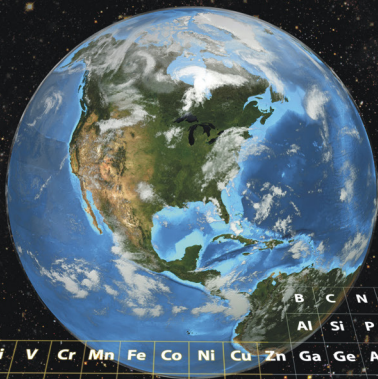


# Environmental Sciences Laboratory

## Uranium-Bearing Evaporite Mineralization Influencing Plume Persistence: Literature Review and DOE-LM Site Surveys

May 2016



U.S. DEPARTMENT OF  
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## 1.0 Introduction

This report on evaporite mineralization was completed as an Ancillary Work Plan for the Applied Studies and Technology program under the U.S. Department of Energy (DOE) Office of Legacy Management (LM). This study reviews all LM sites under Title I and Title II of the Uranium Mill Tailings Radiation Control Act (UMTRCA) and one Decontamination and Decommissioning site to provide (1) a summary of which sites have evaporite deposits, (2) any available quantitative geochemical and mineralogical analyses, and (3) references to relevant reports. In this study, “evaporite” refers to any secondary mineral precipitate that occurs due to a loss of water through evaporative processes. This includes efflorescent salt crusts, where this term refers to a migration of dissolved constituents to the surface with a resulting salt crust, where “salt” can refer to any secondary precipitate, regardless of constituents.

The potential for the formation of evaporites at LM sites has been identified (SRNL 2013, 2014a, 2014b) and may have relevance to plume persistence issues. Evaporite deposits have the potential to concentrate and store contaminants at LM sites that could later be re-released. These deposits can also provide a temporary storage mechanism for carbonate, chloride, and sulfate salts along with uranium and other contaminants of concern (COCs). Identification of sites with evaporites will be used in a new technical task plan (TTP) Persistent Secondary Contaminant Sources (PeSCS), for any proposed additional sampling and analyses. This additional study is currently under development and will focus on determining if the dissolution of evaporites has the potential to hinder natural flushing strategies and impact plume persistence.

This report provides an initial literature review on evaporites followed by details for each site with identified evaporites. The final summary includes a table listing of all relevant LM sites regardless of evaporite identification.

Current and past site leads or site hydrologists completed a questionnaire designed to determine sites with the presence of evaporites that may form near contaminated groundwater seeps or discharge points or surface water. The questionnaire also asked the respondents to identify any relevant documents relating to soil or evaporite sampling. When available, a summary of relevant excerpts, figures, or identified documents is given in the site summary. An electronic copy of the available references and all original questionnaires are stored in the appendix of this report, which can be found at: [S:\Project\\_Share\Evaporite AWP](S:\Project_Share\Evaporite AWP). This report provides summaries for the following sites where the site lead identified the presence of evaporites:

- Bluewater, New Mexico, Disposal Site
- Grand Junction, Colorado, Site
- Grand Junction, Colorado, Processing Site
- Green River, Utah, Disposal Site
- Mexican Hat, Utah, Disposal Site
- Monument Valley, Arizona, Processing Site
- Rifle, Colorado, Old and New Processing Sites
- Riverton, Wyoming, Processing Site
- Shiprock, New Mexico, Disposal Site

From the above sites with identified evaporites, the Riverton, Wyoming, Processing Site is considered a “test site” for the evaluation of new conceptual models related to evaporites and other secondary contaminant sources creating plume persistence issues (Dam et al. 2015). Data from the Riverton site are presented in more detail in Section 9.0.

The following sites were identified as not having any surficial evaporites and are not summarized in this report:

- Ambrosia Lake, New Mexico
- Burrell, Pennsylvania
- Canonsburg, Pennsylvania
- Durango, Colorado
- Edgemont, South Dakota
- Falls City, Texas
- Gunnison, Colorado
- L-Bar, New Mexico
- Lakeview, Oregon
- Lowman, Idaho
- Maybell West, Colorado
- Monticello, Utah
- Parkersburg, West Virginia
- Salt Lake City, Utah
- Shirley Basin South, Wyoming
- Sherwood, Washington
- Spook, Wyoming
- Tuba City, Arizona

The above sites without identified surficial evaporites should not be strictly considered as having no potential for evaporite formation, since the formation of evaporites in the subsurface is a possibility. Subsurface evaporite formation is more likely to occur in arid environments, but may not have been identified due to a lack of data. Subsurface evaporites have the potential to create plume persistence issues if the water table rises into these evaporite zones and mobilizes contaminants. The potential for this condition is discussed in SRNL 2014a for the Bluewater, New Mexico, Disposal Site (see quote in Section 3.0), but is considered minimal due to the deeper water table (approximately 150 ft). Any site without identified evaporites should consider that future changes in site conditions could produce surficial and/or subsurface evaporites and/or dissolve existing subsurface evaporites that have not been identified.

Three sites (Maybell, Naturita, and Slick Rock, Colorado) had no information available on previous soil sampling or evaporite deposits within the site boundaries. The site lead indicated there was the possibility for evaporites on these sites, but to their knowledge they have never

identified any. The new PeSCS TTP will address the possibility of visits to these sites to identify evaporites. These sites have supplemental standards (Maybell) or alternate concentration limits (Naturita and Slick Rock).

For sites with information on evaporites, relevant documents identified the evaporite deposits with various descriptors, including efflorescent crusts, stained soils, and salt crusts. Most of the relevant documents focused on potential risks to human health or ecological exposure from surficial evaporites (as part of LM Goal 1: Protect Human Health and the Environment), rather than on understanding the influence these evaporites might have on plume persistence (also related to LM Goal 1). This report summarizes any available information on surficial and subsurface evaporite deposits that may have contaminants of importance for plume persistence issues.

The figures included throughout this report are from previous reports and various aerial images. As such, these figures reflect the formatting from their original preparation and all figure sources are indicated. These figures are reproduced in this report to highlight the occurrence of evaporites at various LM sites.

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## 2.0 Evaporite Literature Review

The purpose of this literature review is to provide the most relevant references for this report on evaporites, with a specific focus on uranium-bearing evaporites, along with a general indication of the overall available literature. Any additional work in other phases may include more-detailed literature reviews on specific topics.

At LM sites, evaporite deposits can occur in areas with high evapotranspiration rates, either related to nearby open surface water bodies or where groundwater is close to or at the surface. In comparison, the majority of literature on evaporites tends to focus on thicker evaporite sequences that form in closed or restricted basins where there is limited or no groundwater or surface water outflow (Prud'homme and Krukowski 2006). Generally, such literature is related to commercial deposits of sodium chloride (halite) or potassium chloride (potash). The resulting sequence of mineral deposition in these basins is well known. With increasing evaporation of seawater, the precipitation sequence is from carbonate minerals first, followed by calcium sulfates, sodium chloride, magnesium sulfates, and then magnesium and potassium chlorides (Prud'homme and Krukowski 2006). However, some literature relates to evaporite deposition and mineralogy being influenced by groundwater flow through these basin settings (Wood and Sanford 1990). A large amount of literature is available on evaporite deposits in general, but literature on evaporites related to trace metals and radionuclides is limited.

The focus of this literature review is from a plume persistence standpoint; specifically, how evaporites on the surface or in the subsurface may contribute to changes in groundwater quality, especially in areas with groundwater plumes that include uranium. At the Riverton, Wyoming, Processing Site, evaporite deposits above the contaminant plume appear to have higher uranium concentrations (DOE 2014). A 2010 flood event at the Riverton site produced a spike in uranium concentrations in several wells and it appears likely that these spikes were related to the dissolution of subsurface evaporites, along with other possible mechanisms. Recently, subsurface evaporites have been identified via trenching and additional coring conducted at the Riverton site. The interaction between evaporites and groundwater contaminant plumes is a relatively new topic of investigation, and no literature could be found that directly discusses evaporites forming above contaminant plumes and their potential long-term influence on groundwater quality. Apparently, such studies have not been done or have not been published; thus, the subsequent discussion focuses on related literature. This related literature includes (1) uranium calcrete deposits, (2) tailings and waste dumps with efflorescent salts (evaporites), (3) dissolution of evaporite deposits, and (4) flushing of saline agricultural lands. The literature review of these four topics is presented as a general discussion with a limited number of references. Additional work related to any of these topics would require expanded literature reviews.

