale and Mississippian limestone about 100 feet below the ground surface. The bedrock appears to be almost flat, with no evidence of faulting. Pleistocene soil and recent surficial loess, clay, sands, and gravel overlay the bedrock. Surface soils in the area are mostly silty deposits from former glacial advances, historical Missouri and Mississippi River flooding, and more recent fill activities. The Coldwater Creek floodplain is mostly flat and sloping towards the creek, although depressions lower than the creek exist in various places. A strip of trees, brush, and grass generally borders the creek banks.

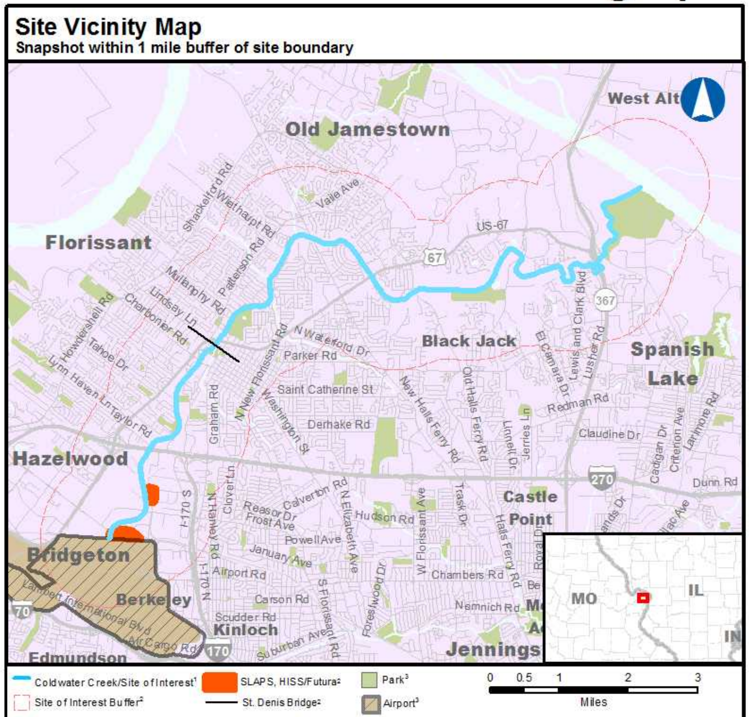
Surface Water and Groundwater

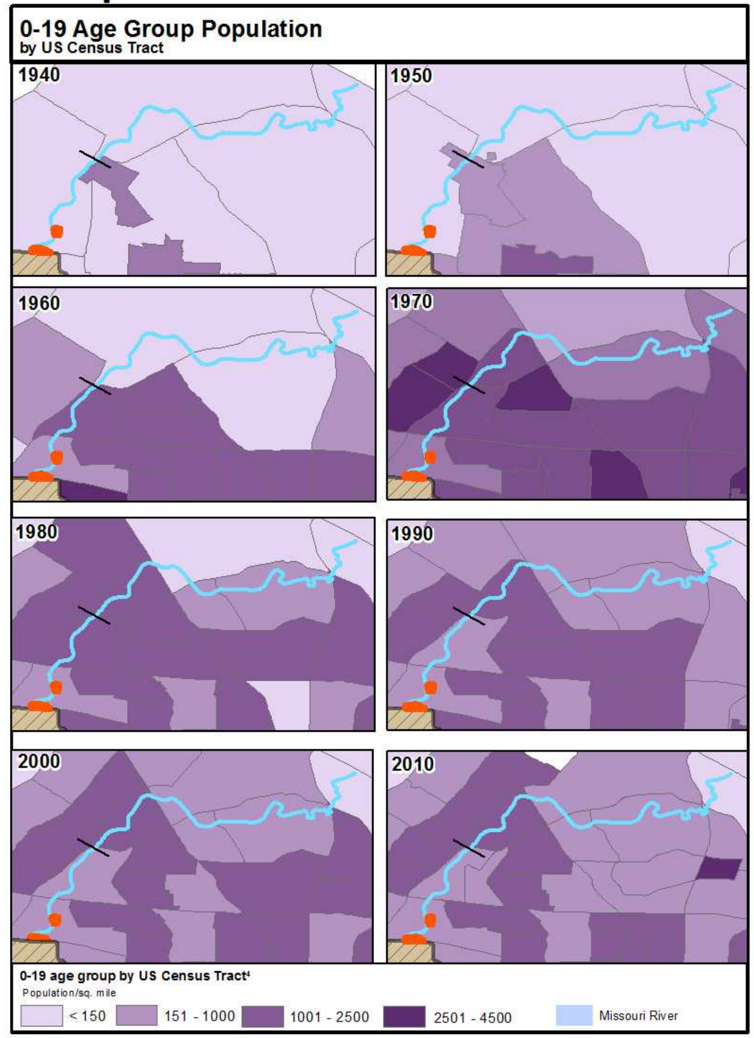
Coldwater Creek is the major drainage feature for the historical source areas near SLAPS. The creek originates south of the St. Louis Airport and flows through a channel under the airport. The creek resurfaces at the south edge of the SLAPS site and flows north past SLAPS, HISS/Futura and associated vicinity properties. In the past, ditches around these historical source areas drained stormwater and other surface water runoff to the creek. After passing the historical source areas, Coldwater Creek continues meandering northward through residential, recreational, and commercial areas of North St. Louis County until it empties into the Missouri River. Coldwater Creek floods regularly, mainly due to flash flooding from summer thunderstorms [14]. According to FUSRAP's review of historical aerial photographs and maps described in the work plan for recent Coldwater Creek investigations, the shape of the creek channel has not changed significantly since 1937, before SLAPS existed [9]. Although the shape of the channel has not changed, the channel itself has been altered to reduce the impact of flooding. The banks have been stabilized by the addition of rip-rap or concrete at various locations along the creek [9].

Surface water serves as a source of drinking water in the metropolitan St. Louis area, but contaminants in Coldwater Creek are unlikely to affect drinking water from surface water sources. A private company supplies drinking water to North St. Louis County using water from the Missouri River; the two intakes are located more than five miles upstream from where Coldwater Creek enters the river [15]. This supplier also uses water from the Meramec River southwest of St. Louis. The City of St. Louis obtains water from two intakes. One is on the Missouri River more than ten miles upstream from where Coldwater Creek enters the river. The other intake is on the Mississippi River, about two miles downstream from the Missouri River and more than five miles downstream of the mouth of Coldwater Creek [16]. All public water is

Figure 3. Demographic information over time, Coldwater Creek area, North St. Louis County, Missouri

Coldwater Creek Site Demographic Snapshot





Demographic Statistics[4,5]

Within 1 mile buffer of site boundary

	Total Population	White	Non White[6]	Children Aged 6 and Younger[7]	Adults Aged 65 and Older	Females Aged 15 to 44	Total Housing Units
1940	3,498	3,344	152	273	242	762	880
1950	7,550	7,288	263	1,069	388	1,816	1,874
1960	26,574	26,401	186	4638	852	5,870	7,092
1970	67,115	65,636	1,478	10,128	2,269	15,854	18,381
1980	65,688	59,319	6,365	6,081	4,276	15,864	20,961
1990	63,103	53,316	9,792	6,130	7,461	14,586	24,123
2000	66,962	48,030	18,935	6,181	9,430	14,747	27,140
2010	66,387	34,763	31,622	5,507	9,597	13,682	28,249

Data Sources: [1]ATSDR GRASP Hazardous Waste Site Boundary Database. [2]ATSDR GRASP. [3]TomTom International BV (2012). [4]US Census 2000 and 2010. IPUMS NHGIS 1940-2010. Steven Manson, Jonathan Schroeder, David Van Riper, and Steven Ruggles. IPUMS National Historical Geographic Information System: Version 12.0 [Database]. Minneapolis: University of Minnesota. 2017 http://doi.org/10.18128/D050.V12.0
Notes:[5]Calculated using area-proportion population estimation spatial anlysis method. [6] Non White may include: Black, American Indian and Alaska Native, Asian, Native Hawaiian and Other Pacific Islander, Some Other Race, and/or Two or More Races. [7]Early censuses 1940-1960 children 5 and under.
Projection: Projection used for all map panels is NAD 1983 StatePlane Missouri East FIPS 2401 feet

treated and in compliance with Safe Drinking Water Act regulations, including radionuclide limits [17–19].

Groundwater at SLAPS and HISS/Futura is found in two aquifers: an unconfined surface aquifer and a confined deep aquifer. The surface aquifer at the source areas has shown elevated levels of radiological contaminants compared to background [6]. Monitoring at the source areas and in Coldwater Creek has not shown evidence that groundwater at the source areas affects Coldwater Creek. As described earlier, all of the homes in the area are currently served by public drinking water drawn from the Missouri River and treated before distribution. In the past, some homes may have used private wells for domestic purposes. A well survey conducted in 1987–88 identified three domestic wells, all abandoned before 1980 [20]. Two of the wells were about half a mile northeast of the HISS/Futura site, and the other was in a residential area more than a mile downstream from the source areas.

Climate

The St. Louis area has a strongly seasonal climate influenced by cold, arctic air masses in the winter and hot, humid air from the Gulf of Mexico in the summer. Spring and fall are transitional seasons where rapid changes in temperature and precipitation can occur due to rapidly moving fronts between air masses. Like all parts of Missouri, St. Louis experiences extreme weather events such as high-intensity rainfall, protracted drought, ice storms, and tornadoes. Heavy thunderstorm events cause flooding in tributaries of the major rivers once or twice a year [14].

ATSDR's Evaluation Process

The following three steps briefly summarize ATSDR's evaluation process [21].

- First, we identify possible *exposure pathways* at the site. An exposure pathway consists of an uninterrupted path from a contaminant source through the water, air, or soil to a person's body where it can possibly cause harm.
- Next, we use environmental data to identify the *contaminants* of most concern. We compare measured levels with appropriate health-based screening values[1] and regulatory limits, recommendations, and typical background levels. Concentrations of radiological materials and/or chemicals that are too low to cause harmful effects are not evaluated further. We evaluate contaminants remaining beyond this step in detail, considering how people are exposed, to see if harmful effects are possible.
- Further evaluation estimates how much of the contaminant a person would come near or take into their body and whether it is enough to cause harmful health effects. For radiologic contaminants, we have to consider the amount of energy absorbed by various

[1] ATSDR calculates comparison values from minimal risk levels published by ATSDR (EMEGs), reference doses published by EPA (RMEGs), or cancer slope factors published by EPA (CREGs). ATSDR currently maintains a tool for viewing comparison values at https://www.atsdr.cdc.gov/sites/brownfields/CVViewer.html.

tissues of the body and target organs, and the type of radiation emitted by the contaminants. To conclude whether exposure to the contaminant is harmful, we compare these estimates with scientific literature reviews of exposures known to cause harmful health effects (non-cancer or cancer).

Appendices of this report present details of ATSDR's evaluation process.

- Appendix A explains how we used and evaluated community input on exposures at the site and followed standard ATSDR procedures to develop reasonable exposure and intake assumptions used in exposure dose calculations.
- Appendix B describes the screening process for radiological and chemical contaminants. It includes tables showing contaminants detected at the site and selected for further evaluation.
- Appendix C describes how we determined representative yet conservative exposure point concentrations of contaminants evaluated in soil, sediment, and water to use in exposure dose calculations.
- Appendix D describes how we calculated estimates of contaminant intake for the exposures evaluated.
- Appendix E details how we calculated the radiological dose for specific organs and the whole body for the estimated exposures and how we estimated increased cancer risk corresponding to the radiological doses. Appendix E also contains detailed dose and risk results.

Evaluation of Community Exposure While Playing or Living Along Coldwater Creek

Description of Exposure Pathway

People playing or living downstream of the source areas near Coldwater Creek (now or in the past) may have been exposed to contaminants that washed down the creek. Residential areas shown in Figure 1 begin ¾ miles downstream from the site; people who played near the creek would go to parks or the creek close to those areas. As described earlier and shown in Figure 2, people in the homes east of the industrial area are relatively close to former storage areas, though nearby industrial facilities and the airport generally block access to Coldwater Creek for recreational purposes. For this report, we consider any area along the creek north of (downstream from) I-270/ Pershall Road to be available for exposure.

The radiologic and chemical contaminants associated with the historical source areas traveled downstream with creek sediments. People could be exposed by contacting sediment, water (with suspended sediment in it), or floodplain soils (contaminated with sediment during flood events). They could take contaminants into their bodies by accidentally swallowing small amounts of sediment, water, or soil. They could also breathe contaminants if their activities suspend enough dust from dry, contaminated soil. If the contaminants are radioactive, people may receive an external dose of radiation just from being near the contamination.

The direct exposures evaluated in this report are the following:

Recreational Exposure

- Accidentally swallowing contaminated soil, sediment, or surface water while playing in and around Coldwater Creek and its floodplain
- Breathing in dust suspended from floodplain soils while playing and riding bicycles or dirt bikes around Coldwater Creek and its floodplain
- Receiving external radiation exposure during recreational activities in and around Coldwater Creek and its floodplain

Residential Exposure

- Accidentally swallowing contaminated residential soil and dust while playing in the yard and inside the home, gardening, or landscaping around Coldwater Creek and its floodplain
- Breathing in dust suspended from residential soil while playing in the yard, gardening, or landscaping around Coldwater Creek and its floodplain
- Receiving external radiation exposure during residential activities in the yard around Coldwater Creek and its floodplain

Note on Exposures near Tributaries of Coldwater Creek

Exposures along Coldwater Creek would likely be higher than exposures that may have occurred or may occur along tributaries that feed into Coldwater Creek. Flood events in which Coldwater Creek backed up into tributaries may have deposited sediments. However, the resulting concentrations on tributary banks and floodplains would not likely be higher than the areas of highest contamination measured in the Coldwater Creek floodplain. FUSRAP samples the 10-year floodplain adjacent to Coldwater Creek, including the mouths of tributaries. If contamination is found in this area, additional sampling is performed [9].

Available Data and Information

ATSDR obtained and reviewed numerous historical and recent reports, correspondence, and articles related to the source areas, Coldwater Creek, and the surrounding area in developing this report. Both a local community group and FUSRAP staff provided site-related documents and historical context. ATSDR staff and contractors also reviewed and used additional documents obtained from online databases of scientific literature and governmental reports.

Many reports described investigations of contamination at the source areas and vicinity properties near them. While the environmental sampling data in these reports is essential for describing the source of the creek's contamination, ATSDR cannot use the data to estimate potential recreational and residential exposures directly, because they do not describe the locations where exposures occurred.

Quantitative estimation of recreational and residential exposures relied on two main sources of information:

- Information from a local community group on how, how often, and for how long children and adults played near the creek or played or worked in their yards near the creek (described below and in Appendix A) [22]. We used this input to develop exposure assumptions for recreational and residential exposures.
- Environmental sampling data describing the levels of site-related contamination in and around recreational and residential stretches of Coldwater Creek. Because these data were collected to design remediation strategies or for monitoring, they may not fully characterize the nature and extent of contamination. We used these data to identify contaminants of concern and determine exposure point concentrations for each contaminant in soil, sediment, and surface water (described below and in Appendices B and C). The data relevant to community exposures included:
    - Sediment and floodplain soil samples from I-270 north to the St. Denis Bridge collected in 2014-2016 [23]
    - Soil and sediment samples along Coldwater Creek from SLAPS to the Missouri River collected between 1986 and 1990 [24]
    - Sediment and surface water from a station near I-270 collected from 1998 to 2014 and from two new stations in residential areas in 2014 [25-41]

In this report, we do not cite all of the numerous documents we reviewed, but we have included a list of documents reviewed but not cited immediately following the numbered references at the end of the text.

Exposure and Intake Assumptions for Recreational and Residential Exposure

To estimate exposures for a given activity, ATSDR needs to use two kinds of assumptions in combination with data on contaminants in the environment. *Exposure assumptions* describe how often people do a certain activity and for how long. *Intake assumptions* are factors to estimate or calculate how much soil, sediment, or water from the environment a person might take into their bodies during the activity. Combining exposure and intake assumptions with concentrations of contaminants allows us to calculate the amount of contaminant taken into the body.

We used community input and Agency guidelines to estimate how much soil, sediment, or water from the creek people could take into their bodies over time

To develop exposure assumptions, ATSDR asked a local community group familiar with Coldwater Creek to provide information about how often people living along Coldwater Creek did various activities in the creek and its floodplain. Appendix A summarizes the input received, and explains how we considered the input, along with ATSDR's standard evaluation procedures, to develop the assumptions used in this assessment. ATSDR developed exposure assumptions for past exposures to represent exposures that occurred between the 1960s and 1990s, when children in the area often played in and near Coldwater Creek. ATSDR also determined more recent exposure assumptions that reflect the decreased amount of time currently spent by children and adults playing in the creek. Tables A5 and A6 of Appendix A summarize the exposure assumptions used in ATSDR's evaluation.

For both past and recent exposures, ATSDR assumed a duration of 33 years, beginning at birth. This duration is ATSDR's default high-end residential occupancy period. Data used to estimate recent exposures (described in the next section) are assumed to represent exposures dating back to the early 2000s, but the 33-year duration of exposure assumes recent exposures could conceivably continue until remedial activities are complete (currently estimated by the FUSRAP program to be in 2033 or 2034).

For intake assumptions, ATSDR used standard defaults and derived factors to describe how much soil, sediment, or surface water a child or adult could breathe in or accidentally swallow while playing or living near Coldwater Creek. We used the same intake assumptions for both past and recent exposures. Tables A7 through A10 of Appendix A summarize the intake assumptions used in this evaluation.

ATSDR used exposure and intake assumptions to estimate:

- Ingestion of soil while playing in and near the creek or playing, gardening, or landscaping in yards of homes near the creek[2]
- Ingestion of sediment and surface water while wading or swimming in the creek
- Inhalation of dust suspended from soil while playing or riding bicycles or dirt bikes near the creek or playing, gardening, or landscaping in yards of homes near the creek

[2] ATSDR evaluated only direct exposure to soils during gardening activities, not consumption of home garden products. Please see page 35 for more information.

ATSDR also used duration and frequency assumptions to estimate external radiation dose during these activities. The following two sections and the appendices provide more information on these topics.

Contaminants of Concern

We looked at all the data and focused on the substances most likely to result in harmful exposure:

Thorium-230
Radium-226
Uranium-238

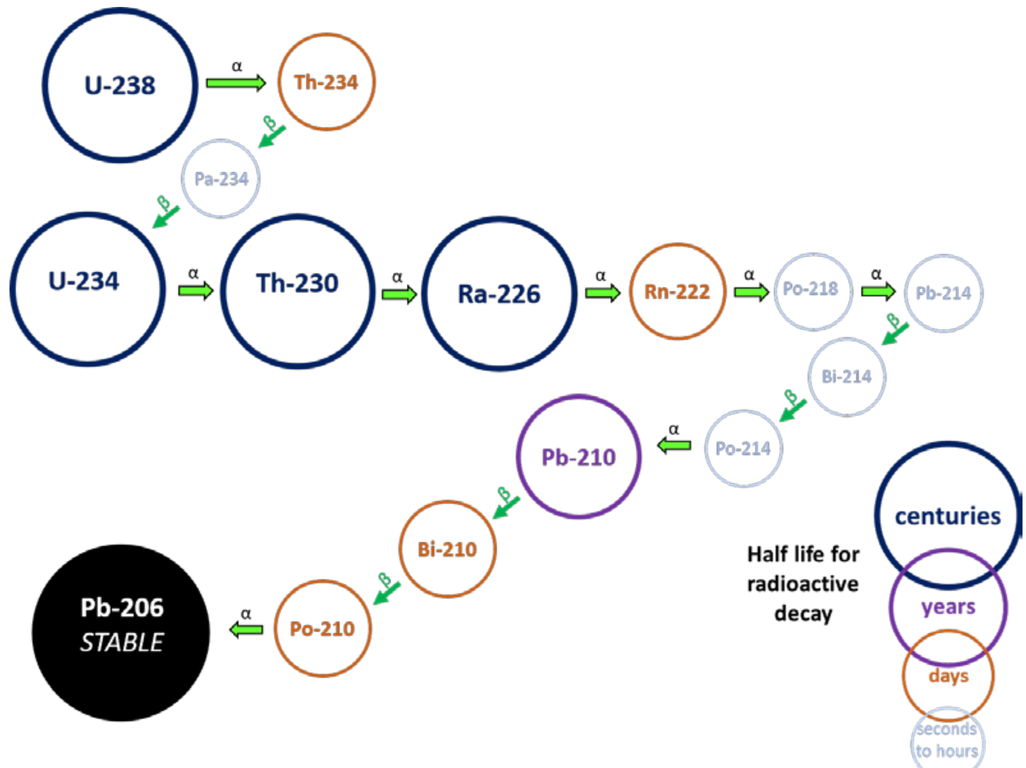
ATSDR reviewed the available data collected from recreational and residential stretches of Coldwater Creek. The data almost exclusively focused on radiological contaminants previously found to be associated with the historical source areas. Appendix B details ATSDR's screening of radiological contaminant data. Of the radiological contaminants detected, thorium-230 (Th-230) was present in soil and sediment at levels consistently above typical background levels (1 to 3 picocuries per gram (pCi/g) for soil and sediment). It was also detected frequently above FUSRAP's remedial goal for Th-230 in soil (14–15 pCi/g). ATSDR included Th-230, radium-226 (Ra-226), and uranium-238 (U-238) in its evaluation of potential community exposures from Coldwater Creek. These contaminants are all long-lasting members of the same radioactive decay chain, depicted in Figure 4. U-238 forms other products as it decays, eventually producing Th-230, which in turn produces Ra-226. Because processing removed uranium from ore during processing, the process waste contains higher concentrations of Th-230 and Ra-226 than unprocessed ore.

Limited data on metals and other non-radiological chemicals in sediment and surface water were available for the recreational and residential stretches of Coldwater Creek. Appendix B also details ATSDR's screening of non-radiological chemical data. Some chemicals were detected in surface water above drinking water screening values, and some were detected in sediment above screening values for residential soil. ATSDR does not expect any identified non-radiological chemicals to contribute substantially to risk of harmful effects from the exposures evaluated in this report.

Data are limited, but ATSDR did not identify any non-radiological chemicals that would be expected to contribute substantial risk from recreational or residential exposures

We recognize that no data on non-radiological chemicals exist for floodplain soils and that very limited data were available for sediment and surface water. However, in the absence of specific data and because the limited data available do not show non-radiological chemicals at concentrations of potential concern, the remainder of this evaluation will focus only on Th-230, Ra-226, and U-238.

Figure 4. Simplified uranium-238 decay chain



Simplified uranium-238 decay chain showing primary radioactive emissions—alpha (α) or beta (β)—released as each unstable atom transforms to a new decay product.

Exposure Point Concentrations for Soil, Sediment, and Surface Water

Representative exposure point concentrations describing the highest levels of contaminant someone might be exposed to over time are needed to determine how much of each contaminant is taken in by people who accidentally swallow or breathe in soil, sediment, or surface water from Coldwater Creek. ATSDR created maps showing the results from soil and sediment sampling, and used graphical and statistical techniques to get high-end estimates of contaminant exposure point concentrations, as described below.

We used mapping and statistics to set the level of contaminants in soil, sediment, or water people would contact over time– either in the past or more recently

- For past exposures to floodplain soil, we used recent soil data from I-270 to the St. Denis Bridge [23]. For each contaminant, we mapped the highest concentration found at any depth for each sample location. We assumed that in the past, these higher concentrations could have been at the ground surface and available for contact. Figure 5 shows an example map of past concentrations of Th-230 in floodplain soil. We split the areas of the creek into several different sectors to see how contaminant levels changed along the creek. In addition, we selected results from several different areas that had higher concentrations of Th-230 and that might be regularly contacted by the same people (labeled "hotspot" areas in the figures and tables). We then used a publicly available program called ProUCL [42] to calculate the 95% upper confidence level on the mean (UCL) of the results falling into the various sectors and sub-areas. Of the various areas for which we obtained recommended UCLs, we used the highest one for the past soil exposure point concentration. We followed the same procedure for Ra-226 and U-238. Appendix C shows the full results.

- For recent exposures to floodplain soil, we used the same data and technique as for past exposures, considering only the top (zero to six-inch) sample of soil. Figure 6 shows the map obtained for evaluating recent exposures to Th-230 in floodplain soil.

Figure 5. Map illustrating evaluation of maximum soil concentration of Th-230 at any depth used to estimate past exposures

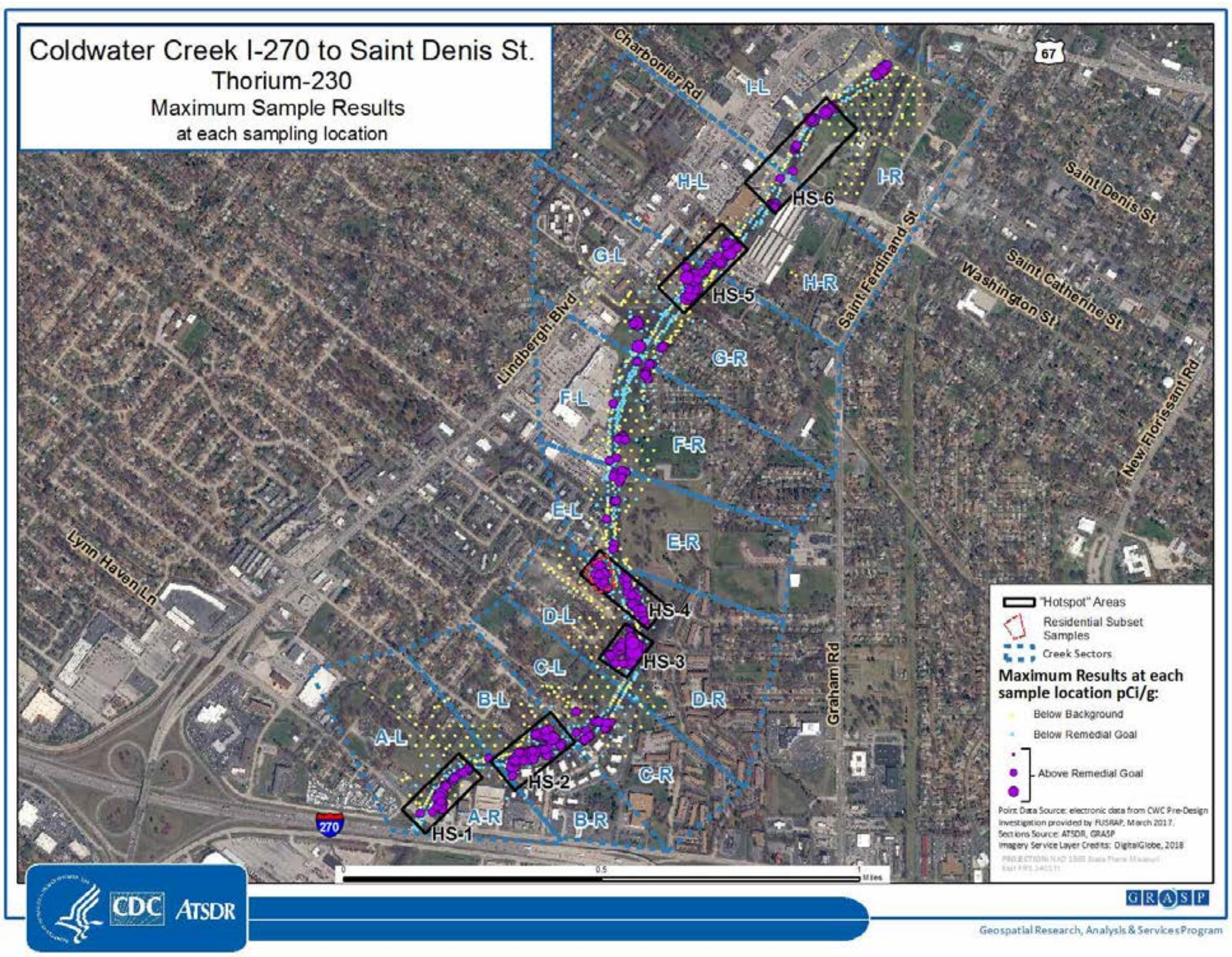
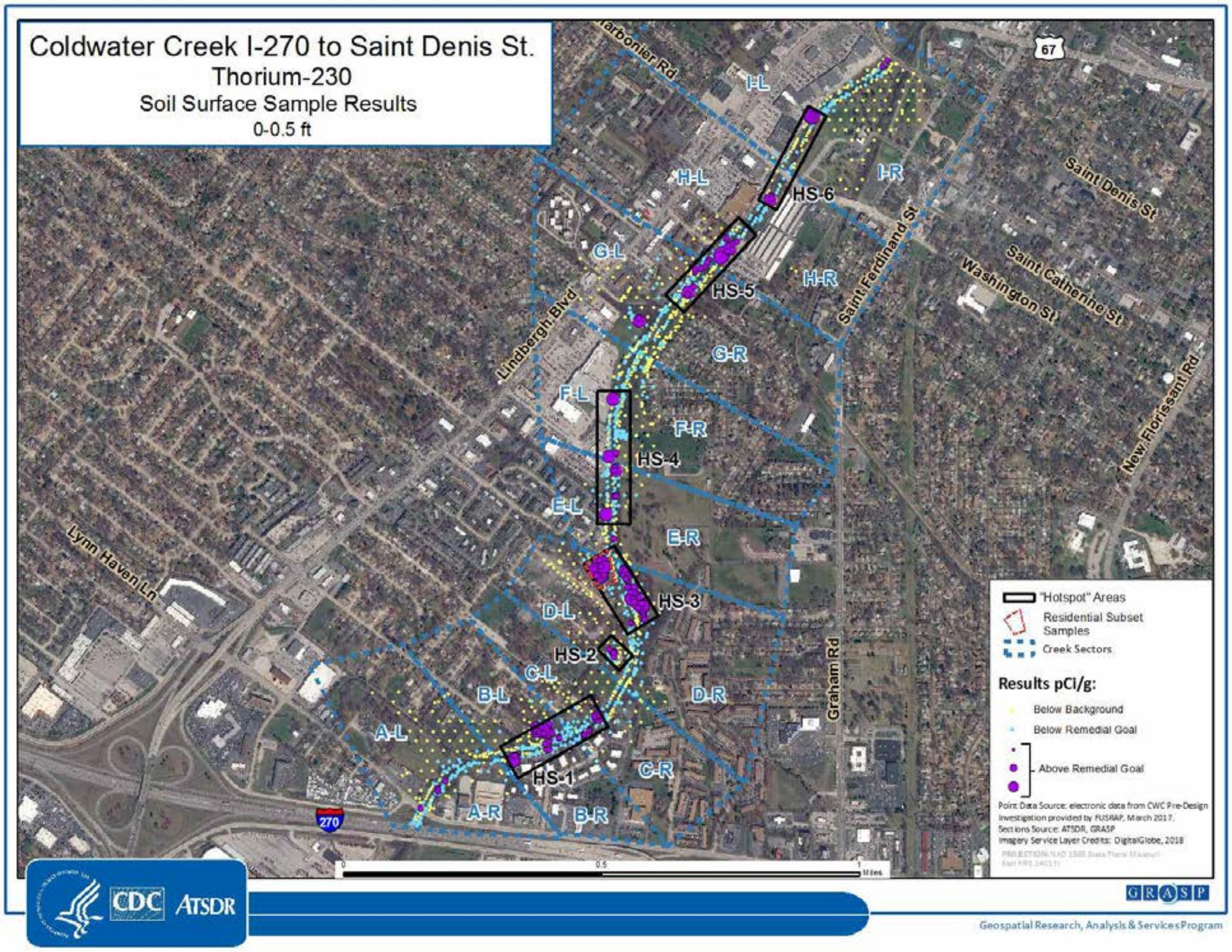


Figure 6. Map illustrating evaluation of surface soil Th-230 data used to estimate recent exposures



- For past exposures to sediment, we followed a similar technique of mapping results for the various sectors of the creek, using soil/sediment data collected in the late 1980s from the water line on each side of the creek [24]. We used ProUCL to determine the highest recommended UCL for the past sediment data.
- For recent exposure to sediment, we used recent sediment data from I-270 to the St. Denis Bridge [23] and mapped the highest concentration of contaminant at any depth. We then used ProUCL to determine the highest recommended UCL for the recent sediment data.
- For surface water, we used a different data set that included surface water samples from 1998-2014 collected at I-270 (at the upstream edge of what we consider the recreational and residential stretches of Coldwater Creek) [25-41]. These results showed no concentrations of Th-230, Ra-226, or U-238 higher than background criteria identified in FUSRAP's feasibility study [6]. For surface water, we used the background criteria for each contaminant as the exposure point concentration.

