Groundwater Report and Request for License Termination

Colorado School of Mines Research Institute Site
Golden, Colorado

Stoller

Prepared by S.M. Stoller Corporation
For Colorado School of Mines
105 Technology Drive, Suite 190
Broomfield, Colorado 80021
November 2013

Table of Contents

List of Tables

List of Figures

List of Appendices

List of Acronyms

AEC	U.S. Atomic Energy Commission
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
cfs	cubic feet per second
COC	compound of concern
CSM	Colorado School of Mines
CSMRI	Colorado School of Mines Research Institute
CSWP	Characterization Survey Work Plan
DCGL	derived concentration guideline
DOC	dissolved organic carbon
EPA	U.S. Environmental Protection Agency
LCS	laboratory control sample
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
MS	matrix spike
MSD	matrix spike duplicate
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NOAA	National Oceanic and Atmospheric Administration
ORP	oxidation/reduction potential
pCi/g	picoCuries per gram
pCi/L	picoCuries per liter
ppb	part per billion
PRP	Potentially Responsible Party
QA/QC	Quality Assurance/Quality Control
RAOA	Removal Action Options Analysis
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RPD	relative percent difference
SSL	soil screening level
TDS	total dissolved solid
TOC	total organic carbon
UAO	Unilateral Administrative Order

Executive Summary

This *Groundwater Report and Request for License Termination* presents the findings of the investigation of groundwater conditions and quality at the site of a former mining research facility located at the north end of the Colorado School of Mines campus adjacent to Clear Creek. Several cleanup actions were previously completed to remove contaminated soil from the former research facility location. All soils were cleaned up to unrestricted-use standards and free released by the Colorado Department of Public Health and Environment (CDPHE). Following the last soil cleanup, two years of quarterly monitoring of groundwater have been completed as required by Radioactive Materials License 1206-01, Amendment 01, Section 15. The monitoring and analysis demonstrate that concentrations of uranium in the groundwater have been reduced such that the plume is shrinking in all dimensions and is stationary. The remaining Licensed Area largely corresponds to the west end of an area also described as the “Lower Terrace,” which consists of a flood plain on the south bank of Clear Creek.

Because the data demonstrating the soil is clean and available for unrestricted use have been presented in previous reports, these data are not presented in this report. Instead, this report presents the uranium data from the groundwater investigation and monitoring. These uranium data include the last eight quarters of monitoring conducted after contaminated soil was excavated from the Lower Terrace in 2010 and all groundwater data collected before the Lower Terrace and Upper Terrace soil excavations. This information was presented in draft form to the CDPHE for review and comment.

Key conclusions about the Site groundwater include the following:

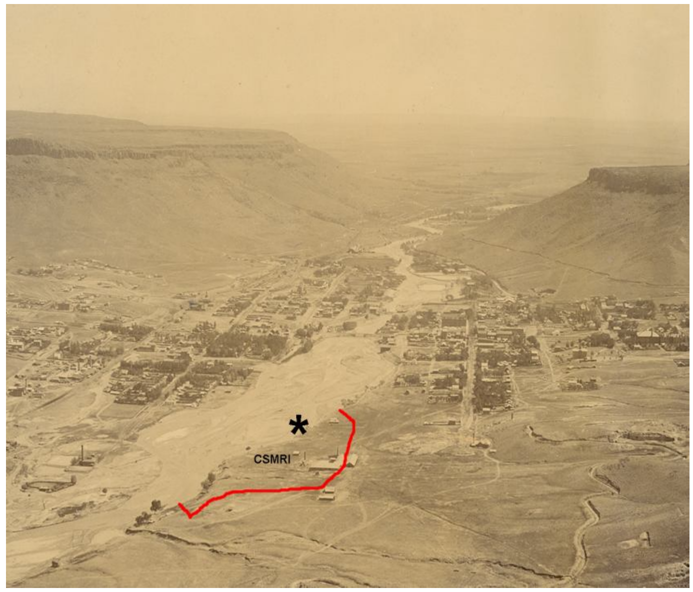
- Since Lower Terrace soil remediation, the uranium plume has and continues to decrease in both extent and concentration.
- Groundwater flow on the Lower Terrace is highly influenced by Clear Creek.
- Ambient levels of uranium in Clear Creek alluvium are elevated due to upstream mining activities and are statistically similar to remaining Site soils.
- Upper Terrace groundwater flows onto the Lower Terrace where Lower Terrace chemical and hydrological processes inhibit the movement of the uranium.
- A developed wetland exists in the central portion of the Lower Terrace enhancing dissolved uranium removal.
- A deep well into the underlying Fox Hills Aquifer shows no elevated uranium in the Fox Hills Aquifer and also shows upwelling of groundwater.
- The area containing the highest dissolved uranium levels is stationary, even though the groundwater is moving at 4 feet per day.
- The most recent data indicate groundwater leaving the Lower Terrace is below 30 µg/L.
- No increase in the uranium concentration in Clear Creek has been observed due to this Site.

Remaining uranium in groundwater within and around the Licensed Area is stationary with no water above the drinking water standard leaving the Site. A strong decreasing trend in both extent and maximum concentration of the uranium plume has resulted from soil removal activities. These decreasing trends will continue as the wetland becomes more mature. Remaining uranium detected in the groundwater is not attributable to any remaining materials associated with the former mining research facility. Lower Terrace groundwater undergoes dilution, dispersion, biological uptake, biological fixation, and adsorption, which in concert prevent migration of dissolved uranium offsite.

There is no need for further groundwater monitoring, investigation, or cleanup in the Licensed Area or adjacent property. The data presented in this report support the recommendation that Radioactive Materials License 1206-01 be terminated without restriction.

This report was prepared with oversight and assistance from the CDPHE, who reviewed and commented on a draft edition of the report. Their comments and our responses are briefly discussed in Section 5, and presented in Appendix 5 of this report.

1. Introduction



The CSMRI Site is located in the foreground, on the right side of Clear Creek. Buildings on site include the coal mine workings and the Golden Brick factory. Circa 1880.

**= Lower Terrace prior to creek channelization*

The Colorado School of Mines (CSM), the School, has been performing cleanup work at the Colorado School of Mines Research Institute (CSMRI) Site for many years. Cleanup efforts have successfully restored Site soils to their background composition. The Lower Terrace groundwater quality has been improved significantly by the effective, focused soil cleanup on the west end of the Lower Terrace. This report presents the data and findings on the Site groundwater and demonstrates that the uranium plume is shrinking in all directions, has reached a steady state, and poses very limited risk to the environment or area residents.

The CSMRI facility, located on the southern bank of Clear Creek in Golden, Colorado, was constructed in the early 1900s on land that was the former location of a coal mine and a brick factory and was a neighbor to several smelters. CSMRI, during its tenure on the Site, released to the environment several compounds of concern (COCs), including uranium, resulting from the experimental and testing projects conducted.

Two primary goals for the cleanup efforts have driven work at the Site. One has been to identify and clean up contamination that occurred during CSMRI operations. Another is to terminate the current radioactive materials license (Radioactive Materials License Number 1206-01, the "License"). This report summarizes the Site history and remediation completed to date and focuses on the restoration work completed on the last remaining area of concern, the groundwater.

CSMRI buildings and settling pond shown just left of the CSM football field. The buildings are located on the Upper Terrace, and the settling pond is on the Lower Terrace. Circa 1972.

This report contains the following sections that provide the basis for demonstrating the Site groundwater quality has greatly improved, has reached a steady state, and the License qualifies for termination.

- Purpose and scope of report
- Site history, including studies, remedial actions, and historic use
- Physical characteristics of the Site
- Regulatory setting and radioactive materials licensing history

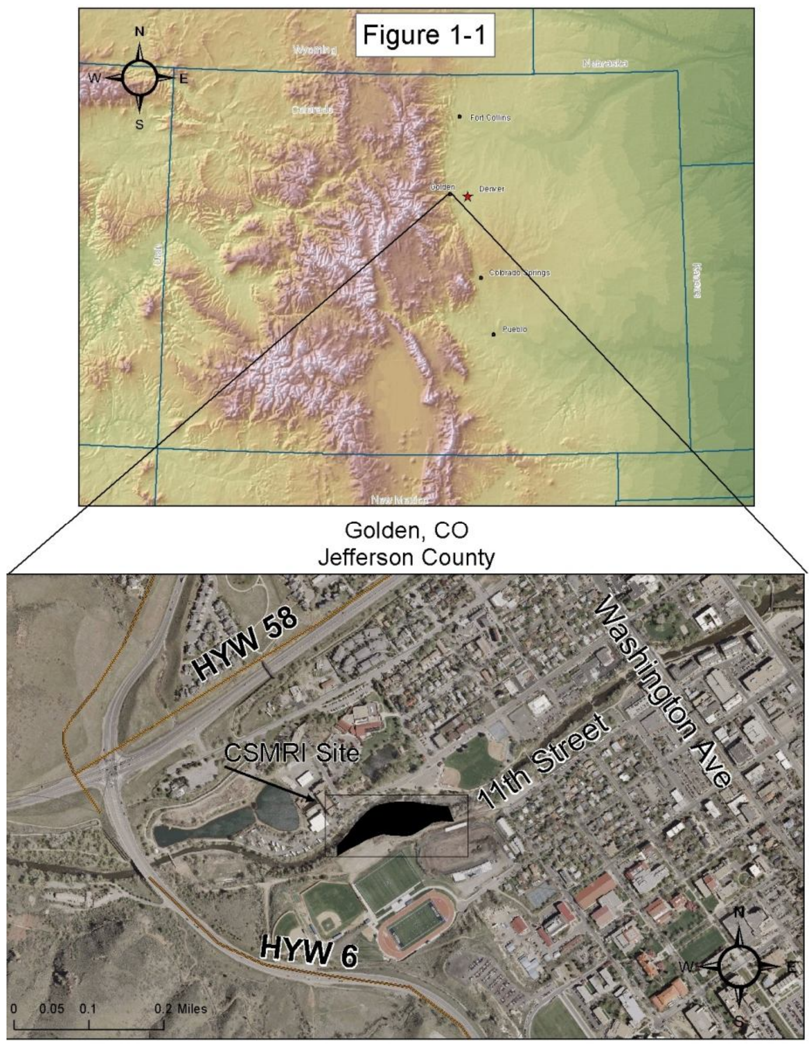
- Remedial approach and goals implemented on the various portions of the Site
- Surface water data and analysis
- Groundwater data, including historical data, current data, contaminants, geochemistry, and hydrology

This report concludes with a summary of Site groundwater data, all of which indicate the diminished uranium plume is in a steady state, decreasing in extent and concentration, and immobile. These criteria are required for license termination. The body of this report presents the data collected and describes how the data relate to the conclusion that the license termination criteria of a shrinking and immobile uranium plume has been achieved at the Site. Details of the data collected, procedures followed, and Site information are provided in appendices that are organized similarly to the report body.

The CSMRI Site as it looks today. The new bike path traverses the edge of the Upper Terrace (right), and the Lower Terrace is to the left along the bank of Clear Creek. Circa 2012.

1.1 Site Description

The Site is located in Jefferson County, Colorado, on the south side of Clear Creek, east of U.S. Highway 6, in the northwest quarter of the northeast quarter of Section 33, Township 3 South, Range 70 West as shown in ***Figure 1-1***. The main entrance to the Site is located at the western end of 11th Street in Golden, Colorado. The Site consists of the Upper Terrace, which is 40 or so feet above the Lower Terrace, which is the active Clear Creek flood plain; the slope from the Upper Terrace down to the Lower Terrace; and the Lower Terrace area. The portion of the original Site still under the purview of the Radiological Materials License is shown on ***Figure 1-2*** and hence forth will be called the Licensed



Area. As shown on ***Figure 1-2***, the Licensed Area is a limited portion of the west end of the Lower Terrace.

The 1880 photo presented on page 1-1 shows the Site before CSMRI activities and before Clear Creek was channelized. At the time the 1880 photograph was taken, the area called the Lower Terrace in this document was still an active alluvial bar within Clear Creek.

A chain-link fence restricted access to the Site during the investigation and cleanup. A settling pond was previously located on the Lower Terrace within the perimeter fence and within the bounds of this investigation (***Figure 1-2***). Starting in 1992, the U.S. Environmental Protection Agency (EPA) cleaned up the pond as part of an Emergency Removal Action under Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC §§ 9601-9675, as amended (CERCLA).

1.2 History of Site Use

Many activities associated with mineral extraction and associated processes have been conducted at the Site and in the general Golden area prior to and during operation of the CSMRI Site. ***Appendix 1*** presents a detailed history of Site use. No groundwater on this Site has been used as a domestic, agricultural, or commercial water source. In fact, the original facility included a water supply tunnel from Clear Creek that passed under the main building. A sump at the end of the tunnel pumped Creek water to supply water for Site use. This was necessary because the shallow groundwater aquifer was unable to provide an adequate source of water.

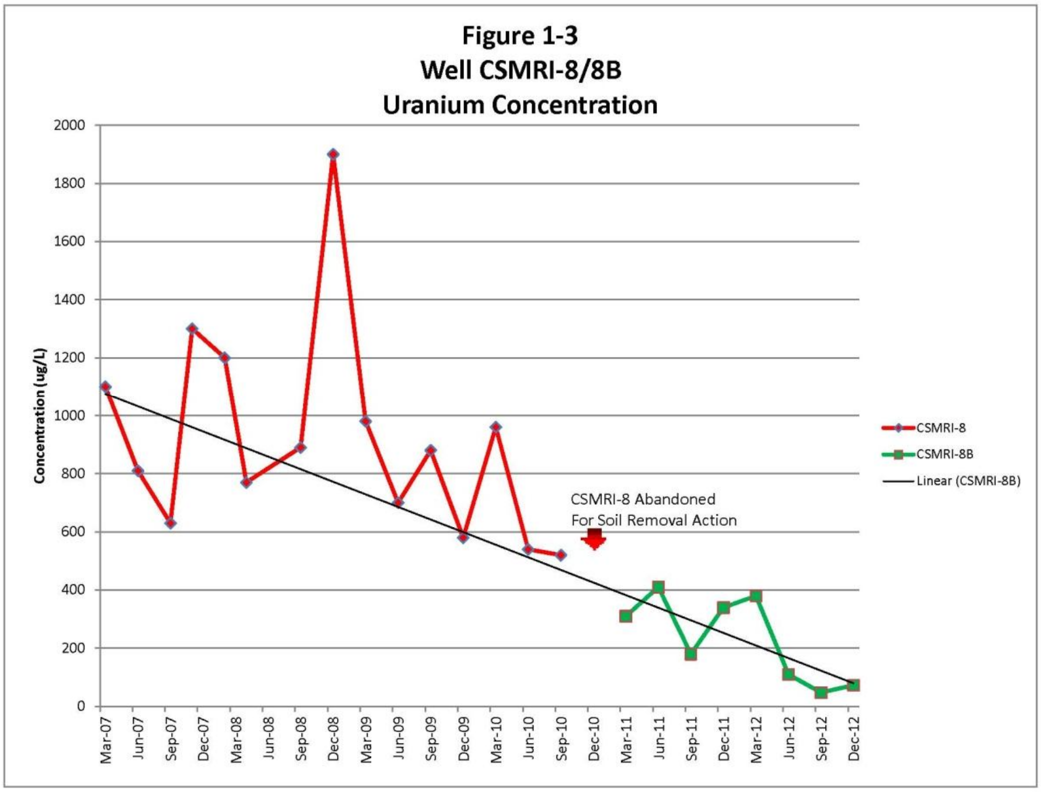
1.3 Purpose and Scope of Report

This report demonstrates that the targeted soil remediation has had a positive impact on the uranium plume in the groundwater in that both the extent and concentration has decreased, and that the plume is immobile. The data contained in the report demonstrate that the requirements for termination of Radioactive Materials License 1206-01, shrinking plume, and no offsite movement of the plume have been achieved. The scope of the report includes data collected during the past eight years of quarterly monitoring, pertinent data derived from reviewing scientific papers and articles on similar groundwater systems, and data collected during Site investigation and soil cleanup work.

At this time, the license covers only groundwater containing uranium, and any unknown sources of radioactive material contributing to uranium in groundwater, within the Licensed Area. This report fulfills license condition No. 15, which requires an analysis of groundwater conditions, including recommendations for closure or further investigation, monitoring, or remedial action as appropriate. The report includes analysis of Site-wide groundwater as a means of understanding what, if any, unknown sources may contribute to uranium in groundwater within the Licensed Area. The analysis presented in this report identified no remaining sources within the Licensed Area as a result of CSMRI operations that are contributing to uranium in groundwater and recommends closure based on current conditions.

The data indicated that prior to cleanup, contaminated soil was acting as a continuing source of dissolved uranium in groundwater. Eight quarters of groundwater monitoring were completed since known remaining contaminated soil was removed. This report presents the body of data collected, interpretations of that data, and long-term changes or trends in the data set.

Sampling, testing, and monitoring at the Site has identified dissolved uranium in the groundwater. The groundwater found to contain elevated levels of uranium is predominately located on the Lower Terrace within the Licensed Area. Cleanup activities have targeted the source of the dissolved uranium and have been successful in reducing the maximum concentration of dissolved uranium in the most impacted monitor well (CSMRI-8B) from 1,900 µg/L to 73 µg/L in the quarterly sampling (***Figure 1-3***). This decreasing trend is observed in the extent of the plume as well as the maximum concentration.



The studies completed to identify the origins of the dissolved uranium have yielded information concerning the groundwater, hydrogeology, and hydrology of the Lower Terrace. Data presented in the following sections depict a site wherein the groundwater flowing through the Lower Terrace, comprised of predominantly Clear Creek surface water, flows across the Site at 4 feet per day. This rate of movement completely replaces all Lower Terrace groundwater every three months, while the area exhibiting elevated uranium concentrations remains static, not moving with the groundwater.

Several mechanisms, including retardation, adsorption, and precipitation, as discussed in Section 4, working in concert result in the remaining uranium concentrations in groundwater at the Site being stationary and immobile.

1.4 CSMRI Cleanup Approach

Goals for cleanup have been to return the Site to maximum beneficial use and to terminate the radioactive materials license. Work at the Site began with the decommissioning and demolition of the buildings and other related facilities of the CSMRI campus more than 20 years ago. Identification, excavation, and shipment of impacted soil for disposal at offsite landfills was completed. Monitor wells installed at and around the Site evaluated the quality of groundwater. Following

Cleanup Accomplishments: CDPHE Conclusions Regarding Soil Restoration

- **The Clay Pits have been adequately characterized and no additional actions are required**
- **The land under the soccer field is adequately characterized and no additional actions are required**
- **Upper Terrace soils have been adequately characterized and no additional actions are required**
- **Lower Terrace soils have been adequately characterized, and no additional actions are required except those that may be necessary to bring groundwater into compliance or change land use**

extensive work at other portions of the Site, monitoring wells placed within the Lower Terrace identified elevated dissolved uranium concentrations. The dissolved uranium in the Lower Terrace groundwater indicated a likely contaminant source in the western portion of the Lower Terrace. Further Site characterization and excavation of Lower Terrace soil found additional soil and material impacted by historical CSMRI activities. Excavation and offsite disposal of contaminated soil completed cleanup work. The cleanup work has been extensively documented in the Revised RI/FS and Proposed Plan (Stoller 2007), the CSMRI Remedial Action Implementation Report (Stoller 2009), and the Final Completion Report, CSMRI Flood Plain (Lower Terrace) Site (Stoller 2011). The CDPHE has released the soil within the Site from the radioactive materials license. Work conducted during the cleanup helped to expand knowledge about the Site and increased the amount of data available regarding the relationship between Clear Creek and the Lower Terrace groundwater, the formations underlying the Lower Terrace, and the contribution of Upper Terrace groundwater to the Lower Terrace. This report presents data collected during cleanup that improves understanding of the Site's groundwater and, specifically, the dissolved uranium within it.

A restrictive covenant was placed on the Upper Terrace groundwater during radioactive materials license restructuring in 2011. The restructuring reduced the Licensed Area to just that portion of the original Site shown on Figure 1-2, releasing the Upper Terrace groundwater from the license.

A detailed list of the COCs and the cleanup goals used during the investigation and remediation goals is included in ***Appendix 1***.

Since CSMRI ended operational activities, a series of investigative and cleanup efforts have occurred, including the former settling pond, the Upper Terrace where the CSMRI facilities were located, the Clay Pits, and the Lower Terrace. Summaries of the activities performed to achieve background levels for each of these areas of concern are presented in chronological order in ***Appendix 1***.

Investigations and Remedial Activities

- **1992 – Soil removal, building demolition, pond closure (EPA)**
- **2002 – Concrete and asphalt characterization (URS/New Horizons)**
- **2003 – Investigation and Characterization – gamma survey, soil sampling, test pits, soil borings (New Horizons)**
- **2004 – Soil excavation (New Horizons)**
- **2004 – Legacy soil sampling (Stoller)**
- **2005 – Legacy soil disposal (Stoller)**
- **2006 – Upper Terrace soil excavation, radiological survey, soil sampling, soil disposal (Stoller)**
- **2007 – Clay pits investigation, monitoring well installation (Stoller)**
- **2010 – Lower Terrace preliminary investigation (Stoller)**
- **2010 – Lower Terrace excavation (Stoller)**
- **2011 – Soil disposal, additional monitoring well installation (Stoller)**

1.5 Regulatory Setting

The CDPHE has provided regulatory oversight for this project. The CDPHE also manages the licensing authority for the radioactive materials license, including license termination activities. To date, the School has submitted 32 quarterly monitoring reports and more than 10 reports documenting investigations and cleanups to the CDPHE for its review and approval.

The School, while pursuing Site cleanup and radioactive materials license termination, also maintains conformance with CERCLA, and the National Oil and Hazardous Substances Pollution Contingency Plan, 40 CFR 300 (NCP) to help ensure effective cost recovery. The CDPHE provides regulatory oversight relative to radioactive materials at the Site and licensing activities related to those materials.

This report addresses the groundwater at the CSMRI Site. The soil within the Site was released by the CDPHE in a letter dated December 15, 2011.

The research work performed historically at the Site related to studies of a variety of ores and minerals. A fraction of those ores and minerals contained naturally occurring radioactive materials. CSMRI possessed a license for the storage, handling, and possession of Naturally Occurring Radioactive Material (NORM) and source material (Colorado Radioactive Materials License number 617-01S). The CSMRI license was terminated in 2012. A license allowing the possession of uranium in groundwater and any unknown sources of material contributing to uranium in groundwater was issued to the School in 2012 for a portion of the Lower Terrace area. Two tables summarizing the chronology of Site licensing actions are included in ***Appendix 1***. ***Table 2*** summarizes a chronology of the U.S. Atomic Energy Commission licensing actions, and ***Table 3*** summarizes the State of Colorado licensing actions at the CSMRI Site.

1.6 History of Closures

Portions of the CSMRI Site have been released for unrestricted use over the past several years. The December 15, 2011, CDPHE letter provides the most comprehensive summary of these actions. That letter states the following:

1. The Clay Pits have been adequately characterized, and no additional actions are required.

2. The land under the soccer field is adequately characterized, and no further action is required.

3. Upper Terrace soils have been adequately characterized, and no further action is required except those that may be necessary to bring groundwater into compliance or to change land use.

4. Lower Terrace (aka “flood plain”) has been adequately characterized, and no further action is required except those that may be necessary to bring groundwater into compliance or to change land use.

2. Physical Characteristics of the Site

Physical Characteristics affecting Site Groundwater

- **Geography**
- **Surficial Geology**
- **Bedrock Geology**
- **Surface Water**
- **Groundwater Use**
- **Ecology**

This section summarizes the physical properties of the Site. Detailed descriptions of the surrounding area, demographics, surface water use, land use, and climate are included in ***Appendix 2***. The geology has a significant impact on the groundwater of both the Upper Terrace and Lower Terrace. Surface water hydrology, groundwater use, and Lower Terrace ecology also influence the Site groundwater and are described below.

2.1 Geography

In general, the Site slopes gently to the north with a major elevation break that separates the Upper Terrace from the Lower Terrace. The Upper Terrace has had several features developed since completion of cleanup, including a soccer field, an access road, a bike path, and parking lot (***Figure 2-1***). The break in slope also separates the Upper Terrace groundwater system from the Lower Terrace groundwater system. The break in slope, as depicted on the 1880 photo in Section 1, used to be the south bank of Clear Creek. Prior to development, the area that is now the Lower Terrace of the CSMRI Site was a channel and a sandbar of Clear Creek.

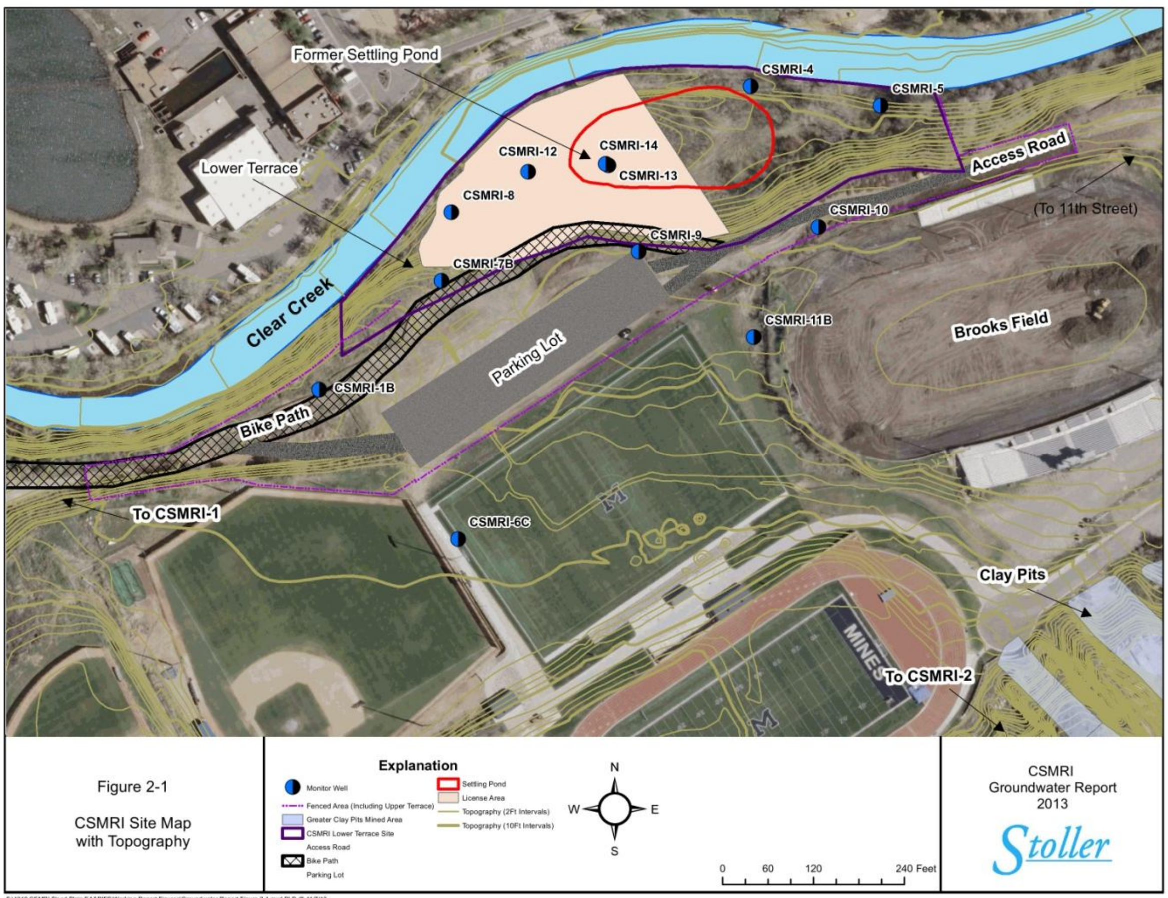


Figure 2-1

CSMRI Site Map with Topography

2.2 Geology

The Site is located along the eastern edge of the Rocky Mountain Front Range foothills. The surficial deposits that overlie bedrock in and around the Site are described below followed by descriptions of the bedrock units.

2.2.1 Surficial Geology

The surficial deposits at the Site consist of varying thicknesses of unconsolidated colluvial and alluvial sediments that are geologically recently deposited. These sediments lie unconformably on top of the bedrock units that underlie the Site. These sediments, from oldest to youngest, are described below and shown on ***Figure 2-2***.

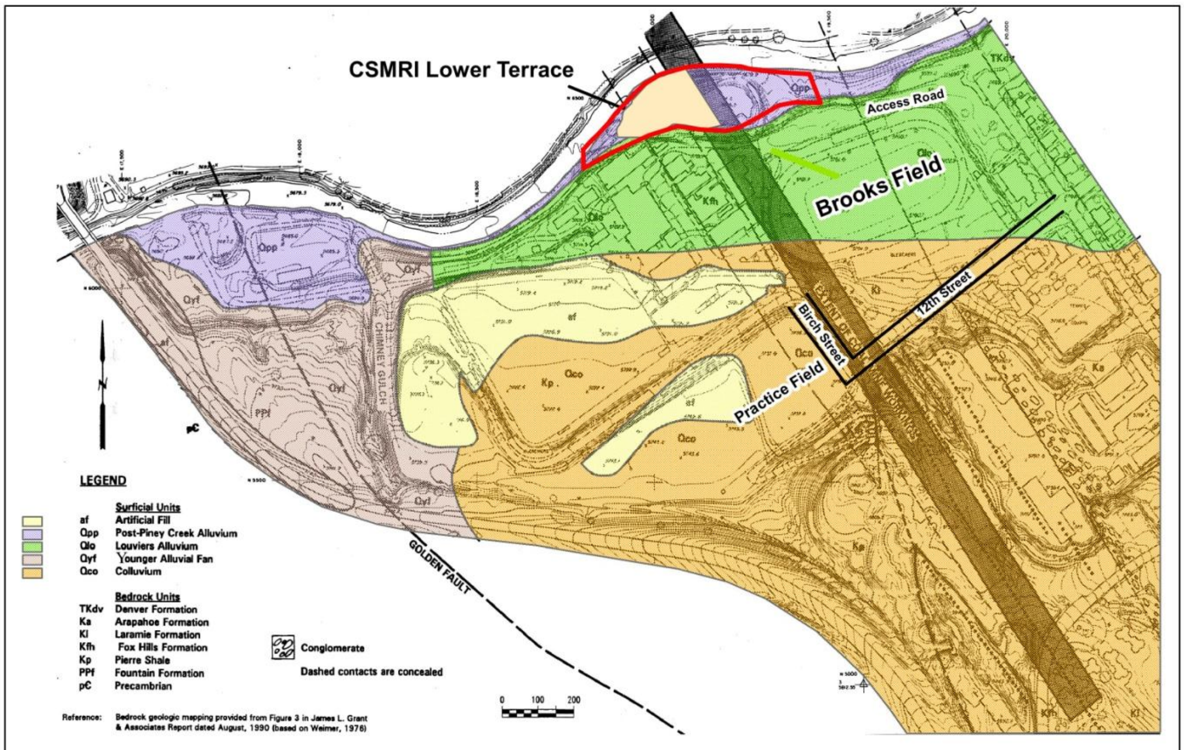


Figure 2-2

Surficial Geologic Map of Site

CSMRI Groundwater Report 2013

Stoller

Louviers Alluvium (Qlo)

The Louviers forms the well-defined Upper Terrace in the Clear Creek valley and is the oldest of the alluvial deposits present in the area. The deposit is typically a coarse, cobbly, sand and gravel, poorly sorted, sitting on a weathered bedrock surface. Based on the subsurface work performed at the CSMRI Site, this unit is about 10 feet thick and extends under the new soccer field, baseball and softball fields, and practice fields. This unit only exists on the Upper Terrace at the Site.

Younger Alluvial Fan Colluvium (Qyf)

This unit is associated with the current Chimney Gulch drainage and overlies the Louviers. This deposit formed before the deposition of the Post-Piney Creek Alluvium. The materials present in the deposit associated with the Chimney Gulch drainage consist of a poorly sorted, heterogeneous mixture ranging from boulders to clay. The upper few feet are clayey silt grading downward to coarser materials. The thickness of this unit is variable but could be as much as 40 feet. This unit only exists on the Upper Terrace.

Colluvium (Qco)

Colluvium consists of materials that have been moved down steep slopes by creep and sheet wash, and at a few places, they represent minor alluvial fan deposits. The colluvial deposits grade into and interfinger with alluvial terrace deposits and the younger alluvial fan deposits. It is mostly a massive to crudely bedded sandy to clayey silt but locally either sand or clay can predominate. Colluvial deposits generally overlie very irregularly sloping bedrock surfaces.

Underlying the colluvial material is an alluvial cobble zone. The cobble zone consists of a small quantity of pinkish-reddish sand intermixed with numerous flat cobbles/boulders (up to 12 inches). See the following description of the Post-Piney Creek Alluvium. Up to 13 feet of this alluvial material was encountered in test borings.

Post-Piney Creek Alluvium (Qpp)

This alluvial unit is present along Clear Creek and is the youngest alluvial unit in the area. It consists of coarse sand and gravel deposits and forms flood plain features similar to the CSMRI Lower Terrace along Clear Creek. This unit was the main unit involved in the Lower Terrace characterization efforts. This unit is also the unit where the elevated uranium in groundwater is located.

Artificial Fill (af)

Fill was identified on the western portion of the Lower Terrace during Site investigation and cleanup work in 2010 (Stoller 2011). Fill on the Lower Terrace consisted of lumber, gravel, and other debris; this fill was completely removed in 2010.

On the Upper Terrace, the identified fill was used primarily for enhancing the usable area of the athletic fields. The fills include tan to brown clay, which is medium to stiff, silty, sandy, and slightly gravelly (athletic field), and the artificial fill consists of silty clay to clayey sand with some gravel and construction debris (softball field area). These artificial fills likely originate from excavations around the CSM complex that placed the fill as an excess soil disposal area. See the Removal Action Options Analysis (RAOA). Some fill identified in various locations contained crucibles, bricks, lumber, coal, and other debris and trash.

2.2.2 Bedrock Geology

Bedrock geology at the Site consists of three distinct geologic formations. A bedrock geologic map of the area is ***Figure 2-3***, and a cross section of the bedrock geology in the Golden area is provided in ***Figure 2-4***.

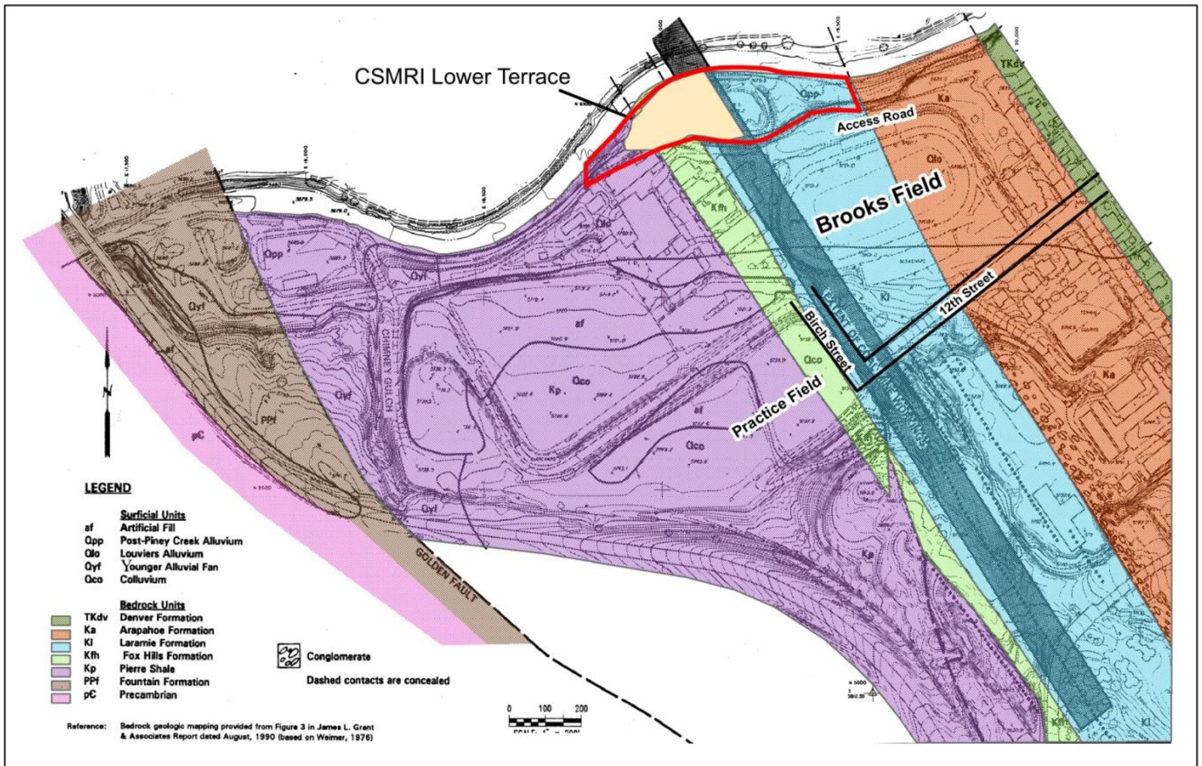


Figure 2-3

Bedrock Geologic Map of Site

CSMRI Groundwater Report 2013

Stoller

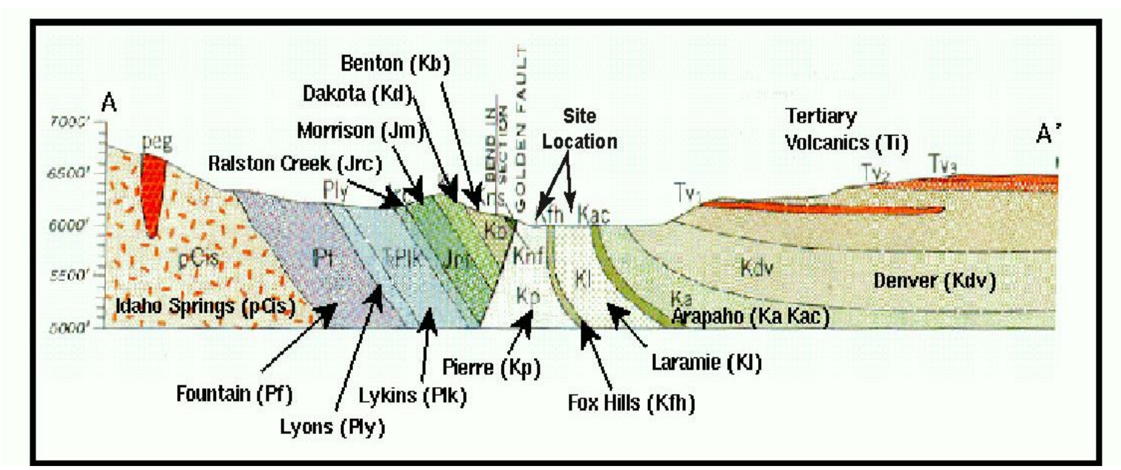


Figure 2-4 Geologic Cross Section in the Vicinity of the Site

Pierre Shale (Kp)

Pierre Shale underlies much of the western side of the Site, including small appearances that are evident along the western end of the former settling pond, exposed by the erosion action of Clear Creek. It is a dark gray shale with minor laminae of tan weathered siltstone and fine-grained sandstone. The Pierre

Shale is estimated to be at least 2,000 feet thick beneath the Site and is a well-documented regional aquitard. Onsite, the Pierre Shale forms a barrier to downward migrating water from rainfall and irrigation. This water forms the Upper Terrace groundwater.