Where uranium-rich groundwater, such as that derived from uranium-rich granitoid rocks, is close to the surface in arid regions, uranium deposits can form in evaporite deposits of calcrete (carbonate-rich evaporites) and gypcretes (sulfate-rich evaporites) (Carlisle 1978). In addition, Carlisle (1980) mentions that the formation of uranium-rich calcretes and gypcretes by capillary rise and evaporation of permanent, perched, or temporary groundwater can occur. The U.S. Geological Survey is currently updating uranium calcrete/gypcrete deposit models for the southwestern United States, specifically for western Texas, where uranium-rich calcrete deposits have been identified in the past (Susan Hall, USGS, personal communication). Ranalli and Yager (in submittal) have developed a conceptual model of calcrete formation in western Texas that may also be applicable to Uranium Mill Tailings Remedial Action (UMTRA) Project sites.

Some literature is available for evaporites related to secondary mineral precipitation upon the discharge and subsequent evaporation of mine drainage, often at the toe of mine tailings impoundments or waste dumps (Romero et al. 2006; Gilchrist et al. 2009; Lottermoser et al. 2005; Tutu et al. 2008). These references indicate that concentrations of trace metals, in what are referred to as efflorescent crusts, can serve as a temporary storage of trace metals during dry conditions with later release to surrounding surface waters during wetter conditions. The majority of literature on mine drainage quality focuses on chemical reactions within the mine tailings or waste dumps and subsequent drainage water quality. Information in the literature on efflorescent crusts is more limited, especially for uranium minerals. However, this body of literature continues to grow as more studies focus on the importance of this mechanism for storage and later release of trace metals that can influence surrounding water quality, and the process may have important analogs to this report.

Large evaporite deposits occur around the world, mostly in identified geologic basins that had enclosed saline waters. Subsequent dissolution of these evaporite deposits can contaminate surrounding groundwater (Apaydin and Aktas 2012). The literature on the dissolution of large evaporite deposits is quite extensive. However, these dissolution processes are generally within the saturated zone (e.g., deep salt beds) and do not consider the potential of unsaturated zone processes with continual dissolution and re-precipitation based on wet-dry cycles, which can occur at many LM sites. In any case, evaporite dissolution literature can provide some information on overall mineral solubilities that influence groundwater quality.

In agricultural settings, too much salinity can cause problems with crop cultivation. A large amount of literature is available pertaining to salinity issues in agricultural fields. This issue occurs when higher-salinity water is used for irrigation, which is then not well drained (i.e., is allowed to evaporate in place). Information from this literature may provide insight into how much recharge is necessary to move agricultural “evaporites” into the underlying groundwater (Cordy and Bouwer 1999). A fact sheet by Bauder et al. (2014) provides an equation for leaching requirements to treat saline soils. Some of the literature on the leaching of salts from agricultural lands is potentially useful as an analogy for evaporite leaching at LM sites. However, the analogy becomes more limited when the focus is on trace metals and radionuclides, as most studies of groundwater contamination near agricultural lands tend to focus on nitrate.

Available literature confirms the formation of evaporites in a variety of settings that contain elevated concentrations of metals, including uranium, which can subsequently become mobile when groundwater recharge occurs. The literature provides information on potential mineral phases, processes for evaporite formation, an indication that these evaporites are readily soluble, and information on water quantities needed to flush out saline soils. However, the literature does not identify a method to quantify changes in groundwater quality following a recharge event that dissolves evaporites. Direct measurement of water quality over time will likely be necessary to better understand the influence of evaporite dissolution on shallow groundwater quality. These measurements are currently being obtained using continuous monitoring tube (multi-level) sampling wells constructed in the unsaturated and saturated zones at the Riverton site (DOE 2015). Such measurements are necessary to confirm the dissolution of evaporites in the unsaturated zone, along with subsequent transport to the groundwater, since predictions of the balance between recharge and evapotranspiration are difficult to determine.

### 3.0 Bluewater, New Mexico, Disposal Site

The Bluewater, New Mexico, Disposal Site was identified as having evaporites within the northern area of the disposal cell (Table 1). Settlement of materials within the disposal cell has resulted in depressions that allow water to pool on the cell cover. The site lead noted the presence of evaporites within these depressions in the past, and the evaporites were sampled during the 2001 annual site inspection (Figure 1). The *2001 Annual Site Inspection and Monitoring Compliance Report for Uranium Mill Tailings Radiation Control Act Title II Disposal Sites* (DOE 2002a) described the gross beta and gross alpha activity on the main tailings disposal cell as negligible. Detailed documentation, such as photos or exact sample locations were not available; however, the original field inspection map from the 2001 inspection shows the approximate location of the evaporite samples (Figure 1).

Figure 2 also shows the approximate location of the sampled area and shows recent (2014) conditions in this area. The source of these evaporites is believed to be runoff from rainwater and snow melt that pools in the depressions after picking up minerals from the cover material. The site lead does not believe the source of water is groundwater seepage from tailings material. Previous sampling showed negligible gross alpha and gross beta activity, and the site lead does not believe the evaporites are a potential source of secondary contamination.

Subsurface evaporites at the Bluewater, New Mexico, Disposal Site are not highly likely, but the process was identified by SNRL 2014a. Quoting from SNRL 2014a:

“Evapotranspiration can also cause uranium mineralization in the capillary fringe by concentration of dissolved constituents in the pore water. It would be accompanied by precipitation of sulfate, carbonate, phosphate, and ultimately chloride minerals. Uranium minerals precipitated by these processes can be secondary sources of uranium when the water table rises through these mineralized zones. . . . At the Bluewater site the water table is deep, approximately 150 feet below surface, and beneath the root zone of phreatophytes. Furthermore, most of the water table aquifer is overlain by rocks that may hold water, even in the semi-arid climate. The Alluvial Aquifer is overlain by the Bluewater Basalt and the San Andres-Glorieta portion of the water table aquifer is mostly covered by the relatively impermeable Chinle Formation. Hence, the only place where evaporation from the capillary fringe may be significant is the narrow portion of the San-Andres-Glorieta Aquifer, adjacent to the disposal cell that is not overlain by the Chinle Formation.”

Table 1. Bluewater, New Mexico, Questionnaire Results

<b>Site Name:</b> Bluewater, New Mexico	
<b>Evaporite Deposits Onsite?</b>	<b>Yes</b>
<b>Specific Location Information</b> Evaporite deposits are present on the cell cover within depressions that have formed from settling within the cell. The evaporite deposits and water runoff could potentially migrate to the north (Figure 1 and Figure 2).	
<b>Seasonal/Compliance Concerns</b> The site lead does not feel that the presence of evaporites on the north side of the disposal cell is a source of contaminant accumulation. Water sources for evaporites are rainwater and snow melt percolation down the cell and pooling in depressions on the cell. The evaporites are from minerals picked up from the rock mineral cover, not tailings related.	
<b>Land Use/Land Cover Changes</b> None since the cell construction was completed.	
<b>Relevant Reports or Documents</b> The evaporites were sampled in 2001 during an annual site inspection. According to the 2001 Annual Site Inspection and Monitoring Compliance Report (DOE 2002a), "the white material was identified as a carbonate mineral, either calcite or dolomite. Gross alpha and gross beta activity was negligible." Photos were not taken during this inspection, and specific sample location data are unavailable. However, the original annual inspection working field map shows the approximate locations (Figure 1).	