Appendix C includes a complete set of maps and tabulates the recommended UCLs from which we selected exposure point concentrations for soil and sediment.

Table 1 summarizes the selected past and recent exposure point concentrations for soil, sediment, and surface water used in this evaluation.

Table 1. Exposure point concentrations for soil, sediment, and surface water at Coldwater Creek

	Past Exposure Point Concentration			**Recent** Exposure Point Concentration		
Contaminant	Soil (pCi/g)*	Sediment (pCi/g)*	Surface water (pCi/L)†	Soil (pCi/g)*	Sediment (pCi/g)*	Surface water (pCi/L)†
Thorium-230	54.5	105.4	4.65	27.3	7.9	4.65
Radium-226	2.5	4.8	0.88	1.9	1.8	0.88
Uranium-238	2.3	4.5	5.05	1.8	1.0	5.05

Used **past** exposure point concentrations to estimate exposures occurring from the 1960s to the 1990s.
Used **recent** exposure point concentrations to estimate potential exposures occurring since the 2000s.

pCi/g = picocuries per gram pCi/L = picocuries per liter

*See Appendix C for explanation of soil and sediment exposure point concentration selection.
†Background criteria for surface water [6]. No positively identified results for surface water in areas at or downstream of I-270 were higher than background criteria.

Radiological Intake, Dose, and Cancer Risk: Evaluation of Radiological Effects

Intake of contaminants depends on the exposure point concentration combined with exposure and intake assumptions. Appendix D describes the equations used to calculate intake, along with example calculations.

We estimated a person's intake of contaminant by multiplying the exposure point concentration by the intake of soil, sediment, or water

We calculated intake by ingestion and by inhalation in picocuries (pCi) for each year of life, assuming exposure begins at birth and continues for 33 years [43].[3] Each year has a different intake since age group, exposure assumptions, and intake assumptions change throughout life.

Intake itself does not completely determine the radiological dose. The radiological dose is a complicated function of what the radiological isotope is, how it enters the body (ingestion or inhalation), how much is taken up by the body, how much is eliminated or metabolized, what organs it is stored in, and how it changes as it radioactively decays. Organs in the body may also receive an external dose from isotopes outside the body. Each radioactive isotope has different

[3] 33 years is the ATSDR-recommended residential occupancy period, upper percentile.

characteristics. Appendix E gives more details about how we used coefficients derived by the International Commission on Radiological Protection (ICRP) and by EPA to determine radiological doses from the exposures evaluated in this report [44,45]. ATSDR estimated doses from intakes (ingestion or inhalation) using ICRP dose coefficients, and we estimated doses from external radiation using EPA external dose coefficients. For inhalation exposures, ATSDR estimated dose using two different ICRP Th-230 dose coefficients corresponding to slow versus medium lung solubility. The actual solubility depends on the chemical form of thorium in the environment and affects the dose received to the lungs versus other internal organs [46]. Tables in this report present a range of doses between those assuming slow lung solubility of Th-230 and those assuming medium solubility.

We calculated dose to specific organs using factors derived by the International Commission on Radiological Protection and by the U.S. Environmental Protection Agency

Increased Risk – What it Means

Risk can be defined as "the probability of any negative outcome"—for example, developing cancer after receiving a radiological dose to an organ. Numerically, risk is expressed as a probability between zero (absolute certainty the event will *not* occur) and one (absolute certainty that it will). For example, based on U.S. cancer rates, the lifetime risk of being diagnosed with any form of cancer in the general population is about 0.385, or about 3,850 out of every 10,000 people [47].

Environmental exposures to radiation typically involve doses far below those that caused cancers and other measurable health effects in exposed populations (such as Japanese atomic bomb survivors, radium dial painters, nuclear industry workers, or medical patients treated with radiation). However, most regulatory and advisory agencies assume every dose of radiation, no matter how small, incrementally increases the risk of developing cancer. These agencies have developed methods to predict the increased risk of cancer to help determine cleanup levels and manage risks in a protective manner.

EPA has developed lifetime attributable risk coefficients to estimate increased risk resulting from a given radiological dose to an organ [48]. ATSDR used these lifetime attributable risk coefficients to estimate the increased risk of cancer for various organs from the recreational and residential exposures evaluated in this report. Appendix E presents more discussion and example calculations.

We estimated increased risk of developing cancer in specific organs from the dose received using EPA-derived coefficients

Preventing or eliminating all risk is impossible. While ATSDR recognizes that all exposures contribute to the risk of cancer, in this report we focus our discussion and conclusions on those risks estimated to be greater than 1 in 10,000. This is the upper bound of EPA's general "target range" for managing risks as part of a Superfund cleanup: 1 in 10,000 to 1 in 1,000,000 [49].

In this report, ATSDR focuses its conclusions and recommendations on doses corresponding to risks greater than 1 in 10,000

To put this value into context, assume the estimated additional cancer risk resulting from a given organ radiological dose is 1 in 10,000. That means that out of 10,000 people who were exposed to the contaminant for the specified length of time to accumulate that dose, one additional cancer might develop from the exposure, above the normally expected rate. An increased lifetime risk of 1 in 10,000 would raise the lifetime risk of developing cancer in the U.S. from 3,850 to 3,851 out of every 10,000 people.

Results and Discussion

Organ-Specific Radiological Dose and Cancers

Children and adults who played and lived near Coldwater Creek in the past (1960s to 1990s) may have had an increased risk of several types of cancer from their exposure to soil, sediment, and surface water. Table 2 shows the cancer sites for which estimated cancer risks were greater than 1 in 10,000 for the past doses calculated as described in Appendix E and the previous sections. Past recreational exposures resulted in elevated risks to the bone surface, lungs, and red marrow, and past residential exposures resulted in elevated risks to these organs plus the skin and breast.

The past doses and risks in Table 2 represent those resulting from high-end exposures described by community members as occurring in the past, when children played almost daily for several hours a day in and around Coldwater Creek. The concentrations of Th-230, Ra-226, and U-238 used in the calculations assumed the highest concentrations at any depth in recent sampling were at the ground surface, and that exposure occurred regularly to the same high concentrations for 33 years. The results presented in Table 2 may be overestimates for those who were farther from the creek, spent less time there, or may have spent time in areas of the creek with less contamination.

Table 2. Summary of organs with elevated* increased cancer risk from 33-year recreational or residential exposures at Coldwater Creek (past years, 1960s-1990s)

	Recreational		Residential	
Organ/ cancer site (higher to lower risk)	Dose, mrem**	Risk, out of 10,000†	Dose, mrem**	Risk, out of 10,000†
Bone surface	5,500–16,000	**4 to 10**	14,000–63,000	**8 to 30**
Lungs	350–700	**1 to 3**	1,300–2,900	**5 to 10**
Red marrow	410–930	0.5 to **1**	920–3,200	**1 to 4**
Skin	130–150	below 1	300–380	**1 to 2**
Breast	110–130	below 1	260–330	0.9 to **1**

*As described in the text, ATSDR considered risks above 1 out of 10,000 to be elevated. Elevated risks shown in **bold.**

**Dose = committed radiological dose to organ for entire 33-year exposure in millirem (mrem, no more than 2 significant figures; see Appendix E). Range corresponds to different lung solubility dose coefficients for Th-230 inhalation (slow to medium).

†Risk = estimated cancer incidence risk to site based on organ exposure dose for 33-year exposure. See Appendix E.

NOTES:

- Doses vary for different organs based on isotope distribution in the body and differing organ weights. ***Because of tissue weighting differences, doses cannot be compared between organs.***
- Dose estimates include external radiation, ingestion, and inhalation.
- The risks shown were estimated without subtracting background levels of Th-230, Ra-226, or U-238. Subtracting background levels reduced all breast cancer risks to below 1 in 10,000; other risks were not substantially affected.
- See Appendix E for details and results for other organ sites.

Table 3 presents estimated dose and risk for more recent exposures, using surface soil data and less frequent but still reasonably high exposure assumptions. As presented in Table 3, more recent recreational exposures do not result in elevated estimated cancer risks. Recent residential exposures result in elevated risks for the bone surface and lungs only. Like the results for past exposures, the results in Table 3 assumed 33 years of exposure to the highest areas of contamination (exposure beginning about 10 or 15 years ago and continuing until projected completion of remedial activities in the 2030s). Because contaminated areas are in the process of cleanup, people exposed in the last 10 to 15 years will likely experience less dose and risk than presented in Table 3.

Table 3. Summary of organs with elevated* cancer risk from 33-year recreational or residential exposures at Coldwater Creek (recent exposures, 2000s and on)

	Recreational		Residential	
Organ/ cancer site (higher to lower risk)	Dose, mrem**	Risk, out of 10,000†	Dose, mrem**	Risk, out of 10,000†
Bone surface	500–1000	below 1	4,600–10,500	**3 to 6**
Lungs	20–35	below 1	180–370	0.7 to **1**

*As described in the text, ATSDR considered risks above 1 out of 10,000 to be elevated. Elevated risks shown in **bold**.
**Dose = committed radiological dose to organ for entire 33-year exposure in millirem (no more than 2 significant figures; see Appendix E). Range corresponds to different lung solubility dose coefficients for Th-230 inhalation (slow to medium).
†Risk = estimated cancer incidence risk to site based on organ exposure dose for 33-year exposure. See Appendix E.
NOTES:

- Doses vary for different organs based on isotope distribution in the body and differing organ weights. ***Because of tissue weighting differences, doses cannot be compared between organs.***
- Dose estimates include external radiation, ingestion, and inhalation.
- The risks shown were estimated without subtracting background levels of Th-230, Ra-226, or U-238. Subtracting background levels did not change the risks substantially.
- See Appendix E for details and results for other organ sites.

In the next sections, ATSDR presents epidemiological and cancer information related to those organ sites identified as having increased cancer risk.

Bone Surface

Thorium, radium, and uranium taken up into the bloodstream are known to build up on bone surface and may be incorporated into the bone matrix. As shown in Table 2, past exposures at Coldwater Creek could result in bone surface doses of up to 63,000 millirem (mrem). Studies showed high rates of bone cancers occurring in people exposed to radium in the early 1900s, including young women who painted watch dials with radium-containing paint and patients treated with radium for medical purposes [50,51]. These workers and patients received very high radiation doses over relatively short periods of time. The lowest bone surface doses associated with bone cancers in these groups were about 18,000,000 mrem, 250 times higher than the highest estimated bone surface doses based on 33 years of exposures at Coldwater Creek.

The corresponding lifetime risk of developing bone cancer based on the estimated past bone surface dose is up to 10 in 10,000 for recreational exposures and up to 30 in 10,000 for residential exposures. These risks include contribution from exposure to background levels of Th-230, Ra-226, and U-238, but do not change substantially if background levels are subtracted. Recent exposures were predicted to result in lower increased risks, ranging from below 1 in 10,000 for recreational exposures to just over 6 in 10,000 for residential exposures.

Based on U.S. cancer rates, the lifetime risk of being diagnosed with cancer of the bone or joint is about 0.1%, or 10 out of 10,000 people [47]. The past risks estimated in this report could increase this risk by a factor of 2 to 4. There are several distinct types of bone cancer. According to the American Cancer Society, there is no method to screen for bone cancer [52]. Signs and symptoms of bone cancer may include pain at the site, swelling, fractures, numbness or tingling, or other symptoms depending on the location of the tumor [52]. These symptoms are often due to other conditions such as injuries or arthritis.

Several tests may help diagnose bone cancer if it is suspected from the patient's symptoms, physical exam, and personal and family medical history. Blood tests may rule out other possible causes for the symptoms. If bone cells are unusually active, blood tests might show high levels of a bone tissue enzyme, but this level could be the result of normal growth and repair and does not reliably predict cancer [53,54]. X-rays in the area of concern might show abnormalities suggestive of cancer. Further imaging tests, including computed tomography (CT) scans, magnetic resonance imaging (MRI) scans, radionuclide bone scans, or positron emission tomography (PET) scans, may give additional information about the size and location of a suspected tumor and whether it has spread. Often, however, the only way to confirm bone cancer is with a tissue biopsy, where cells from the bone are removed surgically and examined under a microscope to see if they are cancerous [53,54].

Based on the exposures estimated in this report, ATSDR does not recommend general screening for bone cancer in people near Coldwater Creek. No test has been shown to reliably find bone cancer in people with no symptoms, and the tests themselves all carry some risk, such as additional radiation exposure or complications from physical procedures. A personal physician will use a patient's individual history, symptoms, age, and gender to determine appropriate testing. ATSDR recommends people share their potential exposure related to Coldwater Creek with their physicians as part of their medical history and consult their physicians promptly if new or unusual symptoms develop.

The MDHSS cancer incidence study did not find a statistically significant elevation in bone cancers from 1996 to 2011 in the combined eight ZIP codes surrounding the creek compared to the rest of Missouri [13]. Radiation-induced solid tumors have a typical latency period of 20 to 40 years, so the study covered years in which some bone cancers resulting from past exposures may have developed. However, the people living in the ZIP codes studied by MDHSS may not be the same people who were most highly exposed while playing or living near Coldwater Creek in the 1960s to 1990s.

Lungs

Inhaled thorium, radium, and uranium may stay in the lungs. Inhalation of alpha-emitting radionuclides has been shown to increase lung cancers in both human epidemiological and animal studies [55,56]. Some of the cancers may have been the result of exposure to radon gas, mostly radon-222 (Rn-222) and its decay products formed in the radioactive decay chain, rather than the materials inhaled. All the contaminants evaluated in this report are in a decay chain that will produce Rn-222 and its progeny as they decay. Our dose estimates include the contribution of Rn-222 formed.

Various studies on uranium miners have shown increased rates of lung cancer attributed to high levels of Rn-222 in the underground mines, though other factors may have contributed [55]. Increased rates of lung cancer were also observed in nuclear industry workers who inhaled uranium compounds [56]. Lung tumors were observed in dogs exposed to the alpha emitter plutonium-239, with lung doses as low as 20,000,000 mrem. Other alpha emitters resulted in lung cancers at similar or higher doses in various animal experiments [56].

The human epidemiology studies cited in ATSDR's toxicological profiles did not report radiological dose to the lung. In animal experiments, lung doses that caused lung cancer are several orders of magnitude higher than those estimated for past recreational or residential exposures at Coldwater Creek (20,000,000 mrem versus up to 2,900 mrem).

The estimated risk of developing lung cancer from the calculated past lung doses are up to 3 in 10,000 for recreational exposures and up to 10 in 10,000 for residential exposures. These risks include contributions from exposure to background levels of Th-230, Ra-226, and U-238, but do not change substantially if background levels are subtracted. Recent exposures were predicted to result in lower increased risks, ranging from below 1 in 10,000 for recreational exposures to just over 1 in 10,000 for residential exposures.

Lung cancer is the second most common form of cancer in the U.S. in both men and women. Based on U.S. cancer rates, the lifetime risk of being diagnosed with cancer of the lung or bronchus is about 6.4%, or 640 out of 10,000 people [47]. The past risks estimated in this report could increase this risk by about 1 to 3%. Chest x-rays or tests analyzing cells coughed up in sputum may help diagnose lung cancer, but low-dose computed tomography (LDCT) is the only method with enough sensitivity and specificity to screen for lung cancer in asymptomatic, high-risk groups [57].

The U.S. Preventive Services Task Force recommends annual LDCT screening in adults aged 55-80 years who smoked a pack of cigarettes a day for 30 years and have smoked or quit smoking within the past 15 years. Screening recommendations from other medical groups vary but agree that screening be targeted to those most at risk [57,58]. The benefits of early detection in high-risk groups outweighs possible harms from LDCT screening, including false positive and false negative results, treatment of cancers that would not have otherwise been detected or cause harm during a person's lifetime, and radiation exposure [57]. For people at lower risk, who have no symptoms, screening may cause more harm than good.

According to the American Cancer Society, early symptoms of lung cancer could include a cough that gets worse and doesn't go away, coughing up blood, chest pain, or shortness of breath [59]. Depending on a patient's symptoms, medical history, and results of a physical exam, a physician may decide to perform a number of imaging or diagnostic tests, including those discussed above, to test for lung cancer.

ATSDR does not recommend any special or additional screening for lung cancer in people near Coldwater Creek. A personal physician will use a patient's individual history, symptoms, age, and gender to determine appropriate testing. ATSDR recommends people share their potential exposure related to Coldwater Creek with their physicians as part of their medical history and consult their physicians promptly if new or unusual symptoms develop.

The MDHSS cancer incidence study did not find a statistical elevation in lung cancers from 1996 to 2011 in the combined eight ZIP codes surrounding the creek compared to the rest of Missouri [13]. Radiation-induced solid tumors have a typical latency period of 20 to 40 years, so the study covered years in which some lung cancers resulting from past exposures would have likely developed. However, the people living in the ZIP codes studied by MDHSS may not be the same people who were most highly exposed playing or living near Coldwater Creek in the 1960s to 1990s.

Red Marrow

Thorium, radium, and uranium taken up into the bloodstream are known to build up on bone surface and may be incorporated into the bone matrix, affecting the red marrow. This may contribute to the risk of leukemia, a cancer of the bone marrow. As shown in Table 2, past exposures at Coldwater Creek could result in red marrow doses of up to 3,200 mrem. Scientific studies have observed excess cases of leukemia in patients who received, on average, red marrow doses of 134,000 mrem—50 times higher than the highest estimated dose in this evaluation [60].

The corresponding risk of developing leukemia from the past estimated red marrow doses is up to 4 in 10,000. The risk includes contribution from exposure to background levels of Th-230, Ra-226, and U-238, but does not change substantially if background levels are subtracted. Recent exposures were predicted to result in less than 1 in 10,000 increased risk.

Based on U.S. cancer rates, the lifetime risk of being diagnosed with leukemia is about 1.51%, or 151 out of 10,000 people [47]. The past risks estimated in this report could increase this risk by about 2 to 3%. There are several distinct types of leukemia, and symptoms may depend on the number of leukemia cells and their location in the body. Some chronic leukemias may not cause any symptoms, but other chronic forms as well as acute leukemias may cause early symptoms including extreme fatigue, night sweats, fever, anemia, or easy bruising or bleeding [61,62]. These symptoms are associated with many other conditions, as well.

Routine blood tests may identify leukemia before a patient has symptoms, because the disease causes changes in the levels and ratios of red blood cells, white blood cells, and platelets. A physician may order blood tests in patients presenting with symptoms and may conduct a physical exam to look for swollen lymph nodes, spleen, or liver. Other tests used to diagnose leukemias include examining cells from samples of bone marrow or the fluid surrounding a person's spinal cord and looking for swollen lymph nodes or signs of infections on a chest X-ray or chest CT scan [61].

ATSDR does not recommend any special or additional screening for leukemia in people near Coldwater Creek. A personal physician will use a patient's individual history, symptoms, age, and gender to determine appropriate testing. ATSDR recommends people share their potential exposure related to Coldwater Creek with their physicians as part of their medical history and consult their physicians promptly if new or unusual symptoms develop.

The MDHSS cancer incidence study found a statistical elevation in leukemia from 1996 to 2011 in the combined eight ZIP codes surrounding the creek compared to the rest of Missouri [13]. The people living in the ZIP codes studied by MDHSS may not be the same people who were most highly exposed playing or living near Coldwater Creek in the 1960s to 1990s. Leukemia induced by low doses of radiation exposure has a much shorter latency period than solid cancers (5-15 years as opposed to 20-40 years for solid cancers).

Skin

In contrast to the other organ doses discussed, the skin's dose is mostly from external exposures. The estimated dose to the skin is as high as 370 mrem and corresponds to a risk as high as 2 in 10,000 for past residential exposures.[4] This risk includes contribution from exposure to background levels of Th-230, Ra-226, and U-238 that contribute about half of the estimated risk. Recent exposures were predicted to result in less than 1 in 10,000 increased risk.

Based on U.S. cancer rates, the lifetime risk of being diagnosed with melanoma, the most aggressive type of skin cancer, is about 2.21%, or 221 out of 10,000 people [47]. The risks estimated in this report could increase this risk by less than 1%.

[4] Risk coefficients for skin exclude non-fatal skin cancers [48].

According to the American Cancer Society, melanoma may cause visible changes to skin moles or warts and can be treated successfully if detected early [63]. Information about how to perform a skin self-exam is available online [64]. People who notice any suspicious marks or changes in their skin should show them to their medical provider. A physician will examine the patient and may take a sample of the suspicious mark for microscopic examination. If the cells are cancerous, the physician may remove the lesion and skin around it and conduct more testing to see if the cancer has spread to other parts of the body [63].

ATSDR does not recommend general screening for skin cancer in people near Coldwater Creek. The U.S. Preventive Services Task Force states that the evidence is insufficient that screening of asymptomatic patients will prevent deaths from skin cancer [65]. A personal physician will use a patient's individual history, symptoms, age, and gender to determine appropriate testing. ATSDR recommends people share their potential exposure related to Coldwater Creek with their physicians as part of their medical history and consult their physicians promptly if new or unusual symptoms develop.

The MDHSS cancer incidence study did not find a statistical elevation in melanoma from 1996 to 2011 in the combined eight ZIP codes surrounding the creek compared to the rest of Missouri [13]. Radiation-induced solid tumors have a typical latency period of 20 to 40 years, so the study covered years in which skin cancers resulting from past exposures would most likely have developed. The people living in the ZIP codes studied by MDHSS may not be the same people who were most highly exposed playing or living near Coldwater Creek in the 1960s to 1990s.

Breast

Past residential exposures at Coldwater Creek could have resulted in doses to the breast up to 320 mrem. Estimated increased breast cancer risks associated with these exposures were slightly elevated for residential past exposures, just over 1 in 10,000. This risk includes contributions from exposure to background levels of Th-230, Ra-226, and U-238. Subtracting these background levels results in an estimated increased cancer risk for all past exposures below 1 in 10,000. Recent exposures were predicted to result in less than 1 in 10,000 increased risk.

Breast cancer is the most common form of cancer in women. Based on U.S. cancer rates, the lifetime risk of women being diagnosed with breast cancer is about 12.41%, or 1,241 out of 10,000 people [47]. The risks estimated in this report could increase this risk by less than 1%. Mammography (x-ray of the breast) is generally recommended to screen for breast cancer in age groups considered most at risk [66,67].

The U.S. Preventive Services Task Force recommends women aged 50 to 74 years have a screening mammogram for breast cancer every 2 years. It also advises women over age 40 to take into account personal factors when deciding whether to begin screening every two years

[66]. Recommendations from other medical groups for screening frequency and ages vary [67]. Possible harm from mammography that detracts from the benefits of early detection include distress and risks of additional testing resulting from false positive results, risks from treatment of cancers that would not have otherwise been detected or cause harm during the patient's lifetime, and radiation exposure [66]. Other imaging tests may be used in conjunction with mammography to screen for breast cancer in higher risk groups, including ultrasound or breast magnetic resonance imaging (MRI) scans [67].

According to the American Cancer Society, early symptoms of breast cancer may include a new lump or mass in the breast, swelling of all or part of a breast, skin irritation or dimpling, or pain [67]. A physician evaluating a patient's mammogram or a patient presenting with symptoms may ask for further imaging tests, but the only way to confirm breast cancer is with a tissue biopsy, where cells from the suspect area are removed surgically and examined under a microscope to see if they are cancerous [67].

ATSDR does not recommend any additional screening for breast cancer for women near Coldwater Creek. Estimated risks were only elevated for past residential exposures. A personal physician will use a patient's individual history, symptoms, age, and gender to determine appropriate testing. ATSDR recommends people share their potential exposure related to Coldwater Creek with their physicians as part of their medical history and consult their physician promptly if new or unusual symptoms develop.

The MDHSS cancer incidence study found a statistical elevation in female breast cancer from 1996 to 2011 in the combined eight ZIP codes surrounding the creek compared to the rest of Missouri [13]. The people living in the ZIP codes studied by MDHSS may not be the same people who were most highly exposed while playing or living near Coldwater Creek in the 1960s to 1990s. Radiation-induced solid tumors have a typical latency period of 20 to 40 years, so the study covered years in which breast cancers resulting from past exposures would most likely have developed.

Other Organ Sites

The community reported a concern about perceived elevated rates of appendix cancers in the area, with some cases occurring in people who played in or near Coldwater Creek while growing up. The appendix lies in the upper large intestine near its junction with the small intestine. Neither ICRP/EPA dose coefficients nor EPA lifetime attributable cancer risk coefficients specifically consider the appendix.

ICRP and EPA dose coefficients are available for both the upper and lower large intestine. EPA lifetime attributable cancer risk coefficients are available for the colon. ATSDR averaged upper and lower large intestine dose coefficients to estimate colon dose and then estimated colon risk using this dose. Although the colon and the appendix are different in many ways, colon risk appears to be the best estimate available of possible risk for appendix cancer. As tabulated in Tables E8 and E9 in Appendix E, ATSDR found that recreational and residential exposures at Coldwater Creek, both in the past and more recently, resulted in estimated increased colon cancer risks below 1 in 10,000. These results suggest that appendix cancer risk would not be elevated from the exposure.

Based on U.S. cancer rates, the lifetime risk of being diagnosed with cancer of the colon or rectum is about 4.3%, or 430 out of 10,000 people [47]. Appendix cancer is much rarer, with an incidence rate estimated at approximately 0.97 out of 100,000 for the year 2009 [68]. Put in terms of lifetime risk of cancer diagnosis, this would correspond to fewer than 10 cases per 10,000 people. For unknown reasons, the incidence of appendix cancer in the U.S. appears to be rising [68]. Reasons could include changes in how medical personnel code cancers or increased use of colonoscopy and imaging which can sometimes identify appendix tumors [68]. However, neither colonoscopy nor imaging have been shown to be sufficient screening methods for appendix cancer [68,69].

The MDHSS cancer incidence studies found a slight statistical elevation in colon cancer, but no statistical elevation in appendix cancer from 1996 to 2011 in the combined eight ZIP codes surrounding the creek, compared to the rest of Missouri [13]. The people living in the ZIP codes studied by MDHSS may not be the same people who were most highly exposed playing or living near Coldwater Creek in the 1960s to 1990s.

Effective Whole-Body Radiological Dose and Other Health Effects

In addition to organ-specific doses, ATSDR estimated effective whole-body radiological doses for residential and recreational exposures at Coldwater Creek. As we described earlier, organ-specific doses can't be compared because organs have different weights and sensitivities to radiation. Effective whole-body dose is a way to account for those differences and determine a dose that represents the overall effect. Effective whole-body dose is more comparable between different exposures and is the basis for radiological standards such as worker limits. We calculated the effective whole-body dose for each year of exposure, as shown in Table 4. We can compare this yearly dose to ATSDR's chronic minimal risk level (MRL) for ionizing radiation.

ATSDR's MRL is for a chronic whole-body dose from ionizing radiation of 100 mrem per year above normal background exposures, regardless of source. ATSDR applies the MRL to doses resulting from either internal exposure or external exposures [56]. Contributors to a person's normal background radiation dose include cosmic radiation; radon gas present in all air; rocks and soil containing natural radioactive elements; and natural radioactive material normally inside the body. In addition, people are exposed to radiation through medical procedures such as x-rays, nuclear medicine exams such as positron emission tomography (PET) scans, and by consumer products such as granite countertops and some ceramics.

Table 4. Summary of effective whole-body 70-year committed radiation dose from recreational or residential exposure at Coldwater Creek

	Highest annual whole-body effective committed dose, mrem per year		ATSDR minimal risk level, mrem per year above background	Natural background, mrem per year[5]
Time frame	Recreational	Residential		
Past exposures (1960s – 1990s)	28–30	57–75	100	360
Recent exposures (2000s and on)	1.9–2	20–22	100	360

NOTES:

- Range corresponds to different lung solubility dose coefficients for Th-230 inhalation (slow to medium, no more than 2 significant figures).
- Dose estimates include external radiation, ingestion, and inhalation.

Estimated doses for people who ate soil regularly as children are higher than shown in this table (see full results in Table E10 in Appendix E). Regular soil pica behavior from ages 1 to 6 increases the highest annual committed effective whole-body dose to:

- 80–104 mrem for past residential exposures
- 31–34 mrem for recent residential exposures

The estimated effective whole-body doses for past or recent recreational and residential exposures are all lower than ATSDR's chronic MRL. People who ate soil regularly when children (exhibited soil pica behavior) had higher estimated effective whole-body doses; however, only one annual dose was estimated at just above the MRL.

The chronic MRL is based on studies showing that natural and artificial sources of ionizing radiation ("background") give a person in the U.S, on average, an effective whole-body dose of 360 mrem per year. No harmful effects have been shown to be associated with this dose. [56,70].[5] Several locations around the world have much higher levels of natural background radiation than the United States. People living in these areas with higher background radiation do not have increased rates of cancer or noncancer health effects compared to other locations.

[5] The MRL is based on the average annual effective dose equivalent from the early 1980s, 360 mrem per year. In 2006, this value was revised upwards to 620 mrem per year based largely on increased doses from medical diagnostic procedures [70]. The MRL remains protective because it is a fraction of the annual average U.S. effective dose.

Uranium Chemical Effects

Uranium poses a risk for non-radiological effects at exposures lower than those that would cause radiological effects. Uranium can cause chemical damage to kidney tubules, the structures in the kidney that maintain balance between waste products and needed compounds in the bloodstream. Uranium exposure leads to microscopic changes in the tubules, which can impair the kidney's function over time or at higher exposures. Inhaling insoluble uranium at very high levels can damage the respiratory tract [71]. We considered oral ingestion of uranium as the most sensitive chemical effect.

As described in Appendix C, ATSDR estimated total uranium chemical exposure point concentrations from radiological U-238 results. We used the same exposure assumptions as for the radiological evaluation to estimate a daily dose of uranium for recreational and residential exposures at Coldwater Creek. These doses are in units of milligrams of uranium per kilogram of body weight per day (mg/kg/day) for chronic exposures. We also evaluated doses to children who exhibited regular pica behavior.

For past exposures, estimated uranium doses ranged from 0.000006 to 0.0001 mg/kg/day for different age groups; the doses for more recent exposures ranged from 0.000003 to 0.00007 mg/kg/day. These doses are lower than ATSDR's minimal risk level for ingestion of soluble forms of uranium of 0.0002 mg/kg/day and would be unlikely to result in any harmful effects.