Fox Hills Sandstone (Kfh)

The Fox Hills Sandstone lies to the east of the Pierre Shale. It is a tan to yellow, fine-grained sandstone with thin beds of siltstone and gray claystone. Water-level measurements collected from the Fox Hills monitoring well (CSMRI-14) have shown that the Fox Hills aquifer beneath the Site is confined and upwelling into the Lower Terrace alluvium. The Fox Hills underlies a part of the eastern-most practice field and some of the former buildings. An outcrop of this formation is visible at the west end of 12th Street south of the Site.

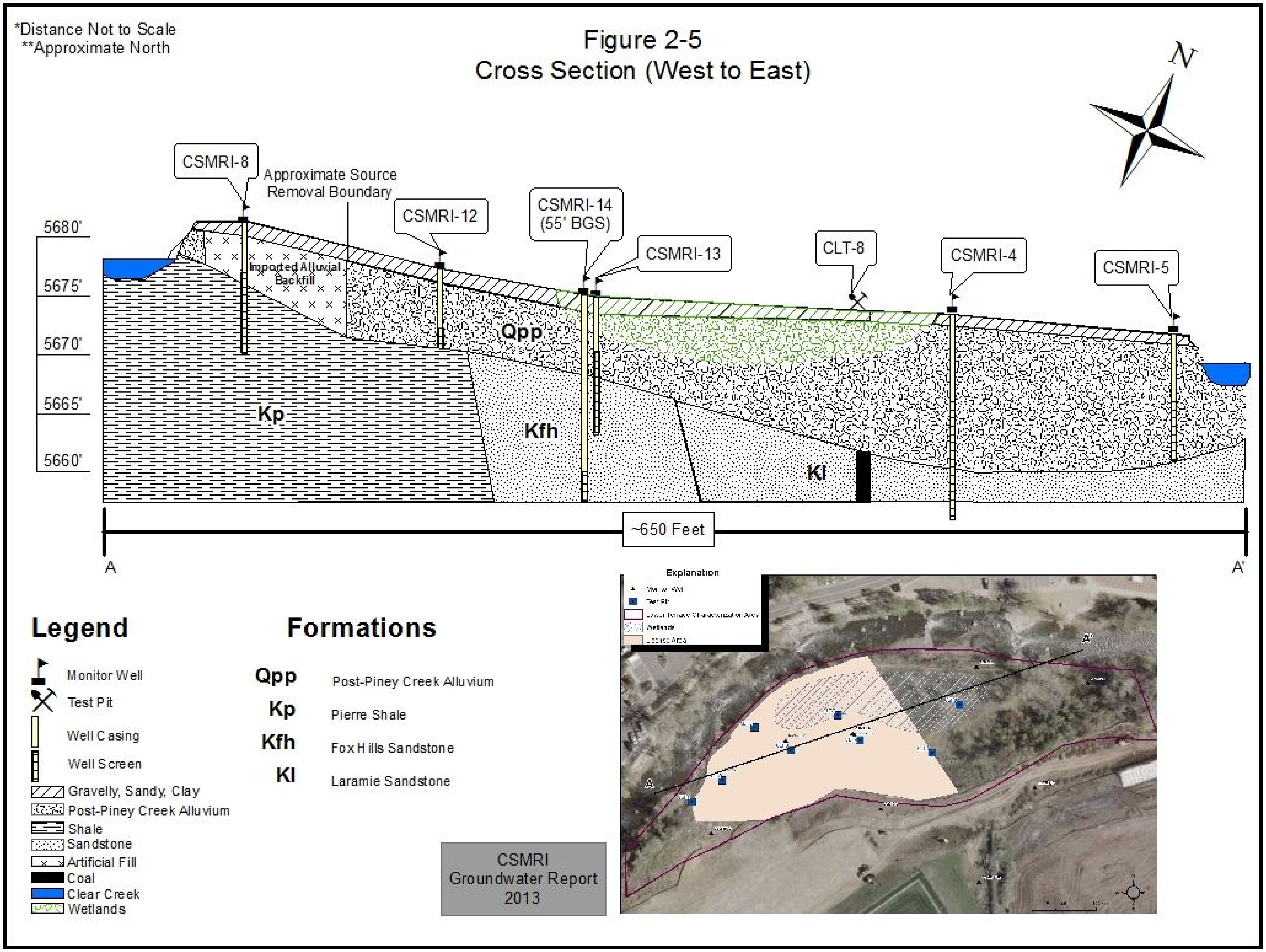
Laramie Formation (Kl)

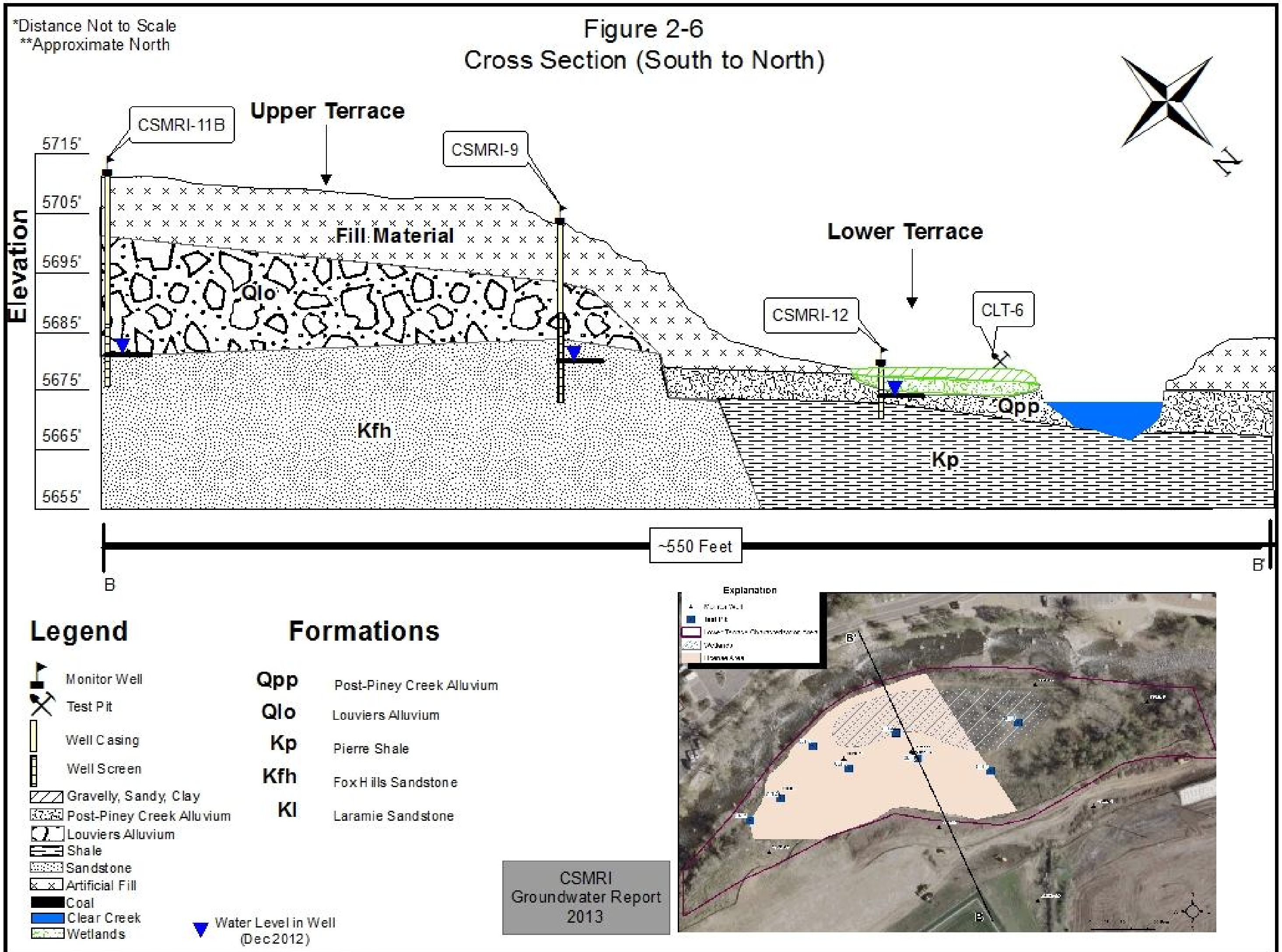
The easternmost formation on the Site is the lower unit of the Laramie Formation. It consists of four major sandstones that alternate with claystone. The sandstones are light gray and fine- to coarse grained. The claystone units contain gray claystone with lesser amounts of black claystone and thin coal seams. Two of these roughly north-south trending seams were mined in the 1800s. Coal was encountered in test pit 8 on east-central portion of the Lower Terrace.

Additional information (e.g., thickness of these surficial deposits) is located in the test pit and boring logs included in previous Remedial Investigation/Feasibility Study (RI/FS) documents. Figures showing the surficial and bedrock geology as well as a detailed discussion of surficial and bedrock geology are included in ***Appendix 2***.

The following geologic cross sections present features of the subsurface geology at the Site. The first is from west to east through the Lower Terrace (***Figure 2-5***) and the second is south to north, including the Upper Terrace, Lower Terrace, and Clear Creek (***Figure 2-6***).

Figure 2-5
Cross Section (West to East)




*Distance Not to Scale
**Approximate North
Figure 2-6
Cross Section (South to North)
N
Upper Terrace
CSMRI-11B
CSMRI-9
Fill Material
Qlo
Lower Terrace
CSMRI-12
CLT-6
Qpp
Kfh
Kp
Elevation
5715'
5705'
5695'
5685'
5675'
5665'
5655'
~550 Feet
B
B'
Legend
Monitor Well
Test Pit
Well Casing
Well Screen
Gravelly, Sandy, Clay
Post-Piney Creek Alluvium
Louviers Alluvium
Shale
Sandstone
Artificial Fill
Coal
Clear Creek
Wetlands
Water Level in Well (Dec2012)
Formations
Qpp Post-Piney Creek Alluvium
Qlo Louviers Alluvium
Kp Pierre Shale
Kfh Fox Hills Sandstone
Kl Laramie Sandstone
CSMRI Groundwater Report 2013
Explanation

2.3 Surface-Water Hydrology/Quality

Clear Creek flows from west to east on the north side of the CSMRI Site. Clear Creek water directly influences the groundwater on the Lower Terrace. Throughout the year, the temperature of Lower Terrace groundwater directly follows water temperature in Clear Creek. Groundwater in the Lower Terrace originates as upstream water in Clear Creek. This link is demonstrated schematically in ***Figure 2-7***.

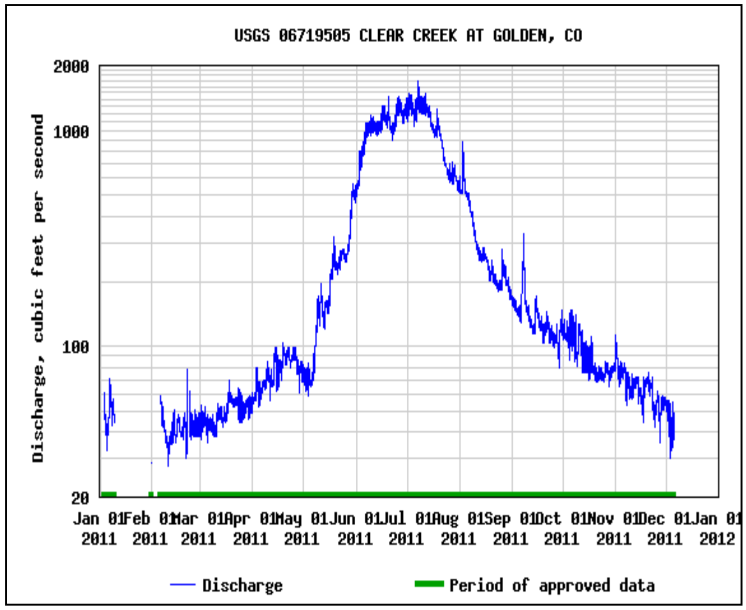
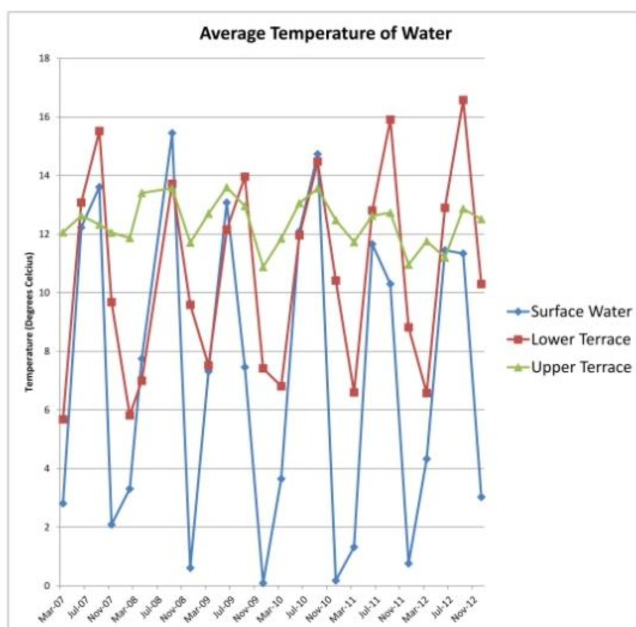


Figure 2-7. Average Water Temperature

Water temperature is the most useful tool for understanding the relationship between the shallow alluvial aquifer and Clear Creek. Both Lower Terrace wells and Clear Creek water show the seasonal fluctuations expected in water temperature. When plotted alongside each other, the temperature data from quarterly surface water samples collected from Clear Creek closely track Lower Terrace wells temperature, demonstrating a clear hydraulic connection. By comparison, wells installed on the Upper Terrace, although consistent with each other, demonstrate no relationship with the Lower Terrace wells and show only negligible seasonal variation. Stream flow in Clear Creek is highly variable over the course of the year. Peak flows are fed by snowmelt in the Clear Creek drainage basin and average approximately 800 cubic feet per second (cfs), usually occurring in late June. The lowest stream flows tend to occur in mid-February with an average of 40 cfs. A hydrograph of Clear Creek from 2011 is shown in ***Figure 2-8.*** These variations in water volumes affect the surface water chemistry. Clear Creek passes through a historic mining region called the Colorado Mineral Belt.



Several reaches of Clear Creek have been designated EPA Superfund sites because of extensive mining operations. Numerous mine adits along the stream contribute to seasonally elevated concentrations of metals, primarily manganese and zinc in the water as well as alluvial sediments that are derived from these mines. This mine waste turned alluvium has contributed to elevated background concentrations of naturally occurring uranium in the Post-Piney Creek Alluvium (which includes the Lower Terrace). This contribution to background concentrations of uranium is discussed in the Work Plan (Stoller 2010). Section 3 provides additional information concerning the surface water, specifically Clear Creek. Information regarding surface water and groundwater hydrology near the

Site is included in ***Appendix 2***.

2.4 Area Groundwater Uses

Ute Ladies' Tresses Orchid

Groundwater wells, applications, and permits were identified for a 1-mile radius around the Site from information provided by the Colorado Division of Water Resources. A copy of that information is included in Appendix B of the New Horizons' 2004 RI/FS. An evaluation of that information shows that as many as 20 wells may be in use within a 1-mile radius of the Site. The identified uses include nine for industrial, ten for domestic, and one for household purposes. Yields range from 1 gallon per minute to as much as 85 gallons per minute. The nearest wells are located on the north side of Clear Creek within 500 to 1,000 feet of the Site. The nearest well on the south side of Clear Creek is over 2,000 feet away. The nine industrial use wells are alluvial wells owned by Coors Brewing Company and are to the northeast of the Site at distances in excess of about 2,000 feet in locations near Clear Creek. Water taken from the industrial use wells, as well as the domestic and household wells, may be used for drinking water purposes according to the Colorado Division of Water Resources use classification.

Details presented on the hydrology in Section 4 demonstrate the movement of groundwater is such that none of these area wells are located downgradient from the Site, thereby eliminating potential impacts.

2.5 Ecology

The ecosystem of the area surrounding Golden is a diverse habitat influenced by a range in elevations that encompasses the plains, foothills, and mountains. Channelization of Clear Creek, construction of artificial ponds, grading projects, changes in vegetation, and other man-made features have created new habitats by altering the natural habitat in the vicinity. Extensive residential development also has occurred over the years, and new development is continuing to the north and south of the Site.

In the 1990s, the U.S. Fish and Wildlife Service indicated that a federally threatened plant species, the Ute Ladies' Tresses Orchid (*Spiranthes diluvialis*), was present in the Clear Creek area near the Site. Ute Ladies' Tresses were found in the Lower Terrace years later during the 2010 investigation. At the time the plants were found, efforts were being made by the federal government to de-list the plant as a threatened species.

A wetland delineation was completed in 2006 on the portion of the Site adjacent to the former settling pond. The study determined that a wetland exists in the center of the Lower Terrace in the vicinity of the former pond area. The Lower Terrace cleanup work was designed to minimize impacts to the wetland, and upon completion no impacts had occurred. As a precaution, a U.S. Army Corps of Engineers Nationwide 38 permit was acquired to allow intrusion into the wetland if necessary. Although Ute Ladies' Tresses are present on the Lower Terrace, no mitigation for these plants was required in the permit. During the work, there was no intrusion into the wetland during characterization or remediation activities and no known orchid plants were impacted.

The wetland is an important feature because it contains biological activity that impacts the chemistry of the groundwater. The wetland biological activity uses available oxygen to decompose organic matter resulting in the formation of reducing chemical conditions that cause uranium to precipitate out of groundwater. In a well developed wetland with limited groundwater flow, this process can use up much of the oxygen in the groundwater resulting in reducing conditions. Passive remediation systems employing the wetland are commonly used to remove metals such as uranium from water. Within a wetland like the one on the Lower Terrace where the wetland is young and just developing with lots of groundwater flow, the reducing zone can be limited to biofilms that form on soil surfaces (Kazuaki Hibiya *et al.* 2004). Conditions within the biofilms can be very reducing while the overall groundwater chemistry is not reducing. This results in uranium being removed from the groundwater and attached to the soil particle.

3 Surface Water

Site Surface Water features:

- **Clear Creek**
- **Wetland**

The main surface water feature associated with the CSMRI Site is Clear Creek. The Lower Terrace also contains the wetland, which is an important feature with respect to the presence or absence of uranium in groundwater. The Lower Terrace was constructed by placing fill directly on a former meander of the creek. This former creek channel acts as a conduit for movement of creek water through the Lower Terrace. Additionally, the potential for movement of contaminants from Site soil to surface water in Clear Creek has been thoroughly investigated. The following sections provide details on Clear Creek condition, hydrology, chemistry, and data that demonstrate the Site has no impact on Clear Creek water quality.

3.1 Clear Creek

Clear Creek is the primary surface-water feature of the Site and general area. Clear Creek is a tributary of the South Platte River with a drainage basin area above the Site of approximately 400 square miles. Clear Creek is fed from precipitation and runoff from areas located along the Continental Divide near Loveland Basin Ski Area. The stream drops over 8,000 feet in about 50 miles from the Divide, passing through steep canyons on its way to the Golden area as seen in ***Figure 3-1.*** Along its course, Clear Creek receives drainage and sediment from multiple mines located in an area known as the Colorado Mineral Belt. Clear Creek flows through Golden and onto the plains to its confluence with the South Platte River in Denver, Colorado. Much of the alluvium within the lower reaches of the Creek has been worked to remove placer deposits of gold, a valuable sediment also originating from the Colorado Mineral Belt.

Clear Creek as it passes the CSMRI Site and enters Golden

A study to determine the ambient uranium concentration in Clear Creek alluvium was completed in 2010 (Stoller 2010). This study showed the ambient uranium concentration of Clear Creek alluvium is elevated and closely matches the concentration of uranium remaining in the licensed area and on the entire Lower Terrace after remediation of the soils. Geochemical testing and analysis summarized in Section 4.3 and detailed in Appendix 4 demonstrated the ambient levels of uranium are sufficiently high to result in groundwater uranium concentrations similar to those observed onsite. A discussion of the ambient uranium study and the analytical results are included in ***Appendix 3.***

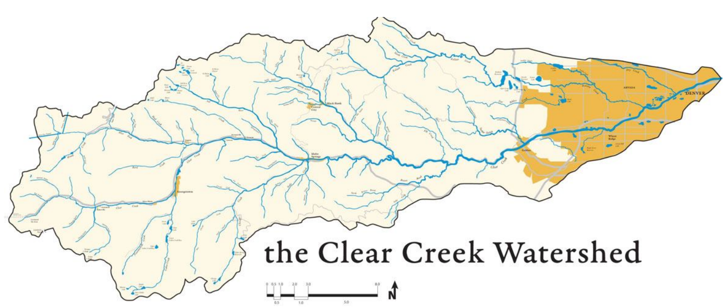


Figure 3-1 Clear Creek Watershed

Clear Creek forms the northern boundary of the CSMRI Lower Terrace. Seasonally, the creek fluctuates in both flow rate and temperature but remains fairly constant in its high dissolved oxygen content. The direct connection between Lower Terrace groundwater and Clear Creek water is demonstrated in

Figure 2-7, where the temperature of the Lower Terrace groundwater is shown to mimic closely the temperature of Clear Creek water. Additionally, elevation measurements on the surface of Clear Creek made adjacent to CSMRI-8 indicated the water level in well CSMRI-8 is lower than Clear Creek, indicative of a losing stream. The same was completed at well CSMRI-5 where a gaining stream was identified. Three surface water sample locations on Clear Creek are sampled and analyzed quarterly. Two of the locations have been regularly sampled since 2005. In 2010, CDPHE requested sampling at a third location. This request was to determine if Lower Terrace groundwater was leaving the Site in the vicinity of well CSMRI-8. All three sample locations are located on the south bank of Clear Creek adjacent to the Site. Surface water samples are analyzed for the same sample parameters as the groundwater samples. Data are presented in Section 3.3.

Clear Creek was sampled to determine if it had been impacted by the Site groundwater or surface water. The three surface water sample locations are provided in ***Figure 3-2.***

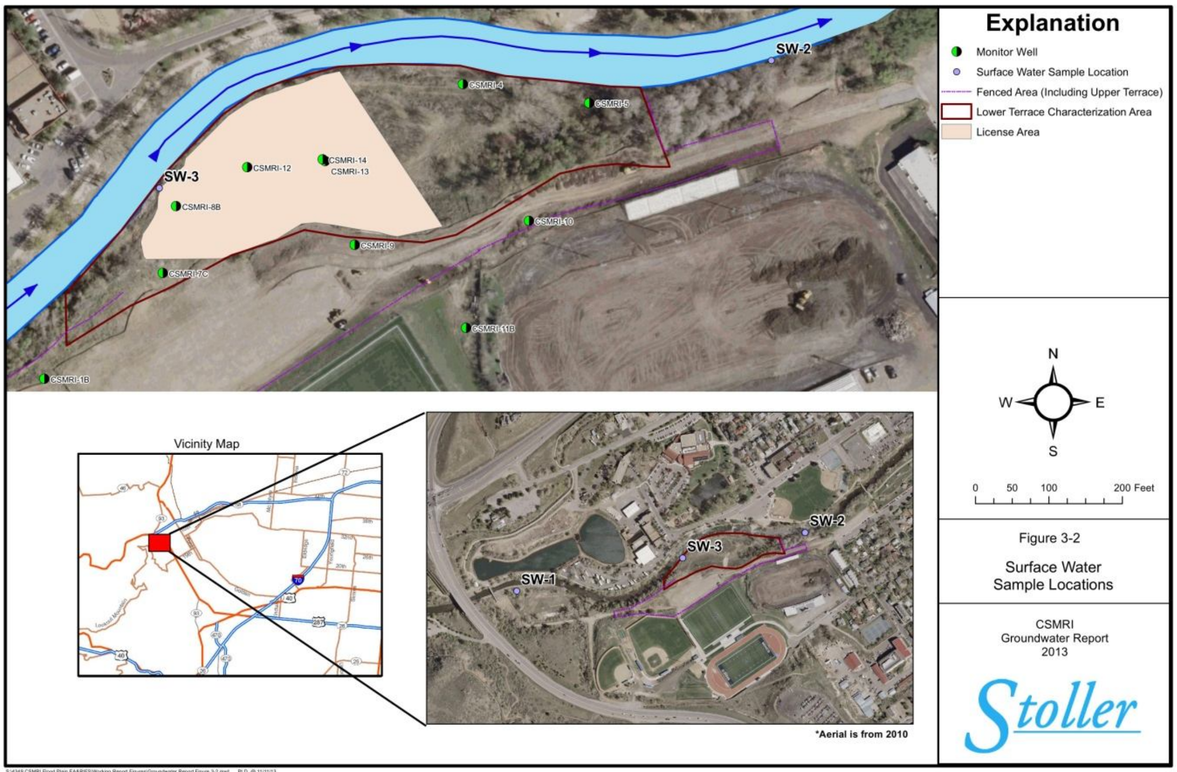


Figure 3-2
Surface Water Sample Locations

- SW-1 is located upstream and serves as baseline data for the water quality of Clear Creek before it enters the Site boundary. This provides the opportunity to assess possible impacts to Clear Creek from the dissolved uranium in groundwater observed in samples from SW-2 or SW-3.

- SW-2 is located downstream from the Site, and water samples collected here would identify changes in water chemistry that could impact downstream receptors because of the contribution from the static area of groundwater containing elevated uranium beneath the Site.

- SW-3 is roughly in the middle of the Site where soil remediation activities occurred. Water samples collected here are immediately adjacent to the highest concentrations of dissolved uranium in groundwater. Sampling at this location was initiated at the request of CDPHE to quantify any impact to Clear Creek immediately adjacent to the highest concentration of uranium in the groundwater.

3.2 Wetland

The wetland located roughly in the center of the Lower Terrace area was created by a slight depression that remained after the former settling pond was cleaned up by the EPA in the 1990s. A certified wetland delineator studied the Lower Terrace, including soil stratigraphy at multiple locations, and concluded that a wetland had developed, although still showing signs of infancy (Stoller 2009). A wetland environment consists of an area where groundwater is shallow and surface water occasionally ponds, allowing a plant and animal community to develop that is specific to the wetland environment. Plant and animal activity in a wetland has an impact on groundwater and surface water. The plant community establishes roots into the groundwater, deposits organic matter both on the surface (fallen leaves) and below the surface (dead roots), and provides food and habitat for the animal community. The animal community, from mice to microbes, breaks down the plant matter, causing it to decay, which consumes oxygen. If sufficient decaying matter is present, the wetland would produce a reducing environment.

Key Surface Water Points:

- **Clear Creek receives drainage and sediments from historic mining operations of the Colorado Mineral Belt**
- **Lower Terrace groundwater is directly connected to Clear Creek surface water**
- **The wetlands that occupy the central portion of the Lower Terrace help to remove dissolved uranium from the groundwater**
- **Analytical results demonstrate that the Site, including the Licensed Area has no impact on surface water concentrations of uranium or any other contaminant**

Wetland chemistry can attenuate heavy metals dissolved in groundwater. On the Lower Terrace, the wetland continues to develop and is likely attenuating some of the uranium dissolved in groundwater. One strategy used to remove heavy metals, including uranium from groundwater is to create a wetland that results in a reducing zone that causes the heavy metals to precipitate out of the groundwater (Dudel *et al*. 2004). The subsurface soil, organic matter, and water chemistry in a wetland actively attenuates dissolved uranium due to the presence of the wetland environment. The CSMRI Lower Terrace wetland is young and continues to develop. The attenuation of uranium will continue to expand over time and increase its ability to remove uranium from groundwater. This indicates that continuing shrinkage of the uranium plume should be anticipated.

3.3 Surface Water Data

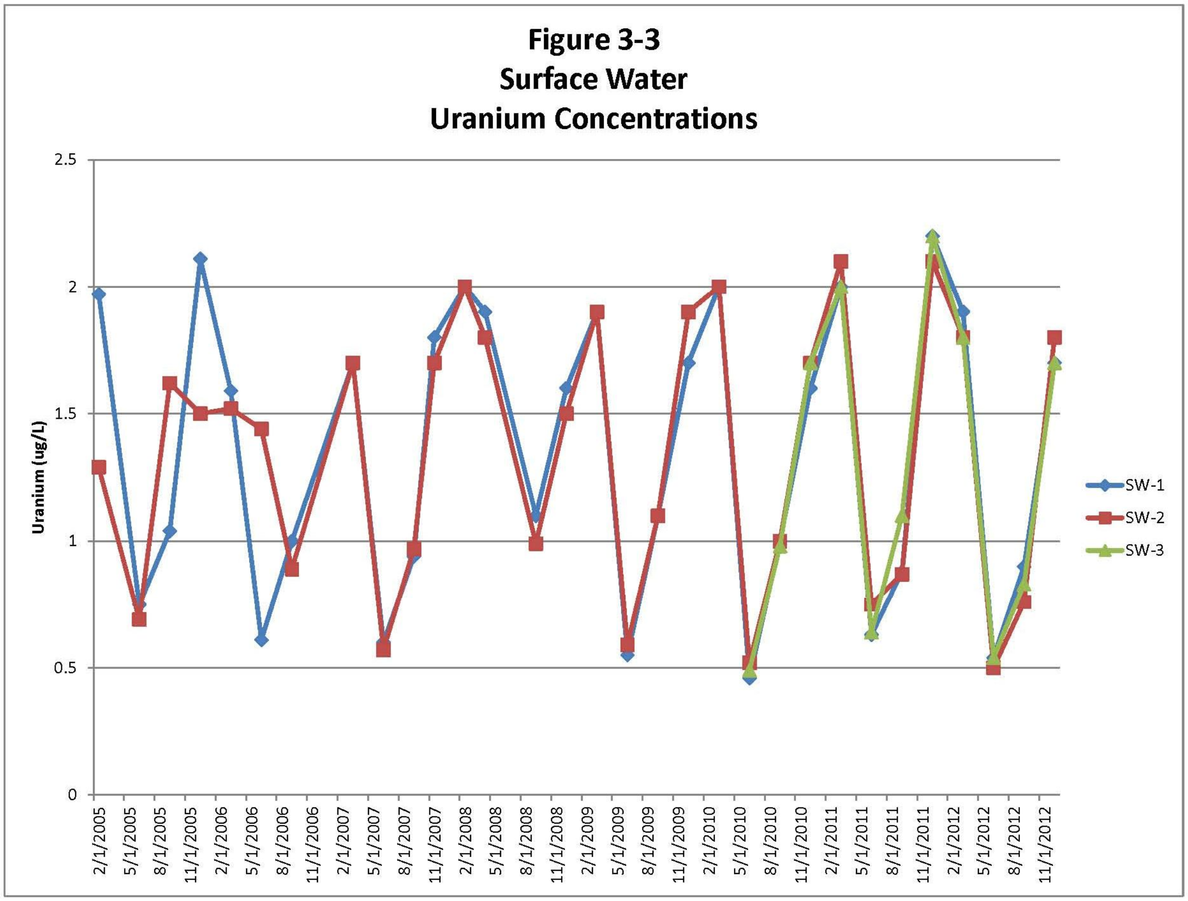
Statistical evaluation of laboratory analytical results from surface water samples presented in ***Table 3-1*** shows no contribution of uranium from the Site to Clear Creek. Clear Creek water samples collected since 2005 have detected dissolved uranium concentrations that range from 0.4 µg/L to 2.2 µg/L. Surface water and groundwater samples from monitoring wells are collected on a quarterly schedule and analyzed. A full list of analytical parameters, sampling procedures, and data quality management are discussed in Section 4. No impact to Clear Creek by uranium or any other compound from the Site has been detected.

Table 3-1
Statistical Comparison of Upstream and Downstream Surface Water Dissolved Uranium Quarterly Analytical Results

Uranium Concentration (µg/L)			
Date	**SW-1**	**SW-2**	**SW-3**
Average	1.35	1.34	1.27
Result Difference SW-1:SW-2	0.006		
% Difference	0.48%		
Correlation Coefficient	0.9906		
R^2 value	0.9812		

NT=Not Tested

Seasonal fluctuations in the surface water uranium range from 2.2 µg/L to 0.46 µg/L. SW-1 averages 1.35 µg/L, SW-2 averages 1.34 µg/L, and SW-3 averages 1.27 µg/L. Between 2005 and 2012, surface water samples from both upstream and downstream of the Site have had a slight increasing uranium concentration trend during the winter months when dissolved uranium concentrations are at their highest, on the order of 0.1 µg/mL. This trend is observed in all surface water sample location data sets. Since there is no discernible change in surface water quality as it moves by the Site, no detectable contamination of Clear Creek waters is resulting from soil or groundwater at the CSMRI Site. A full list of quarterly results is presented in ***Table 2*** in ***Appendix 3***. Data since 2005 are graphically displayed on ***Figure 3-3*** and show the relationship between upstream and downstream uranium results.



Data from the wetland were collected primarily in 2010 during the Lower Terrace characterization activities. Test pits were excavated and soil and water samples collected to determine the nature and extent of COCs in soil, refine our understanding of the groundwater uranium distribution, and provide samples to Whetstone for geochemical modeling.

Results from samples collected during the characterization effort are presented in the Preliminary Flood Plain (Lower Terrace) Characterization report as Appendix A in Environmental Assessment and Characterization (Stoller 2010). These results refined the understanding of the extent and distribution of uranium in groundwater and delineated soil uranium concentrations across the Lower Terrace. Additional activities were conducted during the characterization study, including installing temporary piezometers to refine our understanding of groundwater flow direction, conducting pump tests to provide data on hydraulic conductivity of Lower Terrace sediments, and performing a geochemical study. The piezometers and the pump tests provided the data needed to better understand the flow direction and rate of Lower Terrace groundwater as detailed in Section 4.

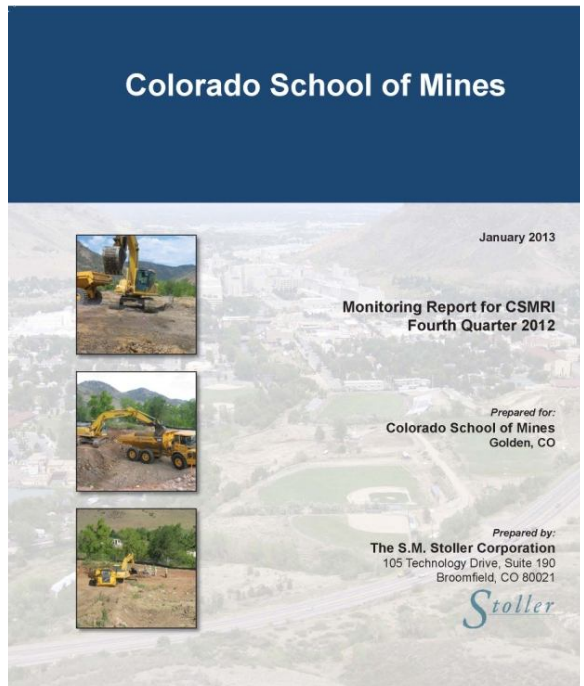
The Whetstone geochemical study provided an understanding of the Lower Terrace's partitioning coefficient or "Kd" (***Appendix 4***). The Kd is a measure of how uranium distributes between soil and groundwater and how uranium concentrations at the Licensed Area are sensitive to geochemical changes in groundwater as it flows from west to east under the Lower Terrace. Each of these results demonstrate that background or ambient levels of uranium in soil can contribute to increased concentrations of uranium in groundwater under oxidizing conditions such as those that exist at the west end of the Lower Terrace.

4. Groundwater

This section presents data collected to provide a comprehensive understanding of groundwater conditions at the CSMRI Site. The history of groundwater monitoring at the CSMRI Site, COCs, impacts of the soil cleanup effort, groundwater geochemistry, and Site hydrology are included.

Two distinct groundwater bodies exist on the CSMRI Site: the Upper Terrace groundwater and the Lower Terrace aquifer. Because these two groundwater bodies are different, they are discussed separately in the following sections. Only the Lower Terrace groundwater is referred to as an aquifer because an aquifer is defined as “a formation that contains sufficient water to yield significant quantities to wells and springs” (Todd 1980). The Upper Terrace groundwater does not qualify as an aquifer for reasons described below.

The relative extent to which each ongoing natural process is responsible for the dramatic decrease in the concentration of dissolved uranium across the Lower Terrace resulting in a stationary plume is unknown. The active processes include dilution and dispersion, adsorption, biological uptake, and microbial activity. Working in concert, these processes inhibit the uranium in the Lower Terrace groundwater from leaving the Site and contain the dissolved uranium to the central portion of the Lower Terrace.



Cover from quarterly monitoring report

4.1 History of Monitoring

Stoller has performed quarterly groundwater and surface water sampling and reporting at the CSMRI Site continuously since February 2005 (8 years). Four wells were present in 2005 (CSMRI-1, CSMRI-2, CSMRI-4, and CSMRI-5), and 14 wells were present in 2012 at the end of the program. A history of groundwater monitoring and surface water sampling events conducted by Stoller since 2005 is shown in ***Table 1*** of ***Appendix 4***. Additional details regarding monitoring well sampling history and the chronology of CSMRI new and replacement well installations are included in ***Appendix 4.***

Groundwater monitoring wells were sampled for eight quarters following completion of Lower Terrace soil cleanup in 2010 to verify the effectiveness of the remedy. Results of that groundwater sampling effort, as well as historical groundwater data trends are presented in the following sections. These results indicate additional groundwater monitoring is not necessary, and due to the stationary nature of the plume, additional data would be unlikely to provide additional insights into the Site hydrology or contaminant distribution.

4.1.1 Monitoring Well Locations

The well data document the nature, extent, and behavior of uranium in the groundwater. Wells were constructed in accordance with Colorado State Engineering Department standard construction techniques (***Appendix 4***) and are located as shown on ***Figure 4-1***.