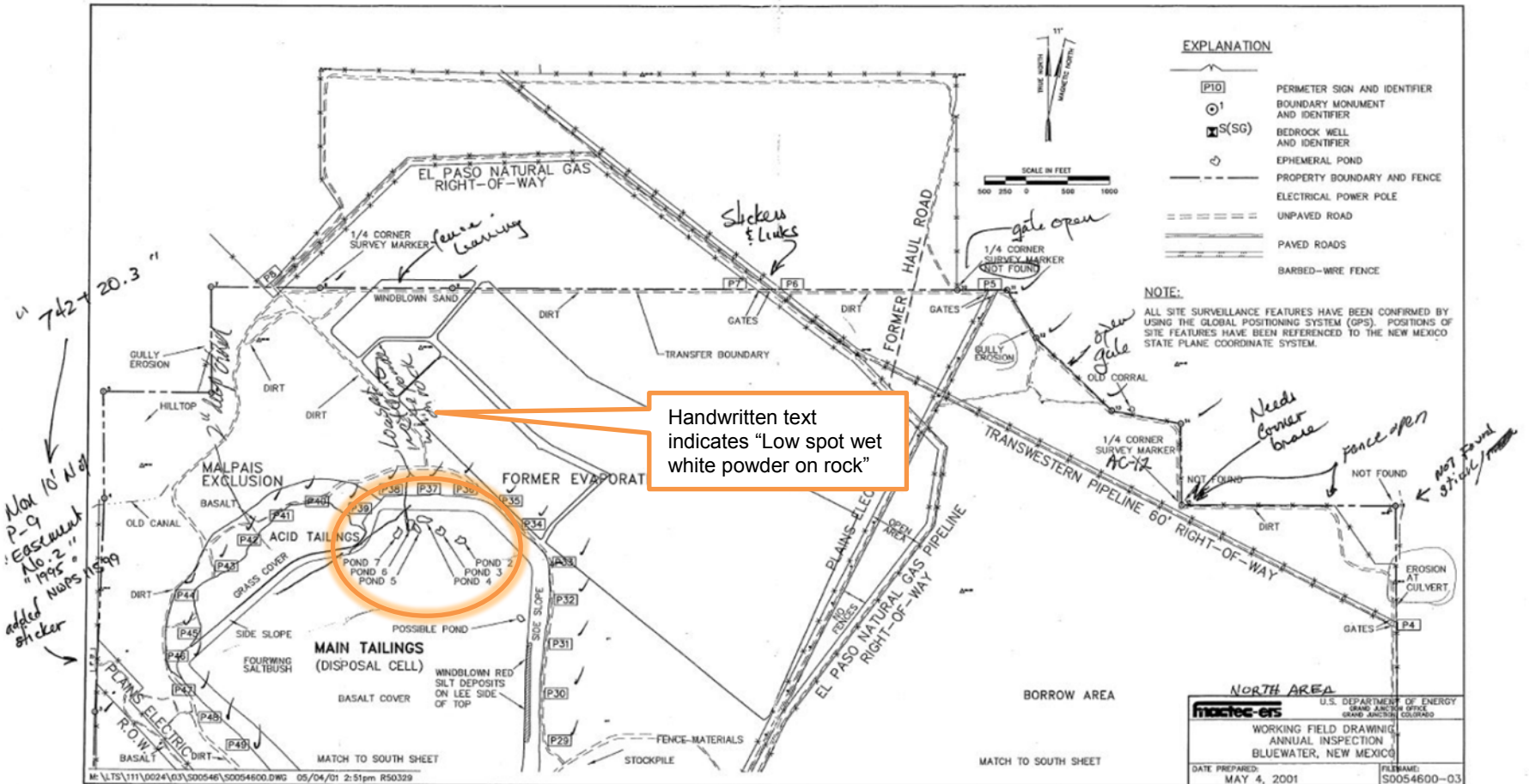


Figure 1. 2001 Annual Site Inspection Drawing with Approximate Sampling Locations. Hand-written notes are from the 2001 site inspection that were added to a working field drawing.

## Bluewater, New Mexico, Disposal Cell



Figure 2. Bluewater, New Mexico, Disposal Cell Evaporite Deposits

## 4.0 Monument Valley, Arizona, Processing Site

The Monument Valley, Arizona, Processing Site was identified as having evaporites (Table 2) within a former evaporation pond area (Figure 3). The evaporation ponds were used to retain and evaporate process water from a former uranium mill. Numerous sampling investigations have produced radiological data dating back to 1961. A 2010 assessment (DOE 2010) describes the evaporation pond area as having historically “contained some of the highest concentrations of radium in the site.”

Following site remediation in 1994, subsurface soils were sampled in 1998 and 2004, and in 2000 DOE conducted an investigation to sample surficial soils across the site (DOE 2010). Figure 4 shows data from the 1998, 2000, and 2004 soil sampling events (subsurface soil samples from 1998 and 2000 only report results of the uppermost sample). Results from these evaluations indicate that most uranium concentrations were less than 10 milligrams per kilogram (mg/kg) (Figure 4) but above background (average crustal abundance for uranium is 1.8–2.7 mg/kg). However, one surficial soil sample near the former evaporation pond had a uranium concentration of 402 mg/kg.

Starting in 2007, personnel working on phytoremediation pilot studies noticed poor plant growth in areas with discolored surface soils in the former evaporation pond (Figure 5 and Figure 6). University of Arizona students sampled these discolored surface soils in 2009 (Figure 4), and results indicated uranium concentrations as high as 442 mg/kg. An additional DOE investigation (DOE 2010) confirmed the high uranium concentration in the surficial soil in the area of the former evaporation pond (Figure 4) with measured uranium concentrations as high as 1,500 mg/kg along with vanadium concentrations as high as 1,300 mg/kg (average crustal abundance for vanadium is 120–190 mg/kg). Uranium isotope ratios ( $^{234}\text{U}/^{238}\text{U}$ ) near unity for these soil samples are indicative of secondary precipitates derived from solutions related to the ore-milling process. A 2010 radiological survey and accompanying RESRAD (RESidual RADioactive material, a computer code developed at Argonne National Laboratory) calculation determined that radiological exposure did not present an unacceptable risk to workers at the site (DOE 2010).

The surficial discolored soils at Monument Valley are unique, as these materials are probably not a direct result of the evaporation of shallow groundwater. The high vanadium content suggests that the soils are uranium/vanadium minerals such as carnotite ( $\text{K}_2(\text{UO}_2)_2(\text{VO}_4)_2 \cdot 3(\text{H}_2\text{O})$ ) or tyuyamunite ( $\text{Ca}(\text{UO}_2)_2\text{V}_2\text{O}_8 \cdot (5-8)\text{H}_2\text{O}$ ) that form because of their low solubility in water when high vanadium concentrations are present. No mineral identification has been completed on these samples to date, but evaporative concentration at the surface would assist in the formation of these minerals. The formation of these low-solubility minerals can maintain high uranium/vanadium concentrations in the soils but limit their mobility in groundwater. Thus, this is a possible reason for the observation of low uranium and vanadium concentrations in groundwater below the former evaporation pond.

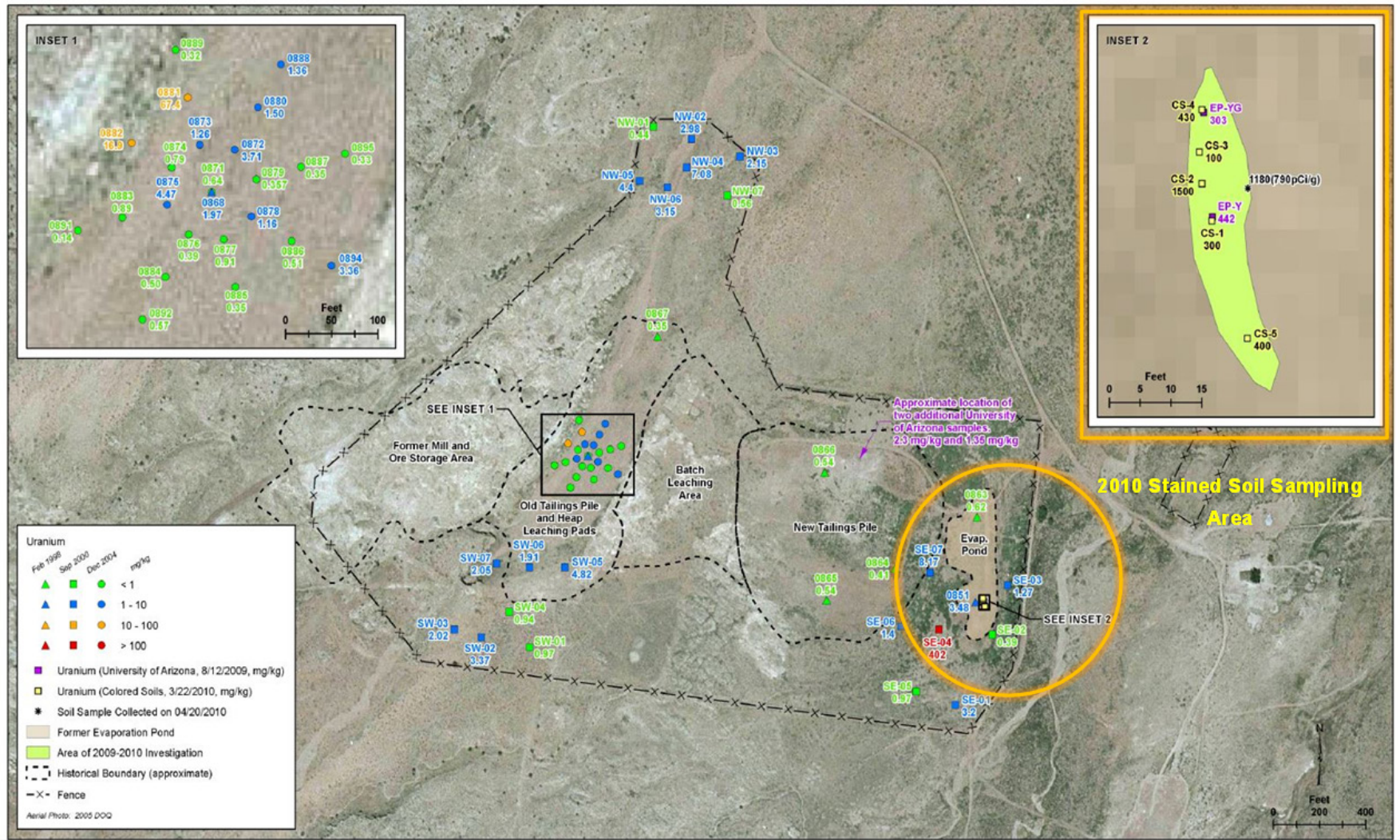
Table 2. Monument Valley, Arizona, Questionnaire Results