Children who exhibited regular pica behavior in the residential scenario (intentionally eating tablespoon amounts of soil three times a week) had estimated doses higher than the intermediate MRL, up to 0.001 mg/kg/day for past exposures and up to 0.0007 for more recent exposures. The actual dose is likely to be smaller than estimated, because much of the uranium in soil is likely to be insoluble and not taken up by the body. The intermediate MRL is based on a study in which rats that were fed uranium for three months at doses as low as 0.06 mg/kg/day showed microscopic structural changes in kidney cells. Higher doses caused the kidneys to function improperly [71]. The intermediate MRL was obtained by dividing the 0.06 mg/kg/day minimal effect level by an uncertainty factor of 300 (three for use of a minimal lowest effect level, 10 for extrapolation from animals to humans and 10 for human variability).

Summary of Findings

As detailed above, ATSDR's evaluation found

- **Recreational** exposures in the **past** (1960s to 1990s) could have resulted in elevated risks for developing bone cancer, lung cancer, or leukemia.
- **Residential** exposures in the **past** (1960s to 1990s) could have resulted in elevated risks for developing bone cancer, lung cancer, leukemia, and (to a lesser extent) skin cancer or bone cancer.

- **Recreational** exposures in **recent** years (2000s and on) did not result in elevated estimated cancer risks.
- **Residential** exposures in **recent** years (2000s and on) could have resulted in elevated risks for developing bone cancer or lung cancer.
- The radiological doses associated with Coldwater Creek exposures were lower than those known to cause specific cancers or other harmful health effects.
- Estimated uranium exposures would not pose any concern for non-radiological kidney effects.

Based on these findings, ATSDR supports efforts to identify and remediate contamination along Coldwater Creek.

People who grew up in the Coldwater Creek area and played often in Coldwater Creek or its floodplain may have had elevated exposures to Th-230 and other radiological contaminants. Based on the properties of these contaminants, the greatest increased lifetime risks would be for developing bone or lung cancers. ATSDR recommends people share their potential exposure related to Coldwater Creek with their physicians as part of their medical history and consult their physicians promptly if new or unusual symptoms develop.

The evaluation described in this report was the only evaluation we identified that could use sampling data from residential areas to estimate exposure and risk numerically. This evaluation cannot answer the many and varied concerns this community raised about exposure, risk, and health.

Community Concerns about Health and Exposure

ATSDR considers community health concerns and other information from the community as it estimates and evaluates exposures at sites. The following pages list and address comments and concerns we received related to health and exposure (in addition to those specifically evaluated in this report). Responses provide the information we know about each concern and may indicate if ATSDR has plans for further research or work on the issue.

ATSDR collected these concerns and questions in various ways to ensure interested community members could give input. We met regularly with representatives of a local community group throughout the evaluation process. In 2015, 2016, and 2017, ATSDR staff spoke directly with community members at a series of public availability sessions about our work at Coldwater Creek. We also communicated through a dedicated email box for the site and by telephone. We received input from over 500 community members through these interactions.

We encourage readers to provide additional concerns or comments during the public comment period for this report. We will address additional concerns and comments received in an Appendix to the final report.

Exposure Concerns

Concern: Is dust in my home contaminated?

ATSDR response: Dirt tracked in from outside can contribute to indoor dust. Depending on the status of soil near your home, dust could contain some radiological contaminants. ATSDR's evaluation of residential exposures included ingestion rates that include soil and indoor dust. We assumed the dust contained the same concentration of contaminants as the soil. To test the validity of this assumption, ATSDR recommends FUSRAP sample indoor dust in a few homes near the floodplain, including those where yards require or required cleanup.

Because the radiological contamination is bound to soil (or dust) particles, normal household cleaning methods, preferably including wet wiping and high efficiency (HEPA) vacuuming, will remove contaminants, if present, from the living space.

Concern: Basements in the area filled during floods; are the sediments left after floodwaters receded contaminated?

ATSDR response: If floodwaters inundated a home's basement directly, some of the sediment washed inside could possibly contain Th-230 or other radiological contaminants. If Th-230 was present in sediments remaining on walls or floors of a basement, residents could accidentally swallow it or disturb it enough to inhale it. To allay community concerns about possible contamination on basement walls, ATSDR recommends FUSRAP test Th-230 concentrations in samples of sediment remaining in selected homes directly flooded by Coldwater Creek in the past.

Basements flooded by rising groundwater tables would be very unlikely to contain radiological contaminants from Coldwater Creek. The Th-230 contamination is bound to soil and sediment particles and not much affected by groundwater flowing past. A rising groundwater table would be unlikely to carry the contaminants into a basement.

Radioactive decay of Th-230 eventually forms radon-222, which could contribute to naturally occurring radon levels in some homes. Differentiating between naturally occurring radon and radon that may be present from Coldwater Creek contamination is not possible. Since radon can contribute to lung cancer risk regardless of the source, ATSDR suggests homeowners have their homes tested for radon and take mitigation action if needed. MDHSS offers Missouri residents free radon test kits. Residents can order the kits online (www.health.mo.gov) or by telephone (573-751-6102 or toll free at 1-866-628-9891).

Concern: Soil from the banks and floodplain of Coldwater Creek was used as backfill when homes in the area were constructed.

ATSDR response: ATSDR recognizes that in the past, soils may have been moved to other locations. We do not have any written records of where soils went, nor past sampling data indicating levels of contaminants in soils or sediments that may have been moved. Therefore, we cannot evaluate health implications of this potential exposure.

If local authorities identify specific locations that received soil or sediment backfill from Coldwater Creek, we recommend FUSRAP perform targeted sampling for radiological contaminants of concern. If radiological contaminants (particularly Th-230) are present above remedial goals, FUSRAP should clean up the location. If several likely locations are tested and found to contain contaminants below remedial goals, this scenario should cause no further concern. We feel this approach will increase the community's confidence that the remedy is protective, whether tests find elevated contaminant levels or not.

Concern: Could sediments from Coldwater Creek have contaminated tributaries during flood events?

ATSDR response: Flood events, particularly from flash floods moving down the creek, could cause some movement of sediment from the creek up a usual tributary. The sediment in the tributary would most likely wash back down into Coldwater Creek after the flood. Any contamination remaining in the tributary's floodplain would likely be at similar or lower concentrations than contamination along the floodplain of Coldwater Creek itself. ATSDR expects that the recreational and residential scenarios evaluated in this report apply to similar exposures in and near tributaries of Coldwater Creek.

According to work plans for investigating Coldwater Creek, FUSRAP is collecting samples in mouths of tributaries to the creek and at some distance upstream from the mouth to confirm that site contaminants are not affecting tributaries [9]. This includes soils and sediments and adjacent properties within the ten-year flood plain of the tributary [72]. ATSDR believes this sampling will be helpful in determining whether past flooding has left contamination in tributaries.

Concern: The community raised many concerns related to consuming food products affected by contaminants in Coldwater Creek. Community members stated that in the past, area schools used produce as well as milk and other dairy products supplied from farms along Coldwater Creek. The produce may have grown in floodplain soil and been watered with creek water. Dairy *cows may have been raised in the floodplain and provided creek water to drink. Community members also told us that in the past, children playing in the creek would eat plants or crawfish from the creek. People frequently grew vegetables in home gardens in the floodplain and ate fruit or nuts from trees growing there. People living near the creek still have home gardens and fruit or nut trees.*

ATSDR response: ATSDR recognizes that contact with products grown in these areas could have indirectly exposed people to contaminants accumulated on the surface or within. Some areas of the floodplain have elevated levels of Th-230. Various food species do take up radiological contaminants from soil, particularly in roots, although not much research is specific to Th-230 [73]. Predicting uptake of radiological contaminants is difficult because it depends on the plant or animal species, the radiological isotope, and specific soil characteristics.

The community raised concerns about consumption of agricultural products and food from the creek itself as past concerns. The area along the creek is no longer used for agriculture. People who are currently concerned about growing plants in floodplain soil can consider gardening practices using clean soil, such as raised beds.

Concern: Community raised concern about residential exposures to sod purchased from a sod farm once located in the Coldwater Creek floodplain.

ATSDR response: Sod grown in Coldwater Creek's floodplain may have been contaminated. However, we do not have any written records of the current location of purchased sod, nor past sampling data indicating levels of contaminants in sod moved elsewhere. Therefore, we cannot evaluate the health implications of this potential exposure.

Concern: Were private wells for drinking and other uses contaminated?

ATSDR response: All of the homes in the area are currently served by treated public drinking water in compliance with Safe Drinking Water Act regulations [17–19]. In the past, a small number of private wells may have been used for domestic and other purposes.

A well survey conducted in 1987–88 identified eight wells within three miles of the HISS site [20]. Three of the wells were domestic wells: two were about half a mile northeast of the HISS/Futura site, and the other was in a residential area more than a mile downstream from the source areas. The domestic wells had been abandoned in 1962, 1968, and 1979 (the report did not indicate which wells were abandoned for each date). In addition to the domestic wells, the survey reported four private wells used for irrigation and one private well used for industrial purposes, all one to three miles west/northwest of the source areas and not near Coldwater Creek.

Groundwater in the surface aquifers at both HISS and SLAPS has shown elevated levels of total uranium compared to background [6]. Groundwater contamination did not appear to be migrating offsite in sampling conducted in the late 1990s [74,75]. Monitoring at that time also showed no evidence that Coldwater Creek was affected by groundwater at the source areas. However, the private wells may have been in use 30 years or more before these findings. Because no groundwater data exist for the time period the wells were in use, we cannot determine the quality and safety of water from private wells identified in the 1987–88 well survey.

Concern: Were workers or area residents exposed to harmful levels of windblown dust from uncovered waste storage piles in the past?

ATSDR response: ATSDR recognizes that from 1946 through about 1974, waste storage piles containing radiological contaminants were present and uncovered at the SLAPS and HISS source areas. During that time, workers or nearby residents could have been exposed by breathing dust blown from the waste piles. We cannot estimate the amount of these potential exposures because very little, if any, air sampling was performed while the storage piles were uncovered.

ATSDR is examining whether we can evaluate these past potential exposures qualitatively using available information about the waste piles and air modeling data. This evaluation would give a high-end estimate of possible exposure of nearby workers and residents to radiological contaminants in air. If air modeling is feasible, ATSDR will release the findings as a separate report. The location and timeframes of potential airborne dust exposures are different from the exposures evaluated in this report.

This exposure pathway is no longer a concern, because the storage piles were reportedly covered for some years and removed completely by 1974. Although some soil contamination remains at properties that haven't been remediated, the few remaining areas are unlikely to contribute significant levels of contaminants to air through windblown dust.

Concern: Community members raised concern that workers near uncovered waste piles in the past carried dust home to their families and children on their clothing and in the interiors of cars.

ATSDR response: ATSDR recognizes that in the past (while the waste storage piles containing radiological contaminants were present and uncovered at the SLAPS and HISS source areas), workers or their families could have been exposed to contaminants by breathing or accidentally swallowing contaminated dust brought home on clothing or in cars. We cannot evaluate these potential exposures because we have no information on how much dust was present and how much contamination was in it.

If ATSDR is able to model windblown dust from storage piles, the results might allow us to evaluate take-home dust exposures.

Concern: Were workers moving soil for flood control projects exposed to harmful levels of radiological contaminants?

ATSDR response: ATSDR's evaluation was for many years of regular incidental ingestion, inhalation, and external exposures. Exposures to workers would be less frequent and of shorter duration than the residential and recreational exposures estimated in this report and would be unlikely to result in exposures of health concern.

Concern: Were workers at Boeing or McDonnell Douglas exposed to harmful levels of contamination from facility flooding?

ATSDR response: We do not have information on dates, severity, or other circumstances of specific flood events at these facilities located close to the SLAPS and HISS sites. If contaminated sediments were suspended in floodwater and workers came in contact with the floodwater, they may have contacted radiological contaminants in the sediment. If the duration of exposure was relatively short and workers did not swallow large amounts of sediment, the radiological dose would be unlikely to contribute appreciably to their normal radiation dose based on typical background exposure.

Health Concerns

Concern: Is there a medical test to see if I've been exposed?

ATSDR response: High doses of ionizing radiation (much higher than estimated in this report) can cause changes in blood or chromosomes that can be medically tested and used to estimate dose [56]. However, these tests cannot measure the low doses we estimated for people playing or living near Coldwater Creek.

People around Coldwater Creek may have been exposed to specific radioactive materials, especially Th-230. Radioactive materials can be measured indirectly by analyzing blood, feces, saliva, urine, or the whole body for different types of ionizing radiation. Specialized radiochemistry laboratories with bioassay expertise perform such testing, usually for occupational monitoring of workers in regular contact with radiation, such as nuclear power plant employees. Th-230 can be analyzed in urine or fecal samples using radiochemical separation followed by alpha spectroscopy.

Whether a bioassay for Th-230 in urine or feces would give useful information about potential past exposures for people who have lived or played near Coldwater Creek is unknown. The estimated intakes of Th-230 in this assessment were many times smaller than allowable limits for radiological workers. Th-230 accumulates in the bone and is slowly released. The body eliminates Th-230 from bone with a biological half-life of about 22 years. Years after exposure, the amount being released in urine or feces would likely be very small and possibly undetectable over instrument background levels. Assessing the body burden from excreta data requires detailed knowledge of when and how the exposure occurred, and the body may excrete much of the intake in a short timeframe of days or months, rather than years.

Concern: What are the recommendations for advanced disease screening for people who grew up in this area?

ATSDR response: Community members concerned about their health should speak to their medical providers and follow recommendations for age- and gender-specific preventive screening. ATSDR does not recommend additional disease screening for residents around Coldwater Creek. Not all current or former residents have experienced exposures as high as assumed by ATSDR in this evaluation. In addition, procedures that could detect the cancers of interest are associated with risk (such as additional radiation from imaging) that may outweigh the potential benefit. A personal physician will use a patient's individual history, symptoms, age, and gender to determine appropriate screening and diagnostic testing.

Concern: Missouri studies showed that several types of cancers were elevated in the zip codes around Coldwater Creek.

ATSDR response: The 2014 MDHSS cancer incidence report showed that rates of some types of cancer were elevated in the combined eight ZIP codes around Coldwater creek from 1996-2011, compared to the rest of Missouri [13]. The cancer types included leukemia, female breast, colon, prostate, kidney, and bladder. The radiological doses estimated for past exposures in this report (1960s to 1990s) were associated with elevated risks for bone cancer, lung cancer, leukemia, skin cancer, and breast cancer.

The estimates in this report were for children and adults who spent large amounts of time playing directly in the most highly contaminated areas of the creek and its floodplain. The people living in the ZIP codes studied by MDHSS may not be the same people who were most highly exposed while playing or living near Coldwater Creek in the 1960s to 1990s. In addition, radiation-induced cancers are indistinguishable from cancers caused by other factors (except possibly at very high exposures never approached at this site) [56]. Studying the relationship between Coldwater Creek exposures and area cancer rates is very difficult because of the time that has passed and the uncertainty in past exposure estimates.

We recommend the state continue to follow cancer incidence in the area. ATSDR is examining other potential exposures from SLAPS and HISS and will work with local health authorities if we identify other exposures that may contribute to observed community cancer rates.

Concern: Could exposures cause fertility issues or miscarriages?

ATSDR response: The radiological doses estimated from recreational and residential exposures near Coldwater Creek were many times lower than those that have been associated with fertility problems. Studies of radiation exposure to the human reproductive system have shown no permanent effects at doses below 200,000 mrem [76]. Studies on pregnancies of atomic bomb survivors did not include assessment of miscarriages before the fifth month of gestation. The studies showed no statistical differences in the rates of stillborn babies or babies who died within 2 weeks of birth compared to unexposed groups [77].

Concern: Could exposures cause birth defects or cancers in the next generations?

ATSDR response: Studies following births to atomic bomb survivors have shown no statistical differences compared to unexposed groups in congenital malformations, stillbirth or death soon after birth, other genetic effects, or cancer in the first 20 years of life [77,78]. Mental retardation and reduced IQ were observed in some children who were exposed *in utero* to high levels of radiation (higher than 20,000 to 40,000 mrem) between eight and 15 weeks after conception. [56]. ATSDR did not locate any information on studies of birth defects in children of radium dial painters [50].

The radiological doses estimated from recreational and residential exposures near Coldwater Creek were many times lower than those associated with reduced IQ and experienced by the atomic bomb survivors.

Concern: We need a health study for chronic low-level radiation exposures like those we experienced.

ATSDR response: The estimates of past exposures in this report involved many assumptions and uncertainties, and currently available biomonitoring methods may not be sensitive enough to quantify past exposures. These factors would limit a study's ability to determine the relationship between past exposure and health outcomes in the community. The relatively recent exposures estimated in this report were much lower than past exposures, and we would not expect them to result in measurable increases in the rate of health effects. In addition, exposures are decreasing or have been eliminated in areas that have been cleaned up. For these reasons, designing and implementing a health study to examine effects of such exposures would be very difficult.

ATSDR is examining other potential exposures from SLAPS and HISS and will work with local health authorities if we identify other exposures that may contribute to the risk of community health effects.

Concern: We need health education for physicians and residents.

ATSDR response: ATSDR has provided some formal and informal health education to local physicians, community leaders, and partner health agencies about exposures and the public health assessment process. ATSDR will continue to work with the community to identify needs and options for educating the public and local medical providers about radiological exposures and health.

Concern: People who grew up near Coldwater Creek should get downwinder status.

ATSDR response: The 1990 Radiation Exposure Compensation Act established a compensation program for people who develop specified diseases after working in the uranium industry, participating in atmospheric nuclear weapons tests, or living downwind of the Nevada Test Site during the years of atmospheric testing of nuclear weapons. More information is available at https://www.justice.gov/civil/common/reca.

ATSDR is an advisory public health agency and does not have authority to grant downwinder status.

Conclusions

Radiological contamination in and around Coldwater Creek, prior to remediation activities, could have increased the risk of some types of cancer in people who played or lived there.

- Children and adults who regularly played in and around Coldwater Creek or lived in its floodplain for many years in the past (1960s to 1990s) may have been exposed to radiological contaminants. ATSDR estimated that this exposure could increase the risk of developing bone or lung cancer, leukemia, or (to a lesser extent) skin or breast cancer.
- More recent exposures (2000s and on) increased the risk of developing bone or lung cancer from daily residential exposure.

ATSDR does not recommend additional general disease screening for past or present residents around Coldwater Creek.

- The predicted increases in the number of cancer cases from exposures are small, and no method exists to link a particular cancer with this exposure.
- Not all current or former residents would have experienced exposures as high as assumed by ATSDR in this evaluation.
- Screening people who have no symptoms has risks, including false negative results, false positive results, risks from treating cancers that might never have caused a problem during a person's lifetime, and additional radiation exposure from diagnostic tests. A personal physician will use a patient's individual history, symptoms, age, and gender to determine appropriate screening and diagnostic testing.

ATSDR supports ongoing efforts to identify and properly remediate radiological waste around Coldwater Creek.

- Th-230 has been found above FUSRAP remedial goals in several areas of the Coldwater Creek floodplain. Reducing Th-230 levels in accessible areas will reduce harmful exposures.
- Waste entered the creek decades ago, and detailed information about how it moved with sediment and into floodplain soil does not exist. Reports of historical use of Coldwater Creek sediment and floodplain soil in other locations indicates a possibility that contamination spread from the floodplain. Identifying and remediating contaminated areas outside the floodplain will reduce potentially harmful exposures.

ATSDR is unable to evaluate other exposure pathways of concern to the community.

- No sampling data exist that would allow ATSDR to estimate exposures from other pathways, such as inhaling dust blown from historical radiological waste storage piles.

Recommendations

ATSDR recommends that:

- Potentially exposed residents or former residents share their potential exposure related to Coldwater Creek with their physicians as part of their medical history and consult their physicians promptly if new or unusual symptoms develop. Upon request, ATSDR can facilitate a consultation between residents' personal physicians and medical specialists in environmental health.
- The state consider updating analyses on cancer incidence, cancer mortality, and birth defects, as feasible.
- FUSRAP continue investigating and cleaning up Coldwater Creek sediments and floodplain soils to meet regulatory goals. To increase knowledge about contaminant distribution and allay community concerns, ATSDR recommends future sampling include
    - areas reported to have received soil or sediment moved from the Coldwater Creek floodplain (such as fill used in construction)
    - areas with possible soil or sediment deposited by flooding of major residential tributaries to Coldwater Creek
    - indoor dust in homes where yards have been cleaned up or require cleanup
    - sediment or soil remaining in basements that were directly flooded by Coldwater Creek in the past
- Signs to inform residents and visitors of potential exposure risks in areas around Coldwater Creek not yet investigated or remediated.
- Public health agencies continue to evaluate, to the extent possible, community concerns about exposure and educate the community about radiological exposures and health.

Next Steps

Upon request, ATSDR will:

- review new data from Coldwater Creek investigations and update conclusions, if necessary
- provide technical support to update cancer incidence or mortality studies in the area and identify needed public health actions
- remain available to provide further technical assistance to the public, partner agencies, or other stakeholders

ATSDR is evaluating the feasibility of conducting modeling to evaluate exposure to windblown dust from historical radiological waste storage piles.

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Appendix A. Documentation of Community Exposure Input and ATSDR Selected Parameters

To estimate exposures, we use information on how often and for how long the activities associated with the exposure occurred. We obtained input on Coldwater Creek activities and timing from a local community group: the following section explains how we used this input. Tables summarizing the selected parameters are included at the end of this appendix. Also included in the summary are ATSDR's selected intake parameters for soil, sediment, and surface water used in the evaluation; these values are based on standard ATSDR guidance modified as appropriate for the Coldwater Creek situation.

Community Input on Exposure Assumptions

We asked a local community group to provide input on how often adults and children of various ages participated in certain activities around Coldwater Creek. The group completed a table of exposure frequencies and times and provided it to ATSDR [22]. Community members indicated that their responses applied mostly to past exposures because children in more recent times have spent far less time in or around the creek. The following describes how ATSDR used the community input to develop exposure assumptions for past and more recent exposures.

Community Input – Recreational Exposure

Suggestions for time spent doing recreational activities near the creek were provided by members of a local group familiar with Coldwater Creek as shown in Table A1.

Table A 1. Input from community considered in developing recreational exposure assumptions

Time spent playing in the creek and its banks

	Summer (out of school)		School year (warm days)		School year (cold/rainy days)	
	Days / week	Hours spent	Days / week	Hours spent	Days / week	Hours spent
Kids 3 or younger	2 - 3	2	3	2	0	
Pre-school-aged kids	3	2	3	2	0	
Elementary-aged kids	5	8	5	2 - 4	2 - 3	1 - 3
Middle school-aged kids	5 - 7	8	5 - 7	2 - 4	2 - 3	1 - 3
High school-aged kids	5	2 - 4	3	1 - 3	2 - 3	1 - 2
Adults	2 - 3	2	3	2	0	

Time spent playing in the parks and woods along the creek (floodplain)

	Summer (out of school)		School year (warm days)		School year (cold/rainy days)	
	Days / week	Hours spent	Days / week	Days / week	Hours spent	Hours spent
Kids 3 or younger	2 - 3	2	3	2	0	
Pre-school-aged kids	3	2	3	2	0	
Elementary-aged kids	5	8	5	2 - 4	2 - 3	1 - 3
Middle school-aged kids	5 - 7	8	5 - 7	2 - 4	2 - 3	1 - 3
High school-aged kids	5	2 - 4	3	1 - 3	2 - 3	1 - 2
Adults	2 - 3	2	3	2	0	

Time spent riding bikes or dirt bikes on trails along creek

	Summer (out of school)		School year (warm days)		School year (cold/rainy days)	
	Days / week	Hours spent	Days / week	Hours spent	Days / week	Hours spent
Kids 3 or younger	N/a					
Pre-school-aged kids	4	2 - 4	2	2	0	
Elementary-aged kids	7	2 - 8	5	2 - 4	2	1 - 2
Middle school-aged kids	7	2 - 8	5	2 - 4	4	1 - 4
High school-aged kids	7	2 - 5	5	2 - 4	2	1 - 3
Adults	2	2	2	2 - 4	0	

Given the number of days per week and hours suggested by community input, ATSDR assumed that the times and days reflected a combination of time spent in the creek and its banks, playing in floodplain areas, and riding bikes or dirt bikes along the creek. Therefore, ATSDR used the exposure frequency and time reported for a combination of activities: playing in either the creek and its banks or its floodplain. This activity, regardless of where it occurs, contributes mainly to ingestion exposure from swallowing of soil, sediment, or water. ATSDR considered the assumptions for time spent riding bikes or dirt bikes separately, because this activity contributes to inhalation exposure from breathing in soil stirred up by biking.

Table A2 below summarizes the recreational exposure frequencies and durations selected by ATSDR for the evaluation. We selected past assumptions to reflect the community input as closely as possible while following ATSDR's standard procedures. We reduced recent exposure frequencies and durations, based on community comments that their estimates reflected past exposures and that people today spend far less time recreating along the creek.

Table A 2. ATSDR selected frequencies for past and recent recreational exposures

Playing in the creek and its banks - exposure assumptions (**past** / *recent*)						
	Summer (out of school)*		School year (warm days)†		School year (cold/rainy days)†	
	Days per week	Hours spent	Days per week	Hours spent	Days per week	Hours spent
Kids less than 3	**3** / *1*	**2** / *0.5*	**3** / *1*	**2** / *0.5*	**0** / *0*	**0** / *0*
Preschool kids	**3** / *1*	**2** / *0.5*	**3** / *1*	**2** / *0.5*	**0** / *0*	**0** / *0*
Elementary kids	**5** / *2*	**8** / *1*	**5** / *2*	**3** / *0.5*	**3** / *0*	**3** / *0*
Middle school kids	**6** / *4*	**8** / *2*	**6** / *2*	**3** / *0.5*	**3** / *0*	**3** / *0*
High school kids	**5** / *4*	**3** / *2*	**3** / *2*	**3** / *0.5*	**3** / *0*	**3** / *0*
Adults	**3** / *2*	**2** / *0.5*	**3** / *2*	**2** / *0.5*	**0** / *0*	**0** / *0*

Riding bikes or dirt bikes on trails along creek - exposure assumptions (**past** / *recent*)						
	Summer (out of school)*		School year (warm days)†		School year (cold/rainy days)†	
	Days per week	Hours spent	Days per week	Hours spent	Days per week	Hours spent
Kids less than 3	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*
Preschool kids	**4** / *1*	**3** / *0.5*	**4** / *1*	**2** / *0.5*	**0** / *0*	**0** / *0*
Elementary kids	**7** / *4*	**5** / *1*	**7** / *2*	**3** / *0.5*	**2** / *0*	**2** / *0*
Middle school kids	**7** / *4*	**5** / *2*	**7** / *2*	**3** / *0.5*	**4** / *0*	**2** / *0*
High school kids	**7** / *4*	**4** / *2*	**7** / *2*	**3** / *0.5*	**2** / *0*	**2** / *0*
Adults	**2** / *2*	**2** / *0.5*	**2** / *2*	**2** / *0.5*	**0** / *0*	**0** / *0*

* Summer break assumed to be 12 weeks.

† School year cold/rainy days assumed to be 20 weeks, based on 17 cold weeks (November through March) plus 3 weeks of rainy days—about 1 day a week—for the remaining school year. School year warm days assumed to be remaining 20 weeks.

Community Input – Residential Exposure

Suggestions for time spent and comments about activities in residential yards near the creek were provided by members of a local group familiar with Coldwater Creek as shown in Table A3.

Table A 3. Input from community considered in developing residential exposure assumptions

Time spent playing in yard

	Summer (out of school)		School year (warm days)		School year (cold/rainy days)	
	Days / week	Hours spent	Days / week	Hours spent	Days / week	Hours spent
Kids 3 or younger	7	8 - 10	7	4	2	2
Pre-school-aged kids	7	8 - 12	7	4	2	2
Elementary-aged kids	7	8 - 12	7	4	2	2
Middle school-aged kids	7	8 - 12	7	4	2	2
High school-aged kids	7	6 - 10	7	4	2	2
Adults	7	2 - 8	7	1 - 3	2	2

Time spent doing gardening or yard work

	Summer (out of school)		School year (warm days)		School year (cold/rainy days)	
	Days / week	Hours spent	Days / week	Hours spent	Days / week	Hours spent
Kids 3 or younger	This age group would be present when their parents worked in yard.					
Pre-school-aged kids	Same as above.					
Elementary-aged kids	Same as above					
Middle school-aged kids	1	1 - 3	1	1 - 3	0	
High school-aged kids	1	1 - 3	1	1 - 3	0	
Adults	2	2 - 5	1	2 - 3	0	

Time spend doing landscaping such as heavy digging

	Summer (out of school)		School year (warm days)		School year (cold/rainy days)	
	Days / week	Hours spent	Days / week	Hours spent	Days / week	Hours spent
Kids 3 or younger	0					
Pre-school-aged kids	5	2 - 8	5	3	0	
	(This age group played in dirt and used toy shovels to dig.)					
Elementary-aged kids	5	2 - 8	5	3	0	
	(This age group played in dirt and used toy shovels to dig.)					
Middle school-aged kids	7	8	5	4	2	2 - 4
	(Dug dirt and built forts instead of landscaping.)					
High school-aged kids	1	3	1	3	0	
Adults	2	2 - 5	1	3	0	

ATSDR used the community's suggestions to develop assumptions for past and recent residential exposures. ATSDR's standard protocol assumes 365 days per year of residential exposure. Child default soil ingestion rates account for bystander exposures and include typical play activities such as digging and playing in dirt. No additional ingestion above the default rates were applied for age groups not actually doing gardening or landscaping activities.

Table A4 below summarizes the residential exposure frequencies and durations selected by ATSDR for the evaluation. Recent exposure frequencies and durations were reduced slightly from past values.

Table A 4. ATSDR selected frequencies for past and recent residential exposures

Playing in yard- exposure assumptions (**past** / *recent*)						
	Summer (out of school)*		School year (warm days)†		School year (cold/rainy days)†	
	Days per week	Hours spent	Days per week	Hours spent	Days per week	Hours spent
Kids less than 3	**7** / *7*	**8** / *2*	**7** / *7*	**4** / *1*	**7** / *7*	**2** / *0.5*
Preschool kids	**7** / *7*	**8** / *2*	**7** / *7*	**4** / *1*	**7** / *7*	**2** / *0.5*
Elementary kids	**7** / *7*	**8** / *2*	**7** / *7*	**4** / *1*	**7** / *7*	**2** / *0.5*
Middle school kids	**7** / *7*	**8** / *2*	**7** / *7*	**4** / *1*	**7** / *7*	**2** / *0.5*
High school kids	**7** / *7*	**8** / *2*	**7** / *7*	**4** / *1*	**7** / *7*	**2** / *0.5*
Adults	**7** / *7*	**8** / *1*	**7** / *7*	**2** / *0.5*	**7** / *7*	**2** / *0.5*

Gardening or yard work - exposure assumptions (**past** / *recent*)						
	Summer (out of school)*		School year (warm days)†		School year (cold/rainy days)†	
	Days per week	Hours spent	Days per week	Days per week	Hours spent	Days per week
Kids less than 3	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*
Preschool kids	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*
Elementary kids	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*
Middle school kids	**1** / *1*	**3** / *1*	**1** / *1*	**3** / *0.5*	**0** / *0*	**0** / *0*
High school kids	**1** / *1*	**3** / *1*	**1** / *1*	**3** / *0.5*	**0** / *0*	**0** / *0*
Adults	**2** / *2*	**5** / *2*	**1** / *1*	**3** / *2*	**0** / *0*	**0** / *0*

Landscaping such as heavy digging - exposure assumptions (**past** / *recent*)						
	Summer (out of school)*		School year (warm days)†		School year (cold/rainy days)†	
	Days per week	Hours spent	Days per week	Days per week	Hours spent	Days per week
Kids less than 3	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*
Preschool kids	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*
Elementary kids	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*
Middle school kids	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*
High school kids	**1** / *1*	**3** / *1*	**1** / *1*	**3** / *0.5*	**0** / *0*	**0** / *0*
Adults	**2** / *2*	**5** / *2*	**1** / *1*	**3** / *2*	**0** / *0*	**0** / *0*

* Summer break assumed to be 12 weeks.