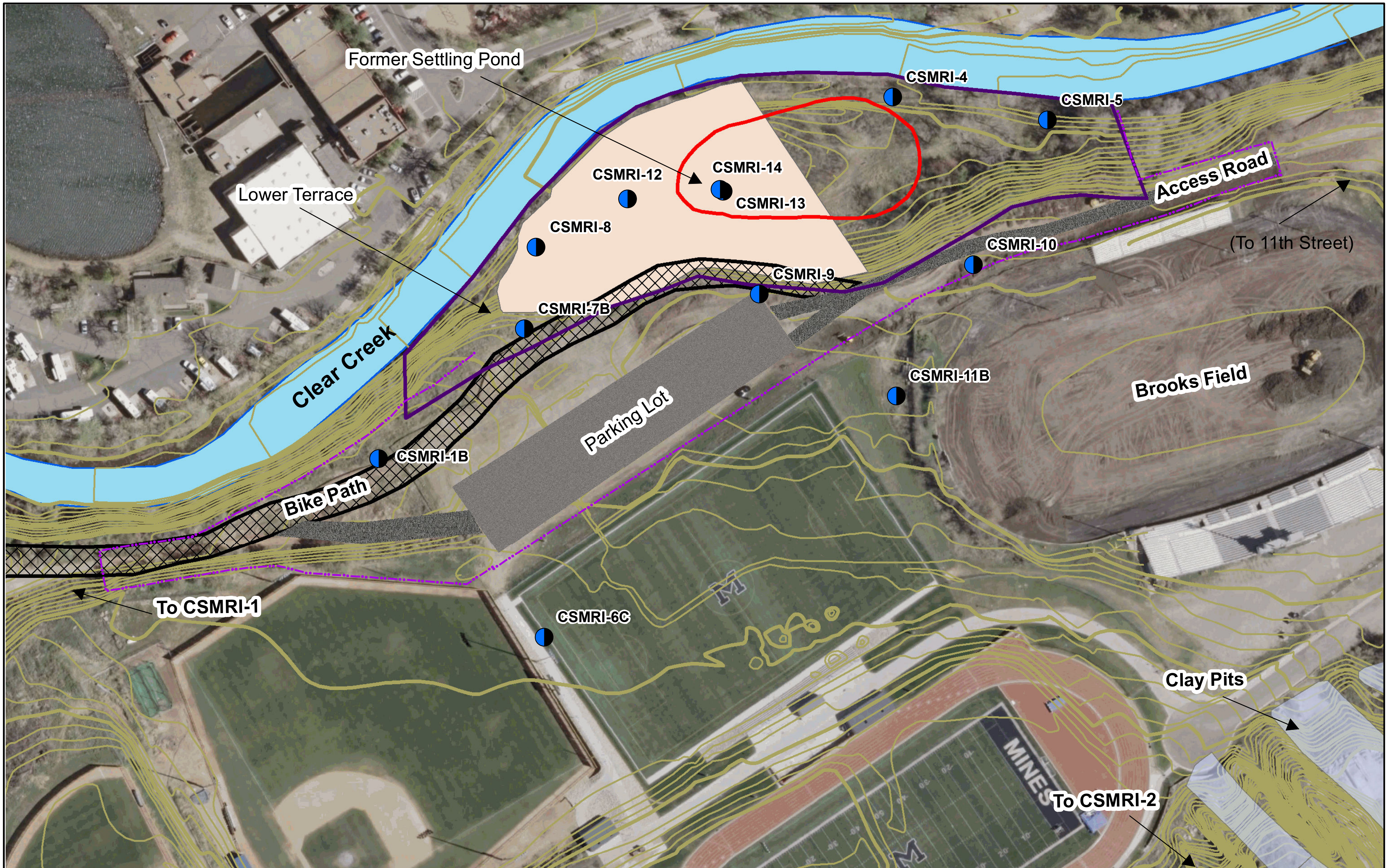


Figure 4-1

CSMRI Site Map with Topography

Explanation

- Monitor Well
- Fenced Area (Including Upper Terrace)
- Greater Clay Pits Mined Area
- CSMRI Lower Terrace Site
- Access Road
- Bike Path
- Parking Lot
- Settling Pond
- License Area
- Topography (2Ft Intervals)
- Topography (10Ft Intervals)

N
W E
S

0 60 120 240 Feet

CSMRI
Groundwater Report
2013

Stoller

S:\4349 CSMRI Flood Plain EA&RIFS\Working Report Figures\Groundwater Report Figure 4-1 Site Map.mxd PLD @ 11/8/13

The distribution of the wells across the Site has allowed mapping of the variation of uranium concentrations in groundwater, tracking of changes in those concentrations over time, and documentation of the shrinkage of areas with elevated concentrations. Additional wells were installed at the request of the CDPHE to answer questions about the origin and migration of uranium detected in groundwater.

Groundwater sampling using peristaltic pump.

Several new wells were drilled in January 2011 to gauge the effectiveness of the Lower Terrace soil cleanup. These new wells included CSMRI-12, CSMRI-13, and CSMRI-14, which were added to the sampling program in the first quarter of 2011. CSMRI-7C and CSMRI-8B were drilled in close proximity to their original locations. Monitor wells CSMRI-6C and CSMRI-11B were over-drilled and deepened in their original locations. ***Table 2*** in ***Appendix 4*** summarizes the reason each well was installed along with the information gained from each well since Stoller began sampling in 2005. In addition to the scheduled quarterly groundwater monitoring, special sampling events have occurred and are summarized in ***Appendix 4***.

4.1.1.1 Monitoring Procedures

Water quality samples were collected in accordance with Stoller's standard operating procedures for groundwater sampling, approved CSMRI Site work plans, and applicable regulatory guidance documents. The water sampling procedures ensured that each sample collected was representative of the groundwater beneath the Site. ***Appendix 4*** presents detailed groundwater collection procedures.

4.1.1.2 Historical Summary of Analytical Data Collected

Wells have been sampled regularly since 2005. A description of compounds and parameters (analytes) that have been added and/or removed from the analytical suites is included in ***Appendix 4***. Further discussion of the data collected is presented in Section 4.1.2. Groundwater samples collected by consultants at CSMRI prior to 2005 along with more recent data are summarized in the quarterly groundwater monitoring reports.

Radiological Technician oversees the removal of a 1-foot lift of contaminated soil. Prior to removal, a grid was established, and field screening instruments were used to identify areas requiring excavation.

4.1.1.3 Aquifer Characteristics

Two distinct bodies of groundwater lie beneath the Site as detailed below.

<u>Upper Terrace Groundwater</u>

Wells on the Upper Terrace were installed to sample the first groundwater layer encountered. This is a shallow layer of groundwater perched on the boundary between the competent bedrock and the overlying younger sediments, as illustrated in ***Figure 2-3***. Depth to the first groundwater layer ranges from about 14 to about 27 feet below ground surface (bgs) in the Upper Terrace. The thickness of this water body as measured in wells ranges between 3 to 10 feet. Upper Terrace groundwater travels along the interface between the surficial alluvial deposits (Louviers Alluvium) and bedrock within a zone of weathered bedrock. Wells within this zone recharge slowly or are purged dry during quarterly sampling, demonstrating the general lack of usable groundwater. Based on the lithology of the soils through which the Upper Terrace groundwater travels, the literature indicates the hydraulic conductivity is relatively low (Todd 1980). This perched water zone is not considered an aquifer because groundwater flow is not sustainable and could not be used as a domestic, agricultural, or commercial water supply.

Wells on the west side of the Site (CSMRI-1B, CSMRI-6C, and CSMRI-7C) have very little water, as demonstrated by their slow recharge during sampling and the fact that after two to six well volumes of water have been removed during preparation for sampling, the wells go dry. These wells are located in the area of the Site underlain by the Pierre Shale, a regional aquitard.

Wells located on the eastern portion of the Upper Terrace (CSMRI-9, CSMRI-10, and CSMRI-11B) have higher rates of recharge. These wells never purge dry during sample collection and are located within an area of the Site underlain by sandstone. Groundwater in the Upper Terrace generally flows to the northeast and north toward the Lower Terrace and Clear Creek. The only Upper Terrace well showing uranium in groundwater above 30 µg/L is well CSMRI-9. Groundwater in the vicinity of this well flows north onto the Lower Terrace. The surficial deposits on the Upper Terrace are mainly recharged by infiltration of precipitation, and to a limited extent, by irrigation of the natural-turf baseball field.

Lower Terrace (Flood Plain)

All Lower Terrace wells except CSMRI-14 are installed into the first groundwater layer encountered. Depth to the first groundwater in the Lower Terrace ranges from 3 to 5 feet bgs. Thickness of this aquifer ranges from 6 to 20 feet. Lower Terrace groundwater travels across the Lower Terrace in the Post-Piney Creek Alluvium of Clear Creek that sits on top of bedrock. The Lower Terrace, seen as a gravel bar in the 1880 photo (first photograph in Section 1) was created during the early 20th century with fill placed over the gravel bar and southern channel of the creek. Wells located in this alluvium recharge rapidly, and aquifer pump testing confirmed a high hydraulic conductivity. This testing indicated a relatively high hydraulic conductivity, which is consistent with relevant literature and is reasonable for this type of geologic setting (Todd 1980).

CDPHE requested the installation of CSMRI-13 and CSMRI-14. CSMRI-14 was installed into the deeper Fox Hills Aquifer to determine if dissolved uranium from the shallow groundwater was affecting the bedrock aquifer beneath it. CSMRI-13 was installed adjacent to CSMRI-14 and shares the same well pad. CSMRI-13 was completed in the shallow alluvium. Static water-level data collected over a period of eight quarters from the two wells determined that the elevation of water in CSMRI-14 is consistently higher, averaging 0.85 ft above the water levels measured in CSMRI-13. The data demonstrate that water upwells from the Fox Hills Formation into the shallow groundwater and that no pathway exists for downward migration into the deeper aquifer. Dissolved uranium data from the two wells support the fact that the deeper aquifer is not impacted by dissolved uranium.

The magnitude of upwelling that occurs from the Fox Hills Aquifer into shallow groundwater is estimated in Section 4.4.3.2. Based on the distinct water types observed in the two wells every quarter it does not appear to be a sufficient quantity to alter the shallow aquifer water type or temperature relationship with Clear Creek. In the last two quarters, water levels in CSMRI-13 were measured at historic lows while at the same time the difference in water levels between the two wells were above average; however, even during these mixing conditions, which favor mixing water type analysis, confirmed different water types (Ca versus Na) in the two wells. If the volume of water upwelling into shallow groundwater from the Fox Hills Aquifer comprised a significant portion of the total water, water type data would be expected to reflect increased Na in shallow groundwater as well as reduce the correlation of water temperature with Clear Creek.

4.1.2 Data

The following sections describe the laboratory analytical suite for groundwater monitoring data, field data, and data quality.

4.1.2.1 Analytical Data

Two CERCLA-certified analytical laboratories performed sample analyses: Test America in Arvada, CO and ALS Laboratory Group in Fort Collins, CO. The analytical suite includes radium (Ra-226/228), dissolved uranium, cations (calcium, magnesium, potassium, and sodium), anions (bicarbonate, carbonate, alkalinity, chloride, and sulfate), dissolved organic carbon (DOC), nitrate/nitrite, and total dissolved solids (TDS). The sample suite is augmented for Lower Terrace wells (CSMRI-8B, CSMRI-12, CSMRI-13, CSMRI-4, and CSMRI-5) to include ferrous iron, ferric iron, and sulfide. An additional augmentation includes a dissolved metals sample taken annually at each well during the second quarter sampling event in June when groundwater levels typically are highest. The analytical suite for metals includes arsenic, barium, cadmium, chromium, lead, mercury, silver, and vanadium.

4.1.2.2 Field Data

Monitoring of field parameters is essential to determine when a sample can be collected for laboratory analysis that is representative of aquifer conditions. Field data were collected for a variety of parameters, including pH, conductivity, dissolved oxygen, oxygen reduction potential (ORP), and temperature.

Water quality data are recorded in the field at each monitoring well and surface water location using a Horiba™ U-22 multi-meter. Parameters are collected every time a well volume of water is removed during purging. For most wells, three sets of parameters are collected prior to sample collection. Other than pH, temperature, and specific conductivity, data from field parameters are generally considered of poor quality because during purging and sample collection water is agitated and not representative of static conditions.

Water temperature, as shown in Section 2.3, demonstrates a hydraulic connection between the surface water from Clear Creek and the Lower Terrace wells. By comparison, wells installed on the Upper Terrace, although consistent with each other, demonstrate no relationship with the Lower Terrace wells and show only negligible seasonal variation ***(Figure 2-7).***

A more detailed discussion of the field parameters that Stoller records during quarterly sampling is included in ***Appendix 4.***

4.1.2.3 Data Quality

Laboratory data reports are generated for all samples analyzed. Sample results undergo a QA/QC review by Stoller's data validation personnel. Data validation reports are generated for each quarterly sampling event and are included in the quarterly report. The data quality indicators used to assess the laboratory data include precision, accuracy, representativeness, completeness, and comparability. A full discussion of these data quality indicators is included in ***Appendix 4.***

4.1.3 Impacts of Soil Cleanup Actions

Section 1 of this report lists the investigations and remedial activities completed on this Site. Section 1 also lists the accomplishments and CDPHE conclusions regarding these remedial activities. Because the groundwater containing elevated concentrations of uranium is predominantly located on the Lower Terrace, remedial activities on this portion of the Site are highlighted below.

Lower Terrace remedial activities focused on soils containing uranium concentrations indicative of CSMRI activities. All uranium-impacted soil removed from the Lower Terrace during Site characterization was stockpiled, and representative samples were collected for laboratory analysis to evaluate the feasibility of different remedial alternatives. The stockpile represented soil conditions in the Lower Terrace prior to cleanup and averaged 15 mg/kg total uranium. After soil removal, samples were collected from the Lower Terrace and analyzed to confirm cleanup goals were met and to quantify uranium that remained in the Lower Terrace. The confirmatory data set consisted of both verification samples collected from the boundaries of excavations as well as data collected during the preliminary Site characterization. Preliminary Site characterization data from test pits was also included. Data from the eastern portion of the Lower Terrace determined those soils were already below cleanup goal. Results from laboratory analysis of these samples determined the average concentration of uranium remaining in Lower Terrace soil to be 6.45 mg/kg.

The soil cleanup decreased uranium levels in the Lower Terrace soils to within the range of those observed in upstream alluvium during the 2010 background study ***(Appendix 3)***. This study was previously discussed in Section 3.1 of this report and is detailed in ***Appendix 3***. The Lower Terrace soil cleanup activities in the fall of 2010 had the most significant impact on groundwater near monitor wells CSMRI-7C and CSMRI-8B where uranium concentrations were highest. These two monitoring wells were co-located in areas that were excavated because of the presence of CSMRI-impacted artificial fill. Impacted soil was excavated until the COCs were below the Site action levels. Where artificial fill was encountered, it was excavated completely until native material was encountered. Excavated areas were backfilled using a clean, heterogeneous mix of fill materials. This mix included imported alluvium fill (6-inch washed rock) from bedrock to about 1 foot below the former ground surface. Top soil material was then placed to pre-excavation grade.

CSMRI-7B was above 30 µg/L uranium each of the three quarters that had sufficient water to be sampled prior to soil excavation, with a mean dissolved uranium concentration of 76 µg/L. Since soil excavation activities, eight quarters of groundwater samples from CSMRI-7C indicate the mean uranium concentration dropped to 6.8 µg/L.

CSMRI-8 was above 30 µg/L dissolved uranium over the span of 15 consecutive quarters, with a high of 1,900 µg/L and a mean concentration of 917 µg/L prior to excavation of contaminated soil. Following excavation and installation of CSMRI-8B, the mean concentration of dissolved uranium decreased to 231 µg/L. These readings continue a downward trend for dissolved uranium concentrations. The impacts of the soil excavation activities are demonstrated in ***Figure 4-2*** showing the mean dissolved uranium concentration in CSMRI-8B prior to soil remediation and the result of the eight quarterly sampling events since soil remediation.

The soil remediation removed uranium impacted soils from the Lower Terrace as well as the slope connecting the Upper and Lower Terraces to As Low As Reasonably Achievable (ALARA). The ALARA designation is supported by having removed impacted soils to the limits of the field instrumentation while the remaining soils in the Licensed Area as well as the entire flood plain are within the 95% confidence limit of background concentration for uranium.

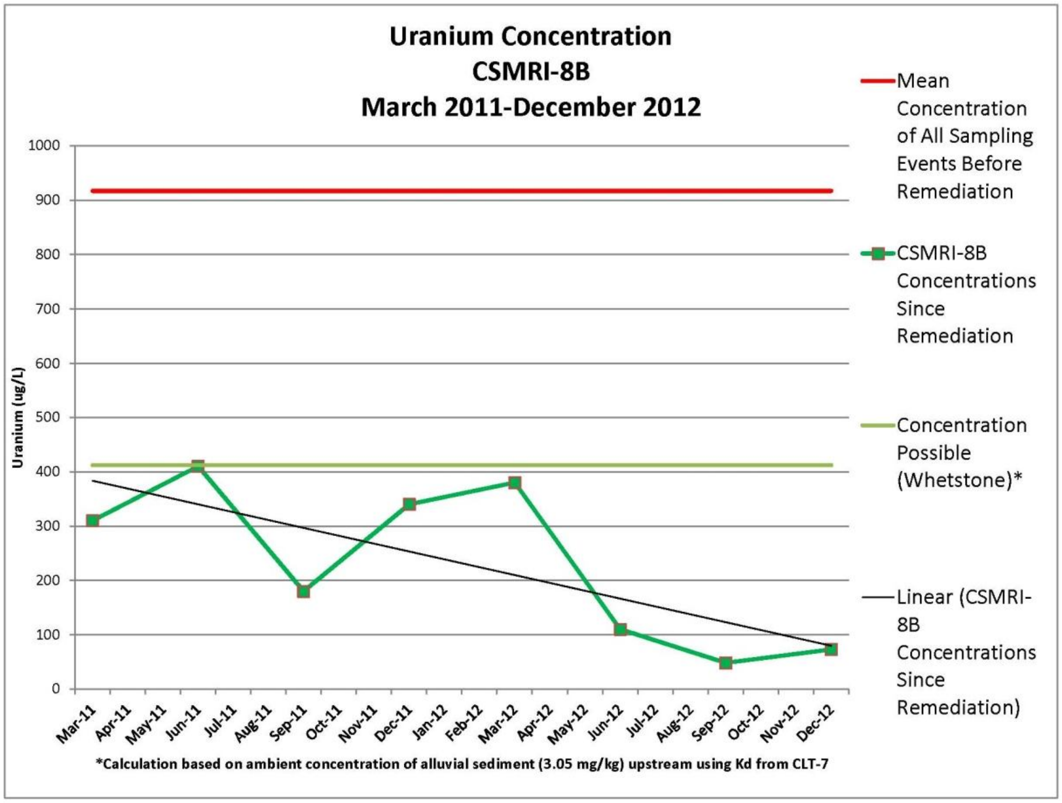


Figure 4-2 CSMRI-8B Dissolved Uranium Concentrations

Prior to soil excavation activities in the fall of 2010, only two monitoring wells (CSMRI-4 and CSMRI-5) were located in the Lower Terrace alluvium. Both of these wells are located several hundred feet to the east of the excavated area in downgradient positions. Analytical results from monitoring well CSMRI-5 have never recorded dissolved uranium above the drinking water standard. In the eight quarters that groundwater samples have been collected from CSMRI-4 following soil excavation, the mean concentration of dissolved uranium has decreased from 57.4 µg/L pre-soil removal to 33.6 µg/L post-soil removal.

No monitoring wells were located on the Upper Terrace prior to the 2006 soil cleanup project. Therefore, the impact of the 2006 soil cleanup project on the groundwater of the Upper Terrace area is difficult to determine.

Monitoring wells CSMRI-4 and CSMRI-5 were the only wells on the Site in 2006 and provide the only baseline data prior to the start of Upper Terrace field activities. These wells are highly influenced by Clear Creek and uranium in Lower Terrace soils. Several new wells were installed on the Upper Terrace and Lower Terrace following the project, including CSMRI-1B, CSMRI-6B, CSMRI-7B, CSMRI-8, CSMRI-9, CSMRI-10, and CSMRI-11.

The soil disturbance associated with cleanup activities can serve to temporarily mobilize contaminants. During a period of months up to two years, contaminant levels in groundwater can increase due to this mobilization. Following increases caused by such disturbance, levels will then fall to the natural state associated with the Site hydrology, soils, and contaminant levels. Following the 2006 cleanup, two wells exhibited temporary increases in dissolved uranium concentrations: Lower Terrace monitor wells CSMRI-4 and CSMRI-5. These short-term increases were likely the result of disturbing the ground and increased surface water application during construction work on the new athletic field, parking lot, and bike path.

4.2 Groundwater Contaminants

Many years of groundwater monitoring at the CSMRI Site identified uranium as the single COC. Two transient elevated levels for Ra-226 have been detected in wells CSMRI-4 and CSMRI-12; no other COCs have been detected above the drinking water standards at the Site.

4.2.1 Nature and Extent of Dissolved Uranium

The nature and extent of groundwater contamination has been thoroughly investigated and delineated. Contaminated soil that could result in dissolved uranium concentrations above those attributed to ambient levels of uranium in Clear Creek alluvium have been removed.

Concentrations of uranium above 30 µg/L have been detected in six wells since groundwater sampling began in 1991. These include two wells completed in the Upper Terrace groundwater (CSMRI-7B and CSMRI-9) and four wells installed in the Lower Terrace shallow alluvial aquifer (CSMRI-4, CSMRI-8B, CSMRI-12, and CSMRI-13).

Dissolved uranium above 30 µg/L has never been detected in the remaining monitoring wells (CSMRI-1, CSMRI-2, CSMRI-5, CSMRI-6B/6C, CSMRI-10, CSMRI-11/11B and CSMRI-14). The exception is well CSMRI-1B, which had two isolated detections. Therefore, these monitoring wells are not discussed further in this report. A summary of analytical data from these wells is included in ***Appendix 4.***

Monitoring well analytical results and data trends for those monitoring wells where dissolved uranium above 30 µg/L has been detected are provided below. Because the Upper Terrace water and associated dissolved uranium has an origin different from water and uranium on the Lower Terrace, it is discussed separately.

4.2.2 Upper Terrace Groundwater Wells

Upper Terrace wells intersect groundwater perched on the boundary between the competent bedrock and the overlying younger sediments. Although Upper Terrace groundwater eventually finds its way to the Lower Terrace along the interface between the surficial deposits and weathered bedrock, it is separate and distinctive from water in the Lower Terrace. Wells within this zone recharge slowly and are not influenced by variations from Clear Creek. The only wells discussed in this section are those that have historically exceeded 30 µg/L.

4.2.2.1 CSMRI-7B/C

Prior to soil cleanup, monitoring well CSMRI-7B exceeded the drinking water standard the three times sufficient water was available to sample. Concentrations of dissolved uranium were 68 µg/L in June 2007, 84 µg/L in June 2010, and 75 µg/L in September 2010. CSMRI-7B was then abandoned in September 2010 prior to soil excavation and cleanup activities. Contaminated soil was found in contact with the well casing. This material was excavated during cleanup activities. Monitor well CSMRI-7C was then re-drilled 1.5 feet from the original location in January 2011. The replacement well was deepened to extend the screen several feet deeper into the Pierre Shale bedrock to create a sump to facilitate collection of quarterly water samples.

In eight quarters of sampling since the soils around the well were removed, dissolved uranium concentrations have not exceeded the drinking water standard. Historical average dissolved uranium concentrations prior to removal of contaminated soil and the eight quarters following cleanup are shown in ***Figure 4-3.***

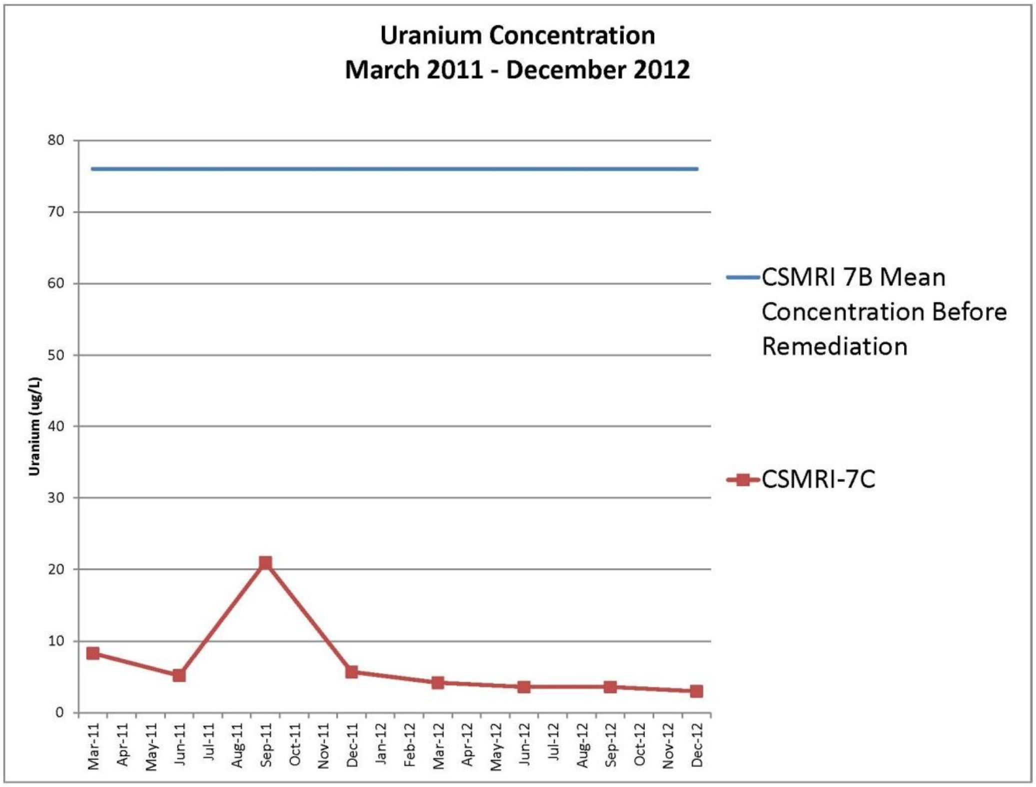


Figure 4-3. CSMRI-7C Dissolved Uranium Concentrations

4.2.2.2 CSMRI-9

The dissolved uranium concentration at monitoring well CSMRI-9 has been above 30 µg/L every quarter since March 2009 and typically measures around 40 µg/L. Well CSMRI-9 is located immediately downgradient from construction activities, including the soccer field, parking lot, and bike path. These construction activities were likely responsible, in part, for the increase. Groundwater in the vicinity of well CSMRI-9 flows north onto the Lower Terrace where it mixes with upwelling groundwater from the Fox Hills as well as water from Clear Creek. The Upper Terrace water also is subjected to the processes taking place on the Lower Terrace that decrease the dissolve uranium concentrations as described in Section 4.4.4.

Key Conclusions for Upper Terrace Groundwater

- Successful remediation resulted in soil and groundwater released by CDPHE
- Insufficient volume of water for use as a domestic, agricultural, or commercial water source
- Groundwater flow rate 16 times less than Lower Terrace aquifer
- Only one well impacted with a mean dissolved uranium of 40 µg/L, only slightly above the drinking water standard

4.2.2.3 Upper Terrace Groundwater Conclusions

Upper Terrace groundwater is not present in sufficient volume to be classified as an aquifer. The Upper Terrace groundwater contributes very little dissolved uranium in excess of 30 µg/L to the Lower Terrace. Upper Terrace groundwater travels along the interface between surficial deposits and weathered bedrock. It is not influenced by Clear Creek surface water or the Lower Terrace aquifer. Key conclusions follow.

- Very limited volume of water is available from the Upper

Terrace perched groundwater zone

- Dissolved uranium concentrations in Upper Terrace wells are generally below 30 µg/L in all but one well (CSMRI-9), and this well has only slightly elevated concentrations typically in the 40 to 50 µg/L range
- The flow rate for the Upper Terrace aquifer is much lower than the Lower Terrace
- The Upper Terrace lacks both the volume of water and the concentrations of dissolved uranium necessary to make sufficient contribution to the Lower Terrace to exceed 30 µg/L uranium

Soil on the Upper Terrace was excavated and cleaned up in 2006 (Stoller 2007) and released (CDPHE 2009, 2011). Uranium was not an identified COC during the Upper Terrace cleanup; therefore, definitive data on the levels of this compound that remained in the soil after the cleanup do not exist. However, the cleanup was successful on other compounds associated with CSMRI activities, making it reasonable to assume that because these compounds were co-located, the vast majority of uranium was also removed. It is unknown whether the slightly elevated level of dissolved uranium that persists in Upper Terrace groundwater is a result of ambient uranium concentrations in soil or human activities. ***Appendix 4*** provides analytical results for dissolved uranium from quarterly monitoring**.**

4.2.3 Lower Terrace Shallow Alluvial Aquifer Wells

Six wells are completed on the Lower Terrace in the shallow alluvial aquifer that is in direct connection with Clear Creek surface water. Of the six wells, only five have ever shown groundwater above 30 ppb, these wells are discussed below. All Lower Terrace wells except one are installed into the first shallow groundwater layer encountered, which ranges from 3 to 5 feet bgs. Thickness of this aquifer ranges from 6 to 20 feet. The Lower Terrace groundwater travels east across the Lower Terrace in the Post-Piney Creek Alluvium of Clear Creek that sits on top of bedrock.

4.2.3.1 CSMRI-8/8B

Monitor well CSMRI-8 was installed following soil removal from the Upper Terrace. This well had dissolved uranium concentrations ranging from 600 to 1,900 µg/L during the first two years of sampling (2007 and 2008) and was the catalyst for cleanup activities on the Lower Terrace. CSMRI-8B was installed in January 2011 to replace CSMRI-8, which was removed during soil excavation and cleanup activities. The original well was installed entirely within artificial fill and in contact with contaminated soil. The new well is located 5.9 feet from its original location and was installed in clean imported alluvial backfill material**.**

Dissolved uranium concentrations in CSMRI-8/8B were lower immediately following removal of contaminated soil and have continued to demonstrate a downward trend. Prior to soil remediation, the mean concentration of dissolved uranium in groundwater was 917 µg/L. In the last eight quarters following soil remediation activities, dissolved uranium concentrations have decreased to a mean of 231 µg/L with the most recent result of 73.0 µg/L uranium in groundwater.

The results of dissolved uranium analytical from monitor well CSMRI-8/8B for pre-(CSMRI-8) and post-(CSMRI-8B) removal of contaminated soil are included in ***Figure 4-4.***

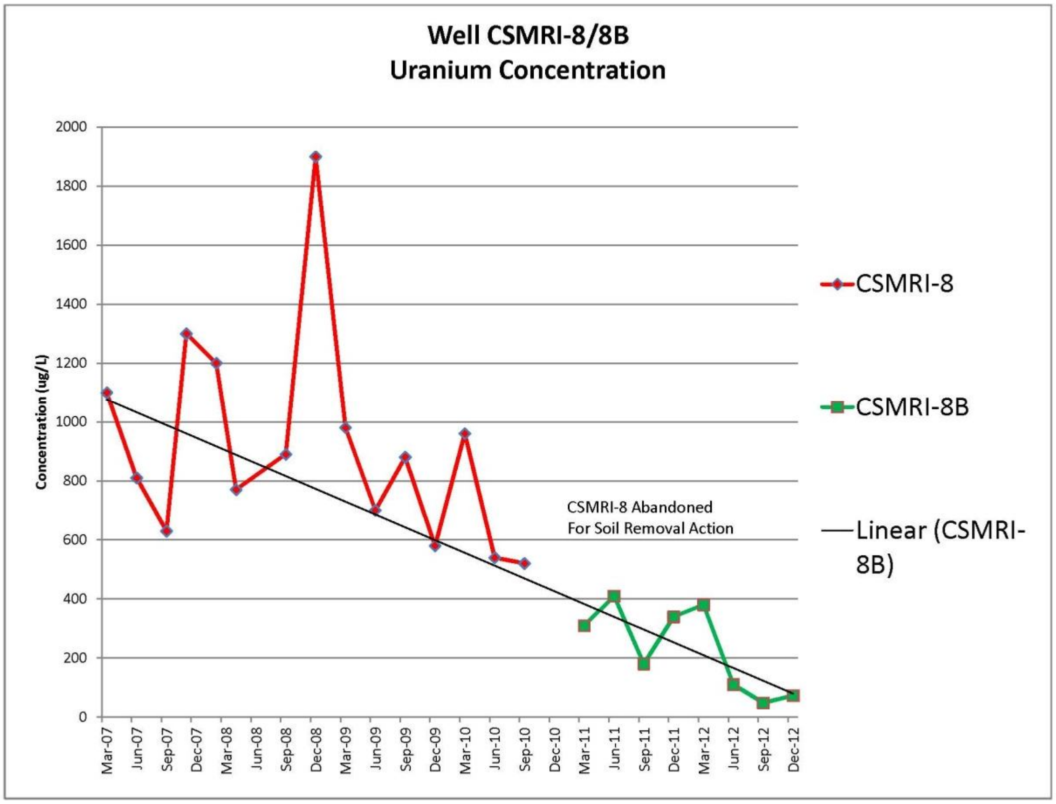


Figure 4-4. CSMRI-8/8B Dissolved Uranium Concentrations

4.2.3.2 CSMRI-12

Monitoring well CSMRI-12 has exhibited similar dissolved uranium concentrations to well CSMRI-8B. CSMRI-12 lies approximately 100 feet northeast of CSMRI-8B, just beyond the eastern extent of the Lower Terrace cleanup effort and just upgradient (west) of the wetland area. With one exception, analytical results from CSMRI-12 have risen and fallen in step with CSMRI-8. This relationship is consistent with the fact that CSMRI-8, which was originally completed in artificial fill, is now in imported alluvial material and is hydrologically connected to CSMRI-12. The correlation between these two wells uranium concentration will continue as both wells are located upgradient of the wetland and upgradient of the Fox Hills upwelling, the two areas where the geochemistry of the groundwater changes causing uranium concentrations to decrease.

In the two years following installation of CSMRI-12, dissolved uranium concentrations have decreased from a mean of 252.5 µg/L for the first four quarters following removal of contaminated soil to a mean of 135 µg/L for the last four quarters. The last quarter sampling showed a concentration of 58 µg/L. Dissolved uranium results for the eight quarters following removal of contaminated soil are presented in ***Figure 4-5.***

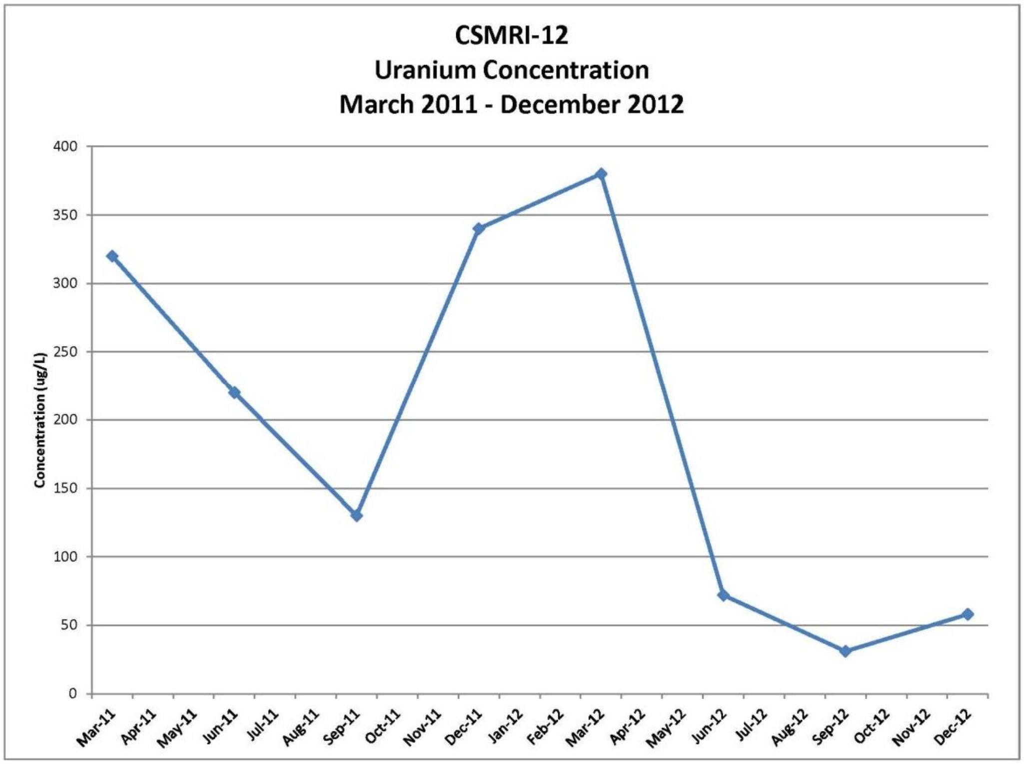


Figure 4-5. CSMRI-12 Dissolved Uranium Concentrations

4.2.3.3 CSMRI-13

Monitoring well CSMRI-13 has exceeded 30 µg/L dissolved uranium each quarter it has been sampled. In the eight quarterly sampling events following installation of CSMRI-13, dissolved uranium concentrations have a mean value of 46 µg/L. This well is approximately 100 feet east of the impacted soil excavation boundary and is located within the wetland area, immediately downgradient from well CSMRI-12. Well CSMRI-13 is installed within the Fox Hills Formation where the upwelling groundwater is located and is installed within the wetland area. Both of these features reduce the uranium in groundwater observed at this well from that observed in wells CSMRI–8 and CSMRI-12. The best-fit line to the well CSMRI-13 data set is a flat line at 46 µg/L. Dissolved uranium results for the eight quarters following removal of contaminated soil are presented in ***Appendix 4.***

4.2.3.4 CSMRI-4

Dissolved uranium concentrations have exceeded 30 µg/L in CSMRI-4 consistently since the soil excavation activities of 2006 on the Upper Terrace. Concentrations remained relatively constant for a period of two years until 2008 when a new stormwater outfall was constructed to divert surface water away from the athletic fields complex and onto the Lower Terrace. Following construction, dissolved uranium concentrations immediately began to increase. Stormwater flowed from the top of the Upper Terrace down the steep embankment over rip rap before spilling onto the Lower Terrace. In September 2009, dissolved uranium in this well reached an all-time high of 160 µg/L.

The new introduction of oxygen-rich surface water into the groundwater system mobilized the ambient levels of uranium (U^{6+}) that were contained in the soil. In late 2009, the storm drain outfall was relocated downgradient approximately 200 feet to the east. Following this relocation, dissolved uranium concentrations in this well returned to 2007 and 2008 levels. This isolated event demonstrates that oxygen levels in Lower Terrace groundwater have a controlling effect on dissolved uranium concentrations. The secondary spike in uranium observed in this well 3 months after Lower Terrace soil removal was expected as the soil removal mobilized uranium that then took 3 months to reach CSMRI-4. This length of time for the spike to reach CSMRI-4 confirms our calculated flow rate for the Lower Terrace.

Figure 4-6 depicts how the analytical results of dissolved uranium in CSMRI-4 have responded to changes in groundwater geochemistry as a result of events such as realignment of the stormwater outfall and soil removal efforts since sampling began in 2005.