<b>Site Name:</b> Monument Valley, Arizona	
<b>Evaporite Deposits Onsite?</b>	Yes
<b>Specific Location Information</b> Surface deposits were evaluated in 2009 and 2010 at the Monument Valley, Arizona, Processing Site located next to the eastern boundary of the site. The deposits formed in what had been the evaporation pond during the site's operation (1955–1968). The deposits are referred to as colored soil precipitates, and analyses indicated elevated uranium and vanadium levels within these soils.	
<b>Seasonal/Compliance Concerns</b> Present year round, more prevalent after rain events. Report done in 2010 indicated that these stained soils did not impact the site's ability to meet the UMTRCA standards.	
<b>Land Use/Land Cover Changes</b> Site surface remediation was completed in 1994. An irrigation system was subsequently put into place for pilot studies to evaluate natural and enhanced attenuation as groundwater remediation strategies. The irrigation system was last used around 2011.	
<b>Relevant Reports or Documents</b> The <i>Radiological Assessment of Stained Soils at the Monument Valley Processing Site</i> (DOE 2010) summarized the data and information obtained from sampling and analyzing the discolored soil precipitates. The assessment noted that "the yellow-and-green-colored samples from the former evaporation pond area were high in vanadium and uranium." A radiological scan performed to evaluate risk to site workers indicated elevated gamma and beta activity. Results of a RESRAD calculation indicated that "risks are well below the allowable exposure rate of 25 mrem per year" (DOE 2010).	



Figure 3. Evaporation Pond at the Monument Valley Site During Milling Operation (March 1993)  
Photo is from the 2010 assessment (DOE 2010). Note orientation of north arrow.





Source: DOE 2010

Figure 4. Uranium Soil Sampling Analytical Results  
 Results are maximum concentrations over all depths sampled. North is toward the top of the page.



Source: DOE 2010

*Figure 5. Stained Soils Sample Area at the Monument Valley Site  
Soil staining occurs along and near the measuring tape (see close-up view in Figure 6).*



Source: DOE 2010

*Figure 6. Close-up Photo of Stained Yellow-Green Soil at the Monument Valley Site*

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## 5.0 Shiprock, New Mexico, Disposal Site

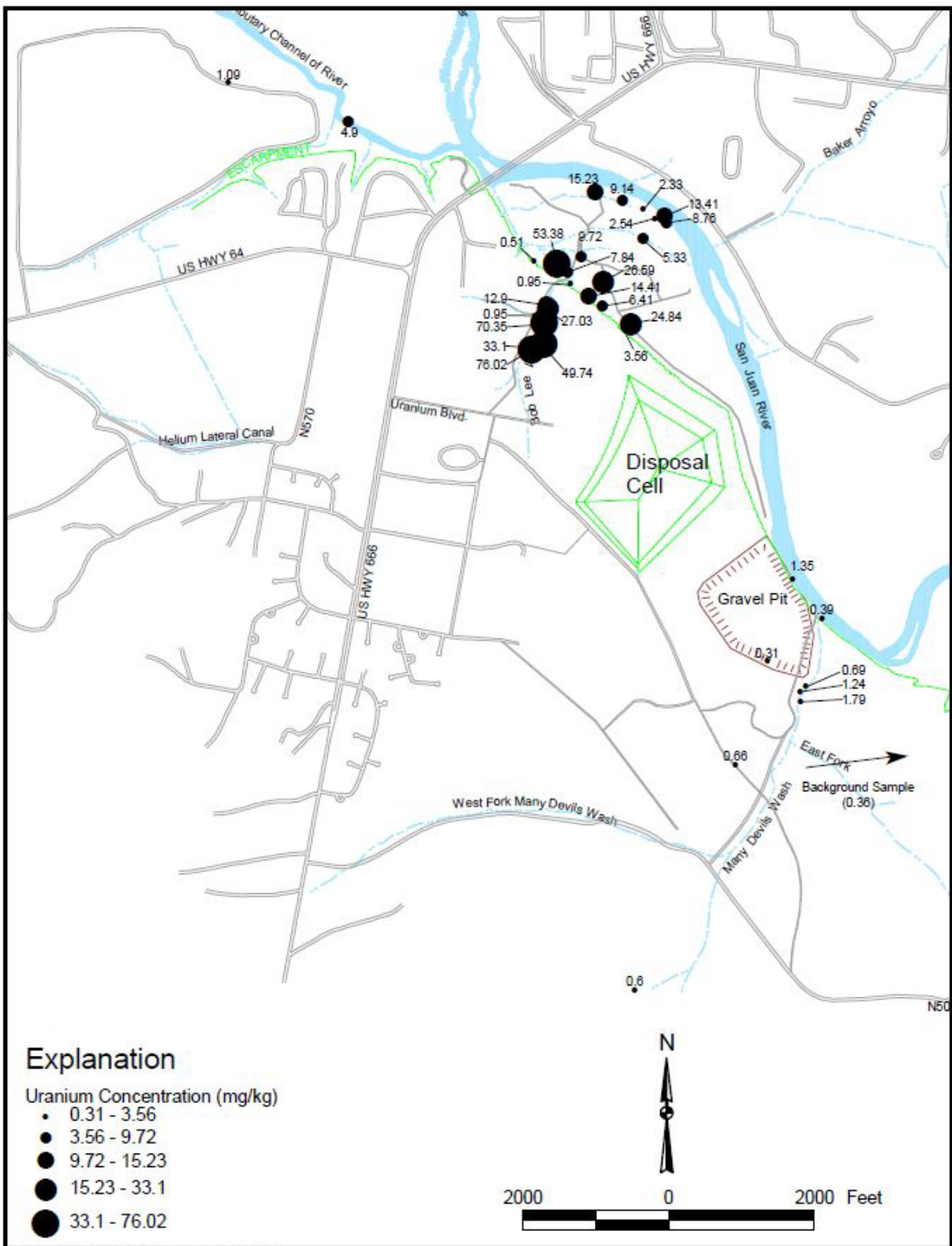
The Shiprock, New Mexico, Disposal and Processing Site has evaporites in many areas throughout the site (Table 3). Although the site lead did not identify specific areas, supporting documentation identifies seep discharge points (DOE 2012). The seep locations provide saline, shallow groundwater that is available to form evaporites. However, these evaporites also form naturally in the surrounding area (DOE 2012).