† School year cold/rainy days assumed to be 20 weeks, based on 17 cold weeks (November through March) plus 3 weeks of rainy days—about 1 day a week—for the remaining school year. School year warm days assumed to be remaining 20 weeks.

ATSDR Additional Assumptions and Example Calculations:

To calculate the average hours per day for each activity, we multiplied the days per week and time per day by weeks of the school year.

- Summer break assumed to be 12 weeks
- School year cold/rainy days assumed to be 20 weeks – based on 17 cold weeks (November – March) plus 3 weeks of rainy days—about 1 day a week—for the remaining school year.
- School year warm (non-rainy) days assumed to be remaining 20 weeks

For example, middle school-aged kids are estimated to ride their bikes

$$7\frac{day}{week} \times 12\ weeks + 5\frac{day}{week} \times 20\ weeks + 4\frac{day}{week} \times 20\ weeks$$

= 264 days a year.

And each day they ride, they spend

$$\frac{(7\frac{day}{week} \times 5\frac{hr}{day} \times 12\ weeks + 5\frac{day}{week} \times 3\frac{hr}{day} \times 20\ weeks + 4\frac{day}{week} \times 2\ \frac{hr}{day} \times 20\ \text{weeks})}{264\ days}$$

= 3.3 hours per day riding their bikes.

As another example, adults are estimated to do landscaping

$$2\frac{day}{week} \times 12\ weeks + 1\frac{day}{week} \times 20\ weeks + 0\frac{day}{week} \times 20\ weeks = 44\ days\ a\ year$$

And each day they landscape they spend

$$\frac{(2\frac{day}{week} \times 5\frac{hr}{day} \times 12\ weeks + 1\frac{day}{week} \times 3\frac{hr}{day} \times 20\ weeks + 0\frac{day}{week} \times 0\ \frac{hr}{day} \times 20\ \text{weeks})}{44\ days}$$

= 4.1 hours per day landscaping.

This is how ATSDR determined the days per year and hours per day used in the evaluation (summarized in the tables following).

Selected Exposure Assumptions for Recreational and Residential Scenarios

Table A 5. Recreational frequency/duration assumptions (past / *recent*)

Age range	Time spent playing in creek, banks, or parks/soil near creek		Time spent riding bikes along creek		Duration, years‡‡
	Hours per day*	Days per year‡	Hours per day*	Days per year‡	
Kids less than 3	**2** / *0.5*	**96** / *32*	**0** / *0*	**0** / *0*	**3** / *3*
Preschool kids	**2** / *0.5*	**96** / *32*	**2.5** / *0.5*	**88** / *32*	**3** / *3*
Elementary kids	**4.4** / *1.0*	**220** / *64*	**3.6** / *0.5*	**224** / *88*	**5** / *5*
Middle school kids	**4.4** / *2.0*	**252** / *88*	**3.3** / *0.5*	**264** / *88*	**3** / *3*
High school kids	**2.7** / *2.0*	**180** / *88*	**3.2** / *0.5*	**224** / *88*	**4** / *4*
Adults	**2** / *0.5*	**96** / *64*	**2.0** / *0.5*	**64** / *64*	**15** / *15*

*Average hours per day on days spent at creek – average over school year & summer break as suggested by community. Days per year used to estimate ingestion exposures which are on a per day basis. Hours per day and days per year used to estimate inhalation and external exposures.
‡ Days suggested by community input
‡‡ Total duration of 33 years represents ATSDR-recommended residential occupancy period, upper percentile

Table A 6. Residential frequency/duration assumptions (past / *recent*)

Age range	Play in yard/ home		Gardening		Landscaping		Duration, years‡‡
	Hours per day*	Days per year‡	Hours per day*	Days per year*	Hours per day*	Days per year*	
Kids less than 3	**4.2** / *1.0*	**365** / *365*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**3** / *3*
Preschool kids	**4.6** / *1.0*	**365** / *365*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**3** / *3*
Elementary kids	**4.6** / *1.0*	**365** / *365*	**0** / *0*	**0** / *0*	**0** / *0*	**0** / *0*	**5** / *5*
Middle school kids	**4.6** / *1.0*	**365** / *365*	**3.0** / *0.7*	**32** / *32*	**0** / *0*	**0** / *0*	**3** / *3*
High school kids	**4.2** / *1.0*	**365** / *365*	**3.0** / *0.7*	**32** / *32*	**3.0** / *0.7*	**32** / *32*	**4** / *4*
Adults	**3.4** / *0.6*	**365** / *365*	**4.1** / *2.0*	**44** / *44*	**4.1** / *2.0*	**44** / *44*	**15** / *15*

* Default child ingestion rates occur every day and include activities such as playing in dirt. Gardening and landscaping assumed to increase exposure to the person doing the activity, not to child bystanders. Hours per day used to estimate inhalation exposure. Days per year used to estimate ingestion exposures which are on a per day basis. Hours per day and days per year used to estimate inhalation and external exposures.
‡ Default residential assumption of daily exposure
‡‡ Total duration of 33 years represents ATSDR-recommended residential occupancy period, upper percentile

Intake Parameters for Recreational and Residential Scenarios

ATSDR used Agency guidance and professional judgment to determine how much soil, sediment, or water children and adults would take in while playing or living near Coldwater Creek. The tables below summarize the intake assumptions used in this evaluation. The assumptions for intakes are the same for past and for recent exposures.

Table A 7. Past and recent recreational ingestion intake assumptions

Age range	Soil ingestion, milligrams per day *	Sediment ingestion, milligrams per day **	Surface water incidental ingestion, milliliters per event†
Kids less than 3	100††	100	30
Preschool kids	100††	100	30
Elementary kids	100	100	30
Middle school kids	100	100	30
High school kids	100	100	30
Adults	50	50	30

*ATSDR-recommended soil only ingestion rates, upper percentile values [79]
**ATSDR-recommended sediment only ingestion rates, upper percentile values [79]
† Assumed one swimming/wading event per day at creek, with about 30 ml (2 tablespoons) of water swallowed each event [professional judgment]
†† Also evaluated soil pica behavior for children between 1 and 6 years old, assuming 5,000 mg of soil ingested once a week during warm, non-rainy days (32 weeks a year) for PAST exposures and twice a year for RECENT exposures [79]. This is based on judgment that in recent years young children are far less likely to access creek areas unsupervised and thus less likely to engage in soil pica activity there.

Table A 8. Past and recent recreational inhalation intake assumptions

Age Range	Particle emission factor, kilogram of soil per cubic meter of air*	Inhalation rate, cubic meter per hour†
Kids less than 3 **	1.18×10^{-6}	1.32-1.74
Preschool kids	1.18×10^{-6}	1.62
Elementary kids	1.18×10^{-6}	1.74
Middle school kids	1.18×10^{-6}	2.04
High school kids	1.18×10^{-6}	2.13
Adults	1.18×10^{-6}	2.26

* Derived by EPA for all-terrain vehicle riding in Colorado [80]. This value is more conservative than EPA's standard soil suspension assumption for recreational exposures, 2.16×10^{-10} kg/m^3 [82] and is consistent with activity-based sampling for dust in other published and unpublished studies, including a site in Missouri with lead-contaminated tailings [81].
† Short-term inhalation rates in cubic meters per hour, males and females combined, moderate intensity, upper percentile values converted from values in Table 6-2 of [83]
- kids less than 1 year old inhale 1.32 cubic meters of air per hour; kids 1 up to 3 years old inhale 1.74 cubic meters of air per hour
- high school kids value is average of rates for ages 14 through 17 (4 year duration); adult value is average of rates for ages 18 through 32 (15 year duration)

**to account for potential inhalation exposures of kids less than 3, we assumed inhalation similar to bike riding for the time they spent playing in and along creek (i.e., 2 hours per day for 96 days a year)

Table A 9. Past and recent residential ingestion intake assumptions

ATSDR age range	Soil and dust ingestion from playing in yard/home, milligrams per day*	Additional soil intake on gardening days, milligrams per day ‡	Additional soil intake on landscaping days, milligrams per day ‡‡
Kids less than 3	100-200**	-	-
Preschool kids	200**	-	-
Elementary kids	200	-	-
Middle school kids	200	100	-
High school kids	200	100	330
Adults	120	100	330

* ATSDR-recommended soil and indoor dust ingestion rates, upper percentile values [79]. Adults value is weighted for 200 mg/day for 18- to 20-year-olds, 100 mg/day for 21- to 32-year-olds.
**Children 6 weeks up to 1 year old ingest 100 mg/day; all others ingest 200 mg/day. Also evaluated soil pica behavior for children between 1 and 6 years old, assuming 5,000 mg of soil ingested 3 times a week during warm, non-rainy days (32 weeks a year) for both PAST and RECENT exposures [79].
‡ ATSDR-recommended value for gardening [79]. Assumed this is added to daily soil and dust ingestion rate.
‡‡ ATSDR-recommended soil and sediment ingestion rates, worker – outdoor (high intensity soil contact) [79]. Assumed this is added to daily soil and dust ingestion rate.

Table A 10. Past and recent residential inhalation intake assumptions

Age range	Particle emission factor, kilogram of soil per cubic meter of air*	Inhalation rate, cubic meter per hour†
Kids Less Than 3	1.18×10^{-6}	1.32-1.74
Preschool Kids	1.18×10^{-6}	1.62
Elementary Kids	1.18×10^{-6}	1.74
Middle School Kids	1.18×10^{-6}	2.04
High School Kids	1.18×10^{-6}	2.13
Adults	1.18×10^{-6}	2.26

* Derived by EPA for all-terrain vehicle riding in Colorado [80]. This value is more conservative than EPA's standard soil suspension assumption for recreational exposures, 2.16×10^{-10} kg/m^3 [82] and is consistent with activity-based sampling for dust in other published and unpublished studies, including a site in Missouri with lead-contaminated tailings [81].
† Short-term inhalation rates in cubic meters per hour, males and females combined, moderate intensity, upper percentile values converted from values in Table 6-2 of [83].
- kids less than 1 year old inhale 1.32 cubic meters of air per hour; kids 1 up to 3 years old inhale 1.74 cubic meters of air per hour
- high school kids value is average of rates for ages 14 through 17 (4 year duration); adult value is average of rates for ages 18 through 32 (15 year duration)

Appendix B. Pathway Analysis and Selecting Contaminants to Evaluate Further

Pathway Analysis

ATSDR evaluates whether people may have come into contact with contaminants from a site by examining *exposure pathways*. Exposure pathways consist of five elements: a contamination *source*; *transport* of the contaminant through an environmental medium like air, soil, or water; an *exposure point* where people can come in contact with the contaminant; an *exposure route* whereby the contaminant can be taken into the body; and an *exposed population* of people actually coming in contact with site contaminants [21].

Completed exposure pathways are those for which all five pathway elements are evident. If one or more elements is missing or has been stopped, the pathway is *incomplete*. Exposure cannot occur for incomplete exposure pathways. For *potential* exposure pathways, exposure appears possible, but one or more of the elements is not clearly defined.

Radioactive materials may result in exposures outside the body as well as from inside. External exposure depends on what type of radiation the material gives off, how far away it is, whether any materials are in between a person and the contaminant, and how long a person spends near the contaminant. These additional considerations determine whether radiation pathways are complete.

A completed exposure pathway does not necessarily mean that harmful health effects will occur. A contaminant's ability to harm health depends on many factors, including how much is present, how long and how often a person is exposed to it, and the toxicity of the contaminant. Further evaluation of the specific exposure occurring is needed to determine whether the exposure could cause harmful effects.

Below, we discuss the five exposure pathway elements as they describe completed exposure pathways relevant to people living or playing downstream of the source sites near Coldwater Creek (either now or in the past).

- The *source* of contamination was historical storage piles at the SLAPS and HISS/Futura sites upstream from residential areas on Coldwater Creek
- *Transport* of the contaminants occurred as they washed or blew into Coldwater Creek and worked their way downstream with creek sediments, eventually being deposited along the creek bed or (after floods) in floodplain areas
- *Exposure points* are and were present along recreational and residential sections of the creek and its floodplain, where people play and live
- *Exposure routes* include touching (or being in the immediate vicinity for radiological contaminants), accidentally swallowing, or breathing in contaminants

- *Exposed population* includes children and adults who played or lived near Coldwater Creek or its floodplain

As described in the body of this report, recreational and residential exposure scenarios evaluated in this report encompass these completed exposure pathways.

Selecting Contaminants to be Evaluated Further

Radiological Screening

Results were available for several radiological contaminants in soil and sediment along Coldwater Creek from I-270 to the St. Denis Bridge. Table B-1 summarizes the radiological data for soil and sediment. Because Th-230 was detected more frequently at higher levels than other radiological contaminants, we evaluated it further. We also included Ra-226 and U-238 for further evaluation. U-238 decays into Th-230, and Ra-226 is produced when Th-230 decays. Other radiological contaminants were not detected frequently or were detected at far lower levels than Th-230, and are not likely to contribute significantly to dose. Those contaminants were dropped from further evaluation. The radiological contaminants processed at the source areas were particulate and would appear more often in solid matrices like soil and sediment. To be conservative, we retained the same contaminants for evaluating surface water as well.

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Table B 1. Radiological contaminants measured in Coldwater Creek and its floodplain (data from 2014-2016)

	Number of positively identified samples / number of samples		Highest positively identified result in picocuries per gram		Reason*
Radioisotope	***Soil***	***Sediment***	***Soil***	***Sediment***	
Radiological Contaminants **Retained** in Evaluation:					
Thorium-230	5865 / 5877	1161 / 1174	465	145	Detected frequently at concentrations significantly above typical background levels (1–3 pCi/g) and remedial goals (RGs) for soil (14-15 pCi/g) or sediment (43 pCi/g).
Radium-226	5875 / 5877	1173 / 1174	11.4	6.2	Detected at concentrations above typical background levels (1–5 pCi/g) and RG for soil (5 pCi/g); formed by radioactive decay of Th-230. Not detected above RG for sediment (15 pCi/g).
Uranium-238	2830 / 5877	77 / 1174	15.1	3.84	Detected at concentrations above typical background levels (1–5 pCi/g); radioactively decays into Th-230 and Ra-226. Not detected above RG for soil (50 pCi/g) or sediment (150 pCi/g).
Radiological Contaminants **Dropped** From Evaluation:					
Thorium-232	5652 / 5877	1011/ 1174	7.13	1.86	Not detected frequently or significantly above typical background levels (0–2 pCi/g).
Radium-228	5863 / 5877	1140 / 1174	1.79	1.4	Not detected frequently or significantly above typical background levels (0–1 pCi/g).
Thorium-228	5644 / 5877	1014 / 1174	4.98	2.24	Not detected frequently or significantly above typical background levels (0–2 pCi/g).
Uranium-235	0 / 5877	0 / 1174	N/A	N/A	No positively identified results.
Actinium-227	268 / 5877	13 / 1174	5.83	3.33	Not detected frequently or significantly above typical background levels (0.1–0.8 pCi/g).
Protactinium-231	47 / 5877	3 / 1174	6.59	3.58	Not detected frequently or significantly above typical background levels (0–1 pCi/g).
Americium-241	0 / 5877	0 / 1174	N/A	N/A	No positively identified results.
Cesium-137	1766 / 5877	0 / 1174	0.63	N/A	Not detected frequently or significantly above typical background levels (0–0.6 pCi/g).
Potassium-40	5877 / 5877	1174 / 1174	27.4	21.6	Not detected frequently or significantly above typical background levels (7–17 pCi/g).

*Cited typical background levels are ranges of soil and sediment backgrounds listed in Appendix D of the Feasibility Study for the St. Louis North County Site, 2003 [6].

Non-radiological Chemical Screening

Few results were available for chemical contaminants in residential or recreational areas of Coldwater Creek. Annual surface water and sediment monitoring including chemical analyses is available from 1991 to 2014 at a sample location at I-270 upstream of the residential areas. In 2014, two additional monitoring locations were added in residential areas [25-41]. Tables B2 and B3 show a summary of the limited available data for surface water and sediment. Some chemical contaminants were detected in surface water at levels higher than ATSDR comparison values[g] for drinking water, and some contaminants were detected in sediment at levels higher than ATSDR comparison values for residential soil.

The use of drinking water and soil comparison values is for perspective. Drinking water comparison values are concentrations that would not be harmful, even if children and adults used the water as their sole source of drinking water every day. Soil comparison values are concentrations that would not be harmful, even if a small child played in their yard on the soil all day, every day. To ATSDR's knowledge, no one has ever used Coldwater Creek as a drinking water source, and sediment is rarely contacted as frequently or regularly as residential soil. We discuss each non-radiological chemical that exceeded a comparison value below.

Antimony – Antimony was detected in surface water, with the highest concentration of 3.3 micrograms per liter (µg/L) slightly above the drinking water comparison value of 2.8 µg/L. The concentration of antimony is not likely to be of concern for surface water exposures, which would involve ingestion of a small fraction of the amount of water assumed for drinking water.

Arsenic – Arsenic was detected in surface water at concentrations up to 3.9 µg/L and in sediment at concentrations up to 46 mg/kg. Both are higher than non-cancer and cancer-based comparison values for drinking water and soil. Arsenic is a known carcinogen and exposure contributes to a person's lifetime risk of cancer [84]. The concentrations of arsenic in sediment and surface water at Coldwater Creek may occur naturally from local geologic conditions; they are similar to background arsenic concentrations that have been measured in urban soils. [85,86]. A "worst case" dose using the highest concentrations of arsenic measured in surface water and sediment and exposure and intake assumptions described in Appendix A of this report was below ATSDR's chronic oral minimal risk level for non-cancer effects. The surface water and sediment exposures evaluated in this report would not be expected to contribute significantly to a person's intake of arsenic.

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[g] ATSDR calculates comparison values from minimal risk levels published by ATSDR (EMEGs), reference doses published by EPA (RMEGs), or cancer slope factors published by EPA (CREGs). ATSDR currently maintains a tool for viewing comparison values at https://www.atsdr.cdc.gov/sites/brownfields/CVViewer.html.

Chromium – Chromium was detected in surface water (up to 15 µg/L) and sediment (up to 80 mg/kg). No comparison value for chromium is available, but a small number of the detected values exceed drinking water and soil comparison values for hexavalent chromium, the most toxic form of chromium. In the absence of a specific source of hexavalent chromium, the less toxic trivalent chromium predominates in surface water and soil/sediment [87]. The concentrations of chromium measured in Coldwater Creek surface water and sediment are within typical ranges measured in the environment [87].

Lead – Lead was detected in surface water and sediment; no comparison value for lead exists. Although no safe level of lead has been identified, the highest concentrations measured in surface water (5 µg/L) and sediment (100 mg/kg) are relatively low, within typical urban background ranges [86,88]. The surface water and sediment exposures evaluated in this report would not be expected to contribute substantially to a child's blood lead level.

Manganese – Manganese was detected in surface water at concentrations up to 753 µg/L, higher than the drinking water comparison value of 350 µg/L. This concentration of manganese is not likely to be of concern for surface water exposures, which would involve ingestion of a small fraction of the amount of water assumed for drinking water.

Methylene Chloride – Methylene chloride was detected in surface water samples at concentrations up to 18 µg/L, higher than the drinking water comparison value of 6.1 µg/L. Methylene chloride is a common laboratory solvent and can easily contaminate environmental samples. The concentration of methylene chloride is not likely to be of concern for surface water exposures, which would involve ingestion of a small fraction of the amount of water assumed for drinking water.

Molybdenum – Molybdenum was detected in surface water at concentrations up to 46 µg/L, higher than the drinking water comparison value of 35 µg/L. This concentration of molybdenum is not likely to be of concern for surface water exposures, which would involve ingestion of a small fraction of the amount of water assumed for drinking water.

Polycyclic Aromatic Hydrocarbons – Several polycyclic aromatic hydrocarbons (PAHs) were detected in sediment samples at levels above soil comparison values. PAHs are a group of over 100 different chemicals formed during incomplete burning of coal, oil, and gas, garbage, or other organic substances like tobacco or charbroiled meat; PAHs are also found in substances like creosote or roofing tar. Some PAHs are synthesized and used to make products like dyes or plastics [89]. PAHs are a very common contaminant, particularly in urban areas. The concentrations of PAHs detected in sediment in Coldwater Creek, while higher than comparison values, are similar to the ranges detected in urban fill soils [90]. The surface water and sediment exposures evaluated in this report would not be expected to contribute significantly to a person's intake of PAHs.

Sodium – Sodium was detected in surface water at concentrations up to 138,000 µg/L. This exceeds the drinking water advisory of 20,000 µg/L for people on sodium-restricted diets [91]. Surface water exposure would be unlikely to contribute significantly to an individual's overall sodium intake.

Thallium – Thallium was detected in surface water samples at concentrations up to 3 µg/L, higher than the drinking water comparison value of 0.2 µg/L. It was detected in sediment at concentrations up to 5 mg/kg, higher than the soil comparison value of 0.78 mg/kg. A "worst case" dose using the highest concentration of thallium measured in surface water and sediment and exposure and intake assumptions described in Appendix A of this report was well below no effect levels in animal studies and only slightly higher than the provisional reference dose developed by EPA for thallium. The surface water and sediment exposures evaluated in this report would not be expected to contribute significantly to a person's intake of thallium [92].

Uranium – Uranium was detected in surface water samples at concentrations up to 10 µg/L, lower than the EPA's maximum contaminant level for drinking water but higher than ATSDR's drinking water comparison value of 1.4 µg/L. Uranium was detected in sediment at concentrations up to 79 mg/kg, higher than the soil comparison value of 14 mg/kg. ATSDR previously identified U-238 as a contaminant for further evaluation; possible non-radiological effects of exposure to uranium are included with the evaluation of possible radiological effects from U-238.

With the exception of uranium, ATSDR did not evaluate any of the above non-radiological contaminants further. Chemical contaminants (whether or not they originate from the SLAPS and HISS/Futura sites) could possibly contribute some risk in recreational or residential scenarios. However, no data on chemicals in floodplain soil are available, and not enough surface water and sediment data are available to evaluate potential exposures fully. Further sampling and evaluation would be needed to fully assess contribution of non-radiological contaminants to community exposure.

Table B 2. Chemical contaminants detected at least once above comparison values in Coldwater Creek surface water near residential areas*

Chemical	Number of detections / number of samples	Highest concentration detected in µg/L	Drinking water comparison value in µg/L**	CV source
Antimony	6 / 31	3	2.8	RMEG
Arsenic	25 / 31	4	2.1 / 0.016	EMEG / CREG
Chromium	12 / 31	15	6.3	EMEG for hexavalent chromium
Lead	10 / 14	5	none†	N/A
Manganese	14 / 14	753	350	RMEG
Methylene chloride	3 / 11	18	6.1	CREG
Molybdenum	31 / 31	46	35	RMEG
Sodium	14 / 14	138,000	20,000	DWA
Thallium	1 / 31	3	0.2	RSL
Uranium	10 / 24	10	30 / 1.4	MCL / intermediate EMEG for soluble salts

*Data collected from 1991-2014 at a point near I-270 upstream of residential areas and in 2014 from two points within residential areas [25-41].

**No one has ever used Coldwater Creek as a drinking water source. Comparing the surface water results against drinking water CVs is for perspective only.

†No ATSDR health based comparison value for lead in drinking water exists because there is no clear threshold for some of the more sensitive health effects from lead exposure. The EPA action level for lead in drinking water is 15 µg/L.

CV – comparison value
µg/L – micrograms per liter
RMEG – remedial media evaluation guide
EMEG – environmental media evaluation guide
CREG – cancer risk evaluation guide
MCL – maximum contaminant level
N/A – not applicable
DWA – drinking water advisory
RSL – regional screening level

Table B 3. Chemical contaminants detected at least once above comparison values in Coldwater Creek sediment near residential areas*

Chemical	Number of detections / number of samples	Highest concentration detected in mg/kg	Soil comparison value in mg/kg**	CV source
Arsenic	33 / 34	46	17	EMEG
Chromium	34 / 34	80	51	EMEG for hexavalent chromium
Lead	16 / 16	100	none†	Not applicable
Polycyclic aromatic hydrocarbons:				
Benz(a)anthracene	13 / 14	40	1.1	RSL
Benzo(a)pyrene*	13 / 14	35	0.12	CREG
Benzo(b)fluroanthene	13 / 14	30	1.1	RSL
Benzo(g,h,i)perylene	7 / 14	6	none	Not applicable
Benzo(k)fluoranthene	13 / 14	34	11	RSL
Carbazole	2 / 14	1	none	Not applicable
Chrysene	13 / 14	47	110	RSL
Dibenz(a,h)anthracene*	3 / 14	1	0.11	RSL
Indeno(1,2,3-cd)pyrene*	8 / 14	5	1.1	RSL
Phenanthrene	13 / 14	93	none	Not applicable
Thallium	12 / 34	5	0.78	RSL
Uranium	15 / 29	79	11	Intermediate EMEG for soluble salts

*Data collected from 1991-2014 at point near I-270 upstream of residential areas and in 2014 from two points within residential areas [25-41].

**Sediment comparison values are not available. Comparing the sediment results against soil CVs is for perspective only.

†No ATSDR health based comparison value for lead in soil or sediment exists because there is no clear threshold for some of the more sensitive health effects from lead exposure. The EPA RSL for residential soil lead is 400 mg/kg.

CV – comparison value
mg/kg – milligrams per kilogram
RMEG – remedial media evaluation guide
EMEG – environmental media evaluation guide
CREG – cancer risk evaluation guide
MCL – maximum contaminant level
N/A – not applicable
DWA – drinking water advisory
RSL – regional screening level

Relevant Toxicological Information for Contaminants Retained for Further Evaluation

The contaminants selected for further evaluation are Th-230, Ra-226, and U-238. The information presented below may include discussion of effects of other isotopes of thorium, radium, or uranium. How a radiological substance behaves in the human body is primarily determined by its chemical nature, so effects of other isotopes are relevant and likely similar, as long as the half-lives in comparison to the human lifespan are similar.

Th-230, Ra-226, and U-238 are naturally occurring radioisotopes. All give off radiation in the form of alpha particles as they decay, and the energy of the alpha radiation emitted is similar. These three radioisotopes all have very long half-lives (many times the human lifespan) and so they will not decay appreciably during a person's lifetime. For these reasons, ATSDR adds the individual isotopes' doses (to an organ or to the whole body) to assess their potential to cause radiological effects.

For Th-230 and Ra-226, radiological effects are expected to predominate (that is, no health effects from their chemical interactions with the body are known to occur before effects from the radiation are observed). Uranium, on the other hand, may cause chemical damage to the kidneys before any radiation effects would be evident. While we include radiological dose from uranium as contributing to the effects of radium and thorium, we also separately consider non-radiological effects of uranium.

Properties, Uses, Distribution in the Body, and Toxicological Effects

Radium

Radium exhibits chemical properties of the alkaline earth metals: the pure element is shiny, silvery white, and somewhat reactive at standard temperature and pressure. All forms of radium are radioactive. Ra-226 has the longest half-life, about 1,600 years [93]. Ra-226 produces radon gas (Rn-222), which is known to cause lung cancer when inhaled.

Historically, radium was used in paint for luminescent clock and watch dials and in medical treatments and devices. Health effects from the occupational and medical exposures that occurred from these uses were studied for decades and form much of our understanding of radium's harmful effects [50,51].

When inhaled, radium will mostly stay in the lungs. When ingested, only a small fraction of radium will be taken into the bloodstream. It goes throughout the body, but it concentrates in the skeletal system due to its chemical similarity to calcium and because soft tissues release the radium relatively quickly compared to bone.

Long-term studies of the radium dial painters showed increases in bone sarcomas (bone cancers) and cancers of the sinuses and jaw (also called head cancers). The Ra-226 isotope appeared to be the main causative agent for head cancers, as these occurred mainly among those exposed to Ra-226 only. No bone cancers were observed in workers with weighted skeletal doses less than 1,000 rads (for alpha radiation, 1,000 rads is equivalent to 20,000,000 mrem) [50,94]. Patients treated with high doses of Ra-224 (mean bone surface dose of 3,000 rads [60,000,000 mrem]) also showed elevations in bone cancers compared to expected rates, as did patients treated with lower doses [94]. The lowest bone surface dose that resulted in a bone cancer was 900 rads (18,000,000 mrem) [94]. Other cancers suggested or shown to result from these radium exposures include cancers of the lung and breast, leukemia, or multiple myeloma; the evidence for these cancers was not as strong as evidence for bone cancers [94].

Thorium

Thorium in pure form is a silvery, moderately hard, malleable metal, part of the actinide group of elements. All forms of thorium are radioactive. Most studies and information on thorium relate to Th-232, as it has a half-life of over 14 billion years and comprises more than 99% of the thorium in nature. Th-230, while not as prevalent, has a half-life of over 75,000 years and may have similar biological effects as Th-232.

Thorium is used in magnesium alloys, tungsten filaments for light bulbs, and mantles for incandescent gas lanterns. Several epidemiological studies, summarized below, have followed workers in these industries to determine effects of thorium exposure.

In the early to mid-1900s, Th-232 was used in a colloidal material called Thorotrast injected in patients to increase contrast for x-rays. The very small particle size of Thorotrast and its route via injection make distribution and clearance of Th-232 in the body different from thorium that is ingested or inhaled. Therefore, health data from Thorotrast patients is of limited use in determining possible effects from environmental thorium exposures [45].

When inhaled, thorium may stay in the lungs or dissolve throughout the body, depending on its chemical form. Thorium oxides and hydroxides dissolve slowly in lung fluid and are generally retained in the lungs; thorium nitrate and all other forms exhibit moderate lung fluid solubility and may enter the bloodstream [45]. When ingested, only a small fraction of thorium will be taken into the bloodstream; most is eliminated in feces. Inhaled or ingested thorium taken into the bloodstream will go throughout the body and concentrate in the skeletal system similarly to radium [94,45,95].

Occupational exposure studies of thorium industrial workers who inhaled thorium ore dust have had inconsistent findings. Studies have shown that thorium workers had higher rates of death from respiratory disease, lung cancer, pancreatic cancer, or rectal cancer. But the studies did not show a strong correlation between the number of deaths and exposure, job type, or length of employment. This brings into question whether the excess deaths were a result of thorium exposure or some other factor (such as silica exposure or higher rates of smoking not accounted for) [95].