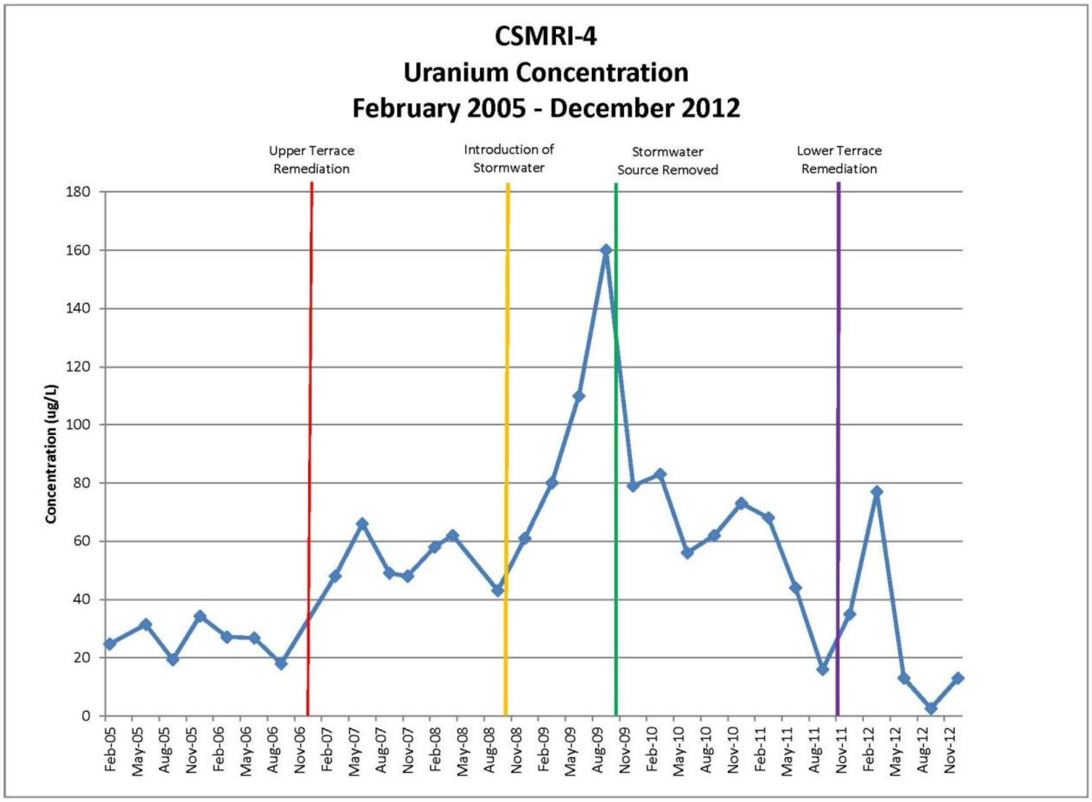


Figure 4-6. CSMRI-4 Dissolved Uranium Concentrations

4.2.3.5 Lower Terrace Conclusions

Lower Terrace groundwater travels through the shallow alluvial aquifer and is directly connected to Clear Creek. This hydrological connection between Clear Creek and Lower Terrace wells is demonstrated by water temperature data (***Figure 2-7***) and groundwater flux calculations in Section 4.4.3.

The Lower Terrace dissolved uranium levels decrease across the Lower Terrace from west to east and have demonstrated a downward trend for all monitoring wells showing uranium levels in excess of 30 µg/L following removal of contaminated soil.

Changes in geochemistry can have significant effects on Lower Terrace groundwater uranium concentrations. This is demonstrated by the increase in dissolved uranium concentrations observed after the introduction of surface water to the area around CSMRI-4.

Monitoring wells CSMRI-4 and CSMRI-5, located downgradient in an area that the flux calculations, indicate is where groundwater exits the Site, demonstrate that, following Lower Terrace remediation, no groundwater above 30 µg/L leaves the Site.

Key Conclusions for Lower Terrace Alluvial Aquifer

- Source removal complete and soil released by the CDPHE
- Dissolved uranium concentrations have decreased in all Lower Terrace wells
- Groundwater chemistry is sensitive to infiltration from Clear Creek, upwelling from the underlying Fox Hills aquifer, and the wetland
- Groundwater above the drinking water standard does not leave the Site

4.3 Geochemistry

The difference in chemistry between Upper Terrace groundwater and Lower Terrace groundwater is demonstrated by geochemical data from samples collected from Site wells. The geochemical difference is explained primarily by the fact that Lower Terrace groundwater is influenced by infiltration from Clear Creek conclusively demonstrated by the temperature relationship discussed in Section 2.3. Further contributing factors to the chemical differences between the Upper Terrace groundwater and the Lower Terrace groundwater likely include impacts resulting from upwelling from the underlying Fox Hills Aquifer and the presence of the wetland environment, which dominates the central portion of the Lower Terrace.

A study to determine the Site-specific partitioning coefficient for uranium was completed. This study concluded that the ambient levels of uranium identified in Clear Creek alluvium can (at this Site) result in uranium in groundwater comparable to the levels observed. A detailed discussion of the geochemical data collected is presented in ***Appendix 4.***

4.4 Hydrogeology

The following sections describe the hydrogeologic properties associated with groundwater beneath the Site. The hydrogeology of the Site is divided between the Lower Terrace where the shallow alluvial aquifer is strongly influenced directly by Clear Creek and perched groundwater on the Upper Terrace, which is not.

4.4.1 Potentiometric Surface (Flow Direction)

Potentiometric surface is based on depth to groundwater relative to the surveyed top-of-casing and represents groundwater elevation under static conditions. Groundwater levels are measured at each well to the nearest 1/100th of a foot (0.01) and used to generate the potentiometric surface and flow direction. The potentiometric surface map is provided as ***Figure 4-7.***

4.4.1.1 Upper Terrace

Groundwater on the Upper Terrace occurs under unconfined conditions in the alluvium/colluvium deposits that overlie the bedrock formations. Groundwater on the Upper Terrace area generally flows to the northeast and north toward the Lower Terrace and Clear Creek. The Upper Terrace groundwater is mainly recharged by infiltration of precipitation and to a limited extent by irrigation of the natural turf baseball field.

The Upper Terrace groundwater flows along the interface of surficial deposits and bedrock and down the terrace slope where it mixes with and becomes part of the Lower Terrace groundwater.

4.4.1.2 Lower Terrace

Groundwater in the Lower Terrace alluvial aquifer also occurs under unconfined conditions. Groundwater flow in the Lower Terrace is heavily influenced by seasonal fluctuations of Clear Creek. Hydrographs of Lower Terrace monitor wells show a relationship between the stage height of Clear Creek and a recorded response in the chemistry and water elevation. Depth to the water table in the Lower Terrace is shallow, ranging from 3 to 5 feet bgs in winter to 0.5 to 2.5 feet bgs in summer due to an increase in flow of Clear Creek. The potentiometric surface of the shallow alluvial aquifer beneath the Lower Terrace shows water moving from west to east as does Clear Creek. Flux calculations confirm this flow direction.

Conducting pump test at CSMRI-8 and recording water level data to determine hydraulic conductivity.

4.4.2 Hydraulic Conductivity Determination

Hydraulic conductivity is the measurement of the formations' ability to transmit water. Aquifer testing methods such as pump tests can determine the hydraulic conductivity. Hydraulic conductivity is dependent on the physical properties of the formation containing the water, so much so that a good estimate of the hydraulic conductivity can be achieved through a literature search.

4.4.2.1 Upper Terrace

Pump tests were not performed on Upper Terrace wells. However, geologic data from well logs and information about the various formations that are present in this area were compared to published values (Todd 1980) to provide an estimate of hydraulic conductivity. The Upper Terrace water occurs at the interface of the bedrock with the overlying sediments, within the weathered bedrock. For the western half of the Site underlain by Pierre shale, the hydraulic conductivity is approximately 0.33 ft/day, and for the other half of the Site underlain by sandstone averages 9 ft/day.

Calculating a groundwater flow velocity from these data provides Upper Terrace flow velocities of 0.02 ft/day for the area underlain by the Pierre Shale to 0.54 ft/day for the area underlain by sandstone. A more detailed discussion of the assumptions used to deduce hydraulic conductivities and groundwater flow velocities from published data is included in ***Appendix 4.***

4.4.2.2 Lower Terrace

Pump tests were conducted on monitor wells CSMRI-8, CSMRI-4, and CSMRI-5 during the preliminary Site characterization work. Potentiometric data downloaded from the pump test transducer/data logger were analyzed using appropriate computer software (AQTESOLV® Pro v. 4.5, with the Theis model and the Moench unconfined model with casing storage and delayed gravity drainage) and are further described in ***Appendix 4.***

The low transmissivity measured in CSMRI-8 was determined to be a result of the monitor well being installed in artificial fill material rather than in the alluvial deposits where both CSMRI-4 and CSMRI-5 were installed. Monitor well CSMRI-8 was removed during the remedial investigation. At that time, the artificial fill was excavated to bedrock and replaced with washed rock similar to the native alluvial fill present across the Site. The well was then re-drilled and completed near its original location. The pump test data collected when the well was embedded in artificial fill were noted in the data set as being conducted on the old well CSMRI-8.

Data recovered from well CSMRI-4 were used to determine the flow velocity for the Lower Terrace. The measured hydraulic conductivity ranged from 69 ft/day to 74 ft/day. These values were used to calculate the groundwater flow velocities of 4.14 ft/day and 4.44 ft/day, respectively. The average flow value was then rounded to 4 ft/day. Details of the pump test results and calculation of the hydraulic conductivity and groundwater flow rate are included in ***Appendix 4.***

4.4.3 Flux Calculations

Flux is the rate of flow per unit area. A better understanding of the combined flow across the Lower Terrace can be achieved by determining the flux. Additionally, flux is used to understand the contribution made to the Lower Terrace groundwater system from other sources, including Clear Creek surface water, upwelling from underlying Fox Hills aquifer, and Upper Terrace groundwater. Groundwater flow (flux) is calculated by using the hydraulic conductivity (k) and the hydraulic gradient (i) to determine the flow velocity (v). This velocity is then applied to the cross-sectional area of the area of interest to determine the total flow.

The following subsections calculate the flow for the groundwater from all sources contributing to the Lower Terrace, along with combined flows on the Lower Terrace. ***Figure 4-8*** shows the areas used for the calculations along with the resulting daily flow rates. Daily flow rates represent the groundwater flow through that section of the Site per day in cubic feet.

4.4.3.1 Upper Terrace

The Upper Terrace has two distinct groundwater flow regimes, the flow through the weathered Pierre shale and the flow through the weathered sandstone (both Fox Hills and Laramie). Well CSMRI-7C is used to represent the Pierre Shale groundwater, and wells CSMRI-9 and CSMRI-10 are used to represent the sandstones. Values used to calculate the groundwater velocity, $v = ki$ where (v) is the velocity, k is the hydraulic conductivity, and (i) is the hydraulic gradient are included in ***Table 4-1***.

Table 4-1
Upper Terrace Flow Properties

Formation	Hydraulic Conductivity (k)	Hydraulic Gradient (i)	Velocity (v)
Pierre Shale	0.33 ft/day	0.06 ft/ft	0.02 ft/day
Sandstones	9 ft/day	0.06 ft/ft	0.54 ft/day

To calculate the volume of water flowing off the Upper Terrace onto the Lower Terrace, the equation Q = Av is used where Q is the flow and A is the cross-sectional area and v is the velocity. ***Table 4-2*** shows the data used for the flow calculation for groundwater leaving the Upper Terrace for the three areas shown on ***Figure 4-8***. The section thickness is the saturated thickness measured in the representative well and the section length is shown on ***Figure 4-8***.

Table 4-2
Upper Terrace Flux Calculation Data

Segment	Velocity (v)	Section length	Section thickness	Cross Sectional Area (A)	Calculated flow (Q)
CSMRI 7C	0.02 ft/day	235 feet	7 ft	1,645 sq ft	33 cu ft/day
CSMRI 9	0.54 ft/day	157 feet	8.5 ft	1,335 sq ft	721 cu ft/day
CSMRI 10	0.54 ft/day	246 feet	4.5 ft	1107 sq ft	597 cu ft/day

These values indicate a total flow from the Upper Terrace onto the Lower Terrace of 1,351 cu ft/day.

4.4.3.2 Lower Terrace

The flow across the Lower Terrace is calculated similarly to the calculations performed for the Upper Terrace. The measured hydraulic conductivity (70 ft/day) and the gradient (0.06 ft/ft) were used to calculate groundwater flow rates for all Lower Terrace wells. Flow velocity of 4.0 ft/day was calculated.

The Lower Terrace is divided into five areas, which demonstrate how the flow volume of groundwater changes across the Lower Terrace. ***Table 4-3*** summarizes the input parameters for each of the Lower Terrace areas. Also included is a calculation for the upwelling from the Fox Hills Aquifer, although this calculation comes with some uncertainty as described below.

Table 4-3
Flow Calculation, Lower Terrace

Segment	Velocity (v)	Section Width	Section thickness	Cross Sectional Area (A)	Calculated flow (Q)
CSMRI 8	4 ft/day	52 feet	3 ft	156 sq ft	624 cu ft/day
CSMRI 12	4 ft/day	104 feet	6.5 ft	676 sq ft	2704 cu ft/day
CSMRI 13	4 ft/day	144 feet	6.6 ft	950 sq ft	3,802 cu ft/day
CSMRI 4	4 ft/day	135 feet	11 ft	1485 sq ft	5,940 cu ft/day
CSMRI 5	4 ft/day	58 feet	5 ft	290 sq ft	1,160 cu ft/day
Fox Hills Upwelling	0.18 ft/day			10,340 sq ft	1,861 cu ft/day

These volumes are shown on ***Figure 4-8.*** The uncertainty associated with the upwelling calculation arises from the variable lithology of the Fox Hills Formation as described in Section 2.2.2. The calculations above assumed a uniform sandstone lithology, which would overestimate the upwelling. To account for the fine-grained portion of the formation as well as the coal bed, the water producing zone’s extent was reduced by 50%. This may still over estimate water produced by upwelling because the effects of upwelling are not observed in the geochemistry or other properties of the shallow Lower Terrace groundwater.

4.4.3.3 Clear Creek

The flow in Clear Creek was measured at the gauging station immediately upstream from the CSMRI Site. This flow, which ranges during the year from 60 cu ft/second up to 1,000 cu ft/second as shown on the hydrograph presented as ***Figure 2-8***. This converts to between 5 million and 86 million cu ft/day. The Lower Terrace with a daily flow through of 6,000 cu ft/day is only 0.1% of the total flow of the creek during low creek flow.

4.4.3.4 Flux Conclusions

By calculating the volume of groundwater flowing from the Upper Terrace to the Lower Terrace and also at different points within the Lower Terrace it allows for some conclusions to be drawn about groundwater movement on the Lower Terrace. Groundwater flow on the Lower Terrace is essentially from west to east and parallel to Clear Creek. This flow direction is confirmed by the relative volumes of water entering and being transmitted by the Lower Terrace alluvium. Conclusions that can be drawn about the groundwater flow follow. These conclusions are arranged starting at the upgradient edge of the Lower Terrace in the vicinity of well CSMRI-8 and progressing downgradient to the east.

- Very little groundwater flows from the Upper Terrace to the Lower Terrace through the weathered Pierre Shale. This is confirmed during well sampling events where wells in this formation recharge very slowly, sometimes so slowly that they do not have sufficient recharge to collect a water sample.

- The majority (95%) of groundwater flowing past well CSMRI-8 cannot be attributed to the Upper Terrace or the underlying impermeable Pierre Shale and therefore must originate from Clear Creek.

- At well CSMRI-8, 95% of the water is coming from Clear Creek; the Lower Terrace remedial effort removed all accessible CSMRI-impacted soils between well CSMRI-8 and the creek; therefore, the uranium must be either coming from natural sources or the minor quantities of soil left surrounding the City of Golden water lines.

- Between well CSMRI-8 and CSMRI-12, the groundwater flow on the Lower Terrace increases by 2,000 cu ft/day, all originating from Clear Creek. Upper Terrace groundwater comprises only 1% of the total flow at well CSMRI-12. This clearly demonstrates the flow on the Lower Terrace is from west to east as there is no other driving force.

- Upwelling from the Fox Hills Aquifer, although uncertain, is insufficient to change the Lower Terrace groundwater chemistry. Whatever the quantity of upwelling, it is causing dispersion and dilution of the groundwater uranium concentrations.

- Upper Terrace groundwater flowing to the Lower Terrace along the Fox Hills weathered zone contributes 720 cu ft/day, or approximately 20% of the total flow.

- The total groundwater flow volume on the Lower Terrace increases between wells CSMRI-13 and CSMRI-4. This increase of 2,100 cu ft/day is comprised of 720 cu ft/day from the Upper Terrace and an uncertain volume of water upwelling from the Fox Hills. Upwelling in excess of 1,400 cu ft/day from the Fox Hills would result in loss of Lower Terrace groundwater to Clear Creek. Conversely, upwelling less than 1,400 cu ft/day would indicate creek water continues to enter the Lower Terrace. Any water leaving the Lower Terrace and entering Clear Creek would be creek water that just entered the Lower Terrace, because the groundwater flow direction limits the movement of the uranium plume toward the creek. Dispersion would be the required mechanism to allow uranium-bearing water to reach the north edge of the Lower Terrace upgradient of well CSMRI-4, and dispersion is insufficient to allow uranium to migrate to the northern edge of the Lower Terrace in this area of the Lower Terrace.

- The maximum flow within the Lower Terrace aquifer is located slightly upgradient of well CSMRI-4. This indicates very little to no groundwater loss to Clear Creek occurs upgradient of well CSMRI-4.

- The thickness and width of the Lower Terrace alluvium decreases by more than 50% between wells CSMRI-4 and CSMRI-5 resulting in a loss of groundwater to Clear Creek starting just upgradient from well CSMRI-4 and continuing past well CSMRI-5, making these wells ideally located to quantify the water quality leaving Site.

- The Lower Terrace total groundwater flow of 6,000 cu ft/day represents less than 0.1% of total flow in Clear Creek.

4.4.4 Contaminant Retardation and Natural Attenuation

Contaminant retardation is the tendency of different materials in groundwater to move through soils at different rates. Interactions between the contaminants and the substrates can slow, or retard, the movement of those contaminants. The retardation of dissolved uranium in the Lower Terrace has not been quantified; however, due to the long history of uranium presence on the Lower Terrace due to the former settling pond, retardation is not thought to play a significant role. Natural attenuation, however, is likely progressing on the Lower Terrace particularly. Attenuation due to adsorption and biological activity, both uptake and fixation, in the wetland is likely taking place and is included in the Site model. The Site conceptual model is discussed in detail in ***Appendix 4.***

4.4.5 Contaminant Fate and Transport

The following sections describe the potential for the uranium observed on the Lower Terrace to be transported offsite and impact offsite receptors or the environment.

4.4.5.1 Potential Routes of Migration

Two potential routes for the offsite migration of the uranium plume in the groundwater exist for this Site: water moving into Clear Creek and groundwater moving into the Fox Hills Formation. However, neither route of migration is active for the uranium plume in the groundwater on the Lower Terrace. The geometry of the Lower Terrace is such that it narrows on the southeastern end of the Lower Terrace forcing the groundwater to exit to Clear Creek at monitor wells CSMRI-4 and CSMRI-5. Dissolved uranium concentrations from CSMRI-5 have never exceeded 30 µg/L, and well CSMRI-4 concentrations have been reduced to below 30 µg/L following soil remediation. In addition, surface water samples collected from Clear Creek upgradient and downgradient of the Lower Terrace confirm no statistical difference between dissolved uranium concentrations in Clear Creek water.

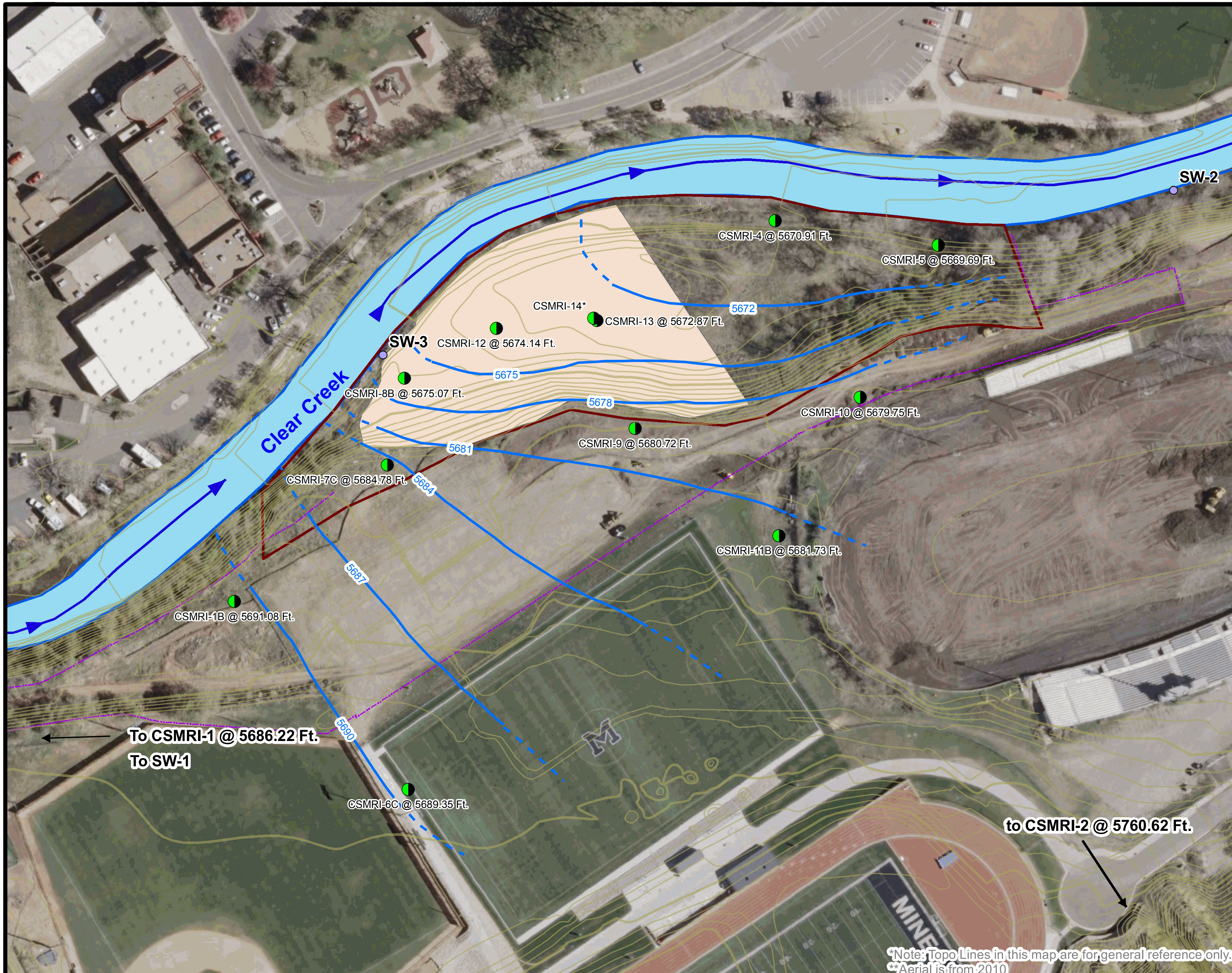
Potential Migration Pathways NOT Active

- Surface Water pathway
- Infiltration into the Fox Hills Formation

CSMRI-13 and CSMRI-14 have demonstrated that water from the Fox Hills Formation is upwelling into the shallow alluvial aquifer, and not migrating downward. This effectively eliminates the Fox Hills as an active route for migration of uranium in the groundwater.

4.4.5.2 Contaminant Fate and Transport Conclusions

Two sources of uranium in groundwater exist for the Lower Terrace. Uranium is transported by Upper Terrace groundwater to the shallow alluvial aquifer beneath the Lower Terrace, and Clear Creek water entering the Lower Terrace picks up naturally occurring uranium in soil and the minor uranium remaining around the City water lines. The details of the estimated 5 yds^3 of soils left around the City water lines at the request of the City Engineer is provided in ***Appendix 1***. Once Clear Creek water enters the Lower Terrace, it oxidizes and mobilizes uranium, and flows east until the Lower Terrace begins to narrow. The fate of this uranium is to be both attenuated within the wetland area and diluted by additional water inputs from upwelling. Very little (less than 30 ppb) uranium in groundwater is leaving the Site as demonstrated by the most recent well sampling data from CSMRI-4 and CSMRI-5. No unacceptable exposure to the uranium in groundwater is occurring or is likely to occur on this Site. Because no uranium above the drinking water standard is leaving the Site, no groundwater uses downgradient of the Site are threatened by the conditions on the Lower Terrace. Based on quarterly surface water analytical results, no measurable release of uranium to surface water has occurred.



Explanation

Potent. GW Contours December 2012

- Potentiometric Contour (3ft)
- Inferred Contour (3ft)
- Monitor Wells
- Surface Water Sample Location
- Fenced Area (Including Upper Terrace)
- License Area
- Lower Terrace Characterization Area

Contours 2009

- Topography (2Ft Intervals)
- Topography (10Ft Intervals)

*CSMRI-14 (Foxhills Fm, Not Used)
Water Elevation: 5673.76 Ft.

N
W E
S

0 50 100 200 Feet

Figure 4-7

Groundwater Potentiometric Elevation Map - December 2012

CSMRI
Groundwater Report

Stoller

S:\4349 CSMRI Flood Plain EA&RIFS\Working Report Figures\Groundwater Report Figure 4-6 Potentiometric Surface.mxd PLD @ 11/7/13

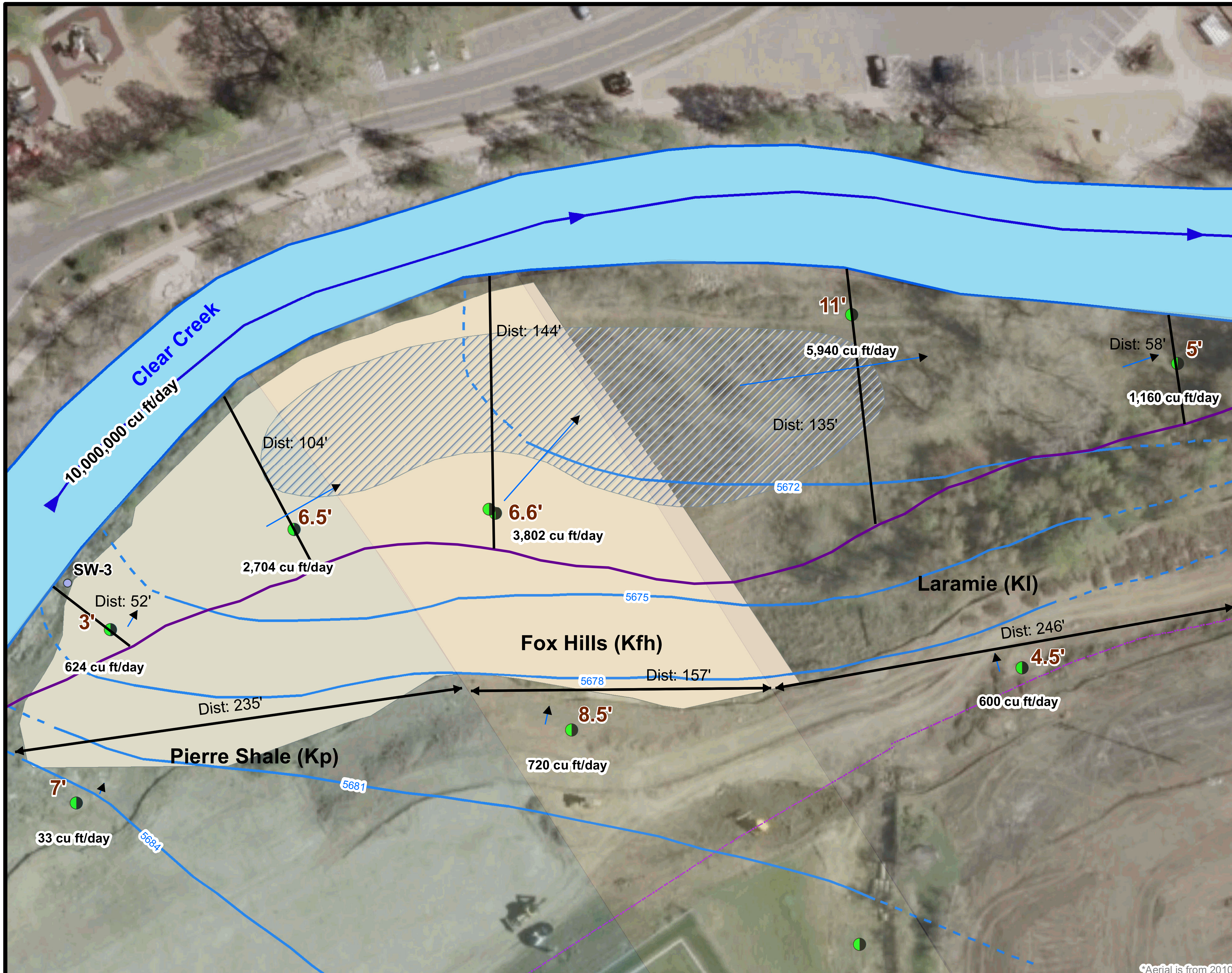


Figure 4-8
Groundwater Flux

CSMRI
Groundwater Report

Stoller

S:\4349 CSMRI Flood Plain EA&RIFS\Working Report Figures\Groundwater Report csmri_potentiometric_dec_2012.v2.mxd PLD @ 10/10/13

5 Comment Responses and Conclusions

A draft copy of this report was provided to the CDPHE for their review and comment. The CDPHE comments and responses to those comments are provided in Attachment 5. The main revision to the report based on CDPHE comments was the completion of the flux calculations to demonstrate the ground water flow on the Lower Terrace and the interaction with Clear Creek. These calculations provide insight into the ground water flow through the Licensed Area and demonstrate that Clear Creek water comprises the majority of ground water on the Lower Terrace and within the Licensed Area.

The previous sections have presented, summarized, and interpreted groundwater data collected at the CSMRI Site. Key information includes the following.

- Groundwater flow on the Lower Terrace is highly influenced by Clear Creek (Section 2.3)
- All identified soil impacted by CSMRI activities has been removed from the Site with the exception of soils surrounding the City of Golden's water lines. Some of the soil removed was in contact with Lower Terrace groundwater resulting in dissolved concentrations of uranium above ambient levels (Section 4.1.3)
- Upper Terrace groundwater flows to the Lower Terrace where it undergoes Lower Terrace chemical processes (Section 4.4.3.1)
- A wetland exists in the central portion of the Lower Terrace that continues to develop and is causing attenuation of some uranium (Section 3.2)
- A deep well into the underlying Fox Hills Aquifer shows no elevated uranium in the Fox Hills groundwater (Section 4.4.3.2) but does show upwelling of Fox Hills water
- The area containing the highest dissolved uranium levels is stationary, even though the groundwater is moving at 4 feet per day (Section 4.4.3)
- Wells CSMRI-4 and CSMRI-5 are appropriately located to intercept ground water leaving the Site and entering Clear Creek. These wells contain water below the uranium drinking water standard of 30 ppb (Section 4.2.3)
- No increase in the uranium concentration in Clear Creek has been observed due to this Site (Section 3.3)

These facts, demonstrated by the data in the section of this report cited, depict a site wherein a stationary area of elevated uranium concentrations are controlled by the physical, biological, and chemical nature of the Site. The area of elevated uranium is contained, has been contracting following the focused remediation, and is not impacting offsite receptors nor does it have the potential to impact offsite receptors in the future.

Conclusions about this Site, based on the above facts, are similar to those of other sites in Colorado with similar levels and conditions are presented below.

- Further monitoring is not necessary, and Site wells should be abandoned following Colorado State Engineer guidance.
- The Site qualifies for license termination based on the immobile nature of the plume, the decreasing trends exhibited by the uranium plume, and the lack of any impact to Clear Creek.

6. References

Anderson 1984. Mary P. Anderson, Movement of Contaminants in Groundwater: Groundwater Transport – Advection and Dispersion, University of Wisconsin, Madison.

Colorado Geological Survey 2001. Earth Science Week 2001, Field Trip Guidebook, "Mineral Resources of Jefferson County"

CDPHE 2009

CDPHE (Colorado Department of Public Health and Environment) 2011. Letter from Edgar Ethington, Radiation Management Unit, to Linn Havelick, Colorado School of Mines, Colorado School of Mines Research Institute, Creekside Facility, Final Completion Report acceptance, December 15.

Dudel, et al. 2004. Gert E. Dudel, Casten Brackhage, Holger Dienemann, martin Mkandawire, Arndt Weiske, Capacity of natural attenuation of trace contaminants from uranium mine tailing waters in nature-like constructed wetlands, Dresden University of Technology, Institute of General Ecology and Environmental Protection, Pienner Straße 8, D-01737, Tharandt, Germany.

Ecology and Environment, Inc. 1993. Volume 1, Summary Report on Site Investigation and Removal Activities, CSMRI Creekside Site, Golden, Jefferson County, Colorado, dated March 17.

Emmons S.F., et al. Geology of the Denver Basin in Colorado: U.S. Geological Survey Monograph 27, 1896.

EPA (U.S. Environmental Protection Agency), 1986. Test Methods for Evaluating Solid Waste, SW-846: Physical/Chemical Methods, Volume II: Field Methods, 3rd Edition, Office of Solid Waste and Emergency Response. Washington, D.C.

EPA (U.S. Environmental Protection Agency), 1991. Guidance on Oversight of Potentially Responsible Party Remedial Investigations and Feasibility Studies (Final): OSWER Directive 9835.1, USEPA, Washington, D.C.

EPA (U.S. Environmental Protection Agency), 1998. Guidance for Quality Assurance Project Plans QA/G-5: EPA/600/R-98/018, USEPA, Washington, D.C.

EPA (U.S. Environmental Protection Agency), 1999. USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review. EPA540/R 99/008.

Grant, 1990. CSM Environmental Sampling & Analysis Program: Claypits Site & CSMRI Facility, James L. Grant & Associates, August 9.

Hibiya et al. 2004. Kazuaki Hibiya, Jun Nagai, Satoshi Tsuneda, Akira Hirata. Simple prediction of oxygen penetration depth in biofilms for wastewater treatment, *Biochemical Engineering Journal*, Volume 19, Issue 1, pp. 61 – 68, July 1,

INTERPRO, Mr. Al Benjamin

New Horizons, 1998. Conceptual Subsurface Sampling & Analysis Plan, CSMRI Site.

New Horizons, 2003. Concrete and Asphalt Removal and Disposal [Final Report], April 11.

New Horizons, 2004. Remedial Investigation / Feasibility Study and Proposed Plan, Colorado School of Mines Research Institute Site, Golden, Colorado, January 21.

Removal Action Options Analysis (RAOA), Colorado School of Mines Research Institute, Golden, Colorado, Submitted to U.S. Environmental Protection Agency, Region VIII, Denver, Colorado, in compliance with Unilateral Administrative Order No. CERCLA-VIII-95-06, multiple authors, June 12, 1995 (3 vols.)

Robson, S.G., 1983. Hydraulic Characteristics of the Principal Bedrock Aquifers in the Denver Basin, Colorado: U.S. Geological Survey Hydrologic Investigations Atlas HA-659, scale 1:500,000.

Robson, S. G, 1984. Bedrock Aquifers in the Denver Basin, Colorado – A Quantitative Water-Resources Appraisal: U.S. Geological Survey Open File Report 84-431.

Robson, S.G., et al. 1981a. Geologic Structure, Hydrology, and Water Quality of the Arapahoe Aquifer in the Denver Basin, Colorado: U.S. Geological Survey Hydrologic Investigations Atlas HA-647, scale 1:500,000.

Robson, S.G., et al. 1981b. Geologic Structure, Hydrology, and Water Quality of the Laramie-Fox Hills Aquifer in the Denver Basin, Colorado: U.S. Geological Survey Hydrologic Investigations Atlas HA-650, scale 1:500,000.

Schöner et al. 2004. Angelika Schöner, Chicgous Noubactep, and Martin Sauter, Assessment of uranium retention in wetlands: Characterisation of bonding strength, considerations regarding reductive precipitation, pp. 4 – 27, Institute of Geosciences, Griedrich-Schiller-University Jena, Germany.

Stoller, 2005a. Dose Assessment for the Emplacement of the CSMRI Site Containerized and Remaining Subsurface Soil into a RCRA Subtitle D Solid Waste Landfill, prepared for Colorado School of Mines, Golden, Colorado, prepared by S.M. Stoller Corporation, March 1.

Stoller, 2005b. CSMRI Creekside Site Draft Report on Background, prepared for Colorado School of Mines Research Institute, Golden, Colorado, prepared by S.M. Stoller Corporation, September 13.

Stoller, 2005c. CSMRI Creekside Site Contaminated Soil Disposal Work Plan, Revision 2, prepared for Colorado School of Mines, Golden, Colorado, prepared by S.M. Stoller Corporation, November 3.

Stoller, 2006. CSMRI Creekside Site Final Site Characterization Work Plan, prepared for Colorado School of Mines, Golden, Colorado, prepared by S.M. Stoller Corporation, May 12.

Stoller 2007a. Clay Pits Area Remedial Site Investigation Report, Colorado School of Mines Research Institute Site, prepared for Colorado School of Mines, prepared by The S.M. Stoller Corporation, April.

Stoller 2007b. Revised Remedial Investigation / Feasibility Study and Proposed Plan, Colorado School of Mines Research Institute Site, The S.M. Stoller Corporation, original RI/FS date: January 21, 2004, revision date: May 2007.

Stoller 2009. CSMRI Remedial Action Implementation Report, prepared for Colorado School of Mines, Golden, Colorado, prepared by S.M. Stoller Corporation, September.

Stoller 2010. Revised Draft Work Plan Environmental Assessment and Characterization Colorado School of Mines Research Institute Site Flood Plain Area, (Preliminary Flood Plain Characterization report, included as Appendix A), prepared for Colorado School of Mines, Golden, Colorado, prepared by S.M. Stoller Corporation, August.

Stoller 2011. Final Completion Report, CSMRI Flood Plain Site, Golden, Colorado, December.

Stoller 2012. Final Gamma Survey Report, Colorado School of Mines Research Institute Site, Flood Plain Area, Golden, Colorado, June.

Todd 1980. Groundwater Hydrology, second edition, David Keith Todd, University of California, Berkeley and David Keith Todd Consulting Engineers, Inc., John Wiley and Sons, New York, 1980.

URS 2001. Characterization Survey Work Plan (CSWP), prepared by URS Corporation, July 23.

URS 2002c. Concrete and Asphalt Characterization Report, May 18.

URS Analytical Results Report, Colorado School of Mines Research Institute Site.

Van Horn, Richard, 1976. Geology of the Golden Quadrangle, Colorado, Geological Survey Professional Paper 872, U.S. Government Printing Office, Washington.

Van Horn 1995

Weimer, R.J., 1976. Cretaceous Stratigraphy, Tectonics and Energy Resources, Western Denver Basin, Colorado School of Mines.

Appendix 1

1.1 History of Site Use

This appendix explains the reference in Section 1.2 in further detail.

Many activities associated with mineral extraction and associated processes have been conducted at the Site and in the general area predating and during operation of the CSMRI Site.

A publication presented by the Colorado Geological Survey (2001) describes the mineral resources of Jefferson County. The publication describes how Jefferson County has a long history of mineral production, from the early coal mines that helped fuel steam locomotives and the gold mills in Clear Creek and Gilpin counties, to the modern crushed stone aggregate quarries that provide much of the raw material for the growth in the Front Range. High-quality clays along the base of the Front Range have been mined for years to make bricks and ceramics. One of the largest single uranium deposits in the U.S. is located only seven miles from Golden and has been mined up until 2000. Gold, derived from the erosion of the large lode deposits to the west, has been mined from the gravels along Clear Creek, sometimes as a byproduct of gravel pits. A small oil field once produced crude oil in Jefferson County.

The publication describes uranium deposits in the area and one of the largest single uranium mines ever to operate in the U.S., the Schwartzwalder Mine, located in the foothills about seven miles northwest of Golden. The underground mine, owned since 1965 by the Cotter Corporation, shut down in March 2000 because of low uranium prices. Total production over the years from the Schwartzwalder Mine has been approximately 17 million pounds of uranium oxide (data retrieved from http://www.cotterusa.com/). An online search for historic mining operations known to contain pitchblende (UO_2) located in the Clear Creek drainage basin identified over 30 mines upstream of the Site (http://www.mindat.org/).