The *Final Site Observational Work Plan for the Shiprock, New Mexico, UMTRA Project Site* (SOWP, DOE 2000) also described the presence of evaporites, mainly within Bob Lee Wash and Many Devils Wash (Figure 7 and Figure 8). These evaporites are mainly composed of sodium sulfate (DOE 2000). Many Devils Wash (Figure 8) is considered a background area with geochemistry influenced by the Mancos Shale, whereas geochemistry in the Bob Lee Wash area (Figure 7) is likely influenced by former uranium-milling operations. Maximum uranium concentrations in Many Devils Wash area salt crusts were 1.79 mg/kg, and the maximum uranium concentrations in the Bob Lee Wash area were 76.02 mg/kg (Figure 7). These values are relative to the total amount of dissolved solids (DOE 2000), which is representative of the water-soluble portion of these salt crusts. The SOWP stated that “evaporation of contaminated water from the soil and seasonally wet sediment at and around the seeps results in the accumulation of these contaminants within salt crusts that form on their surfaces.” Three samples were analyzed for mineralogy using X-ray diffraction, and the results indicated the dominant mineral to be thenardite ( $\text{Na}_2\text{SO}_4$ ) with minor amounts of blödite ( $\text{Na}_2\text{Mg}(\text{SO}_4)_2 \cdot 4(\text{H}_2\text{O})$ ) and possible sideronatriite ( $\text{Na}_2\text{Fe}(\text{SO}_4)_2(\text{OH}) \cdot 3(\text{H}_2\text{O})$ ). Other phases found in the samples were quartz and calcite. These results are consistent with the high soluble concentrations of sodium and sulfate, but they do not necessarily indicate mill-related rather than natural occurrence of soluble salts.

The SOWP recognized that plants could accumulate minerals in the salt crusts through root uptake and form an exposure pathway for herbivores and their predators. The salt crust samples were therefore analyzed for nitrate, sulfate, uranium, and other constituents to determine the potential risk from ingestion. Analytical results indicated that the risk to wildlife was inconsequential (DOE 2000). The references focused on identifying potential exposure risk and did not address the potential for evaporites to contribute to plume persistence.

Table 3. Shiprock, New Mexico, Questionnaire Results

<b>Site Name:</b> Shiprock, New Mexico	
<b>Evaporite Deposits Onsite?</b>	<b>Yes</b>
<b>Specific Location Information</b>	
Evaporites are ubiquitous throughout the Shiprock site. Specific locations for deposits from groundwater discharge points are not known. However, reports on contaminated seep discharges were identified in the 2012 <i>Multivariate Statistical Analysis of Water Chemistry in Evaluating the Origin of Contamination in Many Devils Wash, Shiprock, New Mexico</i> (DOE 2012). The SOWP also discusses Many Devils Wash and the presence of "surface salt crusts" within the ephemeral drainage channel.	
<b>Seasonal/Compliance Concerns</b>	
Most prevalent after rain event, but can be found year round.	
<b>Land Use/Land Cover Changes</b>	
The Shiprock site is within the community of Shiprock, and land use can vary. The floodplain area has shown signs of transient use and littering from trespassers. Major land use and cover changes have not occurred since completion of site cleanup in 1986.	
<b>Relevant Reports or Documents</b>	
DOE (2012) evaluated the chemistry of seep water occurring in three desert drainages: Many Devils Wash, Salt Creek Wash, and Eagle Nest Arroyo. The 2000 SOWP discusses "salt crusts" as "potentially complete pathways between mill site contaminants and ecological receptors of the floodplain."	



Source: DOE 2000

Figure 7. Uranium Concentrations in Salt Deposits at the Shiprock Site

# Shiprock, New Mexico Site



Figure 8. Evaporite Deposits in Many Devils Wash at the Shiprock Site





*Figure 9. Evaporite Deposits at the base of Bob Lee Wash at the Shiprock Site*

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## 6.0 Grand Junction, Colorado, Site

The Grand Junction, Colorado, Site was identified as having evaporites within the northern area of the site (Table 4). This site is a DOE Defense Decontamination and Decommissioning Program site that transferred to LM in 2003. This area has wetland vegetation cover near the evaporation deposits. Recent monitoring of surface water and groundwater locations (Figure 10) within this area shows that some samples exceeded U.S. Environmental Protection Agency (EPA) groundwater standards. Uranium concentration exceeded the groundwater standard (0.030 milligram per liter [mg/L]) in the evaporite area near well 10-19N (0.15 mg/L). Uranium in surface water samples exceeded the EPA groundwater standard at the North Pond (0.15 mg/L), South Pond (0.39 mg/L), and the wetland area (1.0 mg/L).

A review of site documents did not identify any specific reports or studies that describe the potential for evaporites to contribute to plume persistence. The *Long-Term Surveillance and Maintenance Plan for the Grand Junction, Colorado, Site* (DOE 2006a) indicates that at the completion of natural flushing, sediment sampling might be conducted to evaluate the "potential residual site risks." Natural flushing is an ongoing remediation strategy for the Grand Junction site, and therefore no actions have been taken to sample sediment in this area. Figure 11 shows recent conditions in the wetland area and the extent of evaporites.

Table 4. Grand Junction, Colorado, Site Questionnaire Results

<b>Site Name:</b> Grand Junction Office Site	
<b>Evaporite Deposits Onsite?</b>	<b>Yes</b>
<b>Specific Location Information</b> Wetland areas at the northern portion of the site have evaporites that follow the general plume configuration. The site lead has noticed some evaporites along the banks of the Gunnison River, but the bank is overgrown with tamarisk, and evaporites may occur more often than is noticed.	
<b>Seasonal/Compliance Concerns</b> Evaporites tend to occur in dry seasons and dissipate during high-flow periods. The site lead does not have concerns that this might impact compliance.	
<b>Land Use/Land Cover Changes</b> None since completion of open land soil remediation in 1994. Remediation of soil beneath Building 20 was completed in 2006 after the building was demolished, and soil remediation occurred in 2014 in the footprint of Building 12A after that building was demolished.	
<b>Relevant Reports or Documents</b> The <i>Long-Term Surveillance and Maintenance Plan for the Grand Junction, Colorado, Site</i> (DOE 2006a), Appendix G, notes that additional sediment sampling at the completion of natural flushing might be prudent to evaluate the "potential residual site risks."	



Figure 10. Grand Junction, Colorado, Site 2015 Sampling Locations

## Grand Junction, Colorado Site



Figure 11. Grand Junction, Colorado, Site Wetland Evaporite Deposits

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## 7.0 Grand Junction, Colorado, Processing Site

The Grand Junction, Colorado, Processing Site was identified as having evaporites within the former mill site area along the floodplain of the Colorado River (Table 5). The evaporites (Figure 12) are present throughout the year but are more prevalent in dry months. The *Final Site Observational Work Plan for the UMTRA Project Site at Grand Junction, Colorado* (SOWP, DOE 1999a) details a surface sediment sampling event that occurred in 1997. During this sampling event, 30 samples were collected along the Colorado River floodplain (Figure 13) and were analyzed using uranium as a key indicator (see Table 4-6 in DOE 1999a). In 12 of the 30 samples, additional analytes were measured (results can be found on Table 4-7 in DOE 1999a). These 12 samples matched locations with corresponding surface water samples. All samples were analyzed following a 5% nitric acid leach. The purpose of the sediment sampling was to determine if mill-related contaminants were in the benthic zone. The samples were therefore collected from beneath or close to standing water (DOE 1999a) and are likely not representative of evaporite deposits. The maximum uranium concentrations were 2.20 mg/kg in onsite samples and 4.36 mg/kg in samples collected downgradient from the site. The downgradient value indicates some remaining influence of the mill site in the sediments (DOE 1999a), as the maximum background uranium concentration in sediment was 2.6 mg/kg.

The SOWP also discusses an analysis of subpile soils, specifically that “mill-related radionuclides and non-radionuclides remaining in place after remediation to surface cleanup standards may pose a potentially unacceptable source of groundwater contamination.” Results indicate that concentrations of arsenic and cadmium in subpile soils are so low that partitioning to groundwater is expected to be insignificant. However, uranium and molybdenum concentrations were high enough in subpile soils, and their  $K_d$  (distribution coefficient) values were low enough, that significant amounts of those contaminants could partition to the groundwater (DOE 1999a). It is unclear if these subpile soil samples contain evaporite or precipitated uranium minerals. The maximum uranium concentration was 45.2 mg/kg, which is well above measured background values of 0.44 to 1.1 mg/kg. Elevated concentrations of uranium in the subsurface may continue to dissolve with recharge events and provide a mechanism for plume persistence.

Two efflorescent samples (evaporites) from the Grand Junction processing site consisted of thenardite ( $\text{Na}_2\text{SO}_4$ ), blödite ( $\text{Na}_2\text{Mg}(\text{SO}_4)_2 \cdot 4(\text{H}_2\text{O})$ ), and watevillite ( $\text{Na}_2\text{Ca}(\text{SO}_4)_2 \cdot 4(\text{H}_2\text{O})$ ), and one sample contained halite ( $\text{NaCl}$ ) (DOE 1999a). These results are from two samples collected near ponds with south-facing slopes that have high evaporation potential from the underlying groundwater and nearby surface water. Trace elements were not measured for these two samples, just major mineralogy using X-ray diffraction. The SOWP (DOE 1999a) states that “These minerals are all soluble and are easily dissolved during periods of rainfall or high river waters and re-precipitated during drier periods.”