Because thorium concentrates on bone surfaces and may remain in the bone matrix for many years, the toxicological issue of greatest concern is effects in the bone caused by radiation from thorium and its decay products over time [95].

Uranium

Uranium is a silvery heavy metal and is part of the actinide group of elements. All forms of uranium are radioactive. U-238, with a half-life of four and a half billion years, comprises over 99.7% of all the uranium on earth. U-238 forms both Th-230 and Ra-226, among other products, as it radioactively decays.

Uranium is present naturally throughout the world in soil, rock, and water. Since the discovery and development of processes to harness energy from nuclear fission, uranium ores have been mined and extracted for use in weapons or power generation. Studies of uranium miners, nuclear industry workers, and people exposed to high concentrations of uranium in groundwater have contributed to knowledge about uranium exposure.

When inhaled, uranium will mostly stay in the lungs. When ingested, only a small fraction of uranium will be taken into the bloodstream. Most of the uranium in blood is filtered by the kidneys and leaves the body in urine; the remainder is distributed throughout the body and retained primarily in the bone, kidneys, or other soft tissue.

The International Agency for Research on Cancer (IARC) has determined that there is inadequate evidence in humans and limited evidence in experimental animals for the carcinogenicity of natural uranium [94]. The main toxicological effect of uranium is chemical damage to kidney tubules, the structures in the kidney that maintain balance between waste products and needed compounds in the bloodstream. Uranium exposure leads to microscopic changes in the tubules, which with time or at higher exposures can impair the kidney's function. Inhaling insoluble uranium at high levels can damage the respiratory tract [68].

Appendix C. Derivation of Exposure Point Concentrations

To determine how much of each contaminant is taken in by children and adults who might accidentally swallow or breathe in soil, sediment, or surface water from in or near Coldwater Creek, ATSDR determined representative exposure point concentrations for the contaminants of concern.

Floodplain Soil

Depth of Soil Used to Estimate Exposure

ATSDR's standard procedure uses soil concentrations in the top three inches (from 0-3 inches below ground surface) to estimate exposure point concentrations. This is the depth of soil primarily contacted during normal activities on the soil. The data for Coldwater Creek included concentrations in floodplain soil collected from 0-6 inches below ground surface. We assumed these 0-6 inch concentrations to represent what children and adults could be exposed to while playing, biking, gardening, or landscaping near the creek. ATSDR assumes no cover material on top of the soil (grass, leaves, pavement, etc.) to obtain the most conservative estimate of potential exposures.

Past vs. Recent Exposure Concentration

The only environmental sampling data available for recreational or residential stretches of Coldwater Creek include floodplain soil and sediment data from 2014–2016 and limited sediment data from the late 1980s. ATSDR is reasonably confident that surface samples from the 2014–2016 floodplain soil sampling can be used to estimate recent exposures within the past 10 or 15 years.

The 2014–2016 data, however, are inadequate to describe exposures that occurred in the more distant past, such as the 1960s to 1990s. No information on floodplain soil from this time period is available. Past floodplain soil contaminant concentrations would depend on how much contamination had washed down from the source areas at various times, how much flooding occurred as contaminants washed downstream, whether subsequent flood events scoured off surface contamination or buried it, and other physical factors. Historical reports describing contamination at the source areas, surrounding properties, drainage ditches, haul roads, and Coldwater Creek did not contain adequate data to describe past contaminant levels in the floodplain in recreational or residential stretches of the creek [20,96–110].

ATSDR examined the 2014–2016 floodplain soil data and found that soil core samples from below the surface often contained the highest concentrations of Th-230. One explanation for this finding is that contamination initially deposited on the surface was covered up over time. To gain a conservative estimate of the possible past surface concentrations, ATSDR assumed that for each location sampled, the highest result at any depth was once at the ground surface and therefore available for exposure.

Soil Exposure Point Concentration

ATSDR uses many conservative assumptions in estimating potential community exposures. When presented with data from a wide area such as the 1.2 miles along Coldwater Creek represented by the floodplain soil data set, we look at the data as a whole but also examine particular areas where a person might have regular exposure. Although a person would not go to the same exact spot every time they do something by the creek, they could potentially go to the same smaller area regularly. We use a statistic called the upper confidence limit on the mean (the 95% UCL) to conservatively estimate the contaminant concentration in the area a person could be expected to go to when they go to the creek. There are a number of ways to estimate the 95% UCL depending on how the data are distributed; ATSDR used a publicly available statistical program called ProUCL to examine the data and suggest the appropriate estimate of the 95% UCL [42].

ATSDR followed the same general mapping procedure (described below) for determining exposure point concentrations for past and recent exposures for Th-230, Ra-226, and U-238. For past exposures, we mapped the maximum concentration at any depth as an estimate of what may have been present at the surface. These maps are shown in Figures C1, C2, and C3, for Th-230, Ra-226, and U-238, respectively. For recent exposures, we mapped surface soil concentration (corresponding Figures C4, C5, and C6).

For either past or recent exposures, Th-230 was present more often and at higher levels than Ra-226 or U-238. As shown, for example, in Figure C1, ATSDR looked at the Th-230 soil results in various ways to estimate the exposure point concentration. First, we separated the floodplain into nine sectors (labeled A through I) along the creek and looked at data from the right and left sides of the creek in each sector. We also considered data from small "hotspot" areas where exceedances of the FUSRAP remedial goal appeared to be clustered ("hotspot" boxes shown on the figure). We further examined a smaller area which appeared to be in or particularly close to residential yards. Using results from each specific area, we used ProUCL to estimate the appropriate 95% UCL for that area. Table C1 shows the statistics for each unit examined for past Th-230 soil exposure. ATSDR used the highest recommended UCL for all the units examined for the Th-230 soil exposure point concentration. Table C1 also shows the corresponding recommended UCLs for Ra-226 and U-238 for the units evaluated for Th-230.

For estimating soil exposure point concentrations for recent exposures, we followed the same process as for past exposures, using surface soil concentrations instead of the maximum concentration at any depth. The recent exposures were analyzed using different "hotspot" boxes than for past exposures, because the Th-230 surface data was clustered differently. All other units evaluated were the same as for past exposures. Figures C4-C6 and Table C2 present recent data analyzed and results.

Figure C 1. Map of Th-230 soil maximum data for Coldwater Creek – PAST exposures

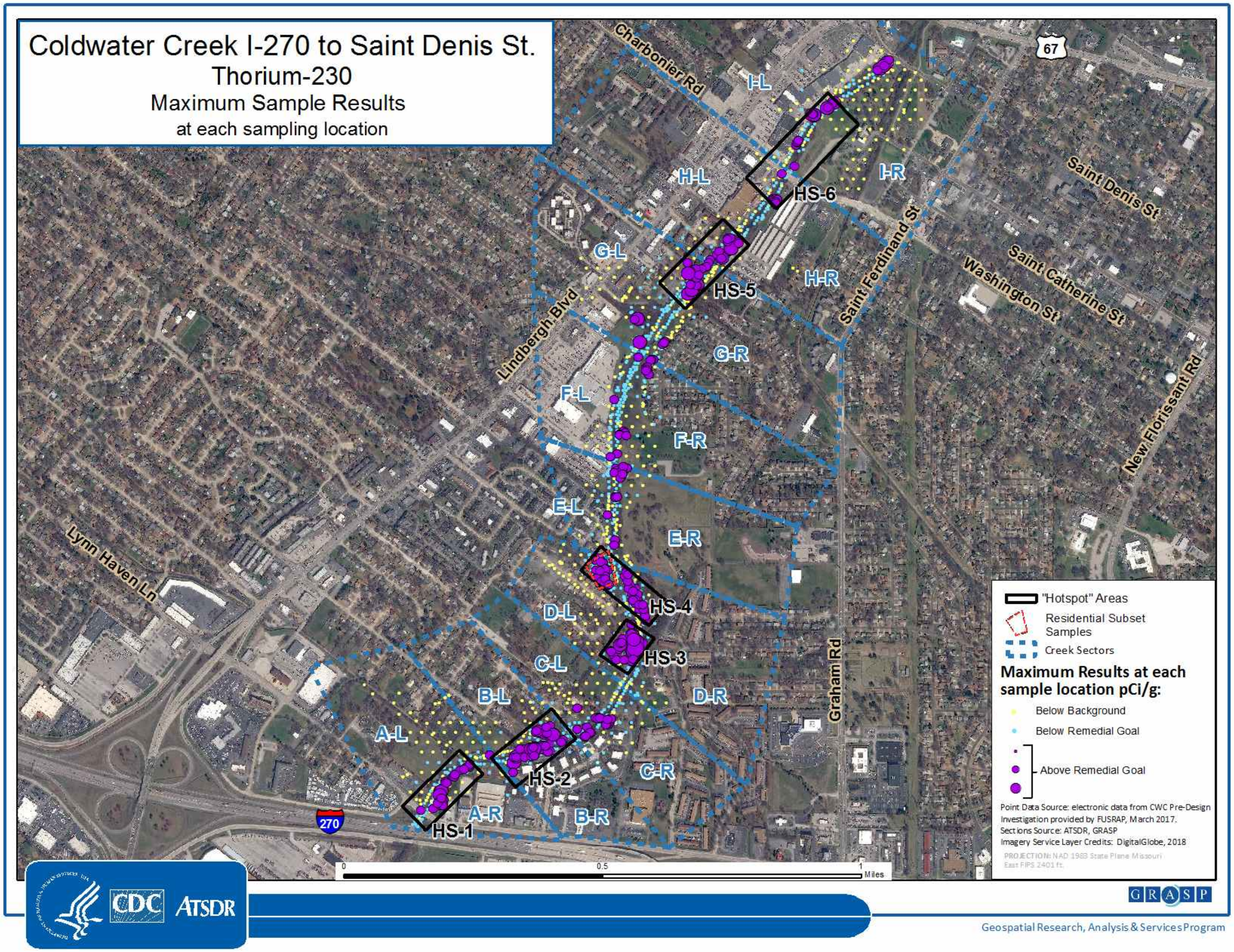

Figure C 2. Map of Ra-226 soil maximum data for Coldwater Creek – PAST exposures

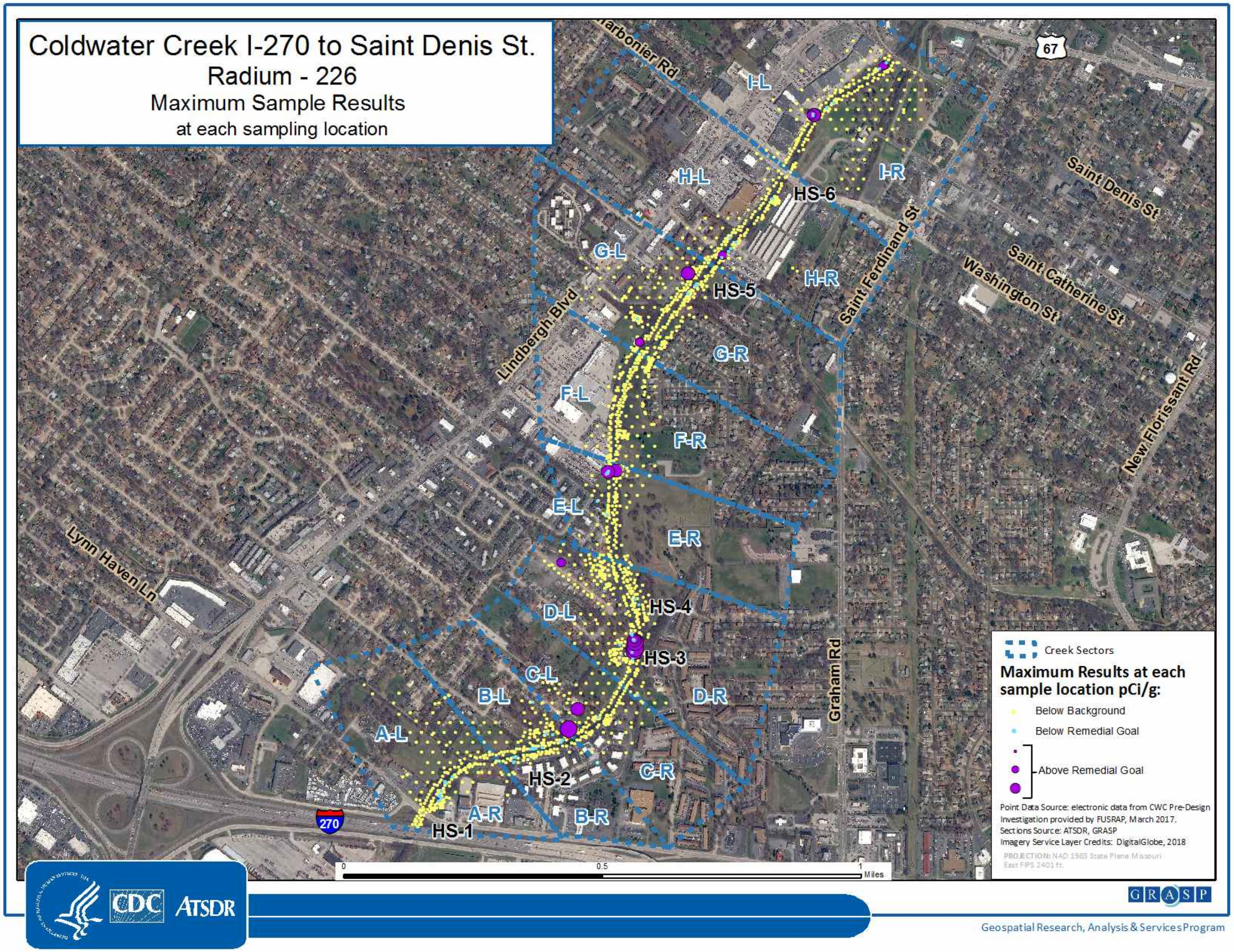

Figure C 3. Map of U-238 soil maximum data for Coldwater Creek – PAST exposures

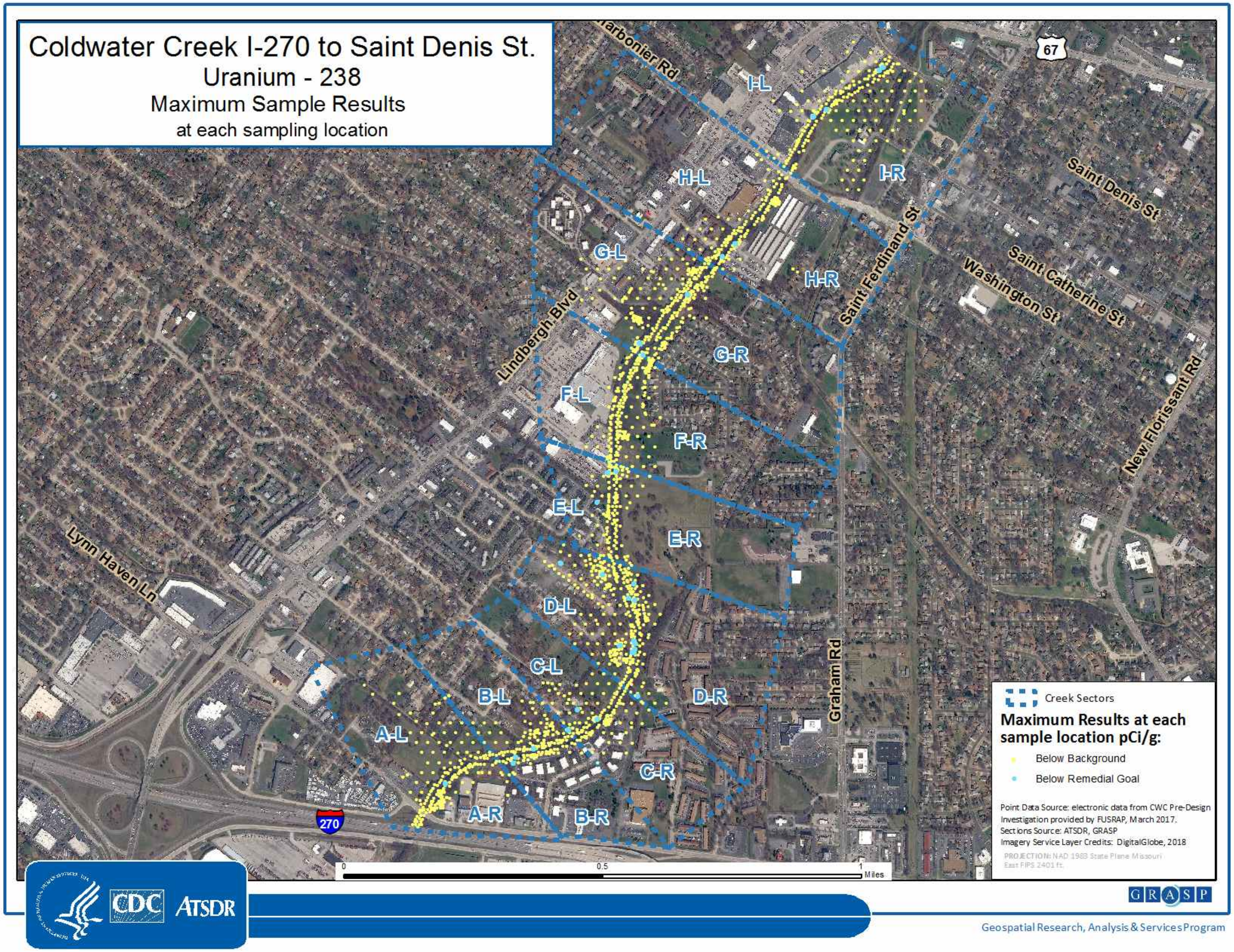

Table C 1. Recommended 95% UCLs for maximum soil for various units along Coldwater Creek – PAST exposures

Maximum at any depth soil data selection	# Positively identified Th-230 results	# of Th-230 results > background †	# of Th-230 results > remedial goal††	Th-230 mean (pCi/g)	**Recommended Th-230 UCL value* (pCi/g)**	Th-230 data distri-bution**	Ra-226 UCL* (pCi/g)	U-238 UCL* (pCi/g)
Sector A - left	96	35	2	3.7	**5.0**	None	1.6	1.1
Sector A - right	102	85	30	13.8	**20.6**	None	2.0	1.4
Sector B - left	116	79	33	16.5	**26.7**	None	2.0	1.5
Sector B - right	54	44	15	15.2	**20.5**	L	2.1	1.6
Sector C - left	78	42	7	6.7	**10.7**	None	2.0	1.7
Sector C - right	66	47	16	8.7	**10.4**	L, G	1.8	1.4
Sector D - left	221	144	55	17.7	**30.6**	None	2.0	1.7
Sector D - right	118	86	29	10.9	**15.8**	None	1.8	1.4
Sector E - left	84	50	2	5.3	**8.5**	None	1.9	1.4
Sector E - right	75	47	14	8.7	**13.7**	None	1.9	1.5
Sector F - left	62	40	3	5.7	**10.0**	L	1.5	1.4
Sector F - right	145	109	14	6.7	**8.8**	None	1.6	1.2
Sector G - left	162	108	21	8.4	**13.8**	None	1.6	1.2
Sector G - right	119	66	16	9.4	**16.4**	None	1.6	1.2
Sector H - left	71	41	9	7.4	**12.9**	None	1.5	1.2
Sector H - right	71	58	21	18.4	**24.8**	L	1.9	1.8
Sector I - left	95	48	16	14.0	**27.6**	None	1.7	1.6
Sector I - right	122	41	5	5.0	**9.3**	None	1.5	1.2
"Hot spot"-1	123	93	31	12.2	**18.0**	None	1.9	1.3
" Hot spot "-2	149	120	48	18.1	**26.9**	None	2.1	1.4
" Hot spot "-3	98	80	32	26.7	**54.5**	L	2.5	2.3
" Hot spot "-4	141	121	52	16.0	**22.0**	None	1.7	1.4
" Hot spot "-5	158	114	43	15.8	**24.5**	None	1.8	1.3
" Hot spot "-6	118	79	25	13.9	**24.2**	None	1.8	1.6
Residential subset	39	37	23	26.3	**33.7**	G	1.9	2.0

†ATSDR considered 3 pCi/g to represent a value statistically different than background
††FUSRAP remedial goal for Th-230 in surface soil is 14 pCi/g
*95% Upper Confidence Limit recommended by ProUCL statistical program based on data distribution [42].
**None: No discernible distribution; G: approximate or adjusted gamma distribution; L: approximate lognormal distribution
Value used as exposure point concentration for "past" soil exposures

Figure C 4. Map of Th-230 surface soil data for Coldwater Creek – RECENT exposures

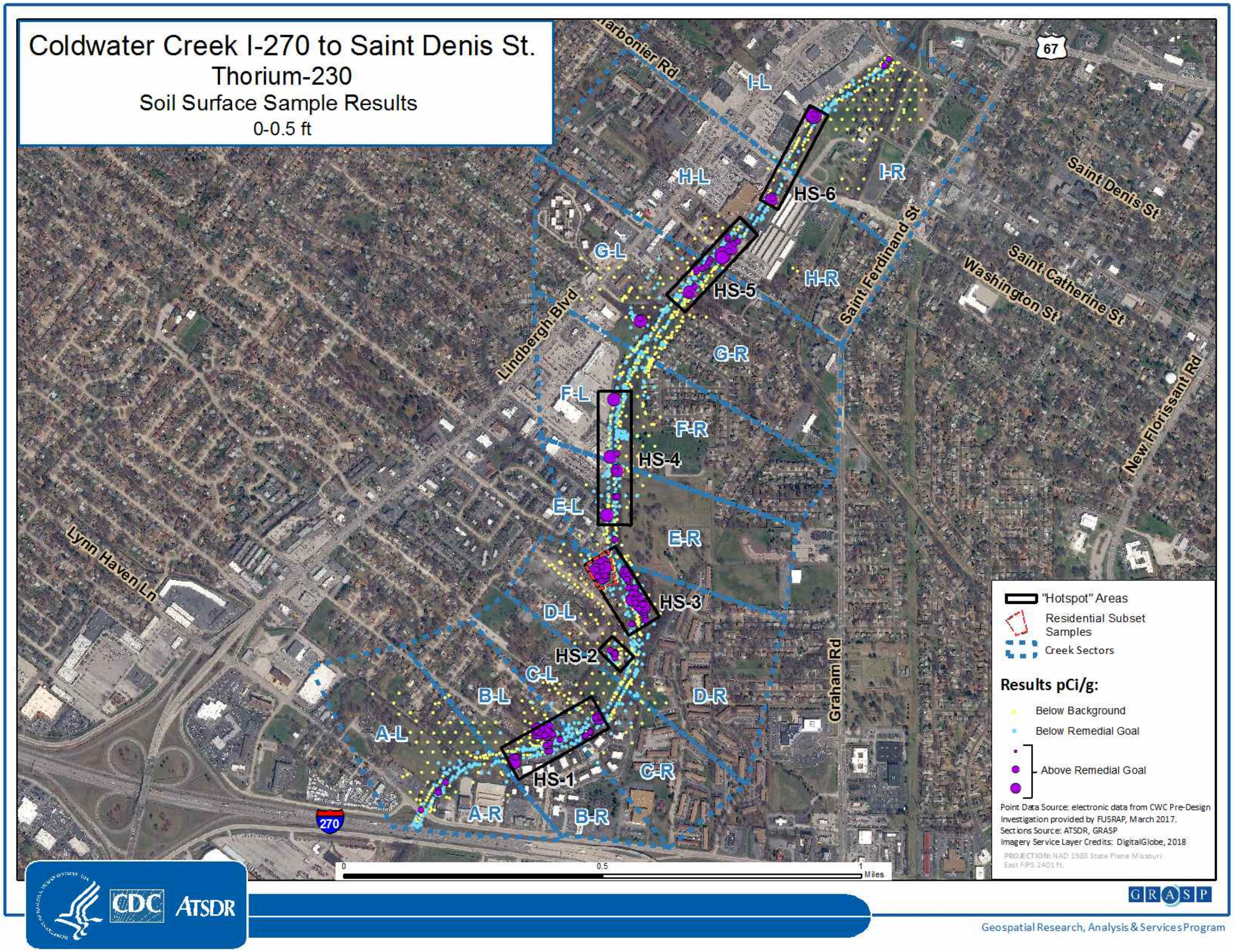

Figure C 5. Map of Ra-226 surface soil data for Coldwater Creek – RECENT exposures

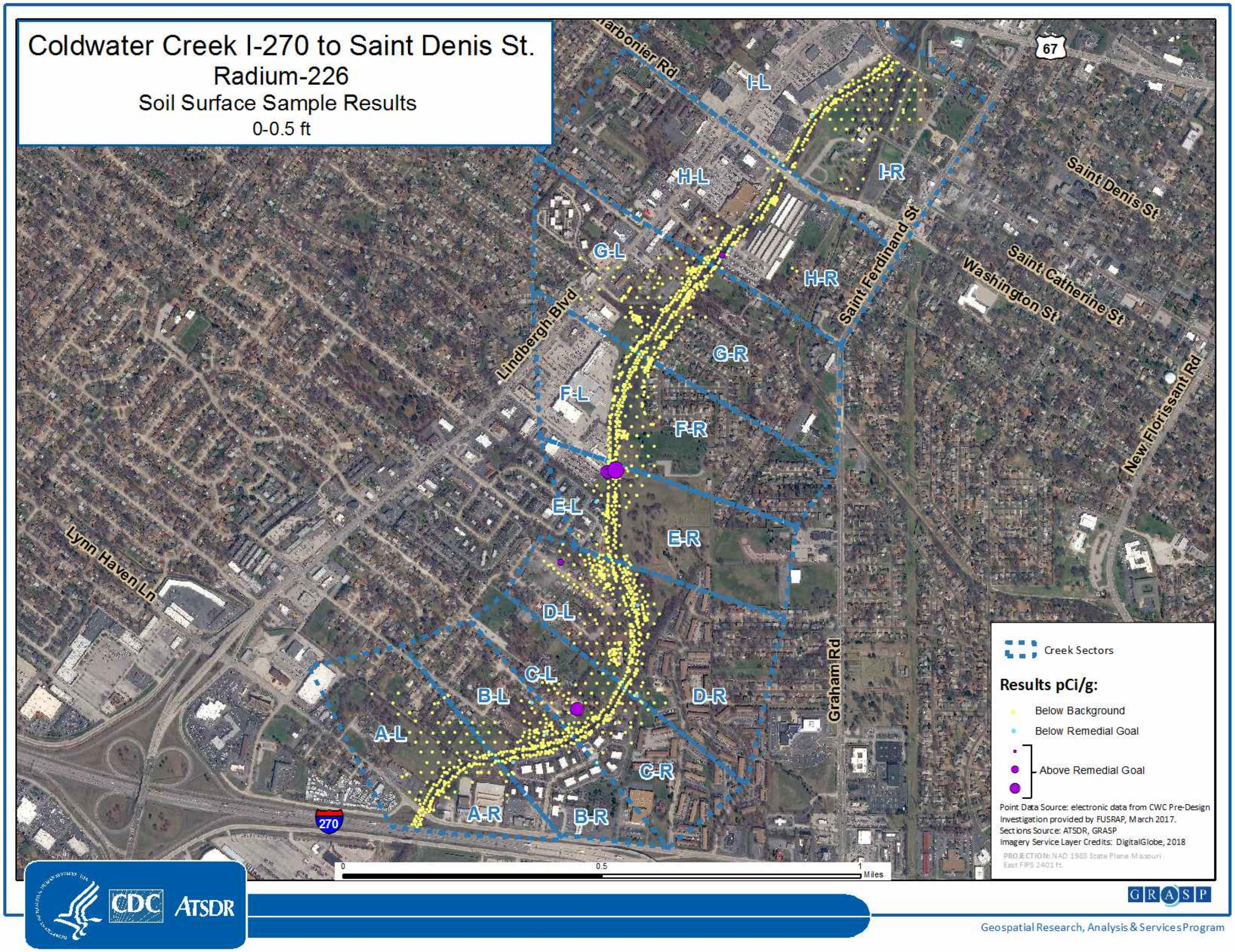

Figure C 6. Map of U-238 surface soil data for Coldwater Creek – RECENT exposures

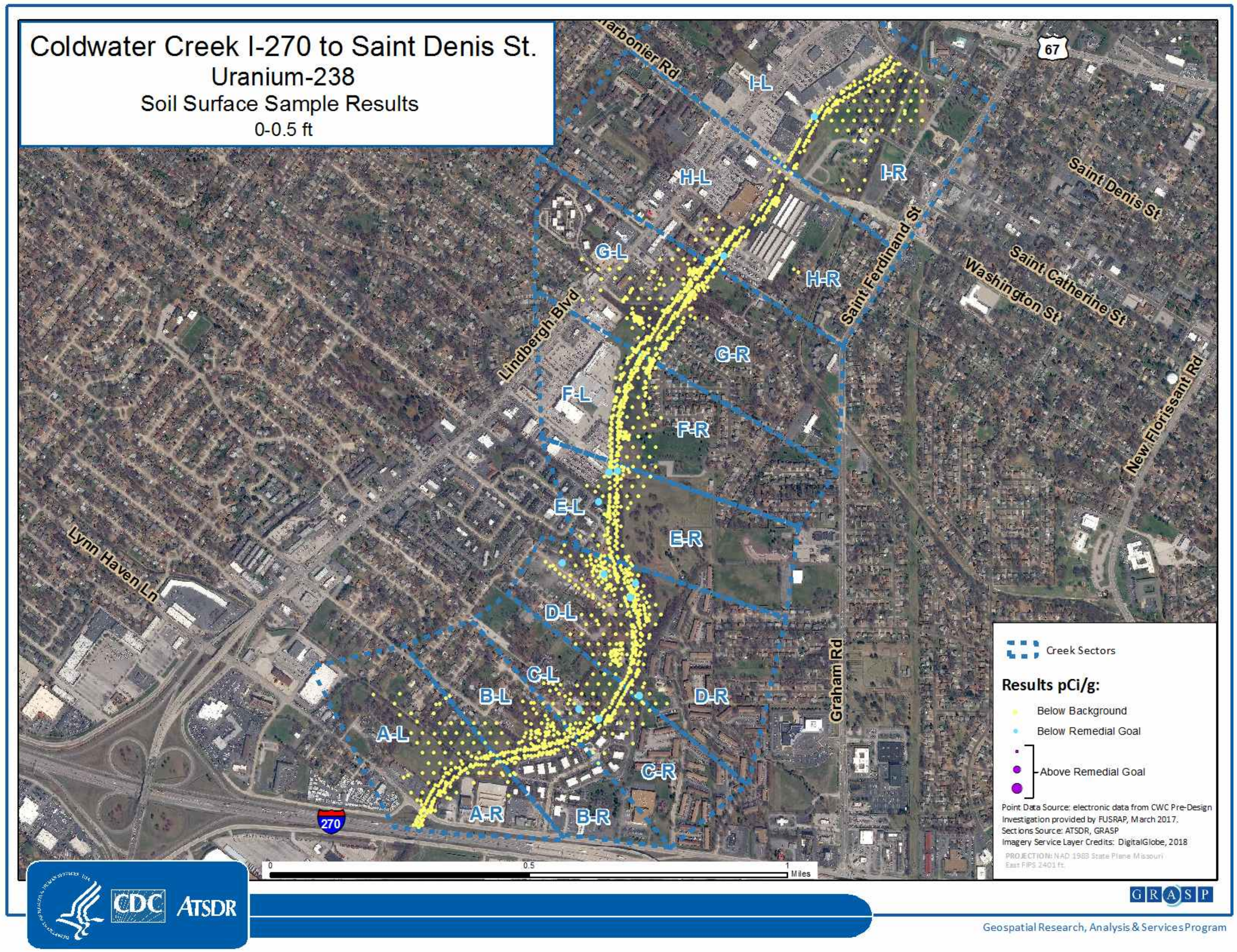

Table C 2. Recommended 95% UCLs for surface soil for various units along Coldwater Creek – RECENT exposures

Surface soil data selection	# Positively identified Th-230 results	# of Th-230 results > background †	# of Th-230 results > remedial goal††	Th-230 mean (pCi/g)	**Recommended Th-230 UCL value* (pCi/g)**	Th-230 data distri-bution**	Ra-226 UCL* (pCi/g)	U-238 UCL* (pCi/g)
Sector A - left	111	31	1	3.0	**4.1**	None	1.5	0.7
Sector A - right	92	71	4	5.5	**7.5**	L	1.7	0.8
Sector B - left	128	76	19	8.0	**12.0**	None	1.6	1.0
Sector B - right	55	40	10	9.5	**11.8**	L, G	1.8	0.7
Sector C - left	97	49	5	5.2	**7.6**	None	1.6	0.9
Sector C - right	63	40	5	5.7	**7.1**	L	1.6	0.9
Sector D - left	245	134	32	7.6	**10.6**	None	1.5	0.8
Sector D - right	142	97	34	9.8	**13.8**	None	1.7	1.0
Sector E - left	85	48	1	4.4	**4.8**	L	1.9	1.3
Sector E - right	94	51	7	5.7	**8.5**	None	1.8	1.0
Sector F - left	58	38	2	5.2	**9.6**	None	1.4	1.1
Sector F - right	166	81	1	4.0	**5.1**	None	1.5	0.7
Sector G - left	180	93	8	4.6	**6.2**	None	1.4	0.7
Sector G - right	135	47	3	3.6	**5.4**	None	1.4	0.7
Sector H - left	60	37	4	5.1	**6.0**	L, G	1.3	0.8
Sector H - right	67	47	8	11.3	**23.4**	None	1.6	1.3
Sector I - left	70	33	5	6.6	**14.4**	None	1.3	0.9
Sector I - right	141	39	0	2.9	**3.7**	None	1.3	0.7
"Hot spot"-1’	210	166	39	9.7	**12.8**	None	1.8	0.8
" Hot spot "-2’	37	23	8	7.8	**12.7**	None	1.6	1.4
" Hot spot "-3’	185	143	58	12.9	**17.3**	None	1.7	0.9
" Hot spot "-4’	226	157	10	6.0	**7.9**	None	1.7	1.0
" Hot spot "-5’	176	116	19	7.6	**12.5**	None	1.4	0.9
" Hot spot "-6’	77	35	5	6.6	**14.2**	None	1.4	1.1
Residential subset	44	41	22	21.5	**27.3**	L, G	1.8	1.8

†ATSDR considered 3 pCi/g to represent a value statistically different than background
††FUSRAP remedial goal for Th-230 in surface soil is 14 pCi/g
*95% Upper Confidence Limit recommended by ProUCL statistical program based on data distribution [42].
**None: No discernible distribution; G: approximate or adjusted gamma distribution; L: approximate lognormal distribution
Value used as exposure point concentration for “recent” soil exposures

Sediment

For past sediment exposures, ATSDR used sediment sampling from the late 1980s. To be conservative, we used the maximum concentration of Th-230, Ra-226, and U-238 at any depth to describe concentration at each location. We followed a similar mapping procedure as described for soil, except we did not separate left and right sides of the creek, and we did not include "hotspot" boxes or the residential subsets. For recent exposures, we used the same procedure except using the more recent sediment data collected from 2014–2016. Figures C7–C12 and Tables C3 and C4 present the mapping and ProUCL results for past and recent sediment exposure point concentration. We used the highest recommended UCL for each contaminant as the sediment exposure point concentration.