Uranium also occurs in another geological setting in the county at the Highway 285 road cut at the Dakota Hogback where a roll-front deposit is visibly exposed in the outcrop. Uraninite and other oxide minerals occur in the upper member of the Dakota Sandstone ("J" Sand). Two small mines produced uranium near the road cut in the late 1950s, the Mann Mine and the Morrison Mine. These mines produced 18,000 pounds of uranium oxide. Several other smaller uranium deposits have been found in the Dakota Sandstone elsewhere in the county.

The publication also describes coal and gold mining activities in the area and states that 55 producing coal mines operated in Jefferson County between 1876 and 1950. Almost seven million tons of coal were removed by blasting, pick, and shovel in that time span. Known as the Foothills coal field, mines existed from the Boulder County line in the north and to the south to near the present intersection of Garrison Street and Ken Caryl Avenue in Littleton. Two of these, the White Ash and New Loveland mines, were located in the immediate vicinity of the Site.

Gold was mined from placer deposits in the gravels of Clear Creek, from west of Golden to the city of Denver. The total recorded production of gold in the county through 1947 was about 12,000 ounces. The largest production of gold occurred during the Great Depression between 1934 and 1937 when a dry-land dredge worked the gravels along Clear Creek west of Golden. Production since then has been relatively small, mostly as a byproduct of sand and gravel operations.

The gold in the Clear Creek gravels is derived from erosion of the large gold deposits in bedrock (lodes) that occur upstream, around Idaho Springs, Central City, Blackhawk, and Georgetown. Placer gold in the Clear Creek gravels was discovered as early as 1859, shortly after the first important gold discovery in Colorado was made in present-day suburban Denver, in Cherry Creek gravels. The prospectors followed the Clear Creek gold upstream to find the bigger lode deposits in the mountains shortly thereafter. This is important to note because gold although mined in placer deposits originated upstream of the Site in a mineralized belt where it occurs with many other minerals including UO_2.

In an excerpt from the Ecology and Environment, Inc. report titled *Summary Report on Site Investigation and Removal Activities CSMRI Creekside Site*, additional history of the Site is discussed. The report states that metallurgical research began in approximately 1912. Historical data indicate that extensive underground coal mining was performed on and under the Site until 1889. The clay pits to the south of the facility were extensively mined beginning in the early 1900s. It is possible that spoils from the original mining activities were used to build up the embankment areas and the playing fields adjacent to the Site. Mr. Al Benjamin (INTERPRO) indicated that a brick kiln may have been located on the Site in the late 1890s. During investigation and excavation, brick debris was noted in most excavations on the west and south half of the property. A mine shaft from coal mining operations beneath the Site is visible in an historic photograph taken from Lookout Mountain in 1880.

The report also states that the Site was a research facility established in the early 1900s to develop mining and extraction methods for metals. Research on the beneficiation of radioactive materials was also conducted on the Site. Activities included the milling of uranium ores and the concentration of some naturally radioactive rare earth elements. Some of the activities involved organic additives with the subsequent generation of wastes. Tailings and waste material containing metals and radioactive material from some of the processes were disposed onsite. Over the years, some of the tailings piles were paved over or buildings were constructed over the piles. Waste streams from the laboratories and pilot-scale operations went into the drainage system, which emptied into the tailings pond. The laboratory fume hoods, where samples were digested and/or assayed, vented to the atmosphere.

Activities associated with several smelter operations in Golden have the potential to release large amounts of arsenic into the atmosphere, which then accumulates in soil in the surrounding areas. Smelters were a big part of Golden, Colorado history, and one was operated across Clear Creek from the Site in the immediate vicinity. These historic operations would have affected the property at the Site and the entire surrounding areas downwind of these smelter operations in Golden, including residential areas.

Although activities conducted by CSMRI have likely impacted the Site with arsenic contamination, the coal mining, area ore smelters, and brick factory operation also contributed to arsenic levels at the Site and surrounding areas. The historic photograph from 1880 shows at least three smelters on the opposite side of Clear Creek as well as a brick factory that were operated in the immediate vicinity of the Site. These smelting operations along with the coal mining and brick factory activities contributed to the arsenic contamination levels at the Site and have resulted in elevated levels for this Site. In this report, when area-wide levels are elevated above natural background concentrations, the term ambient concentration is used.

The CSMRI Site was operational from 1912 until approximately 1987. Numerous mineral research projects (some of which involved the mineral extraction and beneficiation of materials that contained levels of radionuclides above background) were conducted. The research projects were conducted in 17 buildings on the CSMRI Site that were subsequently razed in the mid-1990s. An impoundment (settling pond) also was situated between the building complex and Clear Creek to store wastewater generated in the laboratories and research facilities. Wastewater discharged from the buildings was transferred to the settling pond through a system of sumps and floor drains in the buildings.

To the south of the operational portion of the Site is an area known as the Clay Pits. Clay was mined from the Clay Pits in the late 1800s, which created a series of open trenches that extended from Clear Creek approximately one mile south, almost to the current location of the Jefferson County Courthouse. By the mid-1900s, the pits were depleted of clay and remained as open trenches.

The pits were soon backfilled with trash and debris, including flood material debris from the 1965 flood of the South Platte River that impacted a significant portion of the lower downtown Denver area (Havelick, personal communication 2006). In May 1973, sediment from the onsite settling pond located on the CSMRI Site was placed in one of the open trenches of the Clay Pits. Over six days, the sludge was buried at an approximate depth of 15 to 20 feet and then covered with crushed ore and earth. This relatively small area, in the context of the entire Clay Pits, is referred to as the Clay Pits area.

1.2 Contaminants of Concern

This appendix explains the reference in Section 1.4 in greater detail.

The suite of compounds released by CSMRI activities to Site soil, as agreed to by the CDPHE are presented in Table 1. This suite of compounds was used for investigations up to the Lower Terrace investigation of 2010. Because the Lower Terrace investigation was focused on identifying and excavating soils acting as a source for the persistent elevated uranium area in the groundwater, uranium metal was added to the list of soil COCs. The table also presents the ultimate cleanup levels attained for each of the COCs during the remedial activities on the Upper Terrace and Lower Terrace.

Table 1
Soil COCs Status

Constituent	Tentative DCGL	Level Attained*	
		Upper Terrace	Lower Terrace
Metals	**mg/kg**	**mg/kg**	**mg/kg**
Arsenic	39	14.8	10.05
Lead	400	99.5	67.94
Mercury (total)	23	0.6	2.27
Molybdenum	390	6.6	4.17
Vanadium	78	32	28.44
Uranium (metal)	14	NA	**5.45
Radioisotopes	**picoCuries/gram**	**picoCuries/gram**	**picoCuries/gram**
Radium 226	4.14	3.52	3.82
Radium 228	4.6	1.95	0.56
Thorium 228	6.47	1.88	0.36
Thorium 230	11.53	2.27	2.62
Thorium 232	3.88	1.76	0.41
Uranium 234	254.9	2.08	1.20
Uranium 235	4.97	0.24	0.07
Uranium 238	21.8	2.14	1.20

Values in table are mean concentrations
*Level Attained is the final mean concentration of the COC after remedial activities were completed.
** Includes confirmatory data set from 2011 soil removal and test pit data from 2010 Preliminary Site Characterization

1.3 Remediation Goals

This appendix explains the reference in Section 1.4 in greater detail.

The primary goal of the School in performing the remediation of the CSMRI Site is to return the area to beneficial use. Early on, the School realized that to achieve this goal, it needed to focus on radioactive materials license termination and maintain CERCLA compliance to allow for cost recovery from PRPs. The CERCLA compliance allows the State to place the financial burden of cleanup on those responsible for the impacts.

To achieve these goals, the remedial work and reporting has also followed this dual path, which contains significant overlap. To comply with CERCLA, the work must meet the Applicable or Relevant and Appropriate Requirements (ARARs) as well as demonstrate the conditions that lead to license termination are also met. These conditions include risk reduction to within acceptable levels both from toxicity and dose and demonstrating the Site has been returned to a condition that is as close to the surrounding area as is reasonably achievable. For this Site, the goal has always been to achieve free release that allows for unrestrictive reuse. To date, the soils on both the Upper Terrace and Lower Terrace have been demonstrated to achieve this and have been closed. This report presents the data, interpretation, and conclusions relative to the groundwater beneath the Site.

1.4 CSMRI Licensing Actions

This appendix explains the reference in Section 1.5 in greater detail.

Table 2
Summary of U.S. AEC Licensing Actions at CSMRI

Time Period	License Details
Terminated 1948	Weinig had License No. R-120 from the U.S. AEC for source material, which terminated in 1948. V2731, V2732. Weinig's clients also may have had separate licenses from the U.S. AEC for research at the Site. V1436.
1958 -1967	The State of Colorado has records of U.S. AEC licensing actions dating from January 1958 through December 1967.
1958 - 1967	U.S. AEC By-product Material License Number: 5-4607-1 (including amendment #1 through amendment #23) dated from January 1958 through December 1967 Issued to: Colorado School of Mines Research Foundation, Inc. Authorized uses: laboratory research; teaching of industrial radioisotopic courses; as a component of a neutron generator for activation analysis; calibration of instruments; measurement of specific gravity of slurry in a pipeline; laboratory tracer studies; monitoring of solutions and slurries; metallurgical studies; neutron generator for activation analysis; experimental curing of thin plastic films deposited on ceramics; studies of molybdenum; geochemical research; to measure wear rate of experimental pipelines and machines and similar laboratory studies; and for the determination of solubility constants.
1966	U.S. AEC Special Nuclear Materials License Number: SNM-972 (for Plutonium), dated August 1966 Issued to: Colorado School of Mines Research Foundation, Inc. Authorized uses: for use in accordance with the procedures described in the licensee's application dated July 20, 1966. Storage only of soil samples.

Table 3
Summary of State of Colorado Licensing Actions at CSMRI

Date	License Details
October 24, 1968	Colorado Radioactive Materials License Number: Colo. 08 – 01 (F) Issued to: Colorado School of Mines Research Foundation, Inc. and Colorado School of Mines Authorized uses: Research, development, and teaching.
March 7, 1969	Amendment No. 2 to License Number: Colo. 08 – 01 (F)
May 25, 1971	Amendment No. 2 to License Number: Colo. 08 – 01 (F)
September 29, 1971	Amendment No. 3 to License Number: Colo. 08 – 01 (F)
February 25, 1972	Amendment No. 4 to License Number: Colo. 08 – 01 (F)
August 16, 1974	Amendment No. 5 to License Number: Colo. 08 – 01 (F)
October 31, 1975	Amendment No. 6 to License Number: Colo. 08 – 01 (F)
	Note: The State does not have record(s) of licensing actions between November 1975 and March 1985.

Table 3
Summary of State of Colorado Licensing Actions at CSMRI

April 10, 1985	Colorado Radioactive Materials License Number: Colo. 617-01S Issued to: Colorado School of Mines Research Institute. Authorized uses: Possess, use, and store.
March 25, 1986	Amendment No. 1 to License Number: Colo. 617-01S
September 11, 1990	Amendment No. 2 to License Number: Colo. 617-01S. Issued to: Colorado School of Mines Research Institute Authorized uses: Possess, use, and store.
October 31, 1997	Amendment No. 3 to License No. 617-01
March 30, 2001	Amendment No. 4 to License No. 617-01
February 11, 2002	Amendment No. 5 to License No. 617-01. Issued to: Colorado School of Mines Research Institute Authorized uses: Possess and store naturally occurring, source and by-product.
May 19, 2005	Amendment No. 6 to License No. 617-01 (same authorized uses)
December 15, 2006	Amendment No. 7 to License No. 617-01 (same authorized uses)
December 19, 2012	Amendment No. 8 License 617-01 terminated for CSMRI **
	Colorado School of Mines License No. 1206-01
**August 22, 2012	**Amendment No.01 License No. 1206-01 CSM assumes responsibility for area covered under CSMRI License No. 617-01 The licensee is authorized to possess and store groundwater containing uranium, and any unknown sources of radioactive material contributing to uranium in groundwater. The Global Revision 3 License No. Colo. 12(})·0I, Amendment No. 01 Page 1 of 4 STATE OF COLORADO RADIOACTIVE MATERIALS LICENSE maximum quantity of these materials which the licensee may possess at any one time is limited to those materials currently on site as a result of prior CSMRI site operations .

1.5 Site Investigations and Remedial Activities

This appendix explains Section 1.6 in greater detail.

Former Settling Pond

On January 25, 1992, a water main owned by the City of Golden broke on the Site and began discharging a large volume of water into the settling pond. EPA's Emergency Response Branch responded in February 1992 and performed the following activities to excavation contaminants and stabilize conditions at the Site:

- Excavation of the contaminated sediments and soil
- Stockpiling of the material (the stockpile)
- Decontamination of building drains
- Demolition and removal of several buildings
- Consolidation of existing drums and disposal of compressed gas cylinders
- Sampling of sediments and water
- Closure of the settling pond

- Pond area restoration and revegetation

EPA subsequently contacted many of the entities that had sent materials to the Site and requested that the stockpile be removed. This culminated in the issuance of a Unilateral Administrative Order (UAO) on December 22, 1994, to certain entities (the respondents). Among other things, the UAO required the respondents to develop and evaluate disposal options for the stockpile (approximately 20,000 cubic yards) and ultimately implement the selected disposal alternative. Some of the respondents prepared a Removal Action Options Analysis (RAOA) report that was issued on June 12, 1995. The RAOA report identified and evaluated various disposal options for the stockpile. The State of Colorado through the School was the only respondent that subsequently implemented the preferred disposal option. The EPA removal action was completed in 1997.

Upper Terrace

The School hired AWS Remediation to raze the remaining research buildings from the Upper Terrace of the Site in the mid-1990s. Following demolition of the buildings, the existing pits and basements were backfilled to grade; building foundations and concrete footers were left in place.

A Characterization Survey Work Plan (CSWP) was prepared by URS Corporation on July 23, 2001. The purpose of the CSWP was to guide field investigation activities to supplement existing data and evaluate the risks associated with the release of residual metals and radioactive materials found in soils within the Fenced Area and the Clay Pits area. URS completed the characterization of the concrete and asphalt slabs and issued two draft final reports on February 11, 2002 and May 18, 2002, respectively.

Demolition of the remaining concrete and asphalt materials was an integral part of the Site characterization process. In April 2002, the School hired New Horizons Environmental Consultants, Inc. (New Horizons) to demolish the remaining concrete and asphalt slabs and to characterize surface and subsurface soils on the Site. New Horizons prepared a comprehensive set of work plans, which guided the characterization activities that were conducted at the Site.

During November and December 2002, remaining concrete and asphalt were excavated and either transported as demolition debris to BFI's Foothills Landfill in Golden, Colorado (a permitted Subtitle D solid waste facility), or transported to Recycled Materials, Inc.'s plant in Arvada, Colorado, for recycling. Detailed documentation regarding the removal of the concrete and asphalt slabs is provided in a report entitled Concrete and Asphalt Removal and Disposal (New Horizons 2003).

During December 2002 and January 2003, New Horizons collected surface and subsurface soil samples, which were analyzed for metals and radionuclides. Quarterly groundwater samples were collected for four quarters beginning in February 2003. The results of the New Horizons' Site investigation activities were presented in the RI/FS and Proposed Plan (New Horizons 2004).

The 2004 Proposed Plan recommended the excavation and offsite disposal of contaminated soils (Alternative 5). The School then received and considered oral and written public comments on the 2004 Proposed Plan. The public comments supported Alternative 5 as the remedial plan for the Site. The School selected this alternative as the remedial action for the Site and documented the remedy selection in a Record of Decision (ROD), which was signed on March 31, 2004.

New Horizons was selected to identify, excavate, and dispose of contaminated soils at the Site. Field activities began in April 2004. During the 2004 field work, six areas were excavated, and a seventh area was partially excavated. By May 2004, it was apparent that excavated soil volumes, concentrations, and projected costs exceeded previously estimated volumes, concentrations, and costs. The work needed to return to the investigation phase to correctly delineate the nature and extent of contamination. Field work was halted, and the Site was stabilized. Approximately 1,870 cubic yards of soil had been excavated, bagged, and stored on the Site by New Horizons during the 2004 excavation work. This bagged soil had been initially slated for disposal at the U.S. Ecology RCRA facility in Idaho. The contract with New Horizons was terminated in the fall of 2004.

In December 2004, Stoller was retained by the School to collect representative soil samples from a random subset of the 455 super-sack containers staged at the Site and to generate a representative data set to evaluate potential disposal options of the containerized material. The soil in the bags averaged 12.6 picocuries per gram (pCi/g) Ra-226. After negotiations between the School and CDPHE, CDPHE agreed to consider a risk assessment, which demonstrated that the Foothills Landfill in Jefferson County could safely manage the bagged soils even though they contained concentrations greater than 3 pCi/g Ra-226 above background, which was CDPHE's previous threshold for waste acceptance into the solid waste landfill. The analytical and risk assessment results were submitted to CDPHE for review in the April 5, 2005 report, *Dose Assessment for the Emplacement of the CSMRI Site Containerized and Remaining Subsurface Soil into a RCRA Subtitle D Solid Waste Landfill* (Stoller 2005a). After review of the dose assessment report, the CDPHE approved shipment of the bagged soils to the Foothills solid waste landfill in a letter dated August 26, 2005. At CDPHE's request, the dose assessment included a hypothetical scenario of 30,000 cubic yards of soil similar to the soil contained in the bags. This scenario reflected possible further soil excavation at the Site and prevented the need to perform a second dose assessment if soils similar to the soils in the bags were excavated. CDPHE approved this hypothetical scenario.

In May 2005, the School contracted Stoller to examine further Site investigation alternatives to move the project toward completion while maintaining the CERCLA framework.

In September 2005, Stoller prepared a Background Evaluation Report for the Site (Stoller 2005b). This report summarized and assessed the results of three previous background studies, two by URS in 2000 and 2002, and one by New Horizons in 2004 (included in the 2004 RI/FS), which attempted to establish ambient concentrations for metals and radioisotopes. CDPHE reviewed the Stoller background report and indicated inadequate soil analytical data existed to justify increasing the proposed cleanup standards for the Site. However, the CDPHE agreed to adjust the ambient level of arsenic to 38 parts per million (ppm), resulting in a tentative Derived Concentration Guideline Level (DCGL) of 39 ppm. Additionally, the CDPHE agreed to use a total mercury standard to guide characterization with some speciated confirmatory data in support. The School determined that pursuing further background studies at that time in response to CDPHE's concerns would not be cost effective and directed Stoller to proceed using tentative cleanup goals approved by CDPHE. However, the School and CDPHE agreed that the School could later demonstrate to CDPHE alternative ambient conditions for different portions of the Site during field excavation work upon field observations and further data. This was a more cost-effective strategy.

In October 2005, Stoller obtained CDPHE approval and a Colorado Department of Transportation permit (Permit Request number 605167) to transport the bagged soil offsite via an access lane on Colorado Highway 6 to BFI Foothills Landfill. Physical construction of this access was completed by New Horizons in 2004 under Access Permit No. 603100.

All bagged soils from the Site were shipped to BFI Foothills Landfill from December 12 through 15, 2005, in accordance with the approved *CSMRI Creekside Site Contaminated Soil Disposal Work Plan* (the Materials Transportation Plan is Appendix A of the work plan) (Stoller 2005c). A total of 112 truck loads containing bagged soil plus two trucks containing other debris from the Site were shipped.

Stoller assisted with designing a strategy to meet the goals of the School while also collecting the necessary Site data for nature and extent determination. Multiple meetings with the CDPHE led to the approved *CSMRI Creekside Site Final Site Characterization Work Plan* (Stoller 2006). This work plan was implemented by Stoller beginning in June 2006. The investigative method selected was to excavate the impacted soil and stockpile it onsite to determine the nature and extent of contamination. This excavation method is analogous to the method used by the EPA to address the former settling pond at the Site. EPA had excavated the former settling pond down to cleanup goals then stockpiled the soil at another location on the Site for further characterization work and disposal purposes. The New Horizons' baseline risk assessment in the 2004 RI/FS had already demonstrated that remedial action was necessary at the Site for the remaining contaminated soil. Because New Horizons was discovering during field work that volumes and concentrations greater than those used in the baseline risk assessment were present, it was clear that the no-action alternative would not be a viable alternative.

On the basis of New Horizons' inability to fully delineate the nature and extent of contaminants at the Site using the traditional approach of collecting soil samples from numerous boreholes, it was determined that the standard characterization approach would not succeed in identifying many areas onsite where contaminants were present. This is due to the heterogeneous distribution of contaminants and their lack of lateral continuity as a result of the historical practice of dumping small quantities of raw and beneficiated materials from research activities over the large footprint of the Site. Simply stated, the accepted approach of drilling boreholes on a grid was impracticable, due to the likelihood of borings failing to locate these isolated piles of impacted material. To delineate nature and extent, understand the volume of impacted material, and develop cost for remedial alternatives, Stoller selected the investigative method of excavating the impacted soil in 1-foot vertical lifts and stockpile it onsite.

Beginning in June 2006, Stoller excavated and segregated contaminated soil above the tentative cleanup goals into two soil stockpiles onsite. Based on data from the original RI, soil was segregated by metals content and activity. Soil with concentrations of COCs above the tentative DCGLs was placed in lined soil stockpiles.

Stockpile A contained material over 100 pCi/g and contained approximately 200 cubic yards of material. Stockpile B contained the majority of the excavated material (less than 100 pCi/g but greater than the tentative DCGLs) and contained approximately 12,500 cubic yards of material.

Creation of the two lined stockpiles eliminated potential for further migration of contaminants to groundwater while a feasibility study was undertaken. The selected remedy was implemented and stockpiles were disposed at offsite landfills. This action permanently eliminated the threat of these soils contaminating groundwater.

Excavated soils had a mean concentration of 40.1 mg/kg for arsenic, 532.2 for lead, 2.3 for mercury, 89.4 for molybdenum, and 44.1 for vanadium, and a mean concentration of 12.2 pCi/g Ra-226.

Stoller sampled the soils after the soils in excess of DCGLs were excavated and placed into the two stockpiles. Results showed that the soils in the Upper Terrace fell below DCGLs. CDPHE determined that the remaining soil in these areas meet the DCGLs.

A final gamma scan was conducted upon completion of the soil segregation activity. This scan of the entire Site was completed to assess the effectiveness of the characterization. To confirm the gamma scan, samples were collected and submitted to both the onsite and an offsite laboratory for final confirmatory data.

Results of Stoller's soil excavation and segregation investigation further demonstrated the reasonableness and necessity of halting the 2004 remedial work by New Horizons. Stockpile B consisted of approximately 12,500 cubic yards with an average of 13.55 pCi/g Ra-226. Under the 2004 RI/FS and

2004 ROD, this soil, plus the 1,800 cubic yards of bagged soil, would have been shipped and disposed of at the U.S. Ecology facility in Idaho at a cost of $9,689,823. In addition, the excavation and segregation investigation created approximately 200 cubic yards in Stockpile A, which averages 84.75 pCi/g Ra-226. This material would have cost $135,522 to dispose of in Idaho under the 2004 RI/FS and 2004 ROD. If New Horizons had continued its field work, there would have been a cost overrun of $8,284,632, or 538 percent above the expected costs under New Horizons' contract to implement the remedy. In addition, the volumes that would have been excavated by New Horizons would have been significantly greater than that estimated by New Horizons in the 2004 RI/FS, because the arsenic ambient level was changed for the Revised RI/FS (Stoller 2007b) to reflect an accurate arsenic ambient level. While the 2006 investigation resulted in a similar volume of impacted soil as that estimated in the 2004 RI/FS, the field methods used in the 2004 remedial action would have yielded a much larger volume of impacted material subject to disposal.

Stoller published its findings in a May 2007 Revised RI/FS. The Revised RI/FS also evaluated alternative remedial actions and proposed Alternative 5B, the offsite disposal of the two stockpiles to two different landfills, an environmental covenant requiring radon mitigation systems in all residences onsite, and continued groundwater monitoring to evaluate the impact that soil excavation and offsite disposal have on improving water quality.

Implementation of the selected alternative was completed in August and September 2007. Eleven trucks filled with soil from Stockpile A were shipped to Clean Harbor's Deer Trail facility in eastern Colorado. Stockpile B soil was shipped to the Allied Waste BFI Foothills Landfill. This shipment included 615 trucks filled with soil and nine trucks filled with Site debris. Details of this remediation are presented in a Remedial Action Implementation Report (Stoller 2009).

Following receipt of the implementation report, the CDPHE issued a letter granting release of the Upper Terrace from the radioactive materials license. This release was later rescinded by CDPHE, and the CDPHE required the fence be replaced around the newly constructed soccer field. Following several months of negotiations, the CDPHE again granted release of the soccer field for play and the fence around the soccer field was removed. Release of the Upper Terrace soils and ground water from the radioactive materials license was granted with an environmental covenant placed on the ground water that restricts its use. This environmental covenant is the only remaining restriction on the use of the Upper Terrace area.

Clay Pits

In 1977, the Clay Pits area where materials dredged from the CSMRI pond had been placed was surveyed by Louis E. Bolis. Mr. Bolis also provided a stamped drawing (Bolis Drawing) of the results of the survey, "Location of Waste Dump, CSM Research Institute." Correspondence from John Schmerber of CSMRI to Larry Doerr of CDPHE in January 1985 states that approximately 500 cubic yards of dredged pond sediments were buried prior to 1972 in the clay pits located just south of the main entrance to CSMRI and that the burial was conducted between vertical sandstone walls and well above the existing water table. The correspondence states that… "the activity of the sludge was never determined but it is assumed to be at or near background levels. This statement is supported through previous correspondence submitted to [CDPHE] by Colorado School of Mines. Further, numerous surveys conducted by your department [CDPHE] have not offered any evidence to the contrary."

The School had previously retained New Horizons and URS to investigate the Clay Pits area. In 1998, New Horizons prepared the Conceptual Subsurface Sampling & Analysis Plan, CSMRI Site. URS implemented the New Horizons' plan in early 1999 with the drilling of two boreholes. The URS report, Analytical Results Report, Colorado School of Mines Research Institute Site, apparently based on additional information located during file research did not look for the sediments in the correct location.

Additional study of the Clay Pits area was conducted by Stoller in 2007. During this investigation, five borings were advanced into the area of suspected waste without encountering any indications of CSMRI waste. The report of findings was submitted to the CDPHE, and the CDPHE concluded that no further action was necessary at the Clay Pits area (Stoller 2007a).

Lower Terrace (Flood Plain)

During the 2006 RI, existing data for the Lower Terrace indicated that only Ra-226 exceeded regulatory guidelines as well as Site tentative DCGLs. Therefore, Ra-226 was the only compound analyzed for during segregation work. A shielded sodium iodide detector was used to count every field sample collected during the soil excavation. Details of the soil excavation activities are documented in *Revised Remedial Investigation / Feasibility Study and Proposed Plan, Colorado School of Mines Research Institute Site* (Stoller 2007b).

Within the limits of the Lower Terrace area, groundwater was encountered in three areas and large trees were jeopardized in two areas. In one location the risk of having the excavation contact and become flooded by Clear Creek forced a stop to soil excavation in that area. In each of these areas soil was left in place that exceeded the cleanup goal.

After the remedy for the Upper Terrace soil was completed, a groundwater monitoring well (CSMRI-8) was installed. Groundwater monitoring following the remediation of Upper Terrace soil indicated a persistent area with elevated uranium predominantly at the west end of the Lower Terrace. Further characterization work was requested of the School by CDPHE to better define the source of the groundwater impacts. After a collaborative effort, including a mid-approval work plan revision, a final work control document was submitted to the CDPHE and approved prior to start of work.

The first phase of work was performed on June 2 and 3, 2010, when eight test pits were dug on the Lower Terrace and data were collected as part of a preliminary Site characterization. Results of this preliminary investigation confirmed the need to take action and were used to prepare for the second phase of work and address concerns brought forth by the CDPHE and the PRPs. The findings of the preliminary Lower Terrace characterization are described in the Preliminary Lower Terrace Characterization report, included as Appendix A in the characterization work plan (Stoller 2010). Data from the preliminary investigation were used to identify the area in the vicinity of CSMRI-8 as the likely source of groundwater contamination.

As part of the preliminary characterization, bedrock and alluvial samples were collected from the formations that underlie the Lower Terrace area from outcrops near the Site. This study was performed because although uranium isotopes were included as a COC in previous RI work, uranium metal was not and these data were needed to determine a tentative cleanup goal protective of Site groundwater. On the basis of this study, the ambient uranium concentrations on the Site were determined to be of 6.45 mg/kg and a cleanup goal of 14 mg/kg was established for uranium metal in Lower Terrace soil.

The preliminary Lower Terrace characterization work produced several key findings crucial to our understanding of groundwater contamination on the Lower Terrace including:

- Performed a background study that established an ambient concentration for uranium in Clear Creek alluvial deposits and development of cleanup guidelines for uranium in soil;
- Conducted groundwater geochemical modeling that included a soil partition coefficients (Kd) and soil screening level (SSLs) for uranium;

- Established the hydraulic conductivity for ground water in flood plain alluvium; and

- Identified the westernmost portion of the Lower Terrace as the source area for the groundwater uranium plume.

Characterization included excavation, sampling, and analysis and began near well CSMRI-8, an area known to contain CSMRI process contaminant fill material. The team excavated two former effluent outfall pipes still present on the hillside. Assessment and characterization of the soils above the groundwater table were completed in 1-foot lifts with the soil being segregated between clean soil (soil less than Site tentative cleanup goals, including uranium at 14 mg/kg) and impacted soil above Site tentative cleanup goals. Characterization by segregation to bedrock was completed in strategic areas of the Lower Terrace.

Soil removal was completed on the entire west end of the Lower Terrace. Soils that were not removed that contained levels of uranium above the tentative cleanup goal, included soils immediately adjacent to Clear Creek and soils surrounding the City of Golden water main. The soils along the bank of the creek were left in place to prevent the creek from flooding the excavation as well as prevent runoff into the creek. The soils immediately surrounding the City water main were left in place at the request of the City Engineer who was on site during the removal of soil in close proximity to the water line. Removing soils near the water main could have destabilized the line and caused a rupture, which would have resulted in a release to Clear Creek. The City Engineer requested we leave the soils that provided stability to the water main.

The excavated soils were transported to a lined staging area on the Upper Terrace in an area prepared for future use as a parking lot. The final stockpile contained 2,800 tons of impacted soil and was periodically inspected and maintained as needed until final remedy implementation.

After characterization activities were complete, the feasibility of several remedial alternatives was evaluated. The primary requirement of the selected alternative was that it be protective of human health and the environment by eliminating, reducing, and/or controlling risks posed through each evaluated Site pathway. The remedy selected included offsite disposal of the characterization soil stockpiled on the Upper Terrace. In December 2011, the remedy was implemented with all stockpiled soil transported and disposed at the Allied Waste solid waste facility north of Golden..

The key findings of the Lower Terrace characterization work concluded:

- Impacted soil from the Lower Terrace was acceptable for disposition in a solid waste landfill; and

- Source material was removed and soil remaining on the Lower Terrace had an average uranium concentration of 5.45 mg/kg, which is within the range of values observed in the Clear Creek alluvium background study.

In 2012, a confirmatory gamma survey was conducted on the entire Lower Terrace and findings reported to the CDPHE indicated ambient levels or radioisotopes across the Lower Terrace (Stoller 2012).

Appendix 2

2.1 Demography and Land Use

This appendix presents further details concerning the physical characteristics of the Site presented in Section 2.

The demographics and potential resource utilization of the Site and surrounding area are important in furthering the understanding of the remedial objectives. The remedy focused on reducing, or if possible, eliminating impacts to resources and health effects to the surrounding population and environment.

Demography

In 2010, the population of the City of Golden was 18,867 based on data from the 2010 U.S. Census. The Golden city limits extend approximately 1.7 miles to the north of the Site, 1.5 miles to the east of the Site, and 3.2 miles to the south of the Site.

Land Use

Land use near the Site includes residential, commercial, and rangeland. The State of Colorado owns a large portion of the surrounding area has a variety of university-related uses, including athletic fields, classrooms, recreational facilities, housing, maintenance, and administration. Additionally, the City of Golden has offices, a community park, recreation center, and a water treatment plant on the north side of Clear Creek across from the Site. The Upper Terrace includes a pedestrian walkway/bike path and a recycled asphalt parking lot used only during School sponsored athletic events. The residential, commercial, municipal, and agricultural facilities and their distances from the Site as obtained by direct field reconnaissance and map measurements are as follows:

- West - condominiums along Clear Creek are located about 1,500 feet west of the Site.
- South - a housing area along Parfet Estates Drive. The closest house is about 1,300 feet from the Site.
- North - a public campground is located about 50 feet from the Site on the north side of Clear Creek. Ponds associated with the City of Golden’s water treatment plant are about 200 feet northwest of the Site. The City of Golden’s offices are about 100 feet to the north. A recreation center is located about 300 feet to the north with a 40-unit apartment building about 300 feet north of the recreation center (600 feet north of the Site). The dairy originally located 3.6 miles north of the Site is no longer in business.
- East - the School’s football stadium shares the eastern boundary with the Site. Condominiums are on the west side of Maple Drive within 150 feet of the eastern gate. The closest house on 12th Street is about 600 feet from the Site. The closest School building is 700 feet to the southeast.

National Historic Preservation Act Considerations

Potential historical and archeological resources were evaluated during preparation of the RAOA. The Colorado Historical Society advised that no significant historical or archeological resources are known in the immediate vicinity of the Site. Additionally, the City of Golden’s Planning Department also advised that no known historical or archeological resources were present on the Site.

2.2 Climate

This appendix presents further details concerning the climate at the Site presented in Section 2.

Information for the local meteorology was obtained from a number of sources. Local weather observation stations near the Site include a National Oceanic and Atmospheric Administration (NOAA)-maintained weather station (precipitation) located about 3.5 miles south of the Site (operational record 1975 to present). The RAOA referenced information weather stations in Wheat Ridge (operational record 1981 through 1988), Lakewood Station (operational record 1962 to 2000), and Golden (operational record 1989 to 1995). Average temperatures and precipitation for the area are available from websites such as http://www.weather.com. The RAOA referenced an anemometer that operated during a period from May 1979 to March 1980. The meter was located about 4,000 feet west of the Site in Clear Creek Canyon (Figure 1). Wind speeds at the anemometer location are biased because of the effects of the canyon but provide directional information relevant to the Site.

Precipitation

Average annual precipitation listed for the Golden area is about 17.1 inches (www.weather.com) but varies significantly along the Front Range. The NOAA weather station located to the south indicates a precipitation average of 13.4 inches (maximum 18.7 inches, minimum 7.5 inches) over 27 years. For the Front Range area, about 70 percent of the total annual precipitation occurs between April and September due to upslope conditions and thunderstorm activity. The greatest amounts of precipitation typically occur in April, May, and June when the average monthly totals exceed two inches. Precipitation minimums occur in December, January, and February when the average monthly precipitation is generally less than one inch. Front Range evaporation potential exceeds the annual total precipitation. Typical total annual pan-evaporation is about 60 inches, and total annual lake evaporation averages about 41 inches. Approximately 71 percent of the evaporation occurs between May and October.

Temperature

The average annual temperature is about 47.3 degrees Fahrenheit (°F). The highest average monthly temperatures typically occur in July and August and range between 68°F to 70°F. In December and January, the lowest average monthly temperatures are generally observed and range between 28°F to 29°F. Area temperatures can range from -26°F to 104°F.

Wind Direction and Speed

Average wind speed information collected from the three weather stations varied little from month to month. The data indicate that maximum winds and wind gusts are higher in the winter than in the summer. Increased wind speeds in the winter are probably due to the passage of storm fronts causing strong down slope conditions. Average annual wind speed in the Denver area is about 9 miles per hour. However, wind speeds are often higher along the foothills near the Site (no Site-specific data were located).

Two major meteorological conditions determine the direction of air movements in the Golden area: synoptic flows and local flows. Synoptic flows are wind patterns that affect areas on the order of several thousands of square miles that are characterized by meteorological systems on the scale of high and low pressure systems as shown on weather maps. In the absence of a dominant synoptic flow, local flows become the prevalent factor in the air movement. These winds typically follow the topography of an area with air flows draining from higher elevations toward the lower elevations.

The Site is in a unique location relative to wind direction that is closely represented by the wind rose (Figure 1). The wind direction information from that location was evaluated and a wind rose was developed to visualize that data. Wind data are an incomplete data set collected from May 1979 to March 1980 and were used as part of the RAOA evaluation. The wind rose shows the percentage of time that the wind blew from each of the 16 wind directions monitored. The wind was calm for only about 1.4 percent of the time during the measurement period. Based on a review of wind rose and area weather data, the predominant wind direction is from the west to east and reflective of drainage flows that are common along the Front Range. On an annual basis, the wind blows from the west approximately 60 percent of the time and from the east approximately 35 percent of the time with minor excursions from the north and south. Midday warming of the plains can generate east to southeast winds, creating an upslope flow along the Front Range. During the night, the cooler air flows down the mountainside across Golden and into the Denver Basin to the east. The night-time flows can start early in the evening and persist into the midmorning and early afternoon.

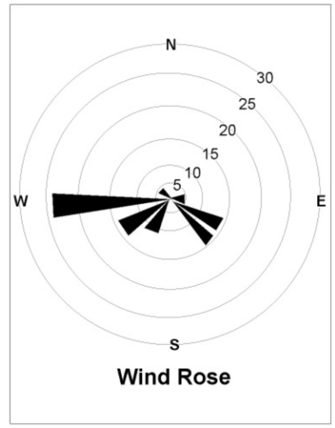


Figure 1. Rose diagram depicting wind direction

2.3 Geology

This appendix presents further details concerning the geologic setting at the Site as presented in Section 2.

The Site is located along the eastern edge of the Rocky Mountain Front Range foothills. The Front Range is a complexly faulted anticlinal arch of primarily Precambrian crystalline rocks that reach elevations of over 14,000 feet. The foothills include the areas where “older” deposits were folded and pushed aside as the “younger” Rocky Mountains uplifted. The foothills rock types range from unconsolidated sediment deposits (25 thousand to 1 million years old) to sedimentary rocks (primarily sandstone and shale – 300 million to 63 million years old) to igneous and metamorphic rocks (over 1 billion years old). These formations remain as horizontal layers beneath Denver and the eastern plains. The Clay Pits area is a surface expression of the unconsolidated sediment deposits (Laramie/Fox Hills sandstone – these deposits have been tilted almost vertical) and the bedrock underlying the Site includes the Laramie, Fox Hills, and Pierre Shale, as shown in the cross section Figure 2-4. The Golden fault, a high-angle reverse fault, is present along the eastern edge of the foothills west of the Site.

In addition to the broader discussion of geology presented here, Section 2 of the report includes two detailed Site-specific cross-sections (Figure 2-5 and Figure 2-6) based on data collected during site characterization work.

Bedrock Structure

Figure 2-3 is a bedrock geologic map of the area showing the Site location and surrounding features. Figure 2-2 shows the surficial geologic deposits found on site. Weimer (1976) developed a geologic cross-section of the Site vicinity. Weimer’s cross section shows that the geologic strata are overturned and steeply dipping. Measurements of the strike of the beds in the Clay Pits area show a North 37° West trend with dips ranging from about 70° to 80° to the west (Grant 1990). Farther east, the beds become vertical and then east dipping. Erosion activity of an earlier Clear Creek event along with construction activities appears to have removed the surface expression of the Laramie/Fox Hills sandstone north of the Clay Pits. The Site is located in an area of surficial deposits overlying (from west to east) the Pierre Shale, Fox Hills

Formation, and the Laramie Formation. As shown in Figure 2-3, the Site is located in the Pierre Shale unit, a sequence that is at least 2,000 feet thick at this location.