Table 5. Grand Junction, Colorado, Processing Site Questionnaire Results

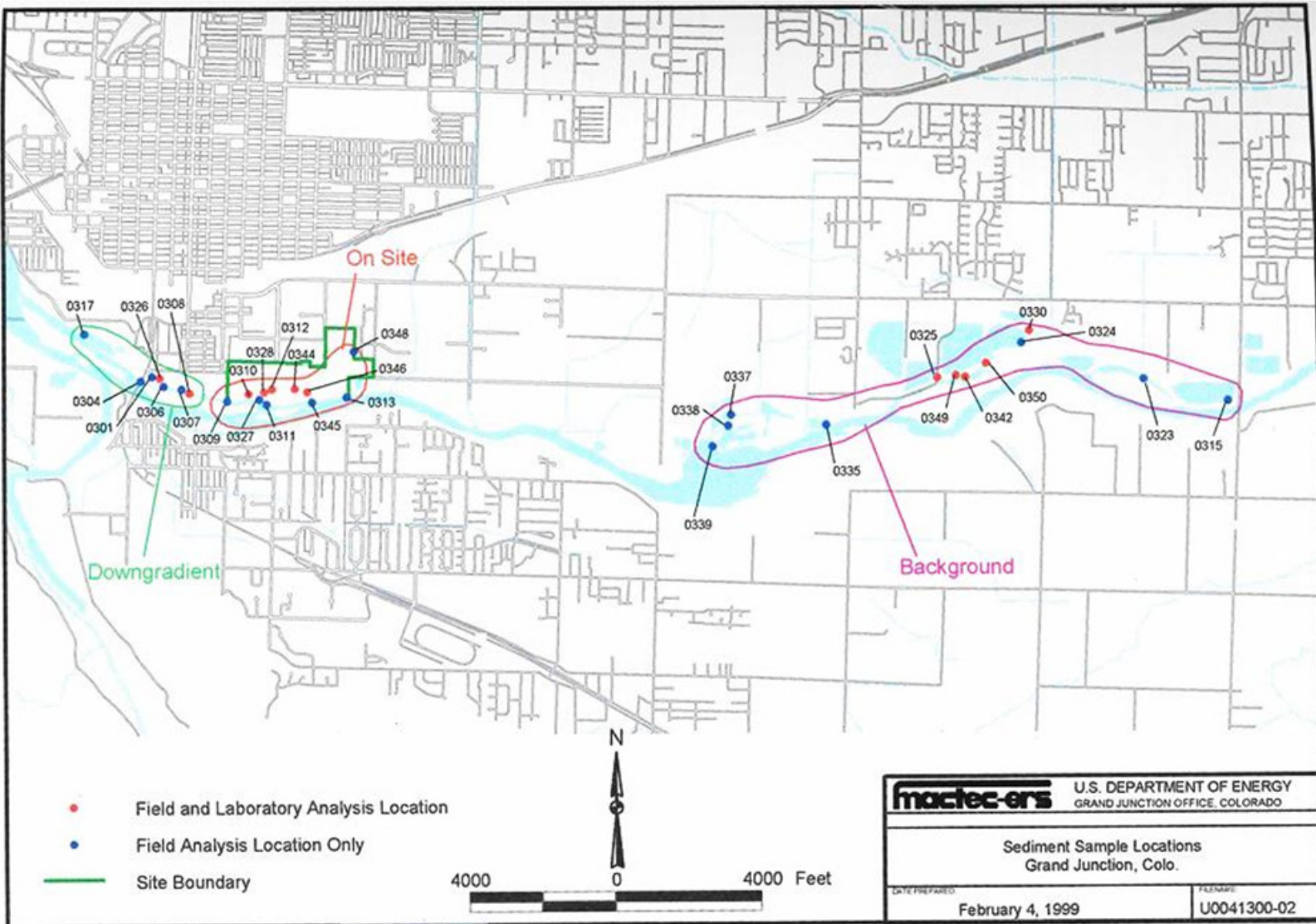
<b>Site Name:</b> Grand Junction Processing Site	
<b>Evaporite Deposits Onsite?</b>	<b>Yes</b>
<b>Specific Location Information</b> Evaporites are present along the river within the floodplain area.	
<b>Seasonal/Compliance Concerns</b> Present year round, more prevalent in dry months, August through October. Supplemental standards are in place for groundwater there, and the site lead does not have any compliance concerns.	
<b>Land Use/Land Cover Changes</b> Surface remediation was completed in 1994, and the area has been developed into a light-use recreational area with a bike path that passes through. No major land disturbances or changes have occurred; however, an amphitheater and other recreational development are expected in the future.	
<b>Relevant Reports or Documents</b> The <i>Final Site Observational Work Plan for the UMTRA Project Site at Grand Junction, Colorado</i> (DOE 1999a) details sediment sampling that occurred in 1997 within the former mill site area.	



## Grand Junction, Colorado, Processing Site



Figure 12. Grand Junction, Colorado, Processing Site Floodplain Evaporite Deposits



Source: DOE 1999a

Figure 13. Grand Junction Processing Site 1997 Sediment Sampling Locations

## 8.0 Rifle, Colorado, Old and New Processing Sites

The Old and New Rifle, Colorado, Sites were identified as having evaporites within the former mill site areas along the floodplain of the Colorado River (Table 6). However, specific locations or potential areas of concern were not defined. The New Rifle site could potentially have evaporite deposits at groundwater discharge points in the western portion of the site, in areas of ephemeral ponds and near a former dewatering pit and holding pond (Figure 14).

The *Final Site Observational Work Plan for the UMTRA Project New Rifle Site* (DOE 1999b) describes two sediment sampling events that occurred within the New Rifle site. The first event used core from wells being installed in 1998. Those samples were used to determine distribution coefficients and did not evaluate the potential for sediments or subpile sediments to be continuing sources of contamination. The second event included subpile sediment sampling specifically to identify continuing source areas. Three samples were collected in background boreholes, and three samples were collected in onsite boreholes (Figure 15). Each sample was analyzed using a synthetic groundwater leaching solution and a 5% nitric acid leaching solution. Maximum uranium and vanadium concentrations for the synthetic groundwater leaching solution were 19.4 mg/kg and 302 mg/kg, respectively. Maximum uranium and vanadium concentrations for the 5% nitric acid leaching solution were 64.7 mg/kg and 614 mg/kg, respectively. These concentrations were in a sample collected from a borehole at a depth of 11 feet below the surface near the center of a former evaporation pond. Background uranium and vanadium concentrations using the 5% nitric acid leach were 0.67 and 4.3 mg/kg, respectively. The full analytical results can be found in Tables 4-7 and 4-8 of the New Rifle SOWP (DOE 1999b). Whether the samples with higher uranium and vanadium concentrations represent the formation of evaporite minerals in the subsurface or formed as uranium mineral precipitation below the former evaporation ponds is unclear. Mineralogical analyses of these samples were not indicated in the SOWP (DOE 1999b).

Table 6. Old and New Rifle, Colorado, Sites Questionnaire Results

<b>Site Name:</b> Old Rifle, Colorado	
<b>Evaporite Deposits Onsite?</b>	Yes
<b>Specific Location Information</b> Evaporite deposits are ubiquitous and can be found throughout the site. It is unclear whether any of the deposits on the site are from contaminated groundwater seeps or discharge points.	
<b>Seasonal/Compliance Concerns</b> Presence is variable with rain events, no compliance concerns.	
<b>Land Use/Land Cover Changes</b> Following remediation, the adjacent lot was empty and was later (around 2008) used as the site for a City of Rifle maintenance building. The main site is used as part of a research program with Lawrence Berkeley National Laboratory.	
<b>Relevant Reports or Documents</b> None that focus on sediment sampling or evaporite deposits as potential sources of continuing contamination.	