Figure C 7. Map of Th-230 sediment maximum data for Coldwater Creek – PAST exposures

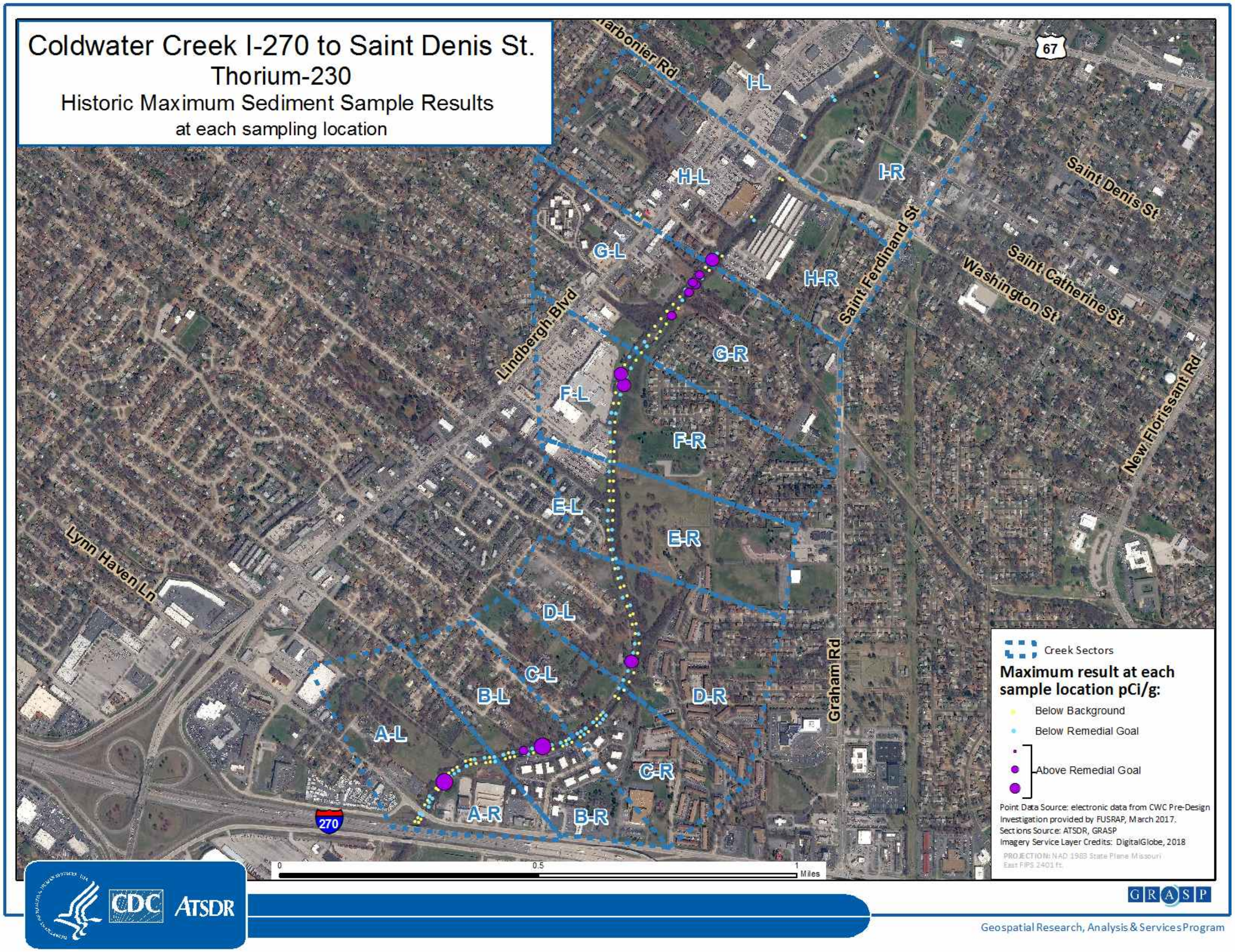

Figure C 8. Map of Ra-226 sediment maximum data for Coldwater Creek – PAST exposures

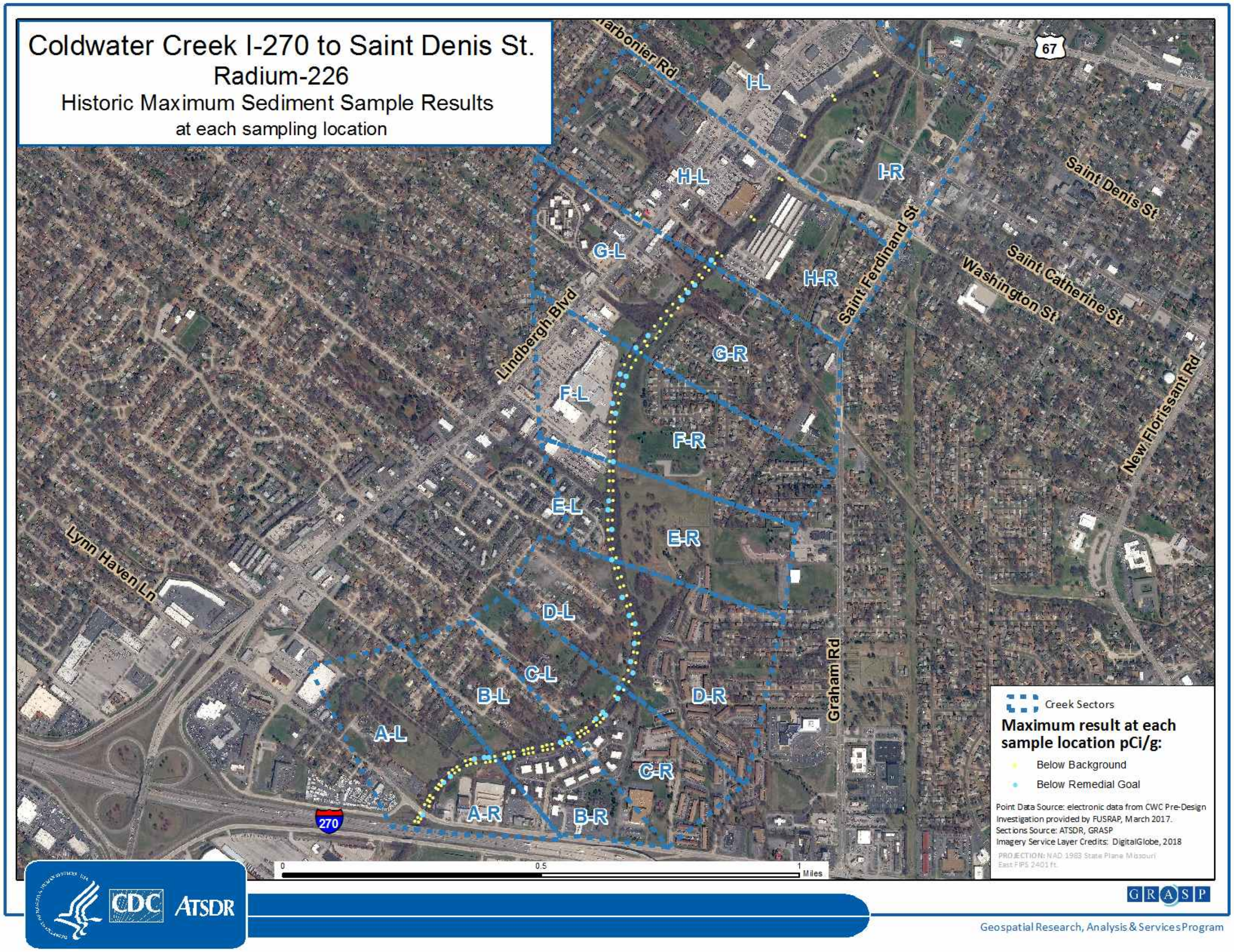

Figure C 9. Map of U-238 sediment maximum data for Coldwater Creek – PAST exposures

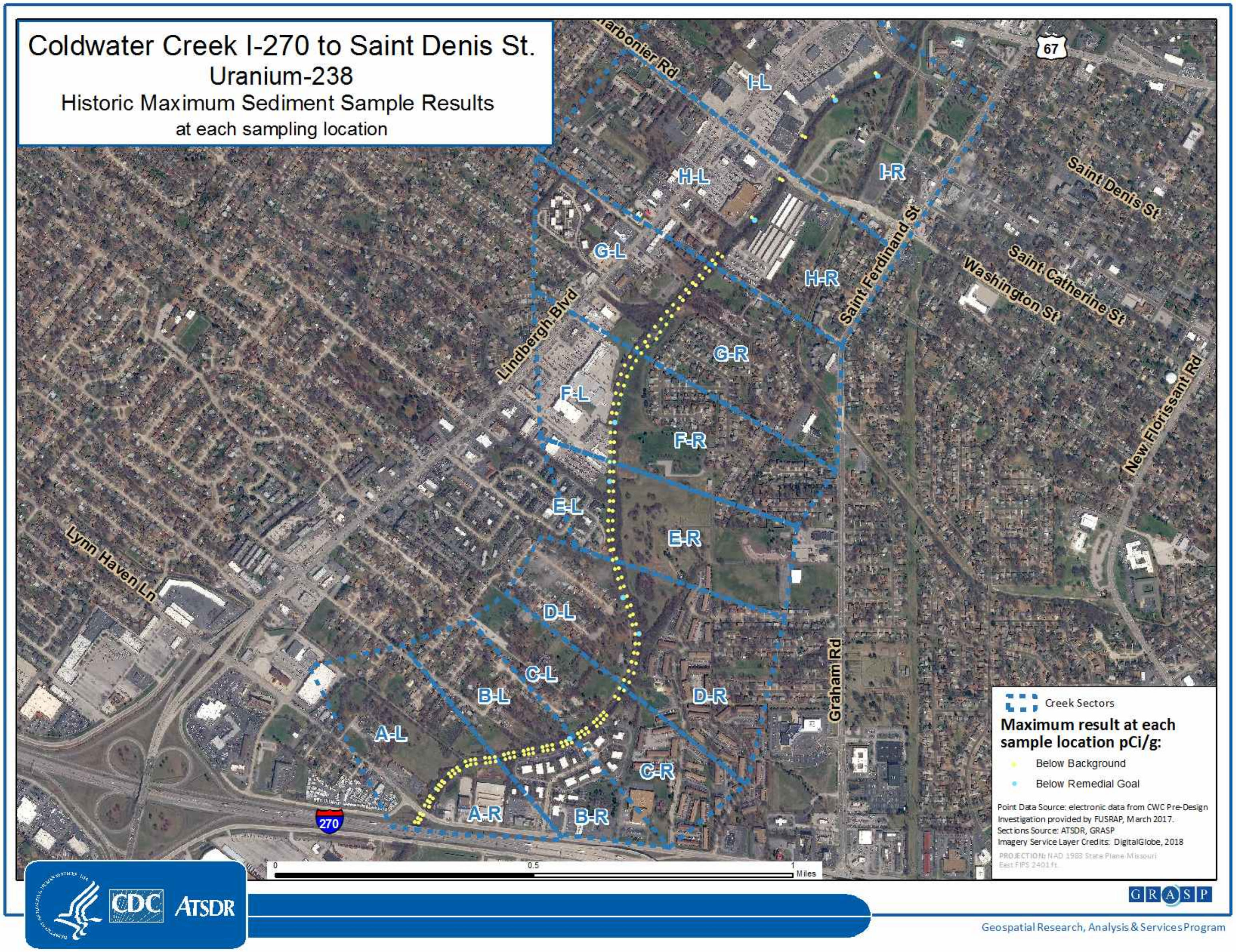

Table C 3. Recommended 95% UCLs for sediment for various units along Coldwater Creek – PAST exposures

Sediment data selection	# Th-230 results	# of Th-230 results > background †	# of Th-230 results > remedial goal††	Th-230 mean (pCi/g)	**Recommended Th-230 UCL value* (pCi/g)**	Th-230 data distri-bution**	Ra-226 UCL* (pCi/g)	U-238 UCL* (pCi/g)
Sector A	36	16	1	11.7	**33.7**	None	2.4	NP
Sector B	24	12	2	15.0	**50.2**	None	2.4	2.0
Sector C	24	13	0	5.9	**10.0**	G,L	3.5	NP
Sector D	28	11	1	11.3	**32.9**	None	3.3	3.9
Sector E	19	6	0	3.2	**6.6**	None	2.8	2.0
Sector F	21	10	2	15.9	**46.2**	None	3.1	2.1
Sector G	22	10	4	14.0	**37.8**	None	4.8	NP
Sector H	12	6	2	17.3	**105.4**	G,L	3.9	2.2
Sector I	6	4	0	10.6	**67.1**	G,L	1.9	4.5

†ATSDR considered 3 pCi/g to represent a value statistically different than background
††FUSRAP remedial goal for Th-230 in sediment is 43 pCi/g
*Upper confidence limit recommended by ProUCL statistical program based on data distribution [42]. All values represent 95% upper confidence limits.
**None: No discernible distribution; G: approximate or adjusted gamma distribution; L: approximate lognormal distribution
NP = Not processed; no results greater than background
Value used as exposure point concentration for "past" sediment exposures

Figure C 10. Map of Th-230 sediment maximum data for Coldwater Creek – RECENT exposures

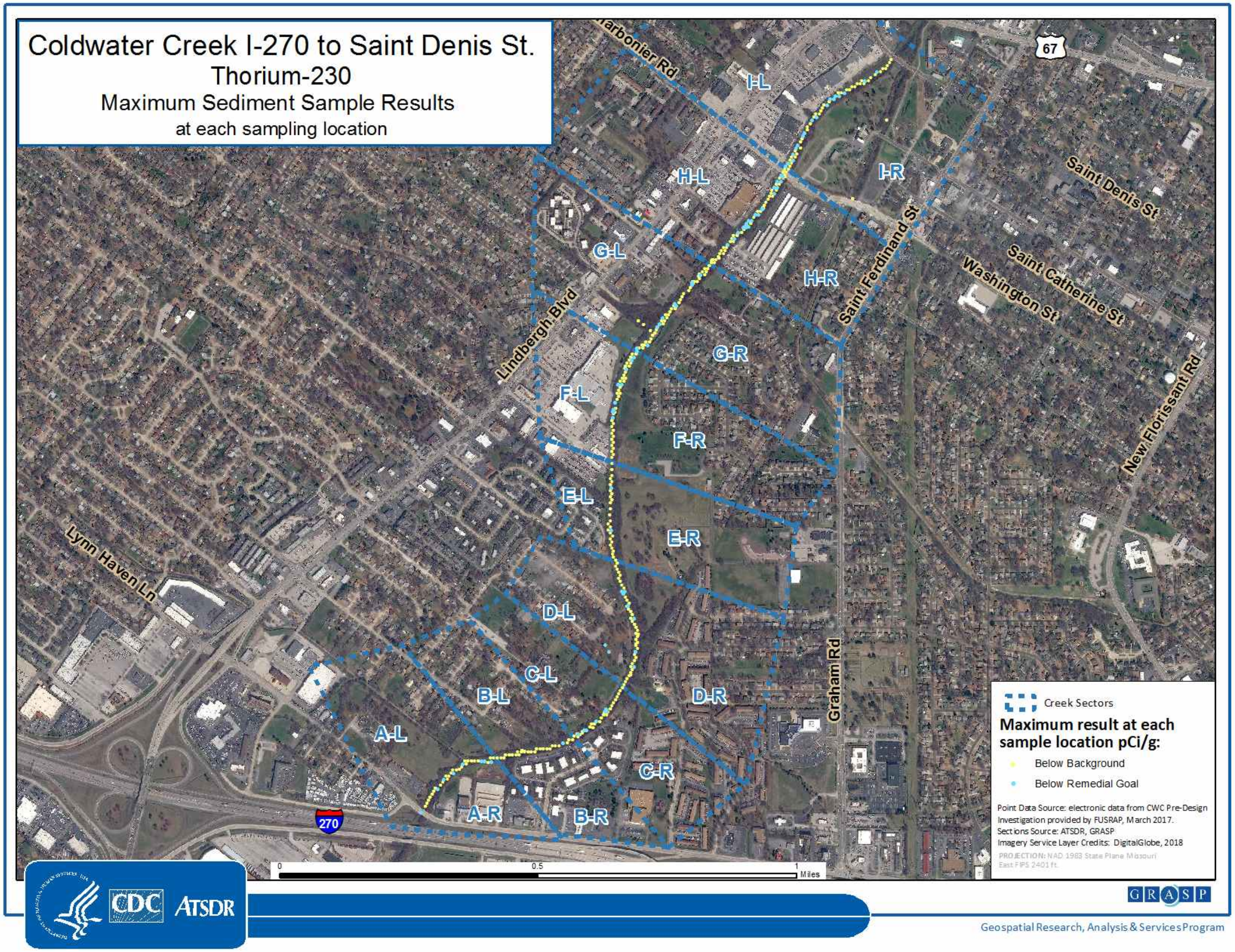

Figure C 11. Map of Ra-226 sediment maximum data for Coldwater Creek – RECENT exposures

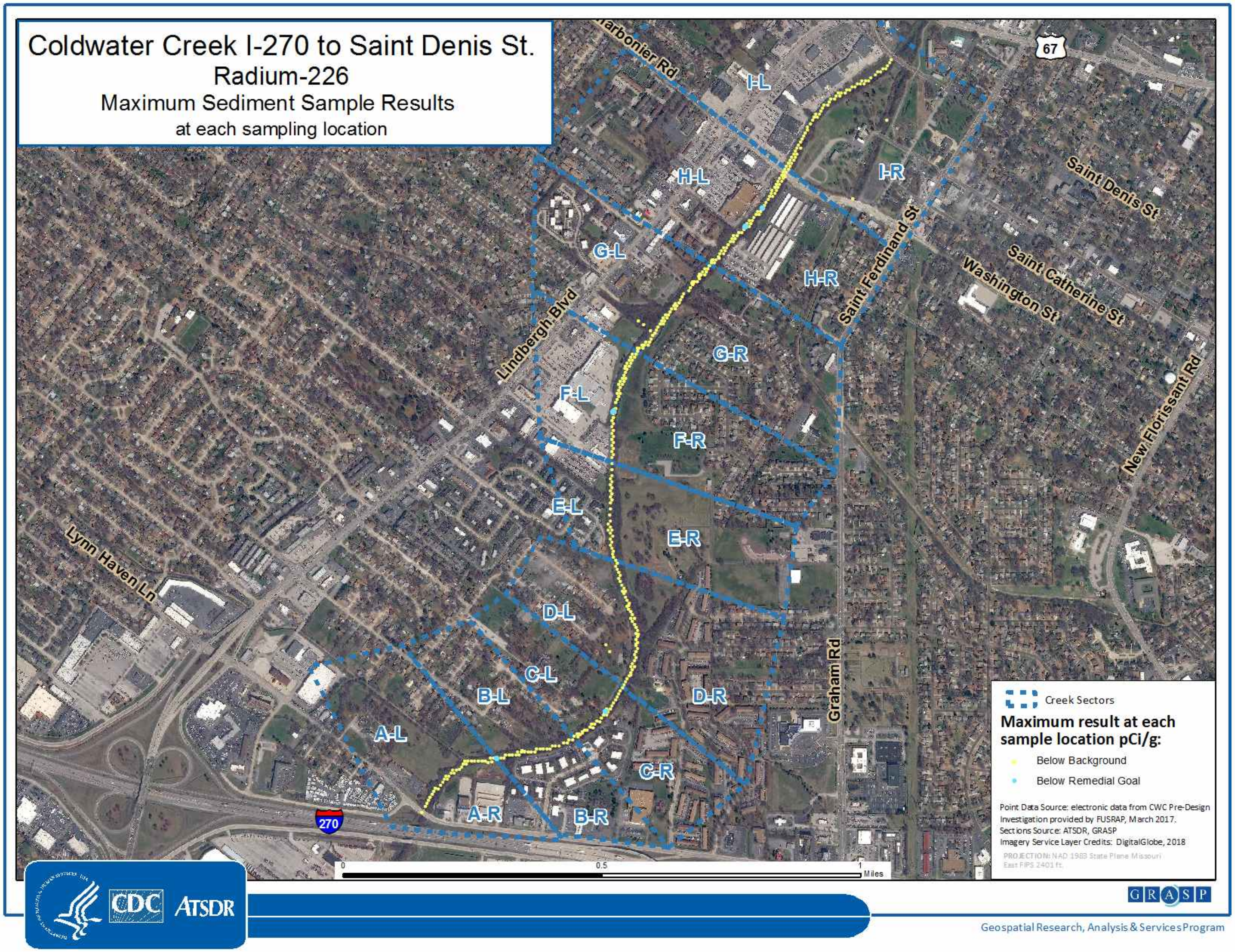

Figure C 12. Map of U-238 sediment maximum data for Coldwater Creek – RECENT exposures

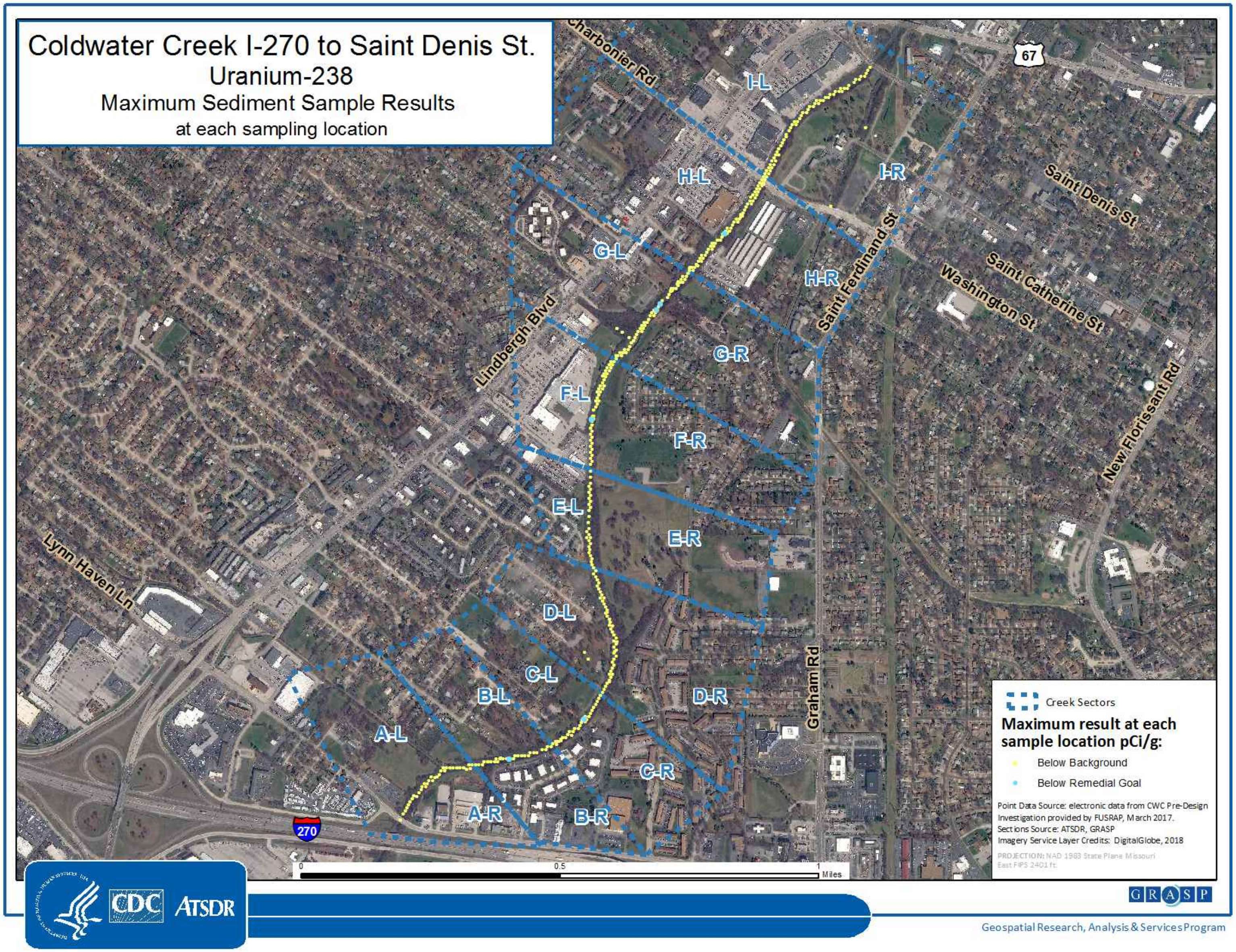

Table C 4. Recommended 95% UCLs for sediment for various units along Coldwater Creek – RECENT exposures

Sediment data selection	# Positively identified Th-230 results	# of Th-230 results > background †	# of Th-230 results > remedial goal††	Th-230 mean (pCi/g)	**Recommended Th-230 UCL value* (pCi/g)**	Th-230 data distri-bution**	Ra-226 UCL* (pCi/g)	U-238 UCL* (pCi/g)
Sector A	34	8	0	2.8	**4.7**	None	1.4	1.0
Sector B	28	1	0	2.7	**7.3**	None	1.8	0.7
Sector C	35	7	0	35	**6.9**	None	1.8	0.8
Sector D	50	9	0	2.1	**3.0**	L	1.3	0.6
Sector E	29	2	0	2.0	**3.7**	None	1.3	0.6
Sector F	47	10	0	3.8	**7.1**	None	1.5	0.8
Sector G	55	11	0	2.7	**4.7**	None	1.4	0.8
Sector H	68	22	0	4.5	**7.9**	None	1.6	0.6
Sector I	60	18	0	3.6	**6.0**	None	1.4	0.5

†ATSDR considered 3 pCi/g to represent a value statistically different than background
††FUSRAP remedial goal for Th-230 in sediment is 43 pCi/g
*95% Upper confidence limit recommended by ProUCL statistical program based on data distribution [42].
**None: No discernible distribution; L: approximate lognormal distribution
Value used as exposure point concentration for "recent" sediment exposures

Surface Water

No surface water samples were collected in the 2014-2016 pre-design investigation. However, environmental monitoring surface water and sediment data have been collected in Coldwater Creek from 1991-2014 from a station near I-270, at the upstream side of the residential area evaluated in this report. The data show no positively identified results higher than FUSRAP's background criteria [6]. For this reason, ATSDR used the background criteria as the exposure point concentration for Ra-226, Th-230, and U-238.

Table C5 summarizes all the exposure point concentrations used in evaluating radiological dose in this report.

Table C 5. Exposure point concentrations (EPCs) for soil, sediment, and surface water at Coldwater Creek

	Past exposures (1960s to 1990s)			**Recent exposures (2000s and on)**		
Contaminant	Surface soil EPC, pCi/g	Sediment EPC, pCi/g	Surface water EPC, pCi/L	Surface soil EPC, pCi/g	Sediment EPC, pCi/g	Surface water EPC, pCi/L
Thorium-230	54.5	105.4	4.65	27.3	7.9	4.65
Radium-226	2.5	4.8	0.88	1.9	1.8	0.88
Uranium-238	2.3	4.5	5.05	1.8	1.0	5.05

pCi/g = picocuries per gram pCi/L = picocuries per liter

Uranium Concentration for Evaluating Non-radiological effects

ATSDR also evaluated chemical effects of uranium in this report. All the recent sediment and floodplain soil sampling reported activity of U-238 or other isotopes in soil in pCi/g rather than total uranium in mg/kg. These samples better represent potential residential exposures than the limited data from annual monitoring reported in the chemical screening section of Appendix A. The monitoring data were not collected from recreational or residential stretches of the creek and included no floodplain soil results. Therefore, we used the exposure point concentrations for U-238 in Table C5, along with information about the activity and relative abundance of natural uranium isotopes, to calculate exposure point concentrations for total uranium.