As evident on Figures 2-3 and 2-4, the Golden fault cuts through the area just west of the Site. Van Horn (1976) characterizes the fault as a moderately to steeply west-dipping reverse fault of large displacement. This fault was extensively evaluated as part of investigations at the Rocky Flats Plant to the north. As a result of these evaluations (summarized in Appendix B of the RAOA), the Golden fault is not an active fault (i.e., movement has not occurred in the past 35,000 years and multiple movements have not occurred in the past 500,000 years).

Bedrock Stratigraphy

The stratigraphic units presented in Figure 2-4 are described below in order of decreasing age, oldest to youngest. These summaries are primarily from Van Horn (1976, 1995 – oral communication for RAOA) and Weimer (1976).

Precambrian (pC) – These metamorphic rocks are resistant but mostly covered by colluvium west of the Site and form the eastern-most slopes of the Front Range. Although outcrops are present, individual units are generally difficult to follow for any distance. Precambrian rocks in this area are believed to be overlain with angular unconformity by the Fountain Formation.

Fountain Formation (PPf) – This sedimentary unit is not exposed in the immediate vicinity of the Site but is believed to be present on the west side of the Golden fault under the alluvial fan materials shown in Figure 2-4. The Fountain is a pink to reddish-orange, coarse- to fine-grained, arkosic conglomeratic sandstone and conglomerate interbedded with lenticular, dark-reddish brown, silty, indurated mudstone and pinkish-gray, fine-grained, quartzose sandstone.

Pierre Shale (Kp) – Small areas of Pierre Shale are evident along the western end of the former settling pond, exposed by the erosion action of Clear Creek. Weimer (1976) characterized the unit as consisting of dark gray shale with minor, thin laminae of tan-weathered limonitic siltstone and silty, very fine-grained sandstone. Pierre Shale underlies much of the Site, including part of the parking area. The Pierre Shale is estimated to be at least 2,000 feet thick beneath the Site.

Fox Hills Sandstone (Kfh) – In the immediate vicinity, exposures of the Fox Hills are limited because of localized faulting. Where exposed, the sandstone is tan to yellow, fine-grained, subrounded, friable, calcareous sandstone with thin beds or laminae of siltstone and gray montmorillonitic claystone. The exposed thickness of the Fox Hills near 12th Street (Figure 2-3) is about 40 feet; however, the exact thickness is questionable because of faulting and could be as much as 75 feet (Weimer 1976). As shown in Figure 2-3, the Fox Hills underlies a part of the eastern-most practice field and some of the former Site buildings and parking area. The outcrop of this formation is visible to the west of the Clay Pits site.

Laramie Formation (Kl) – The Laramie is well exposed in a clay excavation south of Birch and 12th Streets. The thickness of the Laramie is about 350 feet and the formation is subdivided into two stratigraphic units. The lower unit (western-most unit) is about 190 feet thick near 12th Street and consists of four major sandstones that alternate with mineable kaolinitic claystone. The thickness of the individual sandstones and claystones varies from 20 to 40 feet. The sandstones are light gray to buff, fine- to coarse-grained, poorly sorted, subangular, and silty. The kaolinitic claystone units contain light to medium-gray, blocky weathering claystone with lesser amounts of dark gray to black carbonaceous claystone and thin coal streaks. Additionally, the lower Laramie contains a mineable coal seam. A monument over the Old White Ash coal mine is located at the intersection of Birch and 12th Streets. The surface trace of the main worked seam is located to the east of the monument and is 8 feet thick; a second mined seam, 10 to 20 feet to the west of the primary seam, is 3 feet thick (Emmons, et al., 1896). These seams were mined in the late 19th century to a distance of about one mile north of Clear Creek and several hundred feet south of 12th Street. The surface trace of the coal mine is presented in Figure 2-3.

The upper Laramie is about 160 feet thick and is similar in lithology to the lower Laramie, except that the sandstones are much thinner and finer grained. Neither coal nor carbonaceous shale is associated with the upper Laramie claystone. Figure 2-3 illustrates how the Laramie underlies the western half of Brooks Field and the eastern portion of the Site.

Arapahoe Formation (Ka) – The Arapahoe overlies the Laramie to the east and is 300 to 500 feet thick. It is composed of discontinuous beds of sandstone and claystone. The exposure in the Clay Pits south of Brooks Field shows the lower Arapahoe is predominantly a conglomerate and conglomeratic sandstone with minor intercalations of gray claystone and siltstone. The upper Arapahoe is not exposed in the immediate area. The Arapahoe underlies the eastern half of Brooks Field and part of the eastern Site access road.

Denver Formation (TKdv) – To the east of the Arapahoe lies the Denver Formation, which is not exposed in the immediate vicinity. The Denver consists of light gray to brown tuffaceous silty claystone, tuffaceous arkose, and esitic conglomerate. The base is marked by the first appearance of volcanic material.

Geologic Characteristics of the Surficial Deposits / Soils

The surficial deposits that overlie the bedrock near the Site include the following (the order presented below does not show the age relationship) and are depicted on Figure 2-2:

- Louviers Alluvium
- Younger Alluvial Fan Colluvium
- Post-Piney Creek Alluvium
- Artificial Fill

More information (e.g., thickness of these surficial deposits) is located in the test pit and boring logs included in previous RI/FS documents.

Louviers Alluvium (Qlo) – The Louviers forms a well-defined terrace in the Clear Creek valley and is the oldest of the alluvial deposits present in the area shown in Figure 2-2. The deposit is typically a coarse cobbly sand and gravel that is poorly sorted. Generally, less than 10 percent silt and clay is present. Just east of the area shown in Figure 2-2, the Louviers has sub-round to round pebbles and cobbles of granitic rocks. Boulders as large as one-foot across are present, but the common large size is 6 inches. Based on the subsurface work performed at this location, this unit is about 10 feet thick and extends south under the baseball and practice fields to the approximate location shown where it narrows against the bedrock. It dominates the Upper Terrace portion of the Site. The Louviers is overlain by younger alluvial fan, colluvium, and artificial fill deposits. Locally, the Post-Piney Creek Alluvium overlies eroded Louviers deposits.

Younger Alluvial Fan (Qyf) – In the location shown in Figure 2-2, this unit is associated with the current Chimney Gulch drainage and overlies the Louviers. This deposit is believed to have formed before the deposition of the post-Piney Creek Alluvium. The materials present in the deposit associated with the

Chimney Gulch drainage consist of a poorly sorted, heterogeneous mixture ranging from boulders to clay. The upper few feet are clayey silt grading downward to coarser materials. The thickness of this unit varies but is expected to be as much as 40 feet in the area mapped in Figure 2-2.

Colluvium (Qco) – Colluvium consists of materials that have been moved down steep slopes by creep and sheet wash, and at a few places, they represent minor alluvial fan deposits. The colluvial deposits grade into and interfinger with alluvial terrace deposits and the younger alluvial fan deposits. It is mostly a massive to crudely bedded sandy to clayey silt but locally either sand or clay can predominate. Colluvial deposits generally overlie very irregularly sloping bedrock surfaces. While this may be typical at many locations, they are known to overlie the Louviers deposits over a portion of the area covered in Figure 2-2.

Underlying the colluvial material is an alluvial cobble zone. The cobble zone consists of a small quantity of pinkish-reddish sand intermixed with numerous flat cobbles/boulders (up to 12 inches). See the following description of the Post-Piney Creek Alluvium. Up to 13 feet of this alluvial material was encountered in the borings. During the 2004 RI, this zone could not be penetrated by the backhoe used for the test pits.

Post-Piney Creek Alluvium (Qpp) – This alluvial unit is present along Clear Creek and the youngest alluvial unit in the area mapped in Figure 2-2. It consists of coarse sand and gravel deposits. This unit was the main unit involved in the Lower Terrace characterization effort.

Artificial Fill (af) – Artificial fill areas were identified during the RAOA and are shown in Figure 2-2. The identified fill was used primarily for highway construction and for enhancing the usable area of the athletic fields and the adjacent area. The fills include tan to brown clay, medium to stiff, silty, sandy, and slightly gravelly (athletic field) and the artificial fill consists of silty clay to clayey sand with some gravel and construction debris (softball field area).

Upon completion of the 2007 RI/FS and implementation of remedial activities, the Upper Terrace portion of Site was released by CDPHE. The School re-graded a large portion of this area and imported fill material to accommodate construction of a new soccer field and an access road from 11th and Maple west to the proposed site of a new parking area immediately north of the soccer field.

In large part, the fill encountered during the RI in the Lower Terrace did not appear to be placed to enhance the useable area on the Lower Terrace or to extend the footprint of the Upper Terrace for development. Fill material was heterogeneous, non-compacted, and contained a variety of debris with no evidence of building foundations or infrastructure. In short, fill on the terrace slope and Lower Terrace appeared to be dumped from the top of the terrace rather than placed. The fill included debris (i.e., large timbers, crucibles, concrete, drum carcasses, metal, pipes, ore, etc.) in a poorly sorted matrix ranging from clay to large boulders. In places the fill appeared to be native alluvial material; however, the presence of manmade objects within this matrix clearly permitted soils to be classified as imported fill.

The following additional artificial fill was identified during the 2007 and 2010 RIs:

- Sandy, silty cobbles mixed with debris assumed to be excavated soil from building foundations and infrastructure on top of the terrace and dumped over the slope
- Imported uniform sand used as bedding material around drainage lines
- Ore from offsite mining operations
- Imported heterogeneous fill mixed with waste from historic laboratory operations

- Bricks and miscellaneous building debris mixed with varying mixtures of clay and sand and cobbles

- A variety of bricks, large hand-hewn timbers, metal, and miscellaneous debris that may in some instances pre-date CSMRI activities

The topographic evaluation also shows that the channel of Chimney Gulch formerly may have been located about 130 feet east of its current location, which would place the old channel beneath the western access road.

Because of the extensive construction activities on the Site, very little “A” horizon material remained (Figure 2). Small areas of an “A” horizon were encountered along the northern side of the eastern and western access road. A treed area located along Clear Creek in the northeastern corner of the Site has a shallow “A” horizon underlain by sandy, silty sub-soils. The majority of the Site is covered with “B” or “C” horizon subsoils that were exposed as the buildings and roads were constructed.

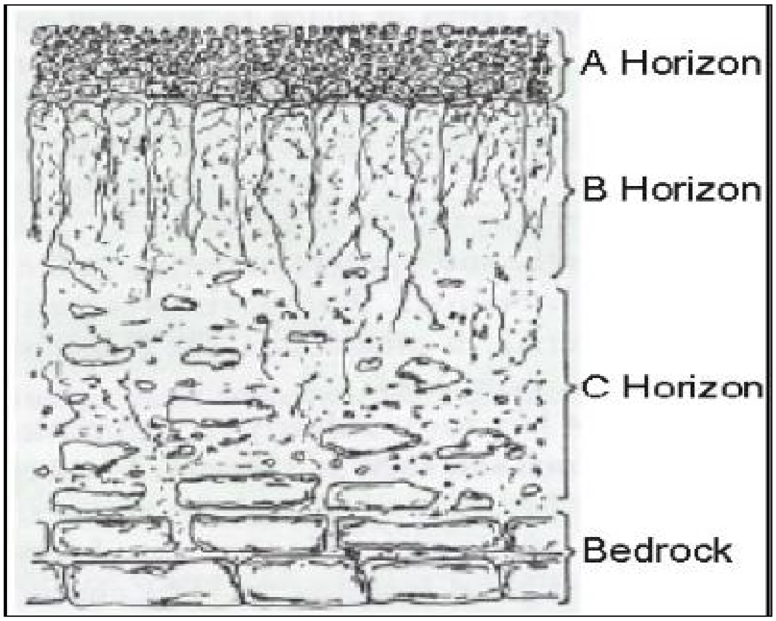


Figure 2. Schematic Representation of a Hypothetical Soil Profile with Underlying Parent Rock

2.4 Surface Water and Groundwater

This appendix presents further details concerning the surface and groundwater use near the Site as presented in Section 2.3.

Surface-Water Uses

Surface water diverted from Clear Creek is primarily used for water supply and secondarily for recreation and irrigation purposes. The City of Golden pulls water from Clear Creek upstream of the Site and treats it for domestic use. Diversions present within approximately one mile of the Site are described in the following sections.

Welch Ditch Diversion (Closed 2006)

This ditch originated on the south side of Clear Creek about 1.8 miles upstream of the Site (west). The Welch Ditch passes approximately 900 feet south of the south end of the Site (about 650 feet south of the Clay Pits) near monitor well CSMRI-2. Water from the ditch is used for irrigation and is not used for domestic purposes. The ditch is unlined and flows along the side of the hill above the Site to the east, through a tunnel and culverts in the vicinity of the School student housing and the Clay Pits. From here, it flows around the southern perimeter of Golden, along the north side of South Table Mountain above the Coors brewery, and then to the east into the Federal Center. The ditch is a major source of groundwater recharge for the Site drainage when it is in operation. Overflow from the ditch is diverted down the Chimney Gulch drainage. The Welch Ditch was permanently closed in 2006.

Church Ditch/City of Golden Diversions

This ditch originates on the north side of Clear Creek about 0.9 miles upstream of the Site (west). The major water users served by the Church Ditch include the cities of Broomfield, Northglenn, Thornton, Westminster, and Arvada. Water is used for municipal purposes, including drinking water. The City of Golden also diverts some of its municipal water at the Church Ditch headgate, and that water is incorporated into the city's drinking water supply. Treatment facilities for Golden are located on the northern side of Clear Creek near the Site.

Agricultural Ditch Diversion

This diversion originates on the south side of Clear Creek about 3,000 feet downstream (east) of the Site. The Agricultural Ditch is the first surface-water diversion downstream of the Site. The major water users served by the Agricultural Ditch include a major municipal supplier to the cities of Lakewood and Wheat Ridge. Some of the water is also used by Arvada, Golden, and unincorporated areas of Jefferson County, in additional to a number of other smaller industrial and agricultural users.

Farmers' Highline Canal and Ditch

This diversion originates on the north side of Clear Creek about 3,500 feet downstream (east) of the Site. The major water users served by the Farmers' Highline diversion include the cities of Westminster, Thornton, Northglenn, and Arvada. Water is used for municipal purposes, including drinking water. Coors and several small irrigation users also divert from the ditch.

Groundwater Uses

Groundwater wells, applications, and permits were identified for a 1-mile radius around the Site from information provided by the Colorado Division of Water Resources. A copy of that information is included in Appendix B of the New Horizons' 2004 RI/FS. An evaluation of that information shows that as many as 20 wells may be in use within a 1-mile radius of the Site. The identified uses include nine for industrial, ten for domestic, and one for household purposes. Yields range from 1 gallon per minute to as much as 85 gallons per minute. The nearest wells are located on the north side of Clear Creek within 500 to 1,000 feet of the Site. The nearest well on the south side of Clear Creek is over 2,000 feet away. The nine industrial use wells are alluvial wells owned by Coors Brewing Company are to the northeast of the Site at distances in excess of about 2,000 feet in locations near Clear Creek. Water taken from the industrial use wells, as well as the domestic and household wells, may be used for drinking water purposes according to the Colorado Division of Water Resources use classification.

No unacceptable exposure to contaminants in groundwater is occurring or is likely to occur. No groundwater uses downgradient of the Site are threatened by the elevated uranium because on the basis of quarterly surface water analytical results there has been no measurable discharge to surface water in excess of surface water standards. Additionally, there are no existing or reasonably anticipated exposures through cross-media transfer, including the following:

- Volatilizations into buildings; no buildings exist on the Site and existing covenants would require engineering controls for new structures
- Hydraulic connections to surface water or other aquifers; no connections exist to surface water on the Site and the Fox Hills aquifer beneath the Lower Terrace is upwelling into the shallow alluvial aquifer
- Agricultural or other non-domestic use; groundwater at the Site is not used for these purposes

Water-Bearing Units

In the area shown in Figure 2-3, groundwater is present in the following bedrock units: the Laramie/Fox Hills units, the Arapahoe, and some of the Denver Formation. Groundwater is also present in the Louviers Alluvium and Post-Piney Creek Alluvium. The Laramie/Fox Hills and the Arapahoe are important aquifers of regional significance and the Louviers Alluvium, Post-Piney Creek Alluvium, and the Denver Formation can be locally significant. Regional studies by Robson (1983 and 1984) and Robson et al. (198la, 1981b) indicate that the outcrop areas for these units in the area covered in Figure 2-3 are part of the recharge area. Recharge is primarily expected to occur from direct rainfall and snowmelt infiltration and by percolation from Clear Creek directly through the alluvium. However, RI observations suggest the reach of Clear Creek along the northern Site border may be a gaining reach because of the artesian nature of Laramie/Fox Hills aquifer in this area (nested wells confirm this gaining nature).

The most relevant water-bearing unit on the western side of the Site is the alluvial deposit above the weathered Pierre Shale (Figures 2-2 and 2-3). The Pierre Shale acts as an aquitard, allowing water from infiltration and nearby stream losses to move downgradient to Clear Creek. The Pierre Shale was encountered in four of the borings installed as part of the 2004 RI. Depth to the unit varied from about 10 feet below ground surface (bgs) north of the former Building 101N location to about 40 feet bgs near the baseball field. The groundwater-bearing zone above the formation varies between about 1 to 4 feet above the unit near the former Building 101N location and between about 6 to 15 feet near the baseball field. Groundwater was encountered about 30 feet below the baseball field and about 54 feet below the practice fields during the RAOA. More detailed discussions of the subsurface conditions, including groundwater are provided in Section 4.

The most relevant water-bearing unit on the eastern side of the Site is the Laramie/Fox Hills aquifer (Figure 2-3). The outcrop of the Arapahoe Formation appears to be located to the east of the Site and does not influence Site hydrology. The water bearing unit underlying the Lower Terrace and observed during RI field work was the Post-Piney Creek Alluvium.

Groundwater Hydrology

This section discusses the local groundwater hydrology of the Upper Terrace and Lower Terrace areas. Groundwater sampling was conducted on a quarterly schedule at the Site to assess water quality impacts and long-term trends.

A complex groundwater system underlies the Site because of the area geology. Bedrock in the vicinity is a complicated system of nearly vertical sediment deposits overlying Precambrian, crystalline bedrock. Sediment layers that once were located deep under the Denver Basin were pushed up as a result of the uplift of the Rocky Mountains. The Site is located at the western edge of the Denver Basin aquifer system, which includes the Dawson, Denver, Arapahoe, and Laramie/Fox Hills aquifers. These aquifers are unconfined along these uplifted beds, and the potentiometric surface (water table) associated with each aquifer is typically closer to the surface than the majority of the aquifer. The aquifers are confined in the deeper, central portions of the basin, providing the pressure required to raise the groundwater potentiometric surface.

Water level measurements from monitoring well CSMRI-14 located in the central portion of the Lower Terrace and completed in the Fox Hills aquifer determined that beneath the Site water from this aquifer is upwelling into shallow alluvium groundwater.

Groundwater in the Upper Terrace and Lower Terrace occurs under unconfined conditions. Groundwater flow in the Lower Terrace area is heavily influenced by the seasonal fluctuations of Clear Creek. Hydrographs of Lower Terrace monitor wells show a strong relationship between the stage height of Clear Creek (USGS station 06719505 Clear Creek at Golden, Colorado) and a recorded response in the chemistry and water elevation. Groundwater in the Upper Terrace area generally flows to the northeast and north toward the Lower Terrace and Clear Creek. The surficial deposits are mainly recharged by infiltration of precipitation and to a limited extent by irrigation of the natural turf baseball field. Section 4 describes groundwater in greater detail.

Surface-Water Hydrology/Quality

The Site is located immediately south of Clear Creek, the primary surface-water conveyance in the area. Clear Creek is a perennial tributary of the South Platte River with a drainage basin area above the Site of approximately 400 square miles. The headwaters of Clear Creek are located along the Continental Divide near Loveland Basin Ski Area. From the headwaters, the stream drops over 8,000 feet in about 50 miles, passing through steep canyons on its way to the Golden area. East of Golden, Clear Creek flows through the plains for about 14 miles to its confluence with the South Platte River in Denver, Colorado.

APPENDIX 3

3.1 Sampling to Determine Ambient Uranium Concentrations

The flood plain consists of Clear Creek alluvial deposits lying unconformably above three steeply dipping bedrock formations. Samples from each of these four deposits (3 bedrock and the one alluvium) were collected from locations not associated with the CSMRI Site and analyzed for total uranium metal to determine a background uranium concentration.

Alluvial river material similar to the CSMRI flood plain deposits was collected from a similar depositional feature (flood plain) approximately 1,000 meters upstream of the Site. To properly assess ambient/background soil conditions and to eliminate bias from previous activities associated with CSMRI, the sediment samples were collected upstream of CSMRI where similar alluvial bars have been deposited.

Background bedrock samples were collected from the formations that underlie the flood plain area from outcrops near the Site. Bedrock formations at the Site include, from older to youngest age, the Pierre Shale, Fox Hills Sandstone, and the Laramie Formation. Each of these formations was encountered in the test pits from west to east, respectively, and these formations are well exposed as near vertical outcrops immediately south of the Site.

Fifteen alluvium and three bedrock samples were collected that were representative of area background conditions, unaffected by historic activities associated with the Site. These samples were submitted to an analytical testing laboratory and tested for the presence of uranium. The analytical results were then used to statistically determine an ambient uranium concentration for the alluvial sediments. Statistical analysis was conducted for ambient concentration determination using the guidelines established by the CDPHE (CDPHE 1997).

The term “ambient” is used in this document to describe background samples collected within the Clear Creek drainage system but upstream of the Site and outside the area influenced by historic activities conducted at the CSMRI. The term ambient was selected to acknowledge that unaltered background samples do not exist along the Clear Creek drainage as a result of historic mining for more than a century. Evidence of this is shown in the 1888 photograph (Appendix G of the Flood Plain Characterization Work Plan) where smelter operations are present just northwest of the CSMRI flood plain site prior to its being developed. Although ambient soil samples were collected from an alluvial bar upstream of these historic smelter activities, there is little doubt that it was impacted by mining operations further upstream.

Analytical results for the ambient concentration of uranium from the alluvial sediments upstream of the CSMRI Site and from bedrock outcrops south of CSMRI have been tabulated and are presented in Table 1.

Table 1
Summary of Ambient Soil Sample Results for Alluvium

Ambient Alluvial Sample Number and GPS Way Point	Uranium Concentration (mg/kg)
00010-001 (Way point 77)	5.50
00010-002 (Way point 78)	2.50
00010-003 (Way point 78) (duplicate of 00010-002)	2.10
00010-004 (Way point 79)	2.40
00010-005 (Way point 80)	1.90
00010-006 (Way point 81)	2.90
00010-007 (Way point 82)	1.70
00010-0081 (Way point 83)	1.50
00010-009 (Way point 84)	1.90
00010-010 (Way point 85)	4.10
00010-011 (Way point 85)	1.60
00010-012 (duplicate of 00010-011)	2.00
00010-013 (Way point 86)	2.90
00010-014 (Way point 87)	7.40
00010-015 (Way point 88)	1.70
00010-016 (Way point 89)	4.50
00010-017 (Way point 90)	5.20
Bedrock Background Sample #	**Uranium Concentration (mg/kg)**
00010-018 (Way point 91) Pierre Shale	1.2
00010-019 (Way point 92) Fox Hills Sandstone	0.430
00010-020 (Way point 93) Laramie Formation	0.100

mg/kg - milligram per kilogram

3.2 Study of Ambient Uranium Concentrations

The following sections describe the field work conducted in the acquisition of ambient alluvial soil samples that were submitted for analytical testing of uranium. The ambient samples provide a baseline concentration of uranium for the Clear Creek alluvium against which the Lower Terrace uranium data can be compared.

Location

Ambient soil samples were collected on the opposite side of and upstream of the CSMRI Site. Previous releases of the former tailings pond from the CSMRI Site would have biased any downstream sampling to establish ambient concentrations of uranium in alluvial deposits within the creek bed area. Accordingly, an upstream location with a similar depositional environment similar to the flood plain area at CSMRI was selected. A hand-held global positioning system (GPS) was used to record the locations of the ambient sample test pits, and the sample locations are presented in Figure 1.

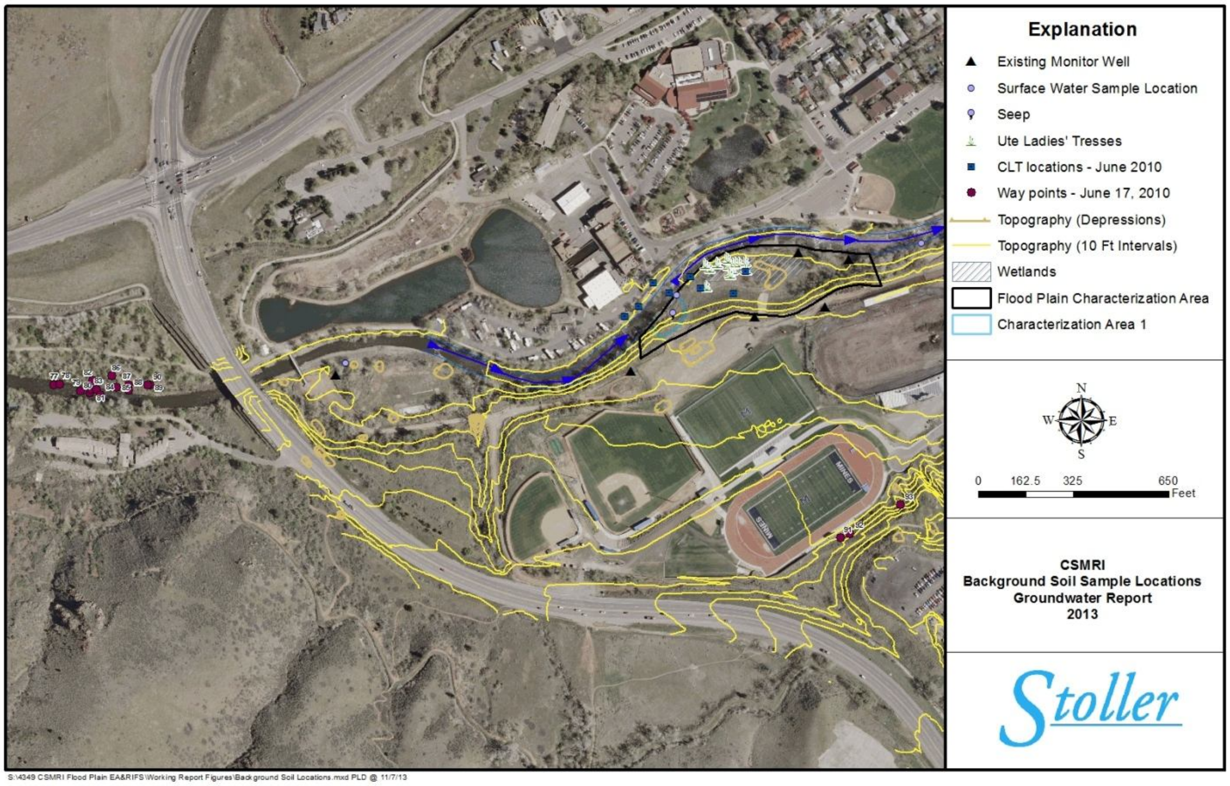


Figure 1. Background Alluvium Soil Sample Locations

Sampling Procedure

Test pits for ambient soil samples were hand dug on June 17, 2010. The pits were extended approximately 12 inches, and disposable plastic scoops were used to collect a sample from the test pit. In many cases, shallow groundwater was encountered due to the proximity to Clear Creek running at its seasonal high. The soil samples were typically poorly sorted, gravelly sand with a thin organic soil horizon at the surface.

The soil sample was placed in laboratory-provided jars and labeled with the sample number, date and time of sampling, and requested analyses. Two duplicate samples were collected by homogenizing the sample and placing the sample into two containers. All sampling equipment was decontaminated between sampling events with distilled water and then dried with paper towels. The ambient uranium samples were then placed in an iced cooler and couriered the same day to ALS Laboratories, Inc. of Fort Collins, Colorado, with a completed chain of custody.

Bedrock background samples of the Laramie Formation, Fox Hills Sandstone, and Pierre Shale were collected south of the CSMRI Site at the outcrops of each formation, as identified on the Colorado School of Mines Geology Trail. Fresh outcrop face exposures were created by scraping back the exposed face and then collecting a sample of bedrock directly into the sample containers. A hand-held GPS was used to record the location of each sample location. These samples were placed in the same iced cooler as with the ambient soil samples and couriered to ALS for analytical testing. No duplicate bedrock samples were collected. Requested parameters included uranium per EPA method SW 6020.

Laboratory Analysis Statistics

Ambient soil results for uranium are presented in Table 1. The data set for the ambient alluvial soil results has a non-normal distribution. This requires the data set be log transformed before statistical analysis. CDPHE guidance (Proposed Soil Remediation Objectives) indicates that log transformed data should have a reverse transformation performed after statistical analysis to get meaningful results. Table 2 provides summary statistics for both normal statistics and log transformed/reverse transformed results.

Table 2
Comparison of Normal and Log Normal Statistics

	Raw Data (mg/kg) (Normal)	Log-Transformed Data (mg/kg)
Mean (μ)	3.047	0.991
Standard deviation (σ)	1.702	0.492
μ+2σ	6.450	7.199
95% UCL	3.922	3.468

Descriptive statistics (normal) of the ambient alluvial samples collected west of the CSMRI Site have been tabulated and are presented in Table 3. The ambient alluvial analysis incorporates the two duplicate alluvial samples for a total of 17 samples (15 samples + 2 duplicates) in the data set.

Table 3
Ambient Alluvial Uranium
Normal Descriptive Statistics (mg/kg)

Mean	3.047
Standard Error	0.413
Median	2.400
Mode	2.900
Standard Deviation	1.702
Sample Variance	2.895
Kurtosis	1.176
Skewness	1.357
Range	5.900
Minimum	1.500
Maximum	7.400
Sum	51.800
Count	17.000
Largest (1)	7.400
Smallest (1)	1.500
Confidence Level	(95.0%) 0.875

The descriptive statistics indicate the average of the ambient alluvial samples is 3.05 mg/kg (ppm) with a standard deviation of 1.7 mg/kg (ppm) and a 95 percent confidence level of 0.875 mg/kg (ppm). The value of uranium concentrations in ambient soil samples ranges from a maximum of 7.4 mg/kg (ppm) to a low of 1.5 mg/kg (ppm). The positive skewness value indicates slightly more observations below the mean than above the mean and the mean is greater than the median value. The positive kurtosis value indicates a peaked distribution.

An evaluation of the Relative Percent Difference (RPD) between the two duplicate sample sets indicates values of 17.4 and 22.2 percent difference. An RPD of less than 50 percent is acceptable given the heterogeneous nature of the poorly sorted alluvial sediments (Chishti 2005).

Analytical results of the flood plain bedrock and background bedrock samples have been tabulated and are presented in Table 4. Three different bedrock formations are present in the flood plain area and the analytical results are separated accordingly.

Table 4
Flood Plain Bedrock and Background Bedrock Analytical Results

Formation	Flood Plain Bedrock Uranium (mg/kg)	Background (Outcrop) Bedrock Uranium (mg/kg)
Laramie	Test Pit 8 0.41	0.100
Fox Hills Sandstone	Test Pit 4 2.0	0.430
Pierre Shale	Test Pit 2 2.4 Test Pit 3 7.7 Test Pit 6 2.0	1.2

mg/kg = milligrams per kilogram

Because of the small data set for each of the formations and varying bedrock lithologies between the test pit sample and the available outcrop samples, a meaningful statistical comparison between flood plain bedrock and ambient bedrock cannot be established. In the case of the Laramie Formation, coal was encountered in Test Pit 8 but a coal outcrop does not exist at the Colorado School of Mines Geology Trail due to historical mining activity resulting in the removal of the near vertical coal beds. Additionally, the Pierre Shale samples collected from the test pits were collected in competent bedrock while the Pierre Shale sample from the outcrop appeared to be coarser grained likely a result of weathering and in closer proximity to the contact with the overlying Fox Hills Sandstone.

Proposed Uranium Concentration for Ambient Site Soil

Based on the results of the analyses and statistical evaluation of ambient alluvial soil collected upstream of the CSMRI Site in a similar depositional environment, a mean uranium value of 3.05 mg/kg (ppm) with two standard deviations of 1.7 mg/kg (ppm) yields an ambient uranium value for this work of 6.45 mg/kg (ppm) and is proposed for ambient alluvial soil. Log transformation of the data results in an ambient uranium concentration (mean + two standard deviations) of 7.2 mg/kg.

3.3 Clear Creek Water

Clear Creek water has concentrations of dissolved uranium that range from 0.4 µg/L to 2.2 µg/L. The highest dissolved uranium concentration for the surface water locations was 2.2 µg/L in December 2011 at SW-1 and SW-3. Table 5 presents a complete listing of the uranium results from surface water sampling events.

Table 5
Statistical Comparison of Upstream and Downstream Surface Water Dissolved Uranium Quarterly Analytical Results

Uranium Concentration (µg/L)			
Date	**SW-1**	**SW-2**	**SW-3**
2/25/2005	1.97	1.29	NT
6/14/2005	0.75	0.69	NT
9/7/2005	1.04	1.62	NT
12/20/2005	2.11	1.5	NT
3/15/2006	1.59	1.52	NT
6/14/2006	0.61	1.44	NT
9/13/2006	1	0.89	NT
3/1/2007	1.7	1.7	NT
6/27/2007	0.6	0.57	NT
9/11/2007	0.94	0.97	NT
11/27/2007	1.8	1.7	NT
2/27/2008	2	2	NT
4/18/2008	1.9	1.8	NT
9/25/2008	1.1	0.99	NT
12/3/2008	1.6	1.5	NT
3/16/2009	1.9	1.9	NT
6/24/2009	0.55	0.59	NT
9/24/2009	1.1	1.1	NT
12/17/2009	1.7	1.9	NT
3/9/2010	2	2	NT
6/9/2010	0.46	0.52	0.49
9/9/2010	1	1	0.98
12/8/2010	1.6	1.7	1.7
3/2/2011	2	2.1	2
6/8/2011	0.63	0.75	0.64
9/21/2011	0.88	0.87	1.1
12/7/2011	2.2	2.1	2.2
3/14/2012	1.9	1.8	1.8
6/12/2012	0.54	0.5	0.54
9/26/2012	0.9	0.76	0.83
12/5/2012	1.7	1.8	1.7
Average	1.35	1.34	1.27
Result Difference SW-1:SW-2	0.006		
% Difference	0.48%		

NT=Not Tested

Appendix 4

4.1 History of Monitoring

This appendix presents further details concerning the history of groundwater monitoring of the Site presented in Section 4.1.

Prior to February 2005, the CSMRI Site was sampled by other consultants at various times. The site was first sampled in January and June 1991 by Grant and Associates, and samples were sent to Barringer Laboratory for analysis. URS Greiner Woodward Clyde performed sampling activities in March, June, and October 1999 and sent samples to CORE Laboratory for analysis. New Horizons Environmental Consultants conducted sampling in February, April, July, and October 2003 and sent samples to Paragon Analytics (now ALS Laboratory Group) for analysis. Since assuming responsibility of the quarterly sampling program, Stoller has continued to send aqueous samples to ALS Laboratory Group to maintain data consistency. However, some samples requiring analysis are hand delivered to Test America, because they have short holding times and the laboratory is in close proximity to the CSMRI Site. These include nitrate (NO_3), nitrite (NO_2), ferrous iron (Fe^{2+}), ferric iron (Fe^{3+}), sulfide (S^{2-}), and total dissolved solids.

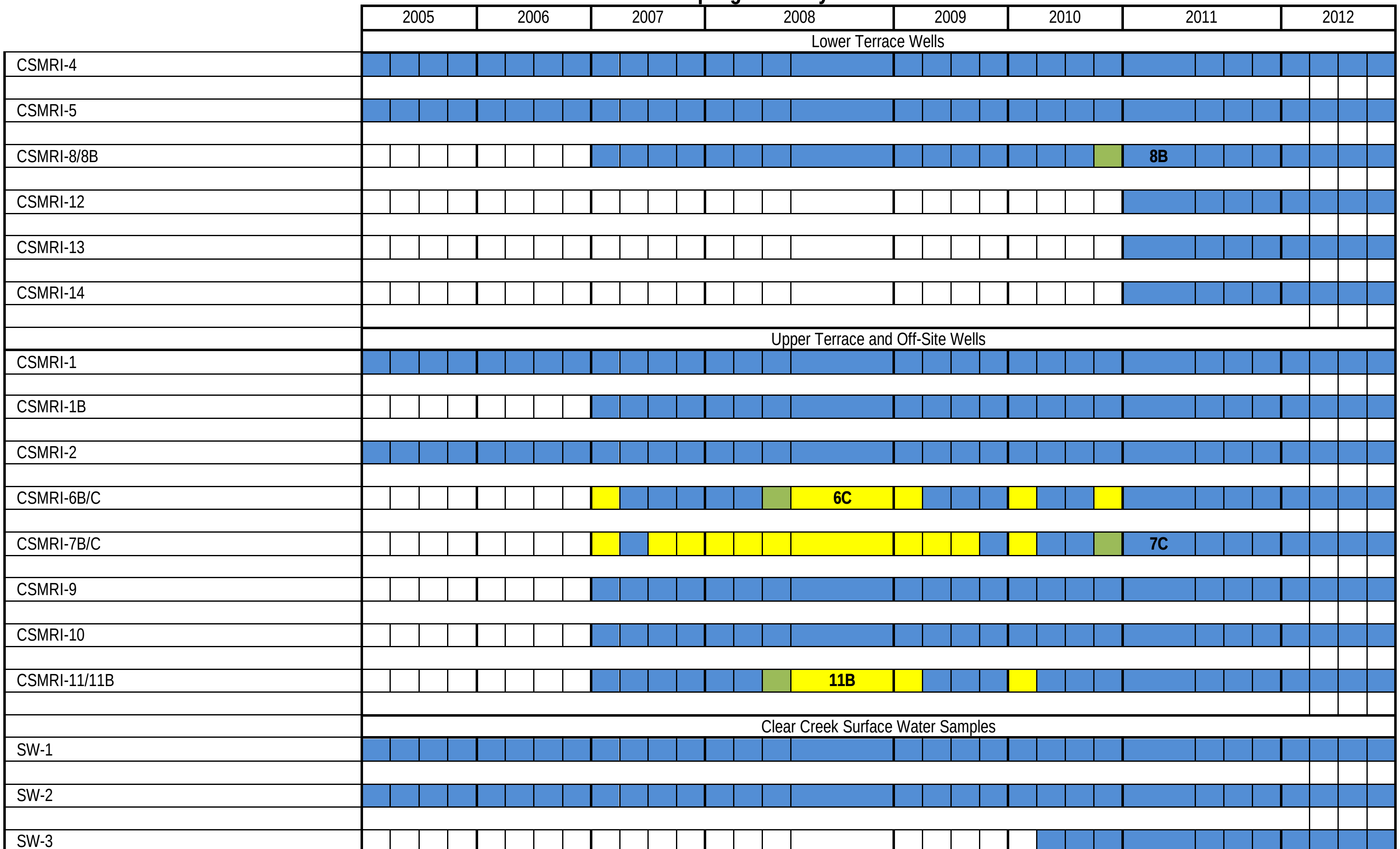
The current groundwater-sampling program implemented by Stoller began in February 2005 with the four existing monitor wells (CSMRI-1, CSMRI-2, CSMRI-4, and CSMRI-5) and surface water locations (SW-1 and SW-2). SW-1 is located upstream of the Site on Clear Creek near CSMRI-1, and SW-2 is located downstream of the Site also on Clear Creek. These sampling locations are included in the current quarterly monitoring program. Prior to Stoller's involvement, one additional site monitor well CSMRI-3 had been sampled by previous consultants and subsequently abandoned.