Table 6 (continued). Old and New Rifle, Colorado, Sites Questionnaire Results

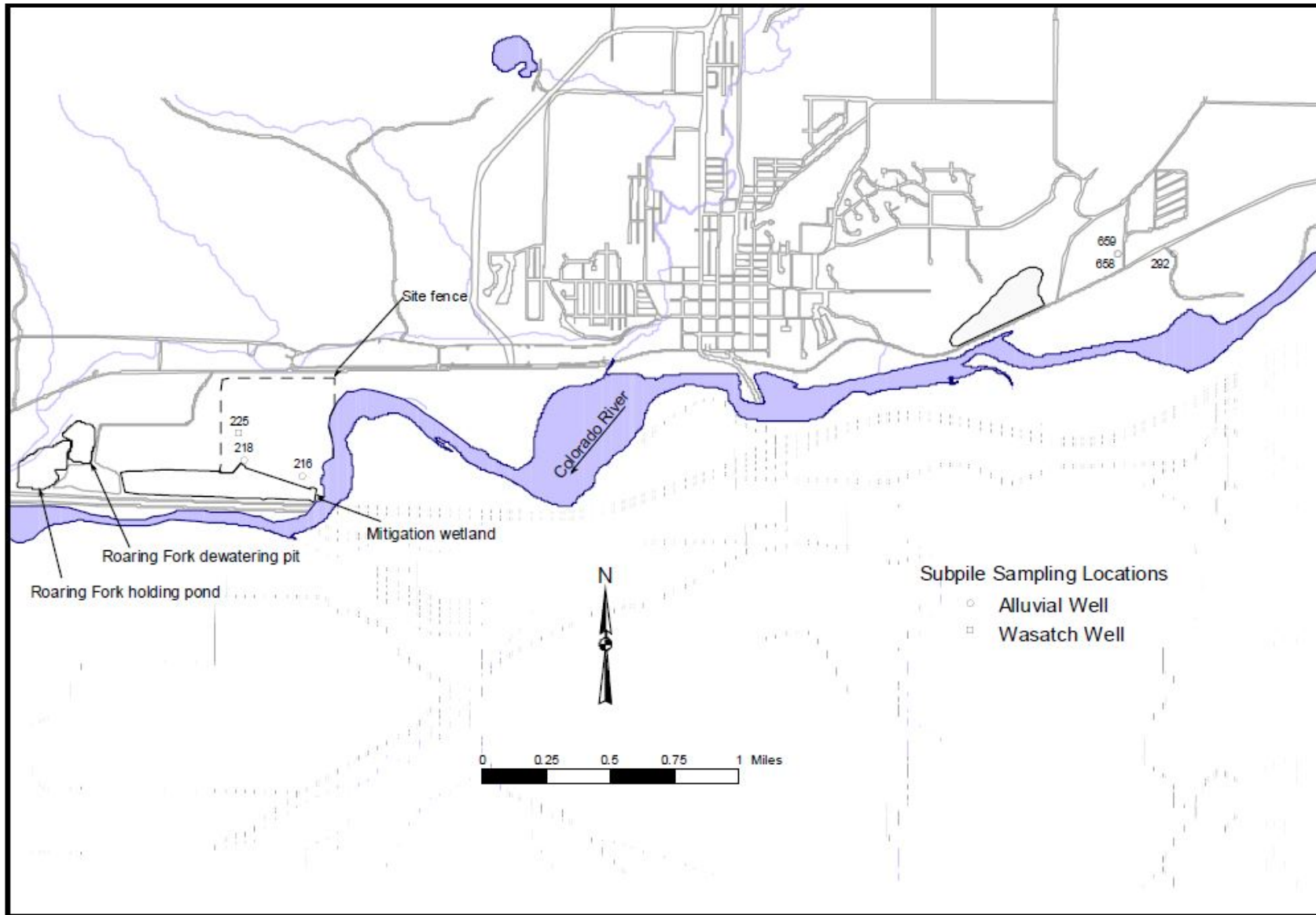
<b>Site Name:</b> New Rifle, Colorado	
<b>Evaporite Deposits Onsite?</b>	<b>Yes</b>
<b>Specific Location Information</b> Evaporite deposits are ubiquitous and can be found throughout the site. In relation to potential groundwater discharge points, ephemeral ponds on the western portion of the site could potentially be a location.	
<b>Seasonal/ Compliance Concerns</b> Presence is variable with rain events.	
<b>Land Use/Land Cover Changes</b> The addition of the City of Rifle Wastewater Plant and a solar array in the area has been the only land use/land cover changes for this area.	
<b>Relevant Reports or Documents</b> The <i>Final Site Observational Work Plan for the UMTRA Project New Rifle Site</i> (DOE 1999b), details soil sampling events that occurred within the New Rifle site. The purpose of the sampling was to determine distribution coefficients.	

# New Rifle, Colorado



Imagery Source Date: 6/3/2014

Figure 14. New Rifle Site Potential Evaporite Locations



Source: DOE 1999b

Figure 15. New Rifle, Colorado, Site 1999 Subpile Sample Locations

## 9.0 Riverton, Wyoming, Processing Site

The Riverton, Wyoming, Site was identified as having evaporites within the site (Table 7) occurring mainly along embankments where groundwater discharges to the Little Wind River, either directly or in abandoned oxbow channels (Figure 16). Evaporites occur naturally throughout the groundwater discharge zones and may or may not be influenced by the contamination plume from the site, depending on location. The *Independent Technical Evaluation and Recommendations for Contaminated Groundwater at the Department of Energy Office of Legacy Management Riverton Processing Site* (SRNL 2014b) discusses mineral accumulation and the potential for evaporative concentration of “dissolved constituents in the water originating at the former processing site,” and the expectation for these constituents to “accumulate as solid evaporites in the vadose zone and near seeps.” One scoping sample was collected near the Little Wind River above the known groundwater plume. This sample was analyzed using two techniques: X-ray fluorescence (XRF) to determine the elemental composition, and X-ray diffraction (XRD) to determine the primary minerals present. Portable XRF data indicated a uranium concentration of 73 mg/kg and a vanadium concentration below the 10 mg/kg detection limit. The primary minerals identified in the sample using XRD included halite (NaCl), quartz (SiO<sub>4</sub>), blödite (Na<sub>2</sub>Mg(SO<sub>4</sub>)<sub>2</sub>·4(H<sub>2</sub>O)), and thenardite (Na<sub>2</sub>SO<sub>4</sub>). SRNL (2014b) concluded that “These values are in the expected range for evaporitic minerals in the western United States, and secondary minerals accumulated in various zones along flow path would be expected to have similar uranium levels. The chemical composition of the sample is generally consistent with an evaporite mineral that accumulates over time, concentrating the constituents of the groundwater in a solid mineral form.” SRNL (2014b) also indicates that additional evaporites may be occurring in the subsurface, and the dissolution of these minerals during high precipitation events could be contributing to plume persistence.

Follow-up work on evaporite sampling in 2014 included a detailed survey and sampling of evaporites along the bank of the Little Wind River in the *Evaluation of Mineral Deposits Along the Little Wind River, Riverton, Wyoming, Processing Site* (DOE 2014) (Figure 17 and Figure 18). The maximum uranium concentration in these evaporite samples was 66 mg/kg, and a background sample contained 1.4 mg/kg uranium. These values were derived from a strong acid digestion of the evaporite samples. In general, the uranium concentrations in the evaporite samples correlated with the uranium content in the underlying groundwater (DOE 2014). The focus of the DOE (2014) study was the evaluation of risk to human health and the environment. The study concluded that there is no radiological risk and no significant risk from surface ingestion by livestock.

Additional Riverton site investigation work in 2015 included trenching and sonic drilling. This work confirmed the presence of subsurface evaporites (Figure 19) in the vadose zone away from the river bank. Preliminary data using a strong acid digestion indicate an increase in uranium concentrations in these subsurface evaporites (up to 10 mg/kg) over the uranium plume compared to uranium concentrations found in the underlying saturated sands and gravels (generally <1 mg/kg) across the site. Uranium concentrations in a relatively continuous unsaturated silt layer are approximately 2.5 times background in areas over the uranium plume and likely contribute to plume persistence issues. Mass calculations indicate that this increase in solid-phase uranium with approximately 15% dissolution is enough mass to contribute the amount of additional uranium seen in the groundwater after the 2010 flood.