To estimate the concentration of total uranium in soil or sediment in milligrams per kilogram, we divided the U-238 value in picocuries per gram by the specific activity of U-238 and then divided by U-238's natural abundance, 99.27%. (The relative abundance of different uranium isotopes would have remained constant regardless of the processing that occurred in the past.) This is shown using the past exposure point concentration determined for U-238 in the example calculation that follows:

$$2.3\frac{pCi}{g\ soil} \times \frac{g\ \text{U-238}}{3.3\times10^{-7}\ Ci} \times \frac{10^{-12}Ci}{pCi} \times \frac{10^{3}\ g\ soil}{kg\ soil} \times \frac{g\ \text{U}}{0.9927\ g\ \text{U-238}} \times \frac{10^{3}\ mg\ \text{U}}{g\ \text{U}} = 7.02\,\frac{mg\ \text{U}}{kg\ soil}$$

Table C6 summarizes the uranium concentrations in soil and sediment used to evaluate chemical effects in this report.

Table C 6. EPCs for evaluating uranium chemical effects at Coldwater Creek

	Total uranium surface soil EPC, mg/kg	Total uranium sediment EPC, mg/kg	Total uranium surface water EPC, µg/L
Past exposures (1960s to 1990s)	7	14	15
Recent exposures (2000s and on)	5	3	15

mg/kg = milligrams per kilogram µg/L = microgram per liter

Values calculated using a specific activity of 3.3×10^{-7} Ci/g for U-238 and a natural abundance of 99.27%. Values rounded to nearest whole number.

Appendix D. Exposure Intake and Example Calculations

Recreational Contaminant Intake Equations and Example Calculations

We calculated annual exposure intake for ingestion and inhalation for each radioactive contaminant using the exposure point concentration in its respective media, intake rates, and frequencies. The numbers shown in example calculations may not be exactly the same as we used due to rounding.

Intake = Soil Ingestion + Soil Inhalation + Sediment Ingestion + Surface Water Ingestion

Soil Ingestion Intake

$$EPC\ \left(\frac{pCi}{g}\right) \times\ sediment\ ingestion\ \left(\frac{mg}{day}\right) \times \left(\frac{1\ g}{1{,}000\ mg}\right) \times$$
$$Days\ per\ year\ playing\ in\ creek\ or\ banks\ \left(\frac{days}{year}\right)$$

For example, the past recreational soil ingestion Th-230 intake for a middle schooler is:

=54.5*100*(1/1,000)*(252) = 1,373.4 pCi Th-230/year

Soil Inhalation Intake

$$EPC\ \left(\frac{pCi}{g}\right) \times\ PEF\ \left(\frac{kg\ soil}{m^3\ air}\right) \times \left(\frac{1{,}000\ g}{1\ kg}\right) \times breathing\ rate\ \left(\frac{m^3}{hr}\right) \times$$
$$hrs\ per\ day\ riding\ bikes\ \left(\frac{hr}{day}\right) \times Days\ per\ year\ riding\ bikes\ \left(\frac{days}{year}\right)$$

For example, the past recreational soil inhalation Th-230 intake for a middle schooler is:

=54.5*1.18×10^{-6}*1,000*2.04*3.3*264 = 114.3 pCi Th-230/year

Sediment Ingestion Intake

$$EPC\ \left(\frac{pCi}{g}\right) \times\ sediment\ ingestion\ \left(\frac{mg}{day}\right) \times \left(\frac{1\ g}{1{,}000\ mg}\right) \times$$
$$Days\ per\ year\ playing\ in\ creek\ or\ banks\ \left(\frac{days}{year}\right)$$

For example, the past recreational sediment ingestion Th-230 intake for a middle schooler is:

=105.4*100*(1/1,000)*(252) = 2,656.1 pCi Th-230/year

Surface Water Ingestion Intake

$$EPC\ \left(\frac{pCi}{L}\right) \times\ surf\ water\ ingestion\ \left(\frac{ml}{day}\right) \times \left(\frac{1\ L}{1{,}000\ ml}\right) \times$$
$$Days\ per\ year\ playing\ in\ creek\ or\ banks\ \left(\frac{days}{year}\right)$$

For example, the past recreational surface water ingestion Th-230 intake for a middle schooler is:

=4.65*30*(1/1,000)*252 = 35.15 pCi Th-230/year

Pica Intake – for children one to six years old

$$EPC\left(\frac{pCi}{g}\right)\times\ pica\ soil\ ingestion\ \left(\frac{mg}{pica\ event}\right)\times\left(\frac{1\ g}{1{,}000\ mg}\right)\times\frac{pica\ events}{year}$$

For example, the past recreational soil pica ingestion Th-230 intake for a pica child is:

= 54.5*5000*(1/1000)*32 = 8,720 pCi Th-230/year for a child eating large amounts of soil once a week during warm, non-rainy days (32 times a year).

This pica intake adds to normal ingestion and inhalation intakes and external dose for estimating resulting dose.

Residential Contaminant Intake Equations and Example Calculations

Intake = Soil Ingestion + Soil Inhalation

Soil Ingestion Intake

$$EPC\left(\frac{pCi}{g}\right)\times\ soil\ ingestion\ \left(\frac{mg}{day}\right)\times\left(\frac{1\ g}{1{,}000\ mg}\right)\times Days\ per\ year\ in\ yard\ \left(\frac{days}{year}\right)+$$
$$EPC\left(\frac{pCi}{g}\right)\times\ gardening\ ingestion\ \left(\frac{mg}{day}\right)\times\left(\frac{1\ g}{1{,}000\ mg}\right)\times$$
$$Days\ per\ year\ gardening\ \left(\frac{days}{year}\right)+$$
$$EPC\left(\frac{pCi}{g}\right)\times\ landscaping\ ingestion\ \left(\frac{mg}{day}\right)\times\left(\frac{1\ g}{1{,}000\ mg}\right)\times$$
$$Days\ per\ year\ landscaping\ \left(\frac{days}{year}\right)$$

For example, the past residential soil ingestion Th-230 intake for a high schooler is:

54.5*200*(1/1,000)*(365) + 54.5*100*(1/1,000)*32 + 54.5*330*(1/1,000)*32

= 4,728.4 pCi Th-230/year

Soil Inhalation Intake

For this calculation, we assume that activities in the yard could suspend soil into the air and that this can be described with the same particle emission factor developed for dirt bike riding. We included time spent playing the yard, gardening, and landscaping to estimate inhalation intake. The intake is given by:

$$EPC\left(\frac{pCi}{g}\right)\times PEF\left(\frac{kg\ soil}{m^3\ air}\right)\times\left(\frac{1{,}000\ g}{1\ kg}\right)\times breathing\ rate\left(\frac{m^3}{hr}\right)\times \left[hrs\ per\ day\ playing\left(\frac{hr}{day}\right)\times Days\ per\ year\ playing\left(\frac{days}{year}\right)+ hrs\ per\ day\ gardening\left(\frac{hr}{day}\right)\times Days\ per\ year\ gardening\left(\frac{days}{year}\right)+ hrs\ per\ day\ landscaping\left(\frac{hr}{day}\right)\times Days\ per\ year\ landscaping\left(\frac{days}{year}\right)\right]$$

For example, the past residential soil inhalation Th-230 intake for a high schooler is:

$54.5*1.18\times10^{-6}*1{,}000*2.13*$ (4.2*365+3.0*32+3.0*32) = 234 pCi Th-230/year

Pica Intake – for children two to six years old

Annual intake is given by:

$$Exposure\ Point\ Concentration\left(\frac{pCi}{g}\right)\times pica\ soil\ ingestion\left(\frac{mg}{day}\right)\times\left(\frac{1\ g}{1{,}000\ mg}\right)\times 3\ \frac{pica\ events}{week}\times\left(\frac{warm, non-rainy\ weeks}{year}\right).$$

For example, the past residential soil pica ingestion Th-230 intake for a pica child is:

54.5*5,000*(1/1,000)*3*32 = 26,160 pCi Th-230/year for a child eating large amounts of soil regularly.

This pica intake adds to normal ingestion and inhalation intakes and external dose for estimating resulting dose.

Appendix E. Radiological Dose and Estimated Increased Cancer Risk

Radiological Dose

Intake itself does not completely determine the radiological dose. Determining the radiological dose resulting from intake is a complicated function of the identity of the radiological isotope, how it enters the body (ingestion or inhalation), how much is taken in, how much is eliminated or metabolized, what organs it is stored in, and how it changes as it radioactively decays. Each radioactive isotope has different characteristics. The International Commission on Radiological Protection (ICRP) has derived dose coefficients for estimating radiological dose from a given intake at different times after exposure for different isotopes, different age groups, and various organs. [43]. EPA has published external dose coefficients to estimate dose to various organs from external exposures to different isotopes [45].

For this evaluation, ATSDR used dose coefficients for the general public obtained from the program "Radiological Toolbox" v. 3.0.0 (available as a download from the Nuclear Regulatory Commission). This program provides internal dose coefficients based on ICRP Publication 68/72 and external doses based on Federal Guidance Report 12 and includes some dose coefficients for organs not specifically listed in the original publications (but derived following the same techniques). The program was created by the same group who provided dosimetry calculations for those publications [111,44,45]. More details about the dose coefficients selected and example calculations for internal and external dose are provided below.

Calculation of Internal Dose

Radioactive material taken up by the body continues to deliver a radiation dose over a person's lifetime. We determined the *70-year committed radiological dose* for each year of intake. The 70-year committed dose is defined as the dose that will accumulate in a person's body from the time of intake to age 70; but this entire dose is considered to occur in the year of the intake. Each year of intake estimated in this report has a corresponding 70-year committed dose. Subsequent years of intake result in additional annual 70-year committed doses. Using coefficients for 70-year committed dose results in the highest estimated annual dose for a given intake.

The individual doses from intake of Th-230, Ra-226, and U-238 can be considered additive because they are part of the same radioactive decay chain and all emit primarily alpha radiation.

The annual 70-year committed dose to a specific organ, resulting from a specific radiological intake, is given by

$$Annual\ Dose_i\left(\frac{millirem}{year}\right) = \sum_{route}\sum_{contaminants} intake\ \left(\frac{pCi}{year}\right) \times DCF_{70-yr,i}\ \left(\frac{millirem}{pCi}\right)$$

Where the annual dose to a specific organ *i* is the annual intake of each isotope by a particular route (ingestion or inhalation) multiplied by the 70-year committed dose coefficient corresponding to the specific organ of interest, isotope, route, and age range of the child or adult during the year of intake; these intake-dose coefficient products are then summed over all the routes and isotopes considered.

For inhalation, different dose coefficients are available depending on how quickly the contaminant dissolves in lung fluid. We used recommended solubility assumptions for inhalation of Ra-226 and U-238. We evaluated Th-230 using both slow-dissolving and moderately-dissolving dose coefficients and present results as a range. Please see the notes in Tables E1-E3 for assumptions used in this evaluation.

Internal dose coefficients for ingestion and inhalation include the contribution of dose from radioactive decay products formed from the material ingested or inhaled for as long as the material is in the body.

Calculation of External Dose

In addition to dose from taking radiological contaminants in the body, a person can get an external dose from radiation outside the body. We calculated external exposures for activities on soil (areas in the floodplain outside of the banks of Coldwater Creek), on sediment (considered to be soil or sediment within the banks of the creek), or in water. Of the recreational time spent in and around the creek as discussed in Appendix A, we assumed 85% of the time is spent on floodplain soil and 15% of the time is spent on sediment within the creek banks. We also assumed, on average, 10 minutes immersed in creek water for each day present around the creek.

To calculate the contribution to total dose from external radiation from soil or sediment, we assumed a person stood on soil or sediment with concentrations of Th-230, Ra-226, and U-238 at the exposure point concentrations derived in Appendix C, uniformly distributed throughout the top 15 centimeters of soil or sediment. Fifteen centimeters roughly corresponds to the 0-6 inch samples for which EPCs were derived. The top 15 cm of soil or sediment is assumed to have an average density of 1.6×10^6 grams per cubic meter (g/m^3), the standard soil density on which the external dose coefficients are based [45].

We assumed this external exposure would occur during recreational and residential activities with exposure frequencies and durations for each year corresponding to those listed in Appendix A.

For a particular isotope *k*, the annual soil external dose is given by the following equation:

$$EPC_{\ k}\left(\frac{pCi}{g}\right)\times\ \rho_S\left(\frac{g}{m^3}\right)\times\ DC_{15cmeff,k}\left(\frac{mrem\cdot m^3}{pCi\cdot hr}\right)\times\frac{hr}{year}\ exposed$$

where:

EPC is the exposure point concentration of isotope *k* in picocuries per gram of soil/sediment,

ρ_S is the soil density (assumed for soil and sediment at the standard 1.6×10^6 g/m^3 used to develop coefficients), and

DC_{15cm} is the 15-cm soil dose coefficient for the public corresponding to the isotope *k* [45]. The units of DC_{15cm} are mrem per (picocurie per cubic meter)-hour.

Sediment doses calculated using the above equation are multiplied by a dose reduction factor of 0.2 for contaminated river shorelines, as recommended by the Federal Guidance Report 12 [45].

For water immersion, the annual surface water external dose is given by the following equation:

$$EPC_{\ k}\left(\frac{pCi}{L}\right)\times\ DC_{WI,k}\left(\frac{mrem\cdot L}{pCi\cdot hr}\right)\times\frac{hr}{year}\ exposed$$

where:

EPC is the exposure point concentration of isotope *k* in picocuries per liter of water,

DC_{wi} is the water immersion dose coefficient for the public corresponding to the isotope *k* [45]. The units of DC_{wi} are mrem per (picocurie per liter)-hour.

The external dose coefficients, unlike internal dose coefficients, do not account for dose from radioactive decay products. To account for external radiation decay products of the U-238, Th-230, and Ra-226 for which we have exposure point concentrations, ATSDR did the following:

- We assumed isotopes not measured between U-238 and Th-230 (Th-234, Pa-234, and U-234) were in secular equilibrium; that is, they have the same amount of radioactivity. We calculated a summed U-238 external dose coefficient by adding the external dose coefficients of U-238, Th-234, Pa-234, and U-234. The U-238 exposure point concentration is multiplied by this summed dose coefficient in the dose calculation.
- Because no isotopes fall between Th-230 and Ra-226, the Th-230 exposure point concentration is multiplied by its Th-230 external dose coefficient in the dose calculation.
- Ra-226 forms radon-222 (Rn-222), a gas that may be lost to the atmosphere. We assumed 50% of the Rn-222 would be lost to the atmosphere and that all remaining isotopes were at secular equilibrium. Thus, we calculated a summed Ra-226 external dose coefficient by adding the Ra-226 external dose coefficient to 50% of the sum of external dose coefficients for Rn-222 and lower decay products. Please see Tables E4 and E5 for more

information. The Ra-226 exposure point concentration is multiplied by the summed Ra-226 dose coefficient in the calculation.

- We summed all external doses for the year of exposure and added to the annual internal dose.

Table E 1. Thorium-230 internal dose coefficients used in Coldwater Creek evaluation

	Ingestion						Inhalation - type S (slow lung solubility)						Inhalation - type M (medium lung solubility)					
Age Range -->	<1	1 to <2	2 to <7	7 to <12	12 to <17	>17	<1	1 to <2	2 to <7	7 to <12	12 to <17	>17	<1	1 to <2	2 to <7	7 to <12	12 to <17	>17
Adrenals	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Bladder	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Bone surface	4.44E-01	4.81E-02	4.44E-02	4.07E-02	4.07E-02	4.44E-02	1.00E+00	9.63E-01	9.26E-01	8.89E-01	9.63E-01	1.04E+00	7.41E+00	7.78E+00	7.41E+00	6.67E+00	7.41E+00	8.52E+00
Brain	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Breast	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Colon	3.04E-03	1.00E-03	5.19E-04	3.22E-04	1.96E-04	1.63E-04	3.15E-03	2.59E-03	1.85E-03	1.33E-03	1.22E-03	1.15E-03	2.67E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Effective (ICRP 60)	1.52E-02	1.52E-03	1.15E-03	8.89E-04	8.15E-04	7.78E-04	1.48E-01	1.30E-01	8.89E-02	5.93E-02	5.56E-02	5.19E-02	2.85E-01	2.74E-01	2.04E-01	1.59E-01	1.56E-01	1.59E-01
Esophagus	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Extratracheal airways	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	7.41E-01	6.30E-01	3.15E-01	2.15E-01	1.33E-01	1.30E-01	2.04E-01	1.63E-01	7.78E-02	5.19E-02	3.22E-02	3.11E-02
Kidneys	2.00E-02	1.78E-03	1.26E-03	9.26E-04	7.41E-04	7.04E-04	3.26E-02	2.78E-02	2.19E-02	1.67E-02	1.63E-02	1.63E-02	3.07E-01	2.96E-01	2.07E-01	1.48E-01	1.33E-01	1.30E-01
Liver	1.78E-02	1.59E-03	1.11E-03	8.15E-04	6.30E-04	5.93E-04	2.85E-02	2.44E-02	1.89E-02	1.44E-02	1.37E-02	1.37E-02	2.70E-01	2.63E-01	1.81E-01	1.30E-01	1.15E-01	1.11E-01
Lower large intestine	3.70E-03	1.48E-03	7.78E-04	4.81E-04	2.78E-04	2.30E-04	3.44E-03	2.78E-03	1.93E-03	1.37E-03	1.22E-03	1.19E-03	2.70E-02	2.56E-02	1.74E-02	1.19E-02	1.00E-02	9.63E-03
Lungs	1.74E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	1.00E+00	8.89E-01	5.56E-01	3.70E-01	3.11E-01	2.85E-01	4.44E-01	3.48E-01	2.19E-01	1.48E-01	1.26E-01	1.07E-01
Muscle	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Ovaries	7.41E-03	7.41E-04	7.04E-04	5.56E-04	4.81E-04	3.67E-04	1.48E-02	1.41E-02	1.26E-02	1.04E-02	9.63E-03	8.52E-03	1.19E-01	1.26E-01	1.15E-01	9.26E-02	8.52E-02	7.04E-02
Pancreas	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Red marrow	5.93E-02	5.19E-03	3.26E-03	2.22E-03	1.74E-03	1.56E-03	8.89E-02	7.41E-02	5.19E-02	4.07E-02	3.70E-02	3.70E-02	8.89E-01	8.15E-01	5.56E-01	3.59E-01	3.07E-01	2.96E-01
Remainder	1.96E-03	1.74E-04	1.19E-04	8.15E-05	6.30E-05	5.56E-05	3.48E-03	2.85E-03	2.11E-03	1.56E-03	1.37E-03	1.33E-03	3.00E-02	2.85E-02	1.96E-02	1.33E-02	1.11E-02	1.07E-02
Skin	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Small intestine	1.85E-03	2.26E-04	1.41E-04	9.63E-05	7.04E-05	5.93E-05	2.74E-03	2.30E-03	1.74E-03	1.26E-03	1.19E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Spleen	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.19E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Stomach	1.78E-03	1.78E-04	1.19E-04	8.15E-05	6.30E-05	5.56E-05	2.74E-03	2.30E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Testes	8.15E-03	8.15E-04	6.30E-04	5.19E-04	4.81E-04	3.70E-04	1.56E-02	1.41E-02	1.19E-02	1.00E-02	9.63E-03	8.52E-03	1.30E-01	1.37E-01	1.07E-01	8.89E-02	8.52E-02	7.04E-02
Thymus	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Thyroid	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Upper large intestine	2.44E-03	6.30E-04	3.37E-04	2.11E-04	1.33E-04	1.11E-04	2.96E-03	2.44E-03	1.78E-03	1.30E-03	1.19E-03	1.15E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03
Uterus	1.70E-03	1.52E-04	1.04E-04	7.41E-05	5.56E-05	5.19E-05	2.70E-03	2.26E-03	1.70E-03	1.26E-03	1.15E-03	1.11E-03	2.63E-02	2.52E-02	1.70E-02	1.19E-02	1.00E-02	9.63E-03

Notes:

-70-year committed dose coefficients for the public obtained from program "Radiological Toolbox" v. 3.0.0, based on ICRP 68/72 [111,44]. Units are mrem per pCi.

-Slow lung solubility recommended by ICRP for Th-230 in absence of data on contaminant solubility [44]. Thorium oxide compounds exhibit slow lung solubility [46]. Higher lung dose will result from slow lung solubility.

-Medium lung solubility exhibited by other thorium compounds besides oxides [46]. Higher bone dose will result from medium solubility.

Table E 2. Radium-226 internal dose coefficients used in Coldwater Creek evaluation

	Ingestion						Inhalation - type M (medium lung solubility)					
Age range -->	<1	1 to <2	2 to <7	7 to <12	12 to <17	>17	<1	1 to <2	2 to <7	7 to <12	12 to <17	>17
Adrenals	1.96E-03	7.78E-04	4.81E-04	3.33E-04	3.00E-04	1.52E-04	4.44E-04	2.96E-04	1.78E-04	1.22E-04	1.11E-04	8.89E-05
Bladder	1.96E-03	7.78E-04	4.81E-04	3.26E-04	2.70E-04	1.48E-04	4.44E-04	2.96E-04	1.78E-04	1.19E-04	1.00E-04	8.89E-05
Bone surface	5.93E-01	1.07E-01	8.52E-02	1.44E-01	3.48E-01	4.44E-02	1.22E-01	4.07E-02	3.15E-02	5.56E-02	1.30E-01	2.74E-02
Brain	1.96E-03	7.78E-04	4.81E-04	3.33E-04	3.00E-04	1.52E-04	4.44E-04	2.96E-04	1.78E-04	1.19E-04	1.11E-04	8.89E-05
Breast	1.96E-03	7.78E-04	4.81E-04	3.22E-04	2.70E-04	1.48E-04	4.44E-04	2.96E-04	1.78E-04	1.15E-04	1.00E-04	8.89E-05
Colon	4.44E-03	2.41E-03	1.30E-03	8.15E-04	5.56E-04	3.67E-04	1.33E-03	9.26E-04	4.44E-04	2.85E-04	1.93E-04	1.63E-04
Effective (ICRP 60)	1.74E-02	3.56E-03	2.30E-03	2.96E-03	5.56E-03	1.04E-03	5.56E-02	4.07E-02	2.59E-02	1.81E-02	1.67E-02	1.30E-02
Esophagus	1.96E-03	7.78E-04	4.81E-04	3.26E-04	2.74E-04	1.48E-04	4.44E-04	2.96E-04	1.78E-04	1.19E-04	1.04E-04	8.89E-05
Extratracheal airways	1.96E-03	7.78E-04	4.81E-04	3.26E-04	2.81E-04	1.48E-04	1.81E-01	1.41E-01	5.93E-02	4.07E-02	2.26E-02	2.22E-02
Kidneys	2.56E-03	9.26E-04	5.93E-04	5.93E-04	8.89E-04	2.19E-04	5.56E-04	3.41E-04	2.19E-04	2.15E-04	3.30E-04	1.30E-04
Liver	1.41E-02	5.56E-03	2.89E-03	1.96E-03	1.48E-03	6.67E-04	3.11E-03	2.07E-03	1.04E-03	7.04E-04	5.56E-04	4.07E-04
Lower large intestine	5.93E-03	3.63E-03	1.93E-03	1.19E-03	7.78E-04	5.56E-04	2.04E-03	1.41E-03	6.67E-04	4.07E-04	2.59E-04	2.19E-04
Lungs	1.96E-03	7.78E-04	4.81E-04	3.30E-04	2.81E-04	1.48E-04	4.44E-01	3.37E-01	2.11E-01	1.41E-01	1.22E-01	1.04E-01
Muscle	1.96E-03	7.78E-04	4.81E-04	3.30E-04	2.85E-04	1.48E-04	4.44E-04	2.96E-04	1.78E-04	1.19E-04	1.07E-04	8.89E-05
Ovaries	2.00E-03	8.15E-04	5.19E-04	3.70E-04	2.81E-04	1.52E-04	4.44E-04	3.07E-04	1.89E-04	1.33E-04	1.04E-04	8.89E-05
Pancreas	1.96E-03	7.78E-04	4.81E-04	3.26E-04	2.81E-04	1.48E-04	4.44E-04	2.96E-04	1.78E-04	1.19E-04	1.04E-04	8.89E-05
Red marrow	7.41E-02	1.11E-02	6.67E-03	8.89E-03	1.52E-02	3.22E-03	1.44E-02	4.07E-03	2.48E-03	3.37E-03	5.56E-03	1.93E-03
Remainder	1.96E-03	7.78E-04	4.81E-04	3.33E-04	2.93E-04	1.48E-04	5.19E-04	3.56E-04	2.04E-04	1.41E-04	1.19E-04	1.00E-04
Skin	1.96E-03	7.78E-04	4.81E-04	3.26E-04	2.78E-04	1.48E-04	4.44E-04	2.96E-04	1.78E-04	1.19E-04	1.04E-04	8.89E-05
Small intestine	2.00E-03	8.52E-04	5.19E-04	3.44E-04	2.89E-04	1.56E-04	4.81E-04	3.19E-04	1.85E-04	1.22E-04	1.07E-04	8.89E-05
Spleen	2.48E-03	8.89E-04	5.93E-04	5.19E-04	7.41E-04	1.96E-04	5.56E-04	3.37E-04	2.15E-04	1.93E-04	2.63E-04	1.19E-04
Stomach	2.00E-03	8.15E-04	4.81E-04	3.33E-04	2.78E-04	1.52E-04	4.44E-04	3.04E-04	1.81E-04	1.19E-04	1.04E-04	8.89E-05
Testes	2.04E-03	8.15E-04	5.56E-04	4.81E-04	2.81E-04	1.48E-04	4.44E-04	3.11E-04	2.04E-04	1.78E-04	1.04E-04	8.89E-05
Thymus	1.96E-03	7.78E-04	4.81E-04	3.26E-04	2.74E-04	1.48E-04	4.44E-04	2.96E-04	1.78E-04	1.19E-04	1.04E-04	8.89E-05
Thyroid	1.96E-03	7.78E-04	4.81E-04	3.26E-04	2.81E-04	1.48E-04	4.44E-04	2.96E-04	1.78E-04	1.19E-04	1.04E-04	8.89E-05
Upper large intestine	2.93E-03	1.44E-03	8.15E-04	5.19E-04	3.70E-04	2.37E-04	8.15E-04	5.56E-04	2.93E-04	1.85E-04	1.37E-04	1.19E-04
Uterus	1.96E-03	7.78E-04	4.81E-04	3.26E-04	2.74E-04	1.48E-04	4.44E-04	2.96E-04	1.78E-04	1.19E-04	1.04E-04	8.89E-05

Notes:

-70-year committed dose coefficients for the public obtained from program "Radiological Toolbox" v. 3.0.0, based on ICRP 68/72 [111,44]. Units are mrem per pCi.

-Medium lung solubility recommended by ICRP for Ra-226 and U-238 in absence of data on contaminant solubility [44].

Table E 3. Uranium-238 internal dose coefficients used in Coldwater Creek evaluation

	Ingestion						Inhalation - type M (medium lung solubility)					
Age Range -->	<1	1 to <2	2 to <7	7 to <12	12 to <17	>17	<1	1 to <2	2 to <7	7 to <12	12 to <17	>17
Adrenals	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	9.26E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Bladder	4.44E-04	1.96E-04	1.48E-04	1.19E-04	1.00E-04	9.26E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Bone surface	2.56E-02	5.93E-03	4.44E-03	5.19E-03	7.78E-03	2.63E-03	4.81E-02	2.70E-02	1.96E-02	2.26E-02	3.59E-02	1.30E-02
Brain	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Breast	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Colon	1.59E-03	9.63E-04	5.19E-04	3.44E-04	2.26E-04	1.93E-04	1.33E-03	1.15E-03	7.78E-04	5.56E-04	4.81E-04	4.81E-04
Effective (ICRP 60)	1.26E-03	4.44E-04	2.96E-04	2.52E-04	2.48E-04	1.67E-04	4.44E-02	3.48E-02	2.19E-02	1.48E-02	1.26E-02	1.07E-02
Esophagus	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Extratracheal airways	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	1.56E-01	1.22E-01	5.19E-02	3.56E-02	1.96E-02	1.93E-02
Kidneys	9.26E-03	3.44E-03	2.07E-03	1.44E-03	1.07E-03	9.26E-04	1.89E-02	1.52E-02	9.26E-03	6.30E-03	4.81E-03	4.81E-03
Liver	1.93E-03	8.52E-04	5.93E-04	4.44E-04	3.70E-04	3.56E-04	4.07E-03	3.70E-03	2.67E-03	1.93E-03	1.74E-03	1.78E-03
Lower large intestine	2.30E-03	1.41E-03	7.78E-04	4.81E-04	3.04E-04	2.56E-04	1.56E-03	1.30E-03	8.15E-04	5.93E-04	5.19E-04	4.81E-04
Lungs	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	9.26E-05	3.63E-01	2.78E-01	1.74E-01	1.15E-01	9.63E-02	8.15E-02
Muscle	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Ovaries	4.44E-04	2.04E-04	1.52E-04	1.22E-04	9.63E-05	9.26E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Pancreas	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Red marrow	3.11E-03	7.04E-04	4.44E-04	4.07E-04	4.81E-04	2.78E-04	5.93E-03	3.15E-03	1.96E-03	1.89E-03	2.15E-03	1.37E-03
Remainder	5.56E-04	2.37E-04	1.70E-04	1.33E-04	1.07E-04	1.00E-04	1.26E-03	1.11E-03	7.78E-04	5.93E-04	5.19E-04	5.19E-04
Skin	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Small intestine	5.56E-04	2.63E-04	1.81E-04	1.37E-04	1.07E-04	1.00E-04	1.00E-03	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Spleen	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Stomach	4.81E-04	2.22E-04	1.59E-04	1.22E-04	1.04E-04	9.26E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Testes	4.81E-04	2.11E-04	1.63E-04	1.33E-04	1.00E-04	9.26E-05	1.04E-03	9.63E-04	7.41E-04	5.93E-04	4.81E-04	4.44E-04
Thymus	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Thyroid	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04
Upper large intestine	1.07E-03	6.30E-04	3.56E-04	2.41E-04	1.67E-04	1.44E-04	1.15E-03	1.00E-03	7.04E-04	5.56E-04	4.81E-04	4.81E-04
Uterus	4.44E-04	1.96E-04	1.48E-04	1.15E-04	9.63E-05	8.89E-05	9.63E-04	8.89E-04	6.67E-04	5.19E-04	4.44E-04	4.44E-04

Notes:

-70-year committed dose coefficients for the Public obtained from program "Radiological Toolbox" v. 3.0.0, based on ICRP 68/72 [111,44]. Units are mrem per pCi.

-Medium lung solubility recommended by ICRP for Ra-226 and U-238 in absence of data on contaminant solubility [46].