In February 2007, following soil remediation activities on the Upper Terrace portion of the Site in the summer of 2006, seven new monitor wells were installed (CSMRI-1B, CSMRI-6B, CSMRI-7B, CSMRI-8, CSMRI-9, CSMRI-10, and CSMRI-11). In the summer of 2008, monitor wells CSMRI-6B and CSMRI-11 were abandoned because their locations interfered with construction of the School's new soccer field. On December 1 and 2, 2008, following construction of the new athletic facilities, two replacement wells (CSMRI-11B and CSMRI-6C) were drilled in close proximity to their original locations.

In September 2010, as part of the Lower Terrace soil characterization and removal of contaminated soil, monitor wells CSMRI-7B and CSMRI-8 were abandoned because they were located within the boundaries of the planned excavation area. In January 2011, three new monitor wells were installed on the Lower Terrace as well as two replacement wells. In addition, two previously drilled well locations were deepened to include a sump for better capture groundwater. The two replacement wells (CSMRI-7C and CSMRI-8B) were located in close proximity to their original locations, 1.5 and 5.9 feet, respectively.

Monitor wells CSMRI-12 and CSMRI-13 were new wells drilled within the Lower Terrace to provide additional water quality and potentiometric surface data following the removal of contaminated soil. CSMRI-14 penetrated into the Fox Hills Formation beneath the shallow alluvium aquifer to collect water quality data and evaluate whether a downward migration pathway existed for the area showing elevated dissolved uranium. The two previously drilled monitor wells CSMRI-6C and CSMRI-11B were both over drilled in their original location to penetrate into the underlying bedrock formation. A history of groundwater monitoring and surface water sampling events conducted by Stoller since 2005 is shown in Table 1 and description of installed monitoring wells is shown in Table 2.

Table 1
CSMRI Well Sampling Summary



Sample Taken
Well Dry
Well Not Yet Installed
Well Temporarily Abandoned

* 6C,7C,8B,11B Represent Replacement of Wells
After Soil Removal Activities

Table 2
Description of Installed Monitoring Wells

Well Number	Reason Installed	Information Learned
CSMRI-1	Installed as upgradient well in Clear Creek alluvium.	Consistently Ca-Cl water type. Background well, dissolved uranium has a mean value of 1.6 µg/L.
CSMRI-1B	Requested by CDPHE to assess groundwater quality on the Upper Terrace following cleanup activities.	Only isolated incidents of dissolved uranium above safe drinking water standard. Not impacted by Clear Creek.
CSMRI-2	Upgradient bedrock (Laramie/Fox Hills) well.	Consistently $Ca\text{-}HCO_3$ water type with average dissolved uranium in groundwater is 0.87 µg/L.
CSMRI-4	Installed to evaluate Lower Terrace groundwater conditions near former settling pond.	The groundwater uranium concentrations decrease moving east across the Lower Terrace. Groundwater geochemistry influenced by Clear Creek and surface water infiltration.
CSMRI-5	Installed to evaluate Lower Terrace groundwater conditions near former settling pond.	Influenced by Clear Creek water. Most downgradient Lower Terrace well. Has never exceeded safe drinking water standard.
CSMRI-6B	Requested by CDPHE to assess quality of Upper Terrace groundwater following cleanup.	Western portion of Upper Terrace has limited groundwater recharge. Has never exceeded safe drinking water standard.
CSMRI-6C	Re-drilled to create a sump for sample collection.	
CSMRI-7B	Requested by CDPHE to assess quality of Upper Terrace groundwater following cleanup.	Limited groundwater recharge on western portion of Upper Terrace. Elevated dissolved uranium.
CSMRI-7C	Re-drilled to create sump for sample collection.	Has never exceeded safe drinking water standard following removal of contaminated soil.
CSMRI-8	Requested by CDPHE. Identified elevated dissolved uranium in groundwater.	Identified westernmost portion of Lower Terrace as having elevated uranium in soil. Influenced by Clear Creek.
CSMRI-8B	Re-drilled near original location to assess conditions on the Lower Terrace following soil cleanup activities.	Contaminated soil removal effective. Uranium contamination decreased from a high of 1,900 to about 100 µg/L following cleanup. Influenced by Clear Creek.
CSMRI-9	Requested by CDPHE to assess quality of Upper Terrace groundwater following cleanup.	Average about 40 µg/L dissolved uranium but has been in the center of several surface disturbances. Waters in this well flow onto the Lower Terrace.
CSMRI-10	Requested by CDPHE to assess quality of Upper Terrace groundwater following cleanup.	Has never exceeded safe drinking water standard.
CSMRI-11	Requested by CDPHE to assess quality of Upper Terrace groundwater following cleanup.	Has never exceeded safe drinking water standard.
CSMRI-11B	Deepened to create a sump for sample collection.	Has never exceeded safe drinking water standard.
CSMRI-12	Requested by CDPHE to assess quality of Lower Terrace groundwater following cleanup.	Groundwater uranium concentrations decrease moving east across the Lower Terrace. Influenced by Clear Creek.
CSMRI-13	Requested by CDPHE to assess groundwater on the Lower Terrace following cleanup of the Lower Terrace.	Groundwater uranium concentrations decrease moving east across the Lower Terrace. Demonstrates impacts of wetlands on geochemistry. Influenced by Clear Creek.
CSMRI-14	Requested by CDPHE to assess the deep Fox Hills aquifer.	Confirmed; upwelling from Fox Hills into shallow alluvial aquifer; the Fox Hills is not impacted by dissolved uranium; water type unique to Site wells.

4.2 Monitoring Well Construction

This section presents further details concerning the location and completion details of groundwater-monitoring wells presented in Section 4.1.1.

Twelve of the 14 wells that are a part of the quarterly groundwater-sampling program are located within the boundaries of the CSMRI Site. Wells CSMRI-2 and CSMRI-1 are located off the CSMRI Site. CSMRI-2 is a background well, located outside the CSMRI footprint south and upgradient of the site and adjacent to the freshman parking lot. CSMRI-1 is also located outside the Site boundary west and upstream of the site, approximately 100 feet south of Clear Creek. CSMRI-4, CSMRI-5, CSMRI-8B, CSMRI-12, CSMRI-13, and CSMRI-14 are located in the Lower Terrace. Monitor wells CSMRI-1B, CSMRI-6C, CSMRI-7C, CSMRI-9, CSMRI-10, and CSMRI-11B are located on the Upper Terrace.

With the exception of monitor wells CSMRI-2 and CSMRI-14, all of the wells are completed in surficial deposits. These wells were slightly over-drilled into bedrock and on the Upper Terrace are screened across the bedrock/alluvium interface to intercept the thin water table. Wells CSMRI-2 and CSMRI-14 were both drilled into the Fox Hills sandstone to the depths of 95 and 55 feet below grade, respectively.

All wells on site, with the exception of CSMRI-2, were screened with 5, 10, or 15 feet of screen. In most cases, 5-foot lengths of screen were used in Lower Terrace monitor wells. These wells tend to be shallow and are largely influenced by Clear Creek, thereby producing large volumes of water. CSMRI-2 was constructed with 30 feet of screen to capture adequate water volume for collecting a sample from the slowly recharging Fox Hills sandstone.

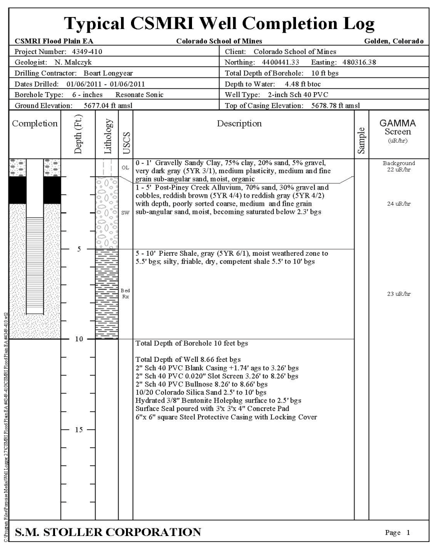


Figure 1. Typical CSMRI Well Completion Log

The wells on site, although installed at different times, were constructed similarly with only minor variations. A sand filter pack extends from the base of the borehole to 2 to 3 feet above the top of the screen. A bentonite seal between 2 and 3 feet thick lies above the filter pack. Bentonite grout fills the remaining annular space between the solid casing and borehole from the top of the bentonite seal to within 1 to 2 feet beneath the ground surface. The well is protected with a steel protective casing set in concrete that extends above grade and is surrounded by a concrete pad. Each well is secured with a lock. A schematic diagram showing a typical CSMRI well completion detail is presented as Figure 1.

4.3 Special Sampling Events

This appendix describes extraordinary sampling events that were performed outside the regularly scheduled quarterly monitoring schedule as referenced in Section 4.1.1.

Radium CSMRI-4 and CSMRI-5, May 2010

During the March 2010 sampling event, Ra-226 was detected in monitor well CSMRI-4 at a concentration of 9.17 pCi/L, which is above the groundwater standard of 5.0 pCi/L. On May 3, 2010, an additional Ra-

226 sample was taken at monitor wells CSMRI-4 and CSMRI-5 to confirm or negate the detection of elevated Ra-226 concentrations. Results of this sampling indicated that the elevated Ra-226 detections were transient and concentrations had decreased to levels normally associated with these wells (below the drinking water standard).

Test Pit and Seep Sampling

On June 2 and 3, 2010, eight test pits were dug within the Lower Terrace as part of a preliminary Site investigation. Groundwater samples were collected from test pits that encountered groundwater. In addition to the test pit samples, a surface water sample was collected from a natural seep located immediately west of monitor well CSMRI-8. The seep was located near several valve boxes associated with City of Golden treated water pipelines and was noticed because the area around the well was perennially wet. A shallow depression was hand dug to act as a sump, and seep water was allowed to accumulate for sample collection using a peristaltic pump. A sample of the seep water was submitted for analytical testing for the presence of dissolved uranium. In addition, the sample was analyzed for trihalomethanes (THMs) to confirm the seep water did not originate from the City of Golden treated water line.

The laboratory analytical results of dissolved uranium as well as the field parameters recorded during sampling from groundwater samples collected from test pits and the seep are presented in Table 3.

Table 3
Groundwater Sample Data from Test Pits June 2010

	Lab Data	Field Parameters					
Test Pit #	Uranium (dissolved) (µg/L)	pH	Conductivity (µs/cm)	Temperature (C°)	Oxidation Reduction Potential (mV)	Turbidity (NTU)	Dissolved Oxygen (mg/L)
CLT-3	250	6.31	1670	14.51	-9	711	11.09
CLT-4	160	6.98	1680	20.82	118	>1000	10.72
CLT-5	35	6.87	Insufficient sample	17.86	110	514	10.64
CLT-6	82	7.26	715	18.91	111	>1000	11.79
CLT-7	69	6.86	1040	19.78	138	363	11.36
CLT-8	86	6.47	1260	13.95	119	139	11.60
CLT-9 (duplicate of CLT-8)	87	6.47	1260	13.95	119	139	11.60
West Seep (west of CSMRI-8)	360	6.94	1330	20.37	3	>1000	6.04

mg/L = milligrams per liter
µg/L = micrograms per liter
µs/cm = microSeimens per centimeter
mV = millivolts
NTU = Nephlometer turbidity units

All groundwater samples collected from test pits exceeded the drinking water standard of 30 µg/L for dissolved uranium. Results ranged from 360 µg/L in the sample collected from the groundwater seep to 35 µg/L in CLT-5 located at the toe of the Upper Terrace slope near the easternmost portion of the characterization area. A clear trend in both quarterly sampling and test pit analytical results demonstrates a decrease in dissolved uranium concentrations across the Lower Terrace from the west to the east. An isoconcentration contour map showing dissolved uranium concentrations from both the second quarter

2010 results of sampling during the week of June 7 through June 10 and test pit analytical sample results collected during June 2 and 3 was combined to provide a snapshot of groundwater quality conditions over a relative short time interval and presented in the preliminary characterization report (Stoller 2010).

The west seep discharge was tested for the presence of THM compounds (chloroform, chlorodifluoromethane, dichlorobromomethane, chlorodibromomethane, and bromoform). Each of these compounds is a byproduct of the interaction of chlorine and organics in water, and the presence of these compounds in groundwater suggests a leaking potable water line. Analytical results indicate these compounds were not detected at concentrations above the analytical reporting limit. Therefore, water emanating from the seep is not the result of a leak from nearby treated water lines but rather groundwater flow from the Upper Terrace. Groundwater on the Upper Terrace had a uranium concentration of 84 µg/L in CSMRI-7B in June 2010, immediately upgradient from the west seep. This indicates that groundwater was interacting with source material located near the seep.

Material from the seep location and surrounding monitoring well CSMRI-7 was subsequently excavated during the source removal effort later that year. The seep has not been observed since that time, and dissolved uranium concentrations in monitor well CSMRI-7C have been below the regulatory limit in the two years following remedy implementation.

4.4 Monitoring Procedures

This section presents further details concerning the groundwater monitoring procedures used for quarterly groundwater-monitoring wells referenced in Section 4.1.1.1 of the report.

Since the goal of groundwater sampling is to collect a representative sample of formation water, standing water within the monitor well is purged before sampling. Well sampling begins by recording the static groundwater-level measurement and measurement of the total depth of the well. These data are needed to create a potentiometric surface map and to calculate the height of the water column and well volume.

Three well volumes of water are then purged from the well unless it goes dry before yielding the desired volume of water. Water quality field parameters are collected after each well volume has been removed. At monitor wells CSMRI-2 and CSMRI-14, water quality parameters are collected every half well volume due to the relatively large purge volume and the fact that both wells routinely purge dry. In addition to these two wells, Upper Terrace monitor wells CSMRI-1B, CSMRI-6C, and CSMRI-7C are sometimes or always purged dry.

If sufficient water remains in the well after purging three well volumes, sampling can begin. Wells are sampled one of two ways, depending on the depth of groundwater. If groundwater lies at a depth of less than 25 feet, dedicated silicon tubing is used to pump water directly out of the well using a peristaltic pump. Water is filtered using a 0.45 micron filter before filling laboratory-supplied sample containers and preserved as needed. For wells that have water at a depth greater than 25 feet, a bailer is used to collect the sample water. Sample water is placed in a dedicated container from which it is then pumped and filtered into laboratory-supplied sample containers. In those cases where the well is purged dry, a sample is collected once the well recharges with sufficient water volume to allow for sample collection. This may include revisiting the well the next day until the required number of sample containers necessary to perform laboratory analysis has been filled.

Sample information is documented on sample collection logs along with water quality data, including a variety of field parameters such as pH, conductivity, dissolved oxygen, oxygen reduction potential, turbidity, and temperature. Sample containers are labeled, placed in coolers, and chilled to 4 degrees Celsius. Some samples have a short hold time (24 hours) and are hand delivered to a nearby analytical laboratory once the day's sampling activities have been completed. Other samples are kept chilled and are delivered under proper chain of custody to the laboratory once sampling is completed.

Sampling equipment either is decontaminated prior to sampling, dedicated to a particular well, or is disposable. This ensures the integrity of sample water and reduces the chance of cross-contamination. During every sampling event, one equipment blank is submitted to verify that proper decontamination procedures are being followed.

4.5 Historical Summary of Analytical Data Collected

This appendix provides additional details regarding the history of the analytical data collected for Site groundwater-monitoring wells as referenced in Section 4.1.1.2 of the report.

The groundwater sampling program has evolved since Stoller began a quarterly monitoring schedule in 2005. The following is a detailed description of analytes that have been added or removed from the analytical suites over the life of the monitoring program.

Groundwater samples collected by other consultants at CSMRI prior to Stoller's involvement in 2005 were analyzed for Ra-226, total uranium, and Th-230 (1991, 1999, and 2003).

Stoller began sampling groundwater at the CSMRI Site in the first quarter of 2005. Four monitor wells and two surface water locations were sampled at this time: CSMRI-1, CSMRI-2, CSMRI-4, CSMRI-5, SW-1, and SW-2. The sampling suite was expanded and consisted of Ra-226/228, thorium-228/230/232, and uranium-234/235/238, dissolved uranium, and dissolved metals (arsenic, barium, cadmium, calcium, chromium, lead, magnesium, mercury, molybdenum, potassium, selenium, silver, sodium, vanadium, and zinc). This same sample suite remained unchanged for all monitor wells and surface water locations through the end of 2006.

New wells were drilled at CSMRI during the first quarter of 2007 to monitor the effectiveness of the soil remediation activities that occurred on the Upper Terrace during the previous summer. Seven monitoring wells (CSMRI-1B, CSMRI-6B, CSMRI-7B, CSMRI-8, CSMRI-9, CSMRI-10, and CSMRI-11) were added to the groundwater-sampling program. The sampling suite was modified to include nitrate, nitrite, and anions (bicarbonate, carbonate, alkalinity, chloride, and sulfate) while U-234/235/238 was removed, dissolved total uranium remained part of the analytical suite. This sample suite remained in effect through the second quarter 2008 sampling event.

In the third quarter of 2008, dissolved metals (with the exception of uranium) were removed from the quarterly sampling suite, and the frequency was reduced to annual sampling in the second quarter. Thorium-228/230/232 was eliminated from the sampling suite. New analytes were added to the sampling suite at this time, including anions (bicarbonate, carbonate, alkalinity, chloride, and sulfate), cations (calcium, magnesium, potassium, and sodium), total organic carbon [TOC], nitrate/nitrite, and dissolved phosphorus. Ferrous and ferric iron samples were added to the Lower Terrace monitor well sampling suite to include CSMRI-1, CSMRI-4, CSMRI-5, and CSMRI-8.

Monitor wells CSMRI-6B and CSMRI-11 were both abandoned due to construction of the new soccer field and were not sampled. This sampling suite remained in effect for three quarters, through the first quarter of 2009. Monitor wells CSMRI-6C and CSMRI-11B were re-drilled in the fourth quarter of 2008 and added back into the quarterly sampling program for the fourth quarter sampling event.

Beginning with the second quarter 2009, TOC was replaced with dissolved organic carbon (DOC). The annual dissolved metals samples were collected during this quarter as well. This sample suite (minus the dissolved metals sample) was the same in the third quarter 2009. Dissolved phosphorus was permanently removed from the sampling suite beginning in the fourth quarter of 2009.

In the first quarter of 2010, TDS samples were added to the sample suite. Sulfide samples were added to the Lower Terrace monitor well sampling suite (CSMRI-4, CSMRI-5, and CSMRI-8). Dissolved metals samples were collected at all monitor wells during the second quarter sampling event. Sampling at surface water location SW-3 began in the second quarter of 2010.

Ferric and ferrous iron samples were discontinued from the CSMRI-1 sampling suite beginning with the third quarter 2010 sampling event. With the exception of the second quarter dissolved metals sampling, the sampling suite established in the third quarter of 2010 has remained in effect for each subsequent quarter without deviation.

4.6 Field Parameters

This appendix describes field parameters recorded to ensure a representative groundwater sample is collected for laboratory analysis as referenced in Section 4.1.2.2.

Monitoring field parameters is essential for knowing when a representative sample can be collected from the aquifer. As part of collecting quarterly water samples for laboratory analysis Stoller also records field data for a variety of parameters, including pH, conductivity, dissolved oxygen, oxygen reduction potential, turbidity, and temperature. Conductivity is closely associated with dissolved uranium concentrations in many wells. Surface water has a lower conductivity than groundwater because the groundwater has been able to react with the minerals in the soil and rocks in the ground for a longer time. Conductivity is important for what it indicates about the concentration of dissolved ions in water. Conductivity has shown an increasing trend since sampling began in 2005. Among the Lower Terrace wells (CSMRI-4, CSMRI-5, CSMRI-8/8B, CSMRI-12, and CSMRI-13), conductivity readings have increased over time and appear to have leveled off since 2010. The three Upper Terrace wells (CSMRI-9, CSMRI-10, and CSMRI-11/11B) have shown a similar increase in conductivity over time beginning in 2007. Monitor wells CSMRI-8B and CSMRI-9 both experienced a noticeable conductivity spike in June 2009. This spike coincided with the highest dissolved uranium result to date for CSMRI-9 at 99 µg/L. The increasing conductivity trend in the Lower Terrace and Upper Terrace wells generally coincides with the increasing concentrations of dissolved uranium seen in monitor wells CSMRI-1B, CSMRI-4, CSMRI-5, CSMRI-9, and CSMRI-10. Despite being several hundred feet west and upgradient of the site (and therefore not affected by site remediation and construction activities, CSMRI-1 also shows a steady increase in conductivity values since 2006.

pH readings have remained consistent over time and do not demonstrate any particular trends. pH readings generally range from 6.5 to 7.5.

Oxidation/reduction potential (ORP) and dissolved oxygen are two field parameters that are difficult to accurately calibrate and measure while in the field. For example, dissolved oxygen is temperature and atmospheric pressure dependent. These conditions change from quarter to quarter as well as throughout the day. Another factor is that the very actions required to collect a water sample, such as bailing and pumping, tend to agitate the water and introduce O_2, and the amount of oxygen introduced is not consistent from well to well. Therefore, these readings can be difficult to accurately compare from quarter to quarter and can be skewed due to the purging method used at the CSMRI Site. Wells are purged using a bailer, which oxygenates the purge water resulting in artificially high dissolved oxygen readings. No useful long-term ORP or dissolved oxygen trends can be discerned from the field data.

4.7 Data Quality

This appendix provides further detail for ensuring that samples collected for laboratory analysis meet the data quality objectives for the groundwater project as referenced in Section 4.1.2.3.

Data Quality

Laboratory data reports are generated for all samples delivered to the laboratory. Sample results undergo a QA/QC review by Stoller's data validation personnel. Data validation reports are generated for each quarterly sampling event and included in the quarterly report. The data quality indicators used to assess the laboratory data include precision, accuracy, representativeness, completeness, and comparability.

Precision

Precision measures the degree of agreement among repeated measurements of the same characteristic (EPA 1986). It may be determined by calculating the standard deviation (for three or more determinations or relative percent difference [RPD] for two samples) for samples taken from the same place at the same time. The EPA National Functional Guidelines set RPD as one of the required measurements of laboratory precision. Generally, precision is calculated for compounds positively detected in both the original and duplicate samples. For two samples, the following formula is used:

$$RPD = |(\text{original-duplicate})/((\text{original} + \text{duplicate})/2)|$$

Precision is measured in laboratory analyses by evaluating matrix spike and matrix spike duplicate (MS/MSD) pairs and pairs of "unspiked" samples and the corresponding duplicates, as specified in each analytical report. The acceptable RPD range, called "advisory limits" is given on the Form III for each analytical report (EPA 1999). Analytical results in which the RPD is above those limits, is qualified, usually with an asterisk (*) or a "P".

Accuracy

Accuracy measures how close results are to the true value and is determined by comparing analysis of standard or reference samples to their actual value (EPA 1986). In practice, accuracy is determined by measuring the level of contamination in method and equipment rinsate blanks; evaluating performance against known laboratory control samples (LCS); evaluating surrogate recovery; and validating MS/MSD samples.

Results for blanks agree with values generally obtained in field investigations. The affected samples have been qualified and the detection limits have been appropriately corrected to reflect the accuracy of laboratory analyses.

EPA protocols tightly control LCS and LCS duplicate (LCSD) failures. The LCS percent recovery must be within the QC limits for the sample data to be accepted (EPA 1999). When an analytical run has LCS or LCSD failures that directly impact the analytes requested, the samples must be re-analyzed. Due to these tight controls, LCS and LCSD samples demonstrate that accuracy was met for each analytical run.

Representativeness

Representativeness is a qualitative measure that evaluates whether samples and measurements are collected in a manner such that the resulting data appropriately reflect the property to be measured (EPA 1998). Representativeness can be affected by the collection of the sample or by the analysis. Problems with representativeness arise if the samples collected do not extract the material from its natural setting in a way that accurately captures the qualities to be measured, or if a subsample is not representative of the sample because the subsample was collected from the most accessible portion of a non-homogenized sample (EPA 1998). Representativeness is most commonly addressed by defining protocols based on standard techniques and adhering to them throughout a study (EPA 1991). These standard techniques are most commonly addressed by using standard sample collection techniques (from SW-846 and other EPA guidance) and homogenizing samples prior to subsampling.

Completeness

Completeness is the comparison between the amount of valid or usable data originally planned to be collected and the amount of data actually collected (EPA 1986).

Comparability

Comparability measures the extent that data can be compared between sample locations and periods of time within a project or between projects (EPA 1986). Data collected during CSMRI field work was comparable with data collected from previous CSMRI field work, as long as past consultants followed the procedures outlined by the EPA (chemical data were obtained using EPA SW-846 methods [EPA 1986] and standard sampling techniques [from SW-846 and other EPA guidance]). Approved laboratories performed all analyses.

4.8 Monitoring Well Summaries for Wells Outside of the Uranium Plume

This appendix provides further details concerning the analytical data collected from monitoring wells outside of the area showing elevated dissolved uranium and supports Section 4.2.1 of the report.

CSMRI-1

CSMRI-1 has never experienced detections above regulatory guidelines among the various analytes that have been tested. This well provides background data for dissolved uranium concentrations in the shallow alluvial deposits and is located several hundred feet west (upgradient) of the main site. A background value shallow alluvial wells was derived by calculating the mean concentration of dissolved uranium (1.7 µg/L) in CSMRI-1 from a total of 31 quarterly analytical results and adding two standard deviations (2 x 0.68 µg/L). The background dissolved uranium concentrations calculated for Clear Creek alluvium based on the 31 quarterly sampling events is 2.96 µg/L. Like Lower Terrace monitoring wells, CSMRI-1 is influenced by the nearby presence of Clear Creek.

CSMRI-2

In March 2009, total Ra-226 and Ra-228 concentrations exceeded the standard of 5 pCi/L with a concentration of 5.05 pCi/L. This is the only radium detection above the regulatory standard despite this well having higher than normal radium concentrations when compared to other CSMRI wells. This well is located outside the boundaries of CSMRI and completed in the Laramie Formation.

CSMRI-5

No Ra-226 or dissolved uranium detected above the regulatory guidelines has been detected in CSMRI-5 since sampling began in 2005. Dissolved uranium concentrations have seen an increase since September 2006. Dissolved uranium concentrations began to increase at a more rapid pace after the stormwater drain that was originally located closer to CSMRI-4 was relocated to the east, in the area of CSMRI-5. During heavy runoff, stormwater was observed pooling adjacent to CSMRI-5. A soil berm was built in April 2012 to divert stormwater away from the well in anticipation that the decrease in the infiltration of stormwater near the well would have the direct effect of causing a corresponding decrease in dissolved uranium concentrations.

The dissolved uranium concentration from the samples collected before and after the earthen berm construction have not yet demonstrated a decreased trend in concentrations, because the well has not had sufficient time to react to the change in conditions. When the stormwater outfall was realigned near CSMRI-4, it took six quarters before the well returned to its previous uranium levels. This well has never exceeded the drinking water standard, and the mean concentration of dissolved uranium for the last eight quarters is 20.0 µg/L

CSMRI-6B/C

Monitor wells CSMRI-6B, and its replacement well CSMRI-6C, have never detected radium or dissolved uranium at concentrations above the drinking water standard. CSMRI-6B had a history of being dry during many quarters, so samples were only collected intermittently in the first two years after its installation. In the last eight quarterly sampling events following removal of contaminated soil, the mean dissolved uranium concentrations in this monitor well is 14.3µg/L.

CSMRI-10

Monitor well CSMRI-10 has never detected radium or dissolved uranium above the drinking water standard. The mean concentrations of dissolved uranium from 24 quarterly samples is 13.6 µg/L.

CSMRI-11/11B

No radium or dissolved uranium has been detected above their respective regulatory guidelines at monitoring well CSMRI-11/11B. This well is located upgradient from CSMRI-10 and experiences similar dissolved uranium concentrations.

CSMRI-14

In March 2012, both CSMRI-12 and CSMRI-14 detected radium above the drinking water standard. CSMRI-14 detected a concentration of 8.04 pCi/L. The Ra-226 detection in March 2012 has never been reproduced in other sampling events where the mean concentration is around 1.0 pCi/L, and it appears to be an isolated transient occurrence.

This well is the only Lower Terrace well completed in the deeper Fox Hills regional aquifer. Groundwater elevation, temperature, and geochemical data verify that this well is not hydraulically connected to Clear Creek. Other Lower Terrace wells completed in the shallow alluvial aquifer have a hydraulic connection; however, it is clear from potentiometric surface data that there is upwelling from the Fox Hills, and no downward migration pathway from the shallow alluvium aquifer exists.

4.9 Dissolved Uranium Concentrations for Monitoring Wells inside Uranium Plume

This section provides the analytical data collected from monitoring wells that define the area of elevated dissolved uranium and support Section 4.2.3 of the report.

CSMRI-4

Table 4
CSMRI-4

Date	Dissolved Uranium (in µg/L)
2/25/05	24.7
6/14/05	**31.4**
9/7/05	19.3
12/20/05	**34.3**
3/15/06	27.1
6/15/06	26.8
9/13/06	17.9 Source Removal Upper Terrace
3/8/07	**48**
6/27/07	**66**
9/11/07	**49**
11/26/07	**48**
2/27/08	**58**
4/17/08	**62**
9/25/08	**43** Stormwater outfall completed end September 2008 and introduces surface water to Lower Terrace
12/5/08	**61**
3/17/09	**80**
6/23/09	**110**
9/24/09	**160**
12/16/09	**79**
3/10/10	**83**
5/03/10	NT Stormwater outfall realigned downgradient of CSMRI-4
6/8/10	**56**
9/10/10	**62**
	Source Removal Lower Terrace
12/7/10	**73**
3/1/11	**68**
6/8/11	**44**
9/20/11	16
12/6/11	**35**
3/13/12	**77**
6/11/12	13
9/27/12	2.6
12/05/12	13

CSMRI-7B/C

Table 5
CSMRI 7B/C

Date	Dissolved Uranium (µg/L)
6/26/07	**68**
6/10/10	**84**
9/10/10	**75**
Post Soil Excavation	
3/1/11	8.3
6/8/11	5.2
9/20/11	21
12/6/11	5.7
3/13/12	4.2
6/11/12	3.6
9/27/12	3.6
12/05/12	3.6

CSMRI-8/8B

Table 6
CSMRI 8/8B

Date	Dissolved Uranium (in µg/L)
3/8/2007	**1,100**
6/27/2007	**810**
9/10/2007	**630**
11/27/2007	**1,300**
2/27/2008	**1,200**
4/17/2008	**770**
9/25/2008	**890**
12/5/2008	**1,900**
3/18/2009	**980**
6/23/2009	**700**
9/24/2009	**880**
12/16/2009	**580**
3/10/2010	**960**
6/8/2010	**540**
9/8/2010	**520**
12/8/2010	NT (well abandoned)
Well 8B (post soil excavation activities)	
3/1/11	***310***
6/7/11	***410***
9/20/11	***180***
12/6/11	***340***
3/13/12	***380***
6/11/12	***110***
9/27/12	***48***
12/05/12	***73***

CSMRI-9

Table 7
CSMRI-9

Date	Dissolved Uranium (in µg/L)
6/26/07	32
9/10/07	35
3/16/09	34
6/22/09	99
9/24/09	43
12/16/09	39
3/11/10	41
6/9/10	48
9/8/10	31
12/7/10	37
3/1/11	43
6/7/11	49
9/21/11	54
12/7/11	46
3/14/11	50
6/11/12	51
9/21/12	51
12/05/12	49

CSMRI-12

Table 8
CSMRI-12

Date	Dissolved Uranium (in µg/L)
3/1/11	320
6/7/11	220
9/20/11	130
12/6/11	340
3/13/12	380
6/11/12	72
9/27/12	31
12/05/21	58

CSMRI-13

Table 9
CSMRI-13

Date	Dissolved Uranium (in µg/L)
3/2/11	42
6/7/11	47
9/20/11	41
12/6/11	51
3/13/12	58
6/11/12	44
9/27/12	42
12/05/12	44

4.10 Water Types

This section provides further detail about how water type data are used to understand to what extent (if any) groundwater at the Site interacts with surface water and supports Section 4.3.1 of the report.

Groundwater at the CSMRI Site is sampled each quarter for anion and cation analysis. Results from these analyses are entered into AqQA™ software, which then creates Piper trilinear diagrams. These diagrams classify the groundwater at each well into one of five water quality types: Na-Cl, Ca-Cl, Ca-HCO_3, Ca-SO_4 and Na-HCO_3. A histogram shows the frequency of water types found in Site monitoring wells during quarterly sampling events.

Well CSMRI-14 is the only monitoring well on site to show a Na-HCO_3 water type. Wells downgradient from this well do not appear to be affected by this different water type, indicating a limited quantity of water is upwelling.

The three surface water samples are classified as Ca-SO_4 type water. The one exception involving a sample collected from SW-2 was classified as Ca-HCO_3, and this result has never been reproduced. Four of the monitor wells located on the Lower Terrace (CSMRI-4, CSMRI-5, CSMRI-8/8B, and CSMRI-12) have been classified as this water type for at least one quarter. These wells classified as having Ca-SO_4 type water present in some sampling events along with water temperature data confirms infiltration of water from Clear Creek into Lower Terrace alluvium. This mixing causes an increase in the concentration of dissolved oxygen within the shallow alluvial aquifer that results in increased uranium mobility.

Based on these distinct water type chemistries, mixing has decreased significantly in Lower Terrace wells the last eight quarters, which is likely attributed to the current drought conditions that have persisted over the better part the sampling period, further evidence that mixing occurs (Figure 2).

Determination of Kd (Partitioning Coefficient)

Development of the characterization work plan (Stoller 2010) required a determination of how much dissolved uranium would be expected in Lower Terrace groundwater if only ambient levels of uranium were present in soil. The School needed to evaluate the success of the soil cleanup based on groundwater uranium concentrations. One way to achieve this is to determine how much uranium from native soil, containing ambient concentrations of uranium, could dissolve in Site groundwater. The partitioning coefficient (Kd) for uranium, which is a measure of uranium’s ability, or willingness, to dissolve into the groundwater, provided this information. Only by knowing the uranium Kd for the Lower Terrace would we be able to know how much uranium could be dissolved in groundwater if all contaminated soil material were removed. The solubility of uranium in groundwater is dependent on many geochemical factors, such as oxygen content, carbonate content, and microbial activity. Variables that determine the solubility of uranium change over time, so the determined solubility is specific to the conditions that exist at the time of testing. The testing only serves to indicate what it could be at any given time.

Based on geochemical groundwater modeling, the average concentration of uranium in Clear Creek alluvium (3 mg/kg) can result in groundwater concentrations as high as 412 µg/L dissolved uranium.

Whetstone Associates, an experienced geochemical modeling firm, was retained to oversee geochemical laboratory testing and to integrate site-specific field and laboratory data into the Site geochemical modeling.

In addition to the calculation of soil partition coefficients and soil screening level (SSLs) for uranium, Whetstone performed geochemical modeling. This modeling determined the ionic state of the uranium in the groundwater and evaluated the potential for uranium to dissolve into groundwater and/or precipitate from groundwater into Lower Terrace alluvium as it moves from west to east along the groundwater flow path.

When evaluating the soil partition coefficient (Kd) and its usefulness in determining the SSLs, it is imperative to understand that the derived Kd is only a snapshot in time of a dynamic groundwater system that is influenced by many factors. Parameters used in the determination of the Kd are highly variable and are not static within the groundwater system and can vary on any given day across the Site. The following variables at this Site impacted Kd determination and the ability of the groundwater to carry more or less dissolved uranium:

- pH
- Dissolved oxygen (DO) ORP
- The form of dissolved uranium; (predominately mobile uranal carbonates at this site)
- Iron (Fe) and aluminum (Al) hydroxides were slightly oversaturated in groundwater (favorable substrates for uranium adsorption)
- Temperature impacts DO, and some forms of U are thermodynamically precipitated
- Microbial community composition and natural organic matter content

Because the Kd is derived from a snapshot of the groundwater chemistry at a particular location and moment in time, the resulting calculated SSL can only determine that at that particular location, under those chemical and physical conditions, the derived SSL is possible. The Whetstone study used Site soil and water samples from the west end of the Lower Terrace where oxidizing groundwater conditions predominate. The Whetstone report was originally presented in the Preliminary Characterization Report for the Lower Terrace (Stoller 2010).

The background or ambient level of uranium concentration was determined from soil samples collected from an upstream Clear Creek flood plain deposit very similar in geomorphology to the Lower Terrace. The mean uranium concentration in soil was determined to be 3.05 mg/kg with a standard deviation of 1.7 mg/kg (Stoller 2009). This study was originally presented in the Preliminary Characterization Report for the Lower Terrace. This background study, including sample procedures, analytical results, and statistical analysis is included as Stoller 2010. Using the geochemical model produced by Whetstone, the background level of 3.05 mg/kg is capable of resulting in a groundwater uranium concentration of 412 µg/L. The calculated value of 412 µg/L uranium is consistent with quarterly groundwater data where the highest concentration of dissolved uranium attained following soil cleanup was 410 µg/L.