Table E 4. External dose coefficients for soil and sediment used in Coldwater Creek evaluation.‡

	External dose coefficient for soil contaminated to a depth of 15 centimeters, in millirem per ((picocurie per cubic meter)-hour)																
Organ	**U-238**	**Th-234**	**Pa-234m**	**Pa-234**	**U-234**	**Soil / Sediment Coefficient for U-238***	**Soil / Sediment Coefficient for Th-230***	**Ra-226**	**Rn-222**	**Po-218**	**Pb-214†**	**At-218†**	**Bi-214**	**Po-214**	**Pb-210**	**Bi-210**	**Soil / Sediment Coefficient for Ra-226***
Adrenals	2.01E-15	1.19E-12	4.69E-12	6.07E-10	1.65E-14	6.13E-10	5.81E-14	1.68E-12	1.23E-13	2.97E-15	7.07E-11	2.35E-13	5.07E-10	2.71E-14	8.77E-14	1.84E-13	2.91E-10
Bladder	2.53E-15	1.32E-12	4.84E-12	6.23E-10	1.85E-14	6.29E-10	6.43E-14	1.83E-12	1.27E-13	3.05E-15	7.44E-11	2.79E-13	5.13E-10	2.77E-14	1.07E-13	1.99E-13	2.96E-10
Bone surface	1.76E-14	5.57E-12	8.93E-12	1.08E-09	7.92E-14	1.09E-09	2.52E-13	5.08E-12	2.40E-13	5.01E-15	1.65E-10	1.52E-12	7.95E-10	4.61E-14	6.24E-13	6.09E-13	4.86E-10
Brain	2.28E-15	1.39E-12	5.28E-12	6.83E-10	1.91E-14	6.89E-10	6.75E-14	1.95E-12	1.41E-13	3.35E-15	8.16E-11	2.79E-13	5.64E-10	3.05E-14	1.02E-13	2.12E-13	3.25E-10
Breast	1.41E-14	1.88E-12	5.97E-12	7.65E-10	3.84E-14	7.73E-10	9.73E-14	2.37E-12	1.64E-13	3.73E-15	9.67E-11	5.03E-13	6.15E-10	3.41E-14	2.27E-13	2.73E-13	3.58E-10
Colon	1.95E-15	1.22E-12	4.66E-12	6.02E-10	1.67E-14	6.08E-10	5.91E-14	1.71E-12	1.24E-13	2.95E-15	7.13E-11	2.37E-13	5.00E-10	2.69E-14	8.57E-14	1.85E-13	2.88E-10
Effective (ICRP 60)	5.68E-15	1.52E-12	6.29E-12	6.77E-10	2.45E-14	6.85E-10	7.55E-14	2.01E-12	1.41E-13	3.32E-15	8.29E-11	3.48E-13	5.55E-10	3.03E-14	1.41E-13	3.83E-13	3.21E-10
Esophagus	1.40E-15	1.07E-12	4.43E-12	5.75E-10	1.45E-14	5.80E-10	5.20E-14	1.59E-12	1.18E-13	2.81E-15	6.73E-11	1.80E-13	4.83E-10	2.56E-14	5.99E-14	1.69E-13	2.77E-10
Extratracheal airways	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kidneys	3.09E-15	1.40E-12	4.95E-12	6.36E-10	2.00E-14	6.42E-10	6.81E-14	1.88E-12	1.35E-13	3.11E-15	7.80E-11	3.16E-13	5.27E-10	2.84E-14	1.27E-13	2.09E-13	3.04E-10
Liver	2.63E-15	1.40E-12	4.92E-12	6.35E-10	1.95E-14	6.41E-10	6.76E-14	1.88E-12	1.32E-13	3.11E-15	7.71E-11	3.00E-13	5.21E-10	2.83E-14	1.15E-13	2.07E-13	3.01E-10
Lower large intestine	1.89E-15	1.20E-12	4.67E-12	6.03E-10	1.65E-14	6.09E-10	5.87E-14	1.71E-12	1.24E-13	2.96E-15	7.16E-11	2.31E-13	5.01E-10	2.69E-14	8.24E-14	1.85E-13	2.88E-10
Lungs	3.12E-15	1.56E-12	5.36E-12	6.89E-10	2.17E-14	6.96E-10	7.53E-14	2.05E-12	1.44E-13	3.37E-15	8.41E-11	3.51E-13	5.63E-10	3.08E-14	1.37E-13	2.28E-13	3.26E-10
Muscle	7.55E-15	1.56E-12	5.43E-12	6.99E-10	2.72E-14	7.06E-10	7.88E-14	2.07E-12	1.47E-13	3.43E-15	8.53E-11	3.75E-13	5.68E-10	3.12E-14	1.59E-13	2.32E-13	3.29E-10
Ovaries	1.73E-15	1.11E-12	4.52E-12	5.85E-10	1.55E-14	5.91E-10	5.51E-14	1.65E-12	1.17E-13	2.87E-15	6.81E-11	2.04E-13	4.91E-10	2.60E-14	6.85E-14	1.75E-13	2.81E-10
Pancreas	1.63E-15	1.14E-12	4.40E-12	5.68E-10	1.55E-14	5.74E-10	5.51E-14	1.63E-12	1.17E-13	2.77E-15	6.77E-11	2.05E-13	4.79E-10	2.52E-14	7.09E-14	1.75E-13	2.75E-10
Red marrow	2.91E-15	1.35E-12	5.28E-12	6.84E-10	1.95E-14	6.91E-10	6.63E-14	1.95E-12	1.41E-13	3.36E-15	8.19E-11	2.63E-13	5.64E-10	3.05E-14	9.97E-14	2.11E-13	3.25E-10
Remainder	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Skin	4.73E-14	2.00E-12	1.09E-10	8.29E-10	7.97E-14	9.41E-10	1.29E-13	2.51E-12	1.75E-13	4.04E-15	1.04E-10	5.93E-13	7.28E-10	3.69E-14	3.01E-13	1.60E-11	4.27E-10
Small intestine	1.77E-15	1.16E-12	4.53E-12	5.87E-10	1.60E-14	5.92E-10	5.64E-14	1.65E-12	1.20E-13	2.88E-15	6.89E-11	2.20E-13	4.89E-10	2.61E-14	7.84E-14	1.79E-13	2.81E-10
Spleen	2.56E-15	1.40E-12	4.96E-12	6.39E-10	1.93E-14	6.45E-10	6.80E-14	1.89E-12	1.33E-13	3.12E-15	7.76E-11	3.01E-13	5.27E-10	2.85E-14	1.15E-13	2.08E-13	3.04E-10
Stomach	2.61E-15	1.37E-12	4.87E-12	6.27E-10	1.91E-14	6.33E-10	6.64E-14	1.84E-12	1.29E-13	3.07E-15	7.53E-11	2.92E-13	5.13E-10	2.80E-14	1.13E-13	2.03E-13	2.96E-10
Testes	1.09E-14	1.79E-12	5.84E-12	7.48E-10	3.36E-14	7.56E-10	9.07E-14	2.28E-12	1.60E-13	3.65E-15	9.36E-11	4.57E-13	6.05E-10	3.35E-14	2.01E-13	2.61E-13	3.52E-10
Thymus	3.16E-15	1.48E-12	5.16E-12	6.64E-10	2.09E-14	6.71E-10	7.24E-14	1.96E-12	1.37E-13	3.27E-15	8.04E-11	3.33E-13	5.39E-10	2.97E-14	1.32E-13	2.17E-13	3.12E-10
Thyroid	3.88E-15	1.47E-12	5.01E-12	6.44E-10	2.16E-14	6.51E-10	7.13E-14	1.91E-12	1.35E-13	3.15E-15	7.87E-11	3.45E-13	5.31E-10	2.87E-14	1.41E-13	2.15E-13	3.07E-10
Upper large intestine	2.00E-15	1.23E-12	4.65E-12	6.01E-10	1.68E-14	6.07E-10	5.96E-14	1.71E-12	1.23E-13	2.95E-15	7.11E-11	2.43E-13	4.99E-10	2.68E-14	8.91E-14	1.85E-13	2.87E-10
Uterus	1.68E-15	1.14E-12	4.49E-12	5.83E-10	1.55E-14	5.88E-10	5.51E-14	1.61E-12	1.18E-13	2.87E-15	6.80E-11	2.11E-13	4.83E-10	2.60E-14	7.39E-14	1.75E-13	2.77E-10

‡ 15-cm soil dose coefficients obtained from program "Radiological Toolbox" v. 3.0.0, based on Federal Guidance Report 12 [111,45]. Po-210 (and other decay products formed at very low frequencies) have a negligible contribution to external dose and are not shown on the table [112]. Sediment doses multiplied by dose reduction factor of 0.2 for contaminated river shorelines, as recommended in Federal Guidance Report 12 [45].

* To account for external dose from daughter products not measured, ATSDR determined dose coefficients for U-238, Th-230, and Ra-226 shown highlighted in blue, assuming secular equilibrium and half of Rn-222 gas lost to atmosphere. The U-238 concentration is multiplied by the sum of dose coefficients U-238 through U-234; the Th-230 concentration is applied to the Th-230 dose coefficient; and the Ra-226 concentration is applied to the Ra-226 dose coefficient plus half of the sum of dose coefficients from Rn-222 through Bi-210.

† Po-218 forms Pb-214 98.98% of the time and At-218 0.02% of the time; for summing, Pb-214 and At-218 coefficients were multiplied by these branching ratios.

** Colon dose coefficient not listed; ATSDR estimated dose coefficient for colon by averaging coefficients for upper large intestine and lower large intestine.

ND = Not determined

Table E 5. External dose coefficients for water used in Coldwater Creek evaluation‡

	External dose coefficient for water immersion, in millirem per ((picocurie per liter)-hour)																
Organ	**U-238**	**Th-234**	**Pa-234m**	**Pa-234**	**U-234**	**Water Coefficient for U-238***	**Water Coefficient for Th-230***	**Ra-226**	**Rn-222**	**Po-218**	**Pb-214†**	**At-218†**	**Bi-214**	**Po-214**	**Pb-210**	**Bi-210**	**Water Coefficient for Ra-226***
Adrenals	1.80E-11	6.51E-09	1.61E-08	2.19E-06	9.16E-11	2.21E-06	3.09E-10	6.83E-09	4.49E-10	1.05E-11	2.68E-07	1.92E-09	1.83E-06	9.59E-11	8.13E-10	5.68E-10	1.06E-06
Bladder	2.43E-11	7.15E-09	1.61E-08	2.17E-06	1.05E-10	2.20E-06	3.39E-10	7.11E-09	4.48E-10	1.03E-11	2.72E-07	2.23E-09	1.85E-06	9.43E-11	9.69E-10	6.07E-10	1.07E-06
Bone surface	2.29E-10	3.37E-08	3.48E-08	4.39E-06	6.05E-10	4.46E-06	1.60E-09	2.36E-08	9.67E-10	1.99E-11	7.17E-07	1.29E-08	3.17E-06	1.83E-10	6.00E-09	2.32E-09	1.97E-06
Brain	2.43E-11	8.65E-09	2.08E-08	2.81E-06	1.22E-10	2.84E-06	4.11E-10	8.83E-09	5.72E-10	1.36E-11	3.44E-07	2.68E-09	2.32E-06	1.24E-10	1.15E-09	7.44E-10	1.34E-06
Breast	2.67E-10	1.22E-08	2.28E-08	3.01E-06	4.47E-10	3.05E-06	7.24E-10	1.05E-08	6.21E-10	1.44E-11	3.88E-07	4.95E-09	2.44E-06	1.31E-10	2.55E-09	1.02E-09	1.43E-06
Colon	1.61E-11	6.35E-09	1.61E-08	2.18E-06	8.80E-11	2.20E-06	3.01E-10	6.71E-09	4.37E-10	1.05E-11	2.62E-07	1.81E-09	1.84E-06	9.55E-11	7.43E-10	5.51E-10	1.06E-06
Effective (ICRP 60)	7.80E-11	8.76E-09	2.64E-08	2.52E-06	1.85E-10	2.56E-06	4.45E-10	8.32E-09	5.15E-10	1.21E-11	3.17E-07	2.97E-09	2.09E-06	1.10E-10	1.39E-09	3.97E-09	1.22E-06
Esophagus	1.28E-11	5.83E-09	1.63E-08	2.21E-06	7.93E-11	2.24E-06	2.77E-10	6.57E-09	4.40E-10	1.07E-11	2.61E-07	1.49E-09	1.87E-06	9.73E-11	5.79E-10	5.24E-10	1.07E-06
Extratracheal airways	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kidneys	3.29E-11	7.96E-09	1.76E-08	2.36E-06	1.23E-10	2.39E-06	3.80E-10	7.67E-09	4.81E-10	1.13E-11	2.92E-07	2.65E-09	1.96E-06	1.03E-10	1.20E-09	6.72E-10	1.13E-06
Liver	2.48E-11	7.75E-09	1.76E-08	2.37E-06	1.12E-10	2.40E-06	3.67E-10	7.68E-09	4.83E-10	1.14E-11	2.93E-07	2.44E-09	1.99E-06	1.04E-10	1.06E-09	6.55E-10	1.15E-06
Lower large intestine	1.51E-11	6.15E-09	1.60E-08	2.16E-06	8.47E-11	2.18E-06	2.91E-10	6.56E-09	4.32E-10	1.05E-11	2.57E-07	1.72E-09	1.83E-06	9.51E-11	6.95E-10	5.36E-10	1.05E-06
Lungs	3.05E-11	9.01E-09	1.96E-08	2.63E-06	1.32E-10	2.66E-06	4.27E-10	8.67E-09	5.37E-10	1.26E-11	3.29E-07	2.95E-09	2.17E-06	1.15E-10	1.30E-09	7.52E-10	1.26E-06
Muscle	1.15E-10	9.12E-09	1.92E-08	2.57E-06	2.33E-10	2.60E-06	4.87E-10	8.49E-09	5.27E-10	1.23E-11	3.23E-07	3.28E-09	2.12E-06	1.12E-10	1.59E-09	7.72E-10	1.23E-06
Ovaries	1.32E-11	5.67E-09	1.59E-08	2.16E-06	7.83E-11	2.18E-06	2.69E-10	6.32E-09	4.01E-10	1.05E-11	2.43E-07	1.55E-09	1.83E-06	9.45E-11	6.05E-10	5.01E-10	1.04E-06
Pancreas	1.33E-11	5.87E-09	1.55E-08	2.09E-06	8.01E-11	2.11E-06	2.79E-10	6.45E-09	4.20E-10	1.00E-11	2.52E-07	1.56E-09	1.79E-06	9.13E-11	6.11E-10	5.17E-10	1.03E-06
Red marrow	3.84E-11	7.44E-09	1.89E-08	2.56E-06	1.27E-10	2.59E-06	3.64E-10	7.89E-09	5.17E-10	1.24E-11	3.09E-07	2.21E-09	2.15E-06	1.12E-10	9.63E-10	6.60E-10	1.24E-06
Remainder	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Skin	9.11E-10	1.77E-08	7.89E-07	3.35E-06	1.27E-09	4.16E-06	1.35E-09	1.24E-08	6.53E-10	1.83E-11	5.99E-07	6.59E-09	3.09E-06	1.36E-10	4.00E-09	3.25E-07	2.02E-06
Small intestine	1.48E-11	6.08E-09	1.57E-08	2.12E-06	8.36E-11	2.14E-06	2.87E-10	6.49E-09	4.24E-10	1.02E-11	2.53E-07	1.68E-09	1.80E-06	9.29E-11	6.83E-10	5.31E-10	1.03E-06
Spleen	2.29E-11	7.72E-09	1.77E-08	2.39E-06	1.09E-10	2.41E-06	3.65E-10	7.68E-09	4.87E-10	1.15E-11	2.95E-07	2.40E-09	1.99E-06	1.04E-10	1.04E-09	6.52E-10	1.15E-06
Stomach	2.53E-11	7.59E-09	1.73E-08	2.35E-06	1.11E-10	2.37E-06	3.60E-10	7.51E-09	4.79E-10	1.12E-11	2.89E-07	2.40E-09	1.96E-06	1.02E-10	1.05E-09	6.43E-10	1.13E-06
Testes	1.37E-10	1.02E-08	1.99E-08	2.65E-06	2.71E-10	2.68E-06	5.45E-10	9.09E-09	5.43E-10	1.27E-11	3.39E-07	3.89E-09	2.15E-06	1.16E-10	1.92E-09	8.55E-10	1.25E-06
Thymus	3.63E-11	8.59E-09	1.84E-08	2.45E-06	1.35E-10	2.48E-06	4.09E-10	8.21E-09	4.99E-10	1.17E-11	3.08E-07	2.88E-09	2.07E-06	1.07E-10	1.30E-09	7.17E-10	1.20E-06
Thyroid	8.45E-11	9.79E-09	2.03E-08	2.71E-06	2.04E-10	2.74E-06	4.91E-10	9.08E-09	5.52E-10	1.30E-11	3.41E-07	3.52E-09	2.21E-06	1.18E-10	1.68E-09	8.25E-10	1.29E-06
Upper large intestine	1.72E-11	6.56E-09	1.63E-08	2.20E-06	9.13E-11	2.22E-06	3.11E-10	6.85E-09	4.43E-10	1.06E-11	2.67E-07	1.89E-09	1.85E-06	9.60E-11	7.91E-10	5.67E-10	1.07E-06
Uterus	1.39E-11	5.87E-09	1.52E-08	2.07E-06	8.05E-11	2.09E-06	2.77E-10	6.36E-09	4.13E-10	9.91E-12	2.48E-07	1.59E-09	1.76E-06	9.00E-11	6.29E-10	5.13E-10	1.01E-06

‡ Water immersion dose coefficients obtained from program "Radiological Toolbox" v. 3.0.0, based on Federal Guidance Report 12 [111,45]. Po-210 (and other decay products formed at very low frequencies) have a negligible contribution to external dose and are not shown on the table [112]. Assumed surface water immersion for 10 minutes per day spent in or around the creek.

* To account for external dose from daughter products not measured, ATSDR determined dose coefficients for U-238, Th-230, and Ra-226 shown highlighted in blue, assuming secular equilibrium and half of Rn-222 gas lost to atmosphere. The U-238 concentration is multiplied by the sum of dose coefficients U-238 through U-234; the Th-230 concentration is applied to the Th-230 dose coefficient; and the Ra-226 concentration is applied to the Ra-226 dose coefficient plus half of the sum of dose coefficients from Rn-222 through Bi-210.

† Po-218 forms Pb-214 98.98% of the time and At-218 0.02% of the time; for summing, Pb-214 and At-218 coefficients were multiplied by these branching ratios.

** Colon dose coefficient not listed; ATSDR estimated dose coefficient for colon by averaging coefficients for upper large intestine and lower large intestine.

ND = Not determined

Estimating Increased Cancer Risk

To estimate the increased risk of developing cancer from the exposures at Coldwater Creek, ATSDR applied lifetime attributable risk coefficients to the doses estimated using ICRP and EPA dose coefficients. Lifetime attributable risks are estimates of cancer incidence and mortality risks due to low doses of ionizing radiation developed by EPA in 2011 [48].

EPA based their estimates on risk models developed by the National Academy of Sciences from epidemiological and radio-biological data including studies of Japanese atomic bomb survivors, medically irradiated patients, and occupationally and environmentally exposed groups [113]. Some model details were modified by EPA to increase their applicability to a wider range of exposures [70]. For bone cancers, EPA used data from studies of people exposed to alpha radiation and divided by a factor of 10 to put the risks in terms of low energy transfer radiation such as gamma rays, x-rays, and electrons [70].

EPA lifetime attributable risk coefficients applied to the organs for which dose coefficients are available and used in this evaluation are shown in Table E6 below. We only show coefficients for the cancer sites we estimated doses for, and for ages up to 30, since those were the only ones used for our 33-year exposure. Because risk is higher at younger ages, the risk estimates in this report will overestimate risks to people exposed later in life.

Table E 6. Selected values from Table 3-12c reported in [48]; sex-averaged lifetime attributable risk coefficients for cancer incidence by age at exposure

Cancer site	Age at exposure					
	0	5	10	15	20	30
Bladder	220	188	160	136	116	84
Bone	10.4	8.0	6.1	4.7	3.5	2.0
Breast	614	480	372	288	222	130
Colon	285	244	207	175	149	107
Kidney	117	54	43	36	30	21
Liver	81	67	55	46	38	26
Lung	547	459	383	320	268	188
Ovary	44	38	31	26	22	15
Leukemia	183	130	101	86	79	69
Skin	1360	722	381	201	106	30
Stomach	190	157	129	106	87	58
Thyroid	252	227	126	68	47	21
Uterus	32	27	22	18	15	10
Total	3,970	2,850	2,230	1,780	1,460	979

Note: Values are presented in cases per 10,000 person-Gray.

ATSDR's estimates for internal and external dose were already corrected for the differences between alpha particles and different types of radiation. Therefore, we multiplied the EPA bone cancer risks by 10 before applying them to estimated doses. In addition, all the risks were divided by 100 to convert the risk per Gray (equivalent to Sieverts for the radiation EPA based their estimates on) to rem.

Table E7 presents the lifetime attributable risk values corresponding to organs for which doses were estimated and used to estimate increased risk of cancer in this report.

Table E 7. Lifetime attributable risk for cancer incidence by age at exposure used in Coldwater Creek evaluation

Organ (ICRP dose)	Cancer site (EPA)	Age at Exposure					
		0	5	10	15	20	30
Adrenals	N/A	~	~	~	~	~	~
Bladder	Bladder	220	188	160	136	116	84
Bone surface	Bone	104	80	61	47	35	20
Brain	N/A	~	~	~	~	~	~
Breast	Breast	614	480	372	288	222	130
Colon	Colon	285	244	207	175	149	107
Esophagus	N/A	~	~	~	~	~	~
Extratracheal airways	N/A	~	~	~	~	~	~
Kidneys	Kidney	117	54	43	36	30	21
Liver	Liver	81	67	55	46	38	26
Lower large intestine	N/A	~	~	~	~	~	~
Lungs	Lung	547	459	383	320	268	188
Muscle	N/A	~	~	~	~	~	~
Ovaries	Ovary	44	38	31	26	22	15
Pancreas	N/A	~	~	~	~	~	~
Red marrow	Leukemia	183	130	101	86	79	69
Remainder	N/A	~	~	~	~	~	~
Skin	Skin	1360	722	381	201	106	30
Small intestine	N/A	~	~	~	~	~	~
Spleen	N/A	~	~	~	~	~	~
Stomach	Stomach	190	157	129	106	87	58
Testes	N/A	~	~	~	~	~	~
Thymus	N/A	~	~	~	~	~	~
Thyroid	Thyroid	252	227	126	68	47	21
Upper large intestine	N/A	~	~	~	~	~	~

Note: Values are presented per 10,000 persons – rem
N/A, ~ = not estimated for attributable cancer risk

Calculation of Risk

We calculated the risk by multiplying the lifetime attributable risk (LAR) by the estimated dose in mrem, with appropriate conversions, using the following equation:

$$Risk = \sum_i LAR_i \left(\frac{1}{10{,}000\ person \cdot rem}\right) \times Dose_i(millirem) \times \frac{1\ rem}{1{,}000\ millirem}$$
$$= \sum_i LAR_i \times Dose_i \times 10^{-7}$$

Complete Organ-Specific Dose and Risk Results

Organ-specific dose and, if available, estimated increased risk of cancer at that site, are presented in Table E8 for past exposures and Table E9 for recent exposures. Estimated increased cancer risks above 1 in 10,000 are highlighted in orange in the tables.

ATSDR recognizes that all exposures may contribute to an increased risk of cancer. As described in the text, in this report we focus our discussion and conclusions on those risks estimated to be greater than 1 in 10,000. This is the upper bound of EPA’s general “target range” for managing risks as part of a Superfund cleanup: 1 in 10,000 to 1 in 1,000,000 [49].

Table E 8. Tabulation of dose and risk results - past exposures at Coldwater Creek

	Committed dose for entire exposure, mrem				**Lifetime attributable risk from 33-year exposure**			
	Recreational		Residential		Recreational		Residential	
Organ	Slow*	Medium **	Slow*	Medium **	Slow*	Medium **	Slow*	Medium **
Adrenals	92	108	208	281	†	†	†	†
Bladder	94	110	213	286	2E-05	2E-05	3E-05	4E-05
Bone surface	5,485	15,851	14,183	62,911	**4E-04**	**1E-03**	**8E-04**	**3E-03**
Brain	102	118	231	304	†	†	†	†
Breast	112	129	255	328	4E-05	5E-05	9E-05	1E-04
Colon	109	126	239	312	2E-05	3E-05	5E-05	6E-05
Esophagus	88	104	199	272	†	†	†	†
Extratracheal airways	316	87	1364	361	†	†	†	†
Kidneys	206	416	476	1,408	1E-05	2E-05	3E-05	8E-05
Liver	191	374	438	1,247	1E-05	2E-05	2E-05	7E-05
Lower large intestine	121	137	260	332	†	†	†	†
Lungs	701	349	2,860	1,303	**3E-04**	**1E-04**	**1E-03**	**5E-04**
Muscle	104	120	235	308	†	†	†	†
Ovaries	139	264	324	845	5E-06	9E-06	1E-05	3E-05
Pancreas	87	103	197	270	†	†	†	†
Red marrow	414	925	921	3,188	5E-05	**1E-04**	1E-04	**4E-04**
Skin	134	150	303	376	6E-05	7E-05	1E-04	**2E-04**
Small intestine	91	107	205	278	†	†	†	†
Spleen	97	113	219	292	†	†	†	†
Stomach	95	111	215	288	1E-05	1E-05	3E-05	4E-05
Testes	160	282	371	887	†	†	†	†
Thymus	99	115	224	297	†	†	†	†
Thyroid	97	113	219	292	1E-05	2E-05	3E-05	4E-05
Upper large intestine	101	117	224	297	†	†	†	†
Uterus	88	105	200	273	2E-06	2E-06	4E-06	6E-06

*Slow lung solubility Th-230 dose coefficient **Medium lung solubility Th-230 dose coefficient
†No organ-specific attributable risk coefficient available mrem = millirem
Orange highlight means estimated lifetime cancer risk was higher than 1 in 10,000 (1E-4).
Bold values indicate risks still greater than 1E-4 after subtracting contribution of background levels of Th-230, Ra-226, and U-238 in soil, sediment, and surface water.

Table E 9. Tabulation of dose and risk results - recent exposures at Coldwater Creek

	Committed dose for entire exposure, mrem				**Lifetime attributable risk from 33-year exposure**			
	Recreational		Residential		Recreational		Residential	
Organ	Slow*	Medium **	Slow*	Medium **	Slow*	Medium **	Slow*	Medium **
Adrenals	8	9	43	52	†	†	†	†
Bladder	8	9	44	53	1E-06	1E-06	7E-06	8E-06
Bone surface	497	998	4,558	10,500	3E-05	6E-05	**3E-04**	**6E-04**
Brain	9	10	48	56	†	†	†	†
Breast	10	11	52	61	3E-06	4E-06	2E-05	2E-05
Colon	10	11	60	69	2E-06	2E-06	1E-05	1E-05
Esophagus	8	9	42	50	†	†	†	†
Extratracheal airways	14	4	172	51	†	†	†	†
Kidneys	18	27	133	245	1E-06	1E-06	8E-06	1E-05
Liver	17	25	122	220	9E-07	1E-06	7E-06	1E-05
Lower large intestine	11	12	71	80	†	†	†	†
Lungs	35	20	370	182	1E-05	7E-06	**1E-04**	7E-05
Muscle	9	10	48	57	†	†	†	†
Ovaries	12	17	80	143	4E-07	5E-07	3E-06	4E-06
Pancreas	8	9	41	50	†	†	†	†
Red marrow	37	59	298	572	4E-06	7E-06	4E-05	7E-05
Skin	12	13	61	70	5E-06	5E-06	3E-05	3E-05
Small intestine	8	9	44	52	†	†	†	†
Spleen	9	10	46	55	†	†	†	†
Stomach	9	9	45	54	1E-06	1E-06	6E-06	7E-06
Testes	14	19	89	152	†	†	†	†
Thymus	9	10	46	55	†	†	†	†
Thyroid	9	9	45	54	1E-06	1E-06	6E-06	7E-06
Upper large intestine	9	10	52	61	†	†	†	†
Uterus	8	9	42	51	2E-07	2E-07	9E-07	1E-06

*Slow lung solubility Th-230 dose coefficient **Medium lung solubility Th-230 dose coefficient
†No organ-specific attributable risk coefficient available mrem = millirem
Orange highlight means estimated lifetime cancer risk was higher than 1 in 10,000 (1E-4).
Bold values indicate risks still greater than 1E-4 after subtracting contribution of background levels of Th-230, Ra-226, and U-238 in soil, sediment, and surface water.

Effective Dose

Effective whole-body doses were estimated for past and recent exposures at Coldwater Creek using appropriate internal and external dose coefficients. Table E10 shows the estimated whole-body doses over the assumed 33-year exposure.

Soil pica behavior may be exhibited by children, typically between the ages of 1 and 6. Regular soil pica behavior increases the estimated effective whole-body doses to the amounts shown in parentheses in Table E10.

Table E 10. Summary of effective doses estimated for past and recent exposures at Coldwater Creek

	Past recreational dose in mrem†		Past residential dose in mrem†		Recent recreational dose in mrem†		Recent residential dose in mrem†	
Age	Slow *	Medium**	Slow *	Medium**	Slow *	Medium**	Slow *	Medium**
0	28	30	57	75	2	2	20	22
1	6 (21)	9 (24)	35 (80)	60 (104)	0.4 (0.9)	0.5 (1)	8 (31)	11 (34)
2	5 (16)	7 (18)	26 (59)	46 (79)	0.3 (0.7)	0.4 (0.8)	6 (23)	8 (26)
3	6 (17)	8 (19)	27 (61)	48 (81)	0.3 (0.7)	0.4 (0.8)	6 (23)	8 (25)
4	6 (17)	8 (19)	27 (61)	48 (81)	0.3 (0.7)	0.4 (0.8)	6 (23)	8 (25)
5	6 (17)	8 (19)	27 (61)	48 (81)	0.3 (0.7)	0.4 (0.8)	6 (23)	8 (25)
6	19	29	29	50	0.8	1	6	8
7	15	24	22	41	0.7	1	5	7
8	15	24	22	41	0.7	1	5	7
9	15	24	22	41	0.7	1	5	7
10	15	24	22	41	0.7	1	5	7
11	18	30	25	49	1	1	5	8
12	18	29	25	48	1	1	5	8
13	18	29	25	48	1	1	5	8
14	13	23	25	48	1	2	6	9
15	13	23	25	48	1	2	6	9
16	13	23	25	48	1	2	6	9
17	12	22	23	48	1	1	5	8
18	3	5	23	47	0.4	0.7	5	8
19	3	5	23	47	0.4	0.7	5	8
20	3	5	21	46	0.4	0.7	4	7
21	3	5	21	46	0.4	0.7	4	7
22	3	5	21	46	0.4	0.7	4	7
23	3	5	21	46	0.4	0.7	4	7
24	3	5	21	46	0.4	0.7	4	7
25	3	5	21	46	0.4	0.7	4	7
26	3	5	21	46	0.4	0.7	4	7
27	3	5	21	46	0.4	0.7	4	7
28	3	5	21	46	0.4	0.7	4	7
29	3	5	21	46	0.4	0.7	4	7
30	3	5	21	46	0.4	0.7	4	7
31	3	5	21	46	0.4	0.7	4	7
32	3	5	21	46	0.4	0.7	4	7

†Dose including regular soil pica behavior between ages 1 and 6 shown in parentheses.
*Slow lung solubility Th-230 dose coefficient **Medium lung solubility Th-230 dose coefficient
mrem = millirem