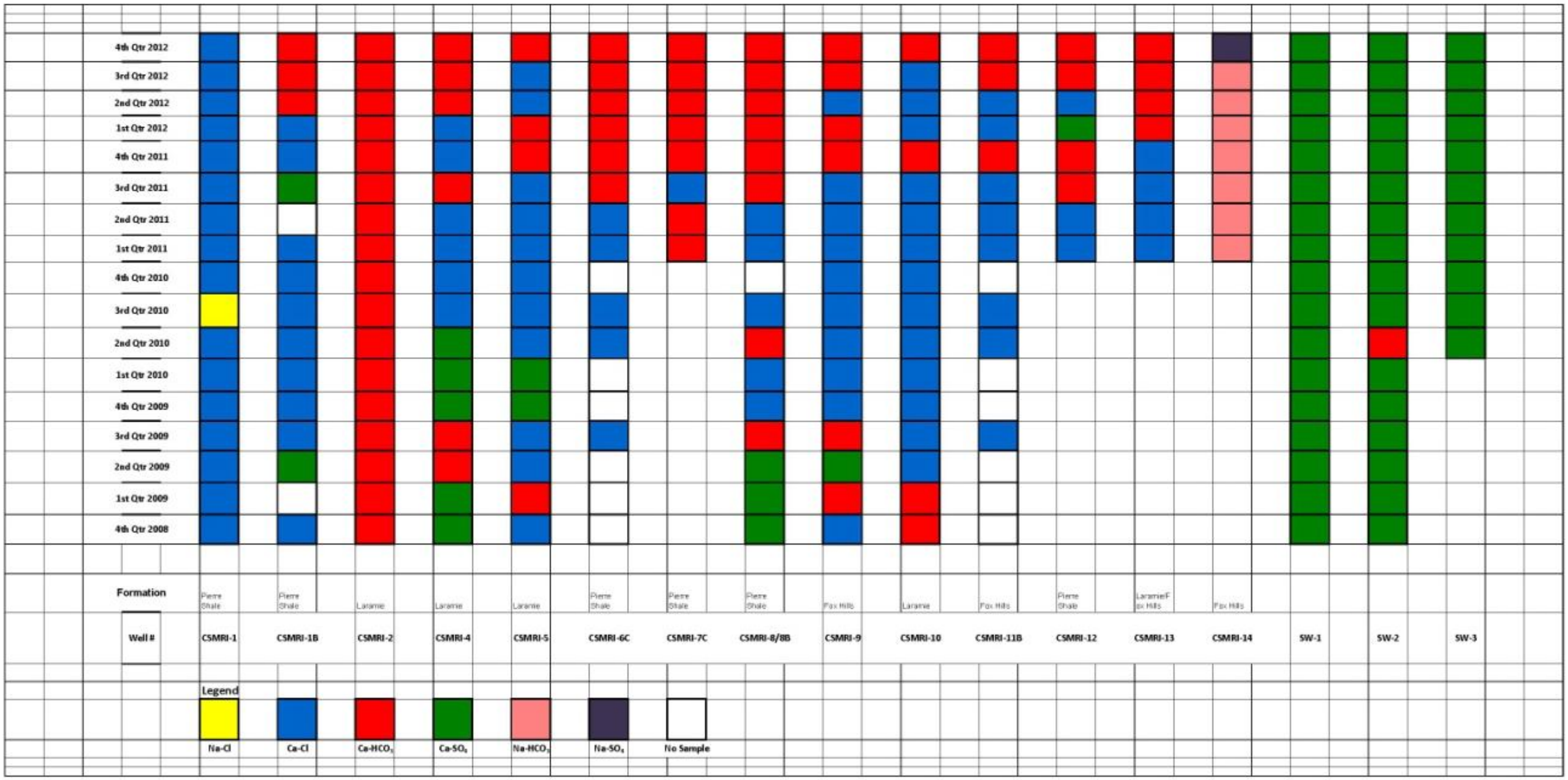


Figure 2. Water Quality Types

4.11 Geochemical Modeling of Uranium

This section explains the reference in Section 4.3 in further detail.

Geochemical modeling was performed to better understand how the uranium concentrations found in the soil may be causing the uranium concentrations found in the groundwater and to determine Site soil screening levels for uranium. The methods used to calculate soil partition coefficients, variables that impact the model, and results of the geochemical modeling effort are described in Section 4.3. The completion of the geochemical modeling work improved the understanding of uranium fate and transport and the physical, chemical, and hydrological nature of the Lower Terrace of the CSMRI Site. The main conclusions from this work are:

- Dissolved uranium in groundwater across the Site decreases toward the east indicating a likely contaminant source for groundwater in the vicinity of CSMRI-8.
- Essentially all dissolved uranium occurs as an easily mobilized carbonate complex, and the Site-specific partitioning coefficient for uranium is very low at less than 0.2 L/kg.
- The ambient concentration of uranium in Clear Creek alluvium is 6.45 mg/kg (mean plus 2 standard deviations), elevated from background by historic mining activities in this area and up Clear Creek.
- The mean concentration of uranium found in the upstream Clear Creek alluvial deposit during the background study background is 3.05 mg/kg. When this uranium concentration is entered into the geochemical model as the SSL, the resulting concentration in groundwater is predicted to be 412 µg/L based on the Site-specific partitioning coefficient.
- Very little soil adsorption of uranium occurs across the Site.
- The consistent shape of the area of elevated dissolved uranium, with highest values centered within the Site and decreasing concentrations toward the east, indicates that the area is stationary within the Lower Terrace.

4.12 Hydraulic Conductivity Determination

This section provides additional detail for the determination of the hydraulic conductivity and flow rate for groundwater on the Upper Terrace and Lower Terrace at the Site as described in Section 4.4 of the report.

Pumping tests were conducted on monitor wells CSMRI-8, CSMRI-4, and CSMRI-5 in conjunction with preliminary Site characterization work. Natural alluvium directly overlays shallow bedrock, and fill has been added over the natural alluvium away from Clear Creek for grading the slope up to the Upper Terrace. The alluvium and fill is poorly graded with grain size range from boulder-sized cobbles to clay. The bedrock surface is coal to the east and shale to the west, both with very low apparent permeability. The surface soils were saturated in low areas and saturated near surface in some test pits. The water table is in the alluvium/fill above the bedrock surface, and groundwater is generally unconfined. It was observed during the digging of test pits that seepage from the alluvium/fill into the pits occurred at several levels that would exhaust with time, appearing as both stratification and localized variation in saturation and free water. These observations indicate vertical/horizontal anisotropy in the alluvium in general, and possibly inconsistent supply of water to the wells under drawdown resulting from localized variation in the aquifer, possibly more likely in the fill than the natural alluvium. The monitor wells are screened from above the static water level through the bottom of the alluvium and into bedrock so the wells intersect the variation in the alluvium. The pumping tests were conducted at very low production rates, so the responses would be sensitive to localized and variable conditions.

Groundwater pump tests were conducted on each of the three monitor wells located within the Lower Terrace. Slug tests, as originally described in the work plans, were not conducted on monitor wells CSMRI-4 and CSMRI-5. Rather a peristaltic pump was used to induce an aquifer response at monitor wells CSMRI-4, CSMRI-5, and CSMRI-8. A 5 pounds per square inch gauge In-Situ Inc. Level Troll 700 pressure transducer/data logger with a usable depth of 11.5 feet of head was used to measure and record responses to the water table from the peristaltic pump. The pump was capable of withdrawing approximately 10 gallons per hour, which was sufficient to induce a response in monitor well CSMRI-8 and a slight response in monitor wells CSMRI-4 and CSMRI-5. The pump test at CSMRI-8 was allowed to run for more than four hours and included a 15-minute recovery test after one hour of pumping; the pump tests at CSMRI-4 and CSMRI-5 were run continuously for two hours and then allowed to recover.

Potentiometric data downloaded from the transducer/data logger were analyzed using AQTESOLV® Pro v. 4.5, with the Theis model and the Moench unconfined model with casing storage and delayed gravity drainage. The storage coefficients and specific yields were restricted to values below 0.15, reflecting the character of the aquifers. Curve matching solutions to Theis and Moench have been summarized and are presented in Table 10. Graphs of the curve fitting of each model and a more comprehensive discussion of the pump tests are included as an attachment.

The low transmissivity observed in CSMRI-8 was subsequently determined during the remedial investigation to be a result of the monitor well being installed in artificial fill material rather than in the alluvial deposits where both CSMRI-4 and CSMRI-5 were installed. Monitor well CSMRI-8 was removed during the remedial investigation. Artificial fill was excavated to bedrock in the area of the well and replaced with washed rock similar to the alluvial fill that is present across the Site. The well was then re-drilled and completed near its original location. When the data are removed from Table 10. the formation appears to have a hydraulic conductivity of 69 ft/day or more across the Lower Terrace.

Table 10
Summary of Lower Terrace Aquifer Properties

Monitor Well	Method	Transmissivity (ft^2/day)	Storativity (storage coefficient)	Specific Yield (%)	Aquifer Thickness (feet)	Hydraulic Conductivity (ft/day)
CSMRI-4	Theis	863	0.15	NA	11.64	74
	Moench	803	0.1	0.15	11.64	69
CSMRI-5	Theis	517	0.05	NA	3.61	143
	Moench	309	0.02	0.15	3.61	86
CSMRI-8	Theis	29	0.02	NA	3.71	7.8
	Moench	22	0.05	0.15	3.71	5.9

Groundwater flow rate differs at various locations throughout the Site. Lower Terrace pump tests were conducted at wells CSMRI-4, CSMRI-5, and CSMRI-8 to determine the hydraulic conductivity of the soil immediately surrounding each well. Both Theis and Moench models were calculated during the pump tests, and it was determined that the Moench unconfined model with casing storage and delayed gravity drainage stimulated the recovery response slightly better than the Theis and was therefore used in determination of each well's hydraulic conductivity. The hydraulic gradient of these wells was determined using the March 2012 Potentiometric Surface Map, which shows water level data from the March 2012 quarterly sampling event. This gradient was determined to be 0.07 ft/ft for CSMRI-4, 0.045

ft/ft for CSMRI-5, and 0.10 ft/ft for CSMRI-8. The groundwater flow rate was then calculated from these two values and the equation:

Hydraulic Conductivity*Hydraulic Gradient=Flow Rate

The flow rates calculated from this formula equal 4.83 ft/day for CSMRI-4 and 3.90 ft/day and for CSMRI-5. Data were not used from CSMRI-8 because it was completed in artificial fill material and not alluvial material. The average flow value was then rounded to 4 feet/day.

No pump tests were performed on Upper Terrace wells, because they lacked sufficient recharge to perform meaningful drawdown test. Because of this, a different method for determining hydraulic conductivity was used. Geologic data from well logs and information about the various formations that are present in this area were compared to published values (Todd 1980) to approximate what the hydraulic conductivity of these units should be. A copy of the representative values of hydraulic conductivity is presented in Table 11.

Table 11 Hydraulic Conductivity

GROUNDWATER MOVEMENT

TABLE 3.1 Representative Values of Hydraulic Conductivity (after Morris and Johnson[45])

Material	Hydraulic Conductivity, m/day	Type of Measurement[a]
Gravel, coarse	150	R
Gravel, medium	270	R
Gravel, fine	450	R
Sand, coarse	45	R
Sand, medium	12	R
Sand, fine	2.5	R
Silt	0.08	H
Clay	0.0002	H
Sandstone, fine-grained	0.2	V
Sandstone, medium-grained	3.1	V
Limestone	0.94	V
Dolomite	0.001	V
Dune sand	20	V
Loess	0.08	V
Peat	5.7	V
Schist	0.2	V
Slate	0.00008	V
Till, predominantly sand	0.49	R
Till, predominantly gravel	30	R
Tuff	0.2	V
Basalt	0.01	V
Gabbro, weathered	0.2	V
Granite, weathered	1.4	V

[a]H is horizontal hydraulic conductivity, R is a repacked sample, and V is vertical hydraulic conductivity.

The three Upper Terrace wells for which flow rate was calculated are screened through the Louviers alluvium. CSMRI-7C is screened from the Pierre Shale, CSMRI-9 is screened from the Fox Hills sandstone, and CSMRI-10 is screened from the Laramie Formation. The Fox Hills and Laramie on the Site are similar formations and according to Todd would likely have a hydraulic conductivity of 4 ft/day. CSMRI-7C in the Pierre Shale would likely have a lower hydraulic conductivity of around 0.4 ft/day.

Hydraulic gradient for each of these wells was calculated in the same manner as the Lower Terrace wells, with the surface map and data from March 2012, and determined to be 0.06 ft/ft at CSMRI-7C, 0.09 ft/ft at CSMRI-9, and 0.055 ft/ft at CSMRI-10. Using the same equation to calculate flow rate as the Lower Terrace wells we determined that the groundwater flow rate of these three Upper Terrace wells is 0.24 ft/day, 0.37 ft/day, and 0.22 ft/day, respectively. Based on this evaluation, a rate of 0.25 ft/day was chosen as a reasonable flow rate for Upper Terrace groundwater.

4.13 Site Conceptual Model

A conceptual model was developed for the CSMRI Site to assist in understanding the data, predict the behavior of the static area showing elevated dissolved uranium in the aquifer going forward, and allow decision makers to visualize complex groundwater processes and interactions. The model contains several essentially constant inputs such as:

- Surface water from Clear Creek,
- Water from the Upper Terrace, and
- Groundwater upwelling from the Fox Hills Formation beneath the shallow alluvial aquifer.

Several processes result from these inputs as well as the presence of the wetland area and an output of groundwater to Clear Creek. Also presented are instances when the model was inadvertently tested by unexpected data and inputs, the results of which strengthened the model. Finally, this discussion of the model, depicted on Figure 3 concludes with bulleted lists of data that support the model.

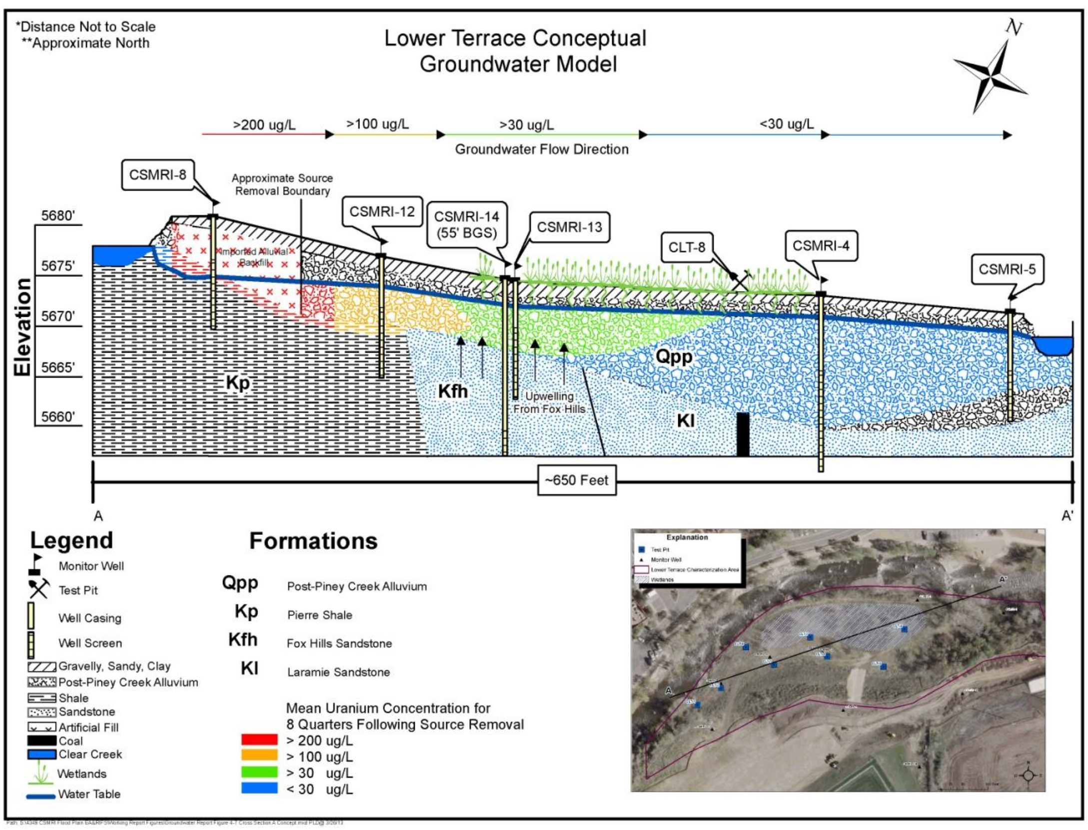


Figure 3. Lower Terrace Conceptual Groundwater Model

The model includes data collected from sampling of soil and groundwater, observations made during site activities, and data recovered during remedial activities. Both the Whetstone study and analytical results from quarterly monitoring demonstrate that the vast majority of uranium is in the form of highly mobile uranal carbonates. As groundwater migrates across the Site, the concentration of uranium decreases, the oxygen content of the groundwater also decreases due to natural biological processes, and the groundwater chemistry changes due to mixing of water from the Upper Terrace, Fox Hills Aquifer, and Clear Creek.

The Site model has Clear Creek water entering the Site at the western end of the Lower Terrace, contacting alluvial material with naturally occurring uranium, mobilizing uranium from this material, then flowing east where a combination of factors such as dilution, dispersion, and biological activity within the wetlands environment all occur contributing to a decrease of dissolved uranium concentrations. The resulting groundwater quality at the east end of the Lower Terrace, where Lower Terrace groundwater exits the site, as demonstrated by wells CSMRI-4 and CSMRI-5, is less than 30 µg/L.

Inputs to the Model

Three distinct water inputs contribute to the Site groundwater, each is discussed and included in the conceptual model. They are surface water infiltration from Clear Creek, groundwater from the Upper Terrace, and groundwater upwelling from the Fox Hills Formation. Each of these inputs is discussed in the following sections; quantities of these waters are based on the flux calculations.

Clear Creek

Water from Clear Creek enters the Lower Terrace along the western (upstream) edge of the Lower Terrace. This conclusion is supported by the following data.

Water temperature data provide a line of physical evidence that Lower Terrace groundwater is predominantly comprised of surface water from Clear Creek. The temperature of the Lower Terrace groundwater varies during the course of each year, matching the variation observed in Clear Creek. In contrast, the temperature of Upper Terrace groundwater is relatively constant throughout the year. This is further supported by the groundwater flux calculations for the Lower Terrace, which demonstrate that 95% of the groundwater flowing past well CSMRI-8 originates from Clear Creek.

Additional evidence supporting the Lower Terrace groundwater being comprised predominantly of Clear Creek water includes the following.

- The chemical classification of Clear Creek water ($Ca\text{-}SO_4$) is consistently found only in surface water samples from the creek. This has been verified in 44 of 45 surface water sampling events. This water type is occasionally observed in Lower Terrace wells (CSMRI-4, CSMRI-5, CSMRI-8/8B, and CSMRI-12), rarely in two Lower Terrace bounding wells (CSMRI-1B and CSMRI-9), and nowhere else.

- The Lower Terrace wells water levels rise and fall with the changing stage of Clear Creek.

- Oxygen content, qualitatively measured in the field, is highest in the wells on the upstream (west) edge of the Lower Terrace and decreases as the water flows east.

Clear Creek water continues to enter the Lower Terrace, adding to the total flow, along the edge of the Lower Terrace next to the creek. This water continues to provide a clean water source for diluting the dissolved uranium concentrations. Just prior to well CSMRI-4, the Lower Terrace starts to narrow and groundwater starts to exit the Lower Terrace into Clear Creek. Water quality data from Clear Creek clearly demonstrates there is no impact to the creek's water quality from the dissolved uranium on the Lower Terrace. This is to be expected when considering the flux calculations that indicate Lower Terrace groundwater (Creek water + Upper Terrace groundwater+ Fox Hills Upwelling groundwater) comprises only 0.1% of the total flow of Clear Creek when the creek is at a low flow time.

Upper Terrace Water

Groundwater from the Upper Terrace moves along the weathered bedrock/alluvial interface and enters the Lower Terrace along its southern edge. The groundwater on the Upper Terrace has very distinct characteristics on the west side of the site where it is underlain by Pierre Shale and the east side where it is underlain by sandstone of the Fox Hills and Laramie Formations. The western portion can be characterized as thin and unusable do to its limited ability to produce significant volume of water. During well sampling, the wells generally exhibit poor recharge and often go dry during the sampling effort. On the eastern portion of the Upper Terrace the groundwater layer is thicker and can move more readily through the weathered sandstone; however, based on its limited ability to provide a usable water source, this groundwater layer is not considered an aquifer.

The quantity of groundwater flowing off the Upper Terrace onto the Lower Terrace (flux) follows the above observations. The quantity of groundwater reaching the Lower Terrace from the area of the Site underlain by Pierre Shale is 33 cu ft/day. The portion of the site underlain by Pierre Shale only comprises a small portion of the Upper Terrace that contributes water to the Lower Terrace. The portion of the Site underlain by sandstone contributes 1,320 cu ft/day to the Lower Terrace.

The Upper Terrace groundwater has less dissolved oxygen than Clear Creek water, has a different geochemical composition, and contains dissolved uranium at concentrations that fluctuate around 30 ppb.

Fox Hills Upwelling

The Fox Hills Formation is a major aquifer for the Denver area. The total exposure of the Fox Hills on the Lower Terrace is approximately 20,000 sq ft. The Fox Hills is bedded fine-grained sandstone with thin beds of siltstone and gray claystone. Only the sandstone portion of this formation readily transmits groundwater. For the flux calculations this portion was estimated to be 50% or 10,000 sq ft.

The deep well that provides the evidence for the upwelling was installed in 2010. The CDPHE requested this well to ensure that none of the Site water containing uranium above the drinking water standard was entering the Fox Hills Formation. The upwelling was verified using water level data that showed the elevation of the top of water in the Fox Hills well is higher than the elevation of the top of water in the shallow well that shares the same location. This confirms water from the deeper aquifer is flowing upward into the Lower Terrace. This water contains little uranium (<2 µg/L) and the oxygen content is low. Water from the Fox Hills Formation is classified as Na-HCO type and is chemically unique on the Site.

Upwelling water, besides allowing for more dilution, results in greater dispersion and keeps the water containing the dissolved uranium near the surface where it is available for biological uptake and greater adsorption to available carbon sources.

Processes

Several processes are occurring in the groundwater of the Lower Terrace: dilution, dispersion, biological activity within the wetlands environment, and adsorption onto sediments and carbon. Each of these processes contribute to varying degrees in different portions of the Lower Terrace and are discussed along with their impact to the groundwater below.

Natural Dilution

Three water sources are actively diluting the area of elevated uranium being naturally formed as Clear Creek water picks up uranium from the ambient alluvial soils. These three waters are, in order of introduction to the system, water from Clear Creek, Upper Terrace water, and upwelling water from the Fox Hills Formation. This is likely the primary mechanism for reducing the concentrations of dissolved uranium in Lower Terrace groundwater, and the influence of each of these is discussed below. These waters dilute the concentration of uranium in the groundwater on the Lower Terrace while impacting the water chemistry.

Clear Creek

Clear Creek water provides the oxygenated water mobilizing uranium at the upstream edge of the Lower Terrace. As detailed in the Implementation Report (Stoller 2009), a small wedge of native alluvial material that separated the Lower Terrace from Clear Creek was not removed during the Lower Terrace remedial action. Clear Creek water entering the Lower Terrace flows through this wedge before entering clean fill used to fill excavations resulting from the remedial action. This clean fill is the only other material this water flows through prior to reaching well CSMRI-8.

At CSMRI-8 the total flow of groundwater through the Lower Terrace is 624 cu ft/day. Of this total flow, groundwater from the Upper Terrace (33 cu ft/day) comprises approximately 5%, with the other 95% being Clear Creek water. Progressing farther east, the percent of water attributable to groundwater from the Upper Terrace increases and water attributable to Fox Hills upwelling enters the system. Based on the flux calculations for various locations farther east of well CSMRI-8, Clear Creek water continues to enter the Lower Terrace until the Lower Terrace begins to narrow in the vicinity of well CSMRI-4. Near well CSMRI-4, Lower Terrace groundwater begins to enter/return to Clear Creek.

A gauging station on Clear Creek is located just upstream from the Lower Terrace. Using the flow rate at this location, during a low flow time of year (late winter) Clear Creek flows at 5 million cu ft/day. The contribution to Clear Creek from Lower Terrace groundwater is less than 0.1% of the total flow of the creek. Eight years of quarterly data on the uranium in Clear Creek demonstrate no measureable effect from dissolved uranium exiting the former CSMRI Site.

Upper Terrace Water

Groundwater flowing toward the Lower Terrace from the Upper Terrace mixes with Lower Terrace groundwater and because it contains less uranium, acts to dilute the uranium concentration in Lower Terrace water. The impact of this is small due to the low volume of water and the concentration of uranium observed in Upper Terrace monitor wells. Temperature data collected during quarterly monitoring events demonstrate the lack of impact this water has on the Lower Terrace water.

Fox Hills Formation Water

Groundwater is upwelling from the Fox Hills Formation, depicted on Figure 3 as squiggly blue arrows in the center of the Lower Terrace. Groundwater from this well (CSMRI-14) has been sampled for eight quarters, and dissolved uranium concentrations range from 1.4 to 2.1 µg/L. By comparison, dissolved uranium concentrations in groundwater samples collected from the shallow alluvium aquifer monitor well CSMRI-13 (which shares the same well pad) range from 41 to 58 µg/L. Water from the Fox Hills

Formation would act to dilute and disperse the uranium in the shallow alluvium aquifer. The upwelling also would tend to keep the uranium-bearing water within reach of wetland biological uptake and fixation.

Dispersion

Dispersion causes mixing of the both the water and the dissolved uranium as the groundwater flows downgradient to the east. Dispersion is a combination of diffusion and mechanical mixing. Mechanical mixing results from the herky-jerky movement of both water and uranium as it forced to move: up, down, left, and right due to the native tortuosity of the microflow paths in the pores of the soil (Anderson 1984).

This tortuous flow, coupled with diffusion, tends to mix the contaminants with cleaner water as the groundwater flows downgradient. Groundwater flow is the predominant factor for spreading contamination, but dispersion plays a part in spreading the contamination somewhat further. Dispersion influences the spread of contamination in all directions: laterally, vertically, and even longitudinally.

The presence of upwelling from the Fox Hills aquifer causes the dispersion to be locally increased due to the upward moving water spreading the uranium-containing water laterally.

Biological Activity

Biological activity within the wetlands area of the Lower Terrace is likely causing some uranium to become immobile. Hibiya et al. (2004) and others have demonstrated that biofilms that form on soil particles are strongly reducing. These films have the ability to reduce uranium and fix it to the particle, when the aqueous geochemistry would otherwise indicate an insufficient reducing environment to allow uranium reduction.

The upwelling Fox Hills groundwater also causes stratification of the Lower Terrace groundwater with clean Fox Hills Formation water pushing the uranium-containing water toward the surface. This puts the uranium water preferentially near the groundwater surface where capillary activity, plant uptake, bacteria fixation, carbon fixation, and localized areas of mild reduction is likely removing some of the uranium from the groundwater.

Adsorption

Adsorption is the process where dissolved particles (uranium) attach themselves to clay minerals, organics, or other particles making them no longer mobile. This process has not been quantified on this site; however, the literature indicates it has the potential to result in a significant decrease in dissolved uranium concentrations (Dudel et al. 2004, Schöner et al. 2004).

Model Conclusions

The one overarching conclusion drawn from the model is groundwater containing dissolved uranium, at a level that could result from background concentrations of uranium in the Post-Piney Creek Alluvium, exists in a limited portion of the Lower Terrace. The portion of the groundwater containing uranium at more than 30 µg/L is not moving downgradient but is stationary. This water exits the site at a dissolved uranium concentration represented by the monitoring wells CSMRI-4 and CSMRI-5 of less than 30 µg/L. A multitude of process work to decrease the uranium concentrations, including dilution, dispersion, biological uptake, biological fixation, and adsorption as the water flows to the east. And, most importantly, there are no impacts to human health or the environment from the Lower Terrace groundwater.

4.14 Critical Evaluation of Conceptual Model

This section describes the evaluation of the conceptual model.

Following conception of the site model, various scenarios were considered to test the model's robustness. Hypotheses were considered to address critical concerns such as what may be acting as the source for the elevated dissolved uranium on the Lower Terrace, where may the source(s) be located, and how could they be mitigated. Several of the possible hypotheses identified early in the investigation were tested and as necessary additional information and/or data were collected and evaluated to address data gaps. Ultimately, all but one of the hypotheses were rejected. The following list of hypotheses were considered during development of the conceptual model as possible sources for the elevated dissolved uranium in groundwater beneath the CSMRI Lower Terrace:

- An unknown source of uranium remained on the Upper Terrace and/or terrace slope
- Hot spots were missed during the characterization, and CSMRI impacted soil is still present on the Lower Terrace
- The water supply tunnel abandoned in place during the characterization contains source material
- A source exists on the west end upgradient of the Lower Terrace
- Ambient concentrations of uranium in alluvium continue to act as a source

The following sections present each hypothesis listed above, the data used to test the reasonableness of each hypothesis, and conclusions as to whether it should be carried forward or eliminated from the conceptual model.

Hypothesis 1: An unknown source for the elevated dissolved uranium is present on the Upper Terrace or terrace slope

The following data were considered when testing whether or not this hypothesis is reasonable:

- The 2006 remediation of the Upper Terrace soils removed metals and radionuclide contamination to below regulatory limits. Cleanup was successfully demonstrated and the Upper Terrace soils closed by the CDPHE.
- Uranium metal was not specifically included as a contaminant of concern; however, evidence gathered during the characterization supports the conclusion that all heavy metal and radionuclide contamination from CSMRI activities were co-located.
- The characterization included evaluation of isotopic uranium and confirmatory sampling verified uranium remaining onsite after soil removal activities were below regulatory guidelines.
- Groundwater from the Upper Terrace is flowing to the Lower Terrace; however, the dissolved uranium concentrations are generally at or below the regulatory guideline. Groundwater on the Upper Terrace is confined to a thin, slow-moving layer where it migrates along the weathered bedrock interface. Slow recharge rates observed during quarterly groundwater monitoring events demonstrate water from the Upper Terrace is insufficient in

volume or dissolved uranium concentrations to provide the source for the uranium contamination within the Lower Terrace.

- The entire Lower Terrace and slope west of CSMRI-8 were removed to bedrock during the 2010 characterization. The only material left in place upgradient of CSMRI-8 was the soil surrounding the City of Golden water lines and native material below the cleanup level. Readings from field screening instruments and confirmatory samples indicated neither of these units were CSMRI-related source material.

- The raw water line was installed along the entire length of the of the terrace slope from west to east at about the mid-point of the slope. During installation, no CSMRI waste or elevated activity was observed in the excavation.

Conclusion

The data do not support the hypothesis that a uranium source exists on the Upper Terrace or terrace slope, and this hypothesis is rejected.

Hypothesis 2: The 2010 characterization failed to identify all CSMRI uranium source material on the Lower Terrace

The following data were considered when testing whether or not this hypothesis is reasonable:

- Soils in a large area that included the central portion of the Lower Terrace were remediated as part of the EPA's Emergency Response in 1993.

- Test pits excavated across the Lower Terrace indicated that the only soil exceeding cleanup goals was located in the westernmost portion of the Lower Terrace. During soil removal, it was confirmed that soil in the western portion of the Lower Terrace in the vicinity of CSMRI-8 exceeded cleanup goals and was removed.

- All CSMRI-impacted soil was removed during the 2010 remedial action from the western portion of the Lower Terrace. Only native alluvium remains in this area.

- A confirmatory gamma survey was conducted on the entire Lower Terrace that indicated ambient levels of radioisotopes across the Lower Terrace.

- Since completion of soil remedial actions, dissolved uranium concentrations have decreased significantly supporting the case that source material was removed.

- Because groundwater flow is from west to east and the highest concentration of dissolved uranium in the groundwater is at well CSMRI-8, the source must be close to or west of well CSMRI-8.

- The area of elevated uranium in groundwater has continually shown a decrease in dissolved concentrations from west to east on the Lower Terrace making a source in the eastern portion of the Lower Terrace impossible.

Conclusion

The data do not support the hypothesis that a CSMRI uranium source exists on the Lower Terrace, and this hypothesis is rejected.

Hypothesis 3: The abandoned water supply tunnel unearthed during the 2010 remediation is providing the source for dissolved uranium

The following data were considered when testing whether or not this hypothesis is reasonable:

- The top of the water supply tunnel was encountered in Pierre Shale bedrock and the tunnel is entirely embedded in competent bedrock with no observable change in grade.
- Review of historic CSM documents confirms the tunnel transported Clear Creek water to a concrete lined well where it was pumped to the surface for use. The length of the tunnel places it in the portion of the Upper Terrace remediated in 2006.
- The tunnel was designed to intersect Clear Creek at or below the 1912 creek level, which was lower than today's level due to more recent man-made efforts to channelize the creek.
- After a 3/8-inch-thick steel plate was placed in front of the entrance to the tunnel, it was filled with an impermeable bentonite plug approximately 3 feet thick and reburied.
- Well water temperature data indicate well CSMRI-8 is in direct connection to Clear Creek and not impacted by Upper Terrace groundwater.

Conclusion

The data do not support the hypothesis that a uranium source exists in the tunnel or that water in the tunnel has any connection to the Lower Terrace groundwater, so this hypothesis is rejected.

Hypothesis 4: An unknown source of uranium exists west of the Lower Terrace

The following data were considered when testing whether or not this hypothesis is reasonable:

- All CSMRI uranium-impacted soil and CSMRI waste identified during the characterization west of CSMRI-8 was removed to the Pierre Shale bedrock from the edge of Clear Creek to the Upper Terrace.
- Confirmatory samples from the west boundary of the terrace slope verified all CSMRI-related uranium-impacted soil to the west was removed from the Lower Terrace to the Upper Terrace during characterization activities.

Conclusion

The data do not support the hypothesis that a uranium source exists west of the Lower Terrace, and this hypothesis is rejected.

Hypothesis 5: Ambient concentrations of uranium adsorbed onto solids in Clear Creek alluvium are responsible for the elevated dissolved uranium

The following data were considered when testing whether or not this hypothesis is reasonable:

- Clear Creek drainage basin receives sediment from multiple mines located in an area known as the Colorado Mineral Belt. Minerals were transported downstream and much of the alluvium within the lower reaches of the creek has been worked to remove placer deposits of gold. A search for historic mining operations in the Clear Creek drainage basin area known to contain pitchblende (UO_2) identified over 30 mines (minedat.org).

- Results of the modeling effort indicated that easily mobilized uranal carbonate complexes are the dominant uranium species account for approximately 99.6 percent of dissolved uranium in the groundwater samples.

- The average ambient concentration of uranium in soils is 3.05 mg/kg, elevated from background by mining activities up Clear Creek.

- Geochemical modeling performed by Whetstone determined that ambient uranium in soil could result in groundwater uranium concentrations as high as 412 µg/L based on the site-specific partitioning coefficient.

- The conceptual model was tested by the introduction of oxygenated water from the stormwater line near CSMRI-4. This dumped thousands of gallons of oxygen-rich water onto the central portion of the Lower Terrace, disrupting the aqueous chemical balance, mobilizing uranium, and causing a spike in wells 4 and 5. The concentration and distribution of the dissolved uranium on the Lower Terrace returned to normal after removal of this water source.

- Dissolved uranium concentrations have decreased to levels consistent with those expected from ambient uranium concentrations since soil remediation activities.

Conclusion

The data support the hypothesis that ambient uranium within Lower Terrace alluvium continues to provide the dissolved uranium observed in monitor wells up to 412 µg/L.

Response to Comments, CDPHE Letter of August 22, 2013

The following paragraphs present the comments raised by CDPHE and provide responses to further support the conclusions given in the draft report. Where practical, references are provided in the comment response to the section of the report that addresses the comment or provides additional information.

Uranium in Soil is at Background

CDPHE Comment: The first argument CSM presents is to compare similar upstream soils with Lower Terrace soils for uranium concentrations. In the geometric form of mean and standard deviation, the two soil populations are very similar and will pass the 95% mean comparison test. However, the Lower Terrace soil uranium concentrations are consistently higher than the upstream soil, and a comparison of populations using the Wilcoxson's Rank Sum test fails at the 1% comparison level. The soil comparison is the strongest argument presented in the report, and should be expanded in the final report. Please bear in mind that the soils argument is indirect, as the regulatory driver is groundwater, not soils. A stronger support to the argument is to compare uranium concentrations in groundwater between the two sites.

Response: The correlation of upstream soil uranium values to the flood plain (Licensed Area) soil values for uranium demonstrates that the alluvium in Clear Creek has elevated uranium from sources outside of CSMRI. The Wilcoxson's Rank Sum test may fail at the 1% comparison, meaning that the likelihood that the two sample populations are identical, is less than 99%. However, the sample populations pass at the 5% comparison level, the widely accepted level for this type of comparison. This matches with the 95% mean comparison test. This is indicative of there being a 95% certainty in the flood plain soils having the same concentration of uranium as the upstream "ambient" soils tested. Collection of groundwater samples from the location of the ambient soil samples is not possible (Section 3.1 and Appendix 3).

Variation of Uranium Concentrations in Groundwater Result from Varying Oxygen Levels

CDPHE Comment: The premise of the second argument is that uranium in groundwater moving through the Lower Terrace is chemically attenuated by a wetlands-induced redox zone. But there is no supporting evidence. The evidence presented actually points to the Lower Terrace being oxidizing and not strongly reducing. This is not a viable argument. An ambient Eh of at least -250 mV is needed to reduce uranium in this water. That condition is not present.

Response: The supporting evidence is that uranium-bearing water enters the wetlands area on the upgradient side and exits the wetlands area on the downgradient end with much less uranium. You are correct in that an Eh of minimally -250 mV is not present (has not been detected) in the bulk groundwater of the Site. The reasons for this are twofold: the wetlands is young and continues to develop and the groundwater flow velocity across the flood plain is high; both of these reasons limit the development of a reducing zone beneath the wetland. However, reduction of uranium has been demonstrated to take place within biofilms that develop on substrates within the water column. This reduction takes place even though the water column is not in a reducing state (Hibiya *et al.* 2004) (Section 2.5). Additional evidence was the large release of the highly oxygenated stormwater from the Upper Terrace, which mobilized uranium causing a record spike for the point of compliance wells, CSMRI-4 (Figure 4-6) and CSMRI-5. This Upper Terrace water overwhelmed the reducing potential of the Lower Terrace wetland and associated biofilms to the point where uranium was no longer precipitated but was mobilized.

Other Comments

CDPHE Comment: To close this site, direct evidence using groundwater data to demonstrate the achievement of closure conditions is needed. The final report should have a substantive quantitative evaluation of the Lower Terrace water flow patterns, water balance, and contamination. This includes contributions from the Upper Terrace and Clear Creek. This information is necessary to evaluate the effectiveness of remediation and to determine the regulatory status of this site.

Response: A site-wide water balance was completed to further demonstrate the flow velocities, directions, volumes, and contaminant loads for the Site groundwater and specifically the Licensed Area on the Lower Terrace. This proved valuable in demonstrating the flow of water on the Lower Terrace and provided strong evidence that the plume is shrinking in all directions and is stationary (Section 4.4.3).

CDPHE Comment: Does the rapid decline of uranium concentrations in wells impacted by known CSMRI contamination (CSMRI-8 and CSMRI-12) support the effectiveness of the 2010 soil remediation?

Response: Yes, these wells are located directly downgradient from the area where impacted soils were removed from the Licensed Area and have decreased in uranium concentration due to the remedial efforts of the School. No more source material is located upgradient of well CSMRI-8, as we removed all possible material. Everything was removed upgradient from well CSMRI-8 except for a berm of native material that protected the excavation from the creek, and the small amount of soil surrounding the City water lines that the City Engineer would not let us remove due to stability concerns. There is no other possible explanation for the reduction in dissolved uranium, except for the success of the soil removal project that reduced uranium levels in soil to ALARA (Figure 4-4).

CDPHE Comment: Do other monitoring well results that appear unaffected by the remediation of the highly impacted soils support a contention that they are cross-gradient hydraulically and represent a different source of uranium? If so, what is the source?

Response: Monitoring wells located downgradient from the Lower Terrace remedial action include wells CSMRI-8, CSMRI-12, CSMRI-13, CSMRI-14, CSMRI- 4, and CSMRI-5. All other wells are either upgradient or cross gradient from the Lower Terrace remedial action (Figure 4-7). Further, all other wells are outside the Licensed Area and have been closed with a groundwater covenant.

CDPHE Comment: Is flow of groundwater from the Upper Terrace into the Lower Terrace a uranium source and/or does it act to increase the flushing action of moveable uranium, if present, in the Lower Terrace?

Response: Upper Terrace groundwater does flow from the Upper Terrace to the Lower Terrace and the Licensed Area. However, the low volume demonstrated by the water balance calculations along with the low uranium concentrations of the Upper Terrace groundwater indicate it is not a source for Lower Terrace or Licensed Area uranium in groundwater (Section 4.4.3).