Table 7. Riverton, Wyoming, Questionnaire Results

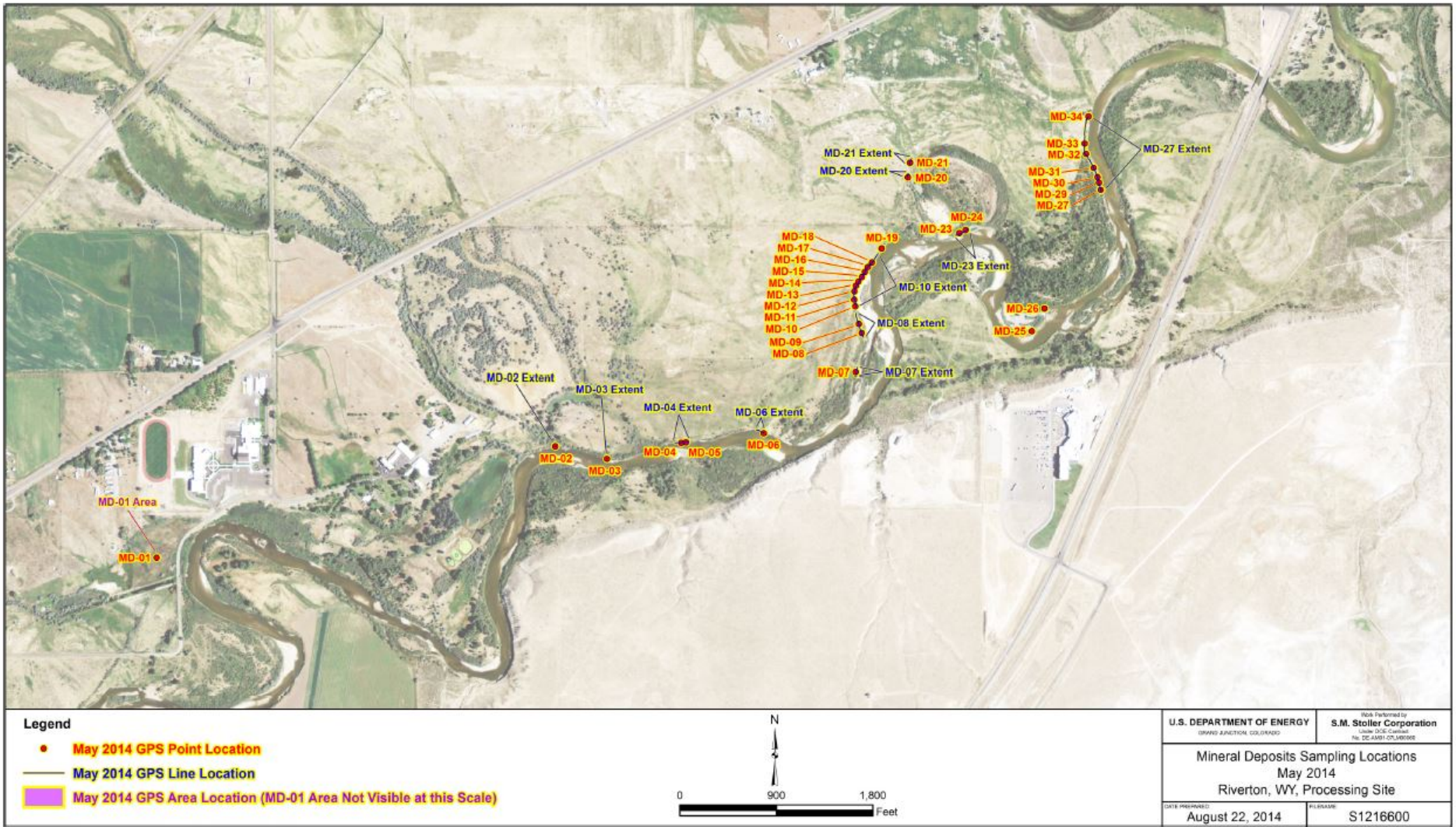
<b>Site Name:</b> Riverton, Wyoming	
<b>Evaporite Deposits Onsite?</b>	<b>Yes</b>
<b>Specific Location Information</b>	
Personnel from Savannah River National Lab conducted sampling in 2013, and LM conducted surface sampling of evaporite deposits during the spring of 2014. The purpose of the 2014 sampling was to determine if the deposits posed any risk to human health or the environment.	
<b>Seasonal/Compliance Concerns</b>	
Surficial evaporite deposits are prevalent during winter when the Little Wind River flow is at its lowest, allowing these evaporites to precipitate from solution. DOE (2014) did not identify any environmental risk or compliance concerns.	
<b>Land Use/Land Cover Changes</b>	
None; livestock grazing has been the land use since completion of remediation.	
<b>Relevant Reports or Documents</b>	
<p>The <i>Independent Technical Evaluation and Recommendations for Contaminated Groundwater at the Department of Energy Office of Legacy Management Riverton Processing Site</i> (SRNL 2014b) discusses the presence of evaporite deposits and recommends increased data collection in areas that have identified secondary source accumulation. Also, the <i>Evaluation of Mineral Deposits Along the Little Wind River, Riverton, Wyoming, Processing Site</i> (DOE 2014) discusses the sampling of mineral deposits and concludes there is no radiological risk and no significant risk from surface ingestion by livestock. This report does indicate that higher concentrations of uranium in the evaporites generally correlate with the higher uranium concentrations in the subsurface groundwater.</p> <p>Additional trenching and subsurface sampling via sonic drilling allowed visual identification of subsurface evaporites in the vadose zone away from the river bank.</p>	





Source: SRNL 2014b

*Figure 16. Riverton, Wyoming, Site Evaporite Mineral Deposits*  
 Top left and right, photographs of white evaporite mineral deposits observed along the escarpment at an abandoned oxbow channel of the Little Wind River. Bottom left shows the location of photographs and sample collection.



Source: DOE 2014

Figure 17. Riverton, Wyoming, Site Mineral Deposit Sampling Locations and Extent of Mineral Deposits



Source: DOE 2014

*Figure 18. Riverton, Wyoming, Site—Example of a Mineral Deposit Sampling Location*



Figure 19. Riverton, Wyoming, 2015: White Evaporites in (a) Trench Photo, (b) Sonic Drilling Core, and (c) Close-up

## 10.0 Green River, Utah, Disposal Site

The Green River, Utah, Site was identified as having evaporites within Brown's Wash (Table 8, and Figure 20 and Figure 21). The June 2014 sampling event indicated that surface water concentrations of uranium at location 0847 (Figure 20) exceeded the background threshold values and surface water standards for nitrate + nitrite as N, selenium, and uranium, which may be due to contaminated alluvial groundwater discharging to the surface in Brown's Wash. The Brown's Wash area is an ephemeral wash, with backwater from Green River entering the wash.

The *Final Site Observational Work Plan for the Green River, Utah, UMTRA Project Site* (DOE 2002b), discusses Brown's Wash as a groundwater discharge point with little surficial drainage, but discharge through evapotranspiration. It is likely that Brown's Wash is a discharge point for contaminated groundwater coming from the disposal site. DOE (2002b) identifies sediment sampling in Brown's Wash in 1993, 1994, and 1995 with maximum uranium concentrations of 27.7 mg/kg (September 1993) and vanadium as high as 15 mg/kg (January 1995). Data from these sampling events led to the inclusion of cadmium, selenium, and uranium in sediments as contaminants of potential concern for the baseline risk assessment. The Green River site is underlain by Mancos Shale, which is likely contributing high concentrations of dissolved constituents to the groundwater. Figure 21 is an aerial image of Brown's Wash that shows current conditions and the evaporite deposits, and Figure 22 shows a close-up view of evaporite deposits within Brown's Wash.

Brown's Wash appears to be an area of natural evaporite formation, which would likely be composed of sodium sulfates similar to those at other sites. Due to the lack of quantitative data, exact minerals and uranium/vanadium concentrations are unknown, as is the potential influence of contaminants on plume persistence.

Table 8. Green River, Utah, Site Questionnaire Results

<b>Site Name:</b> Green River, Utah	
<b>Evaporite Deposits Onsite?</b>	<b>Yes</b>
<b>Specific Location Information</b> Evaporite deposits are present along Brown's Wash, where groundwater seeps into the wash.	
<b>Seasonal/Compliance Concerns</b> Brown's Wash has extended periods without discharge; peak periods of evaporite deposits are observed before the monsoon months (July–September).	
<b>Land Use/Land Cover Changes</b> None since surface remediation was completed in 1989.	
<b>Relevant Reports or Documents</b> The <i>Final Site Observational Work Plan for the Green River, Utah, UMTRA Project Site</i> (DOE 2002b), discusses Brown's Wash and the potential for contaminated tailings fluids to have provided a source of recharge to part of this alluvial system in the past.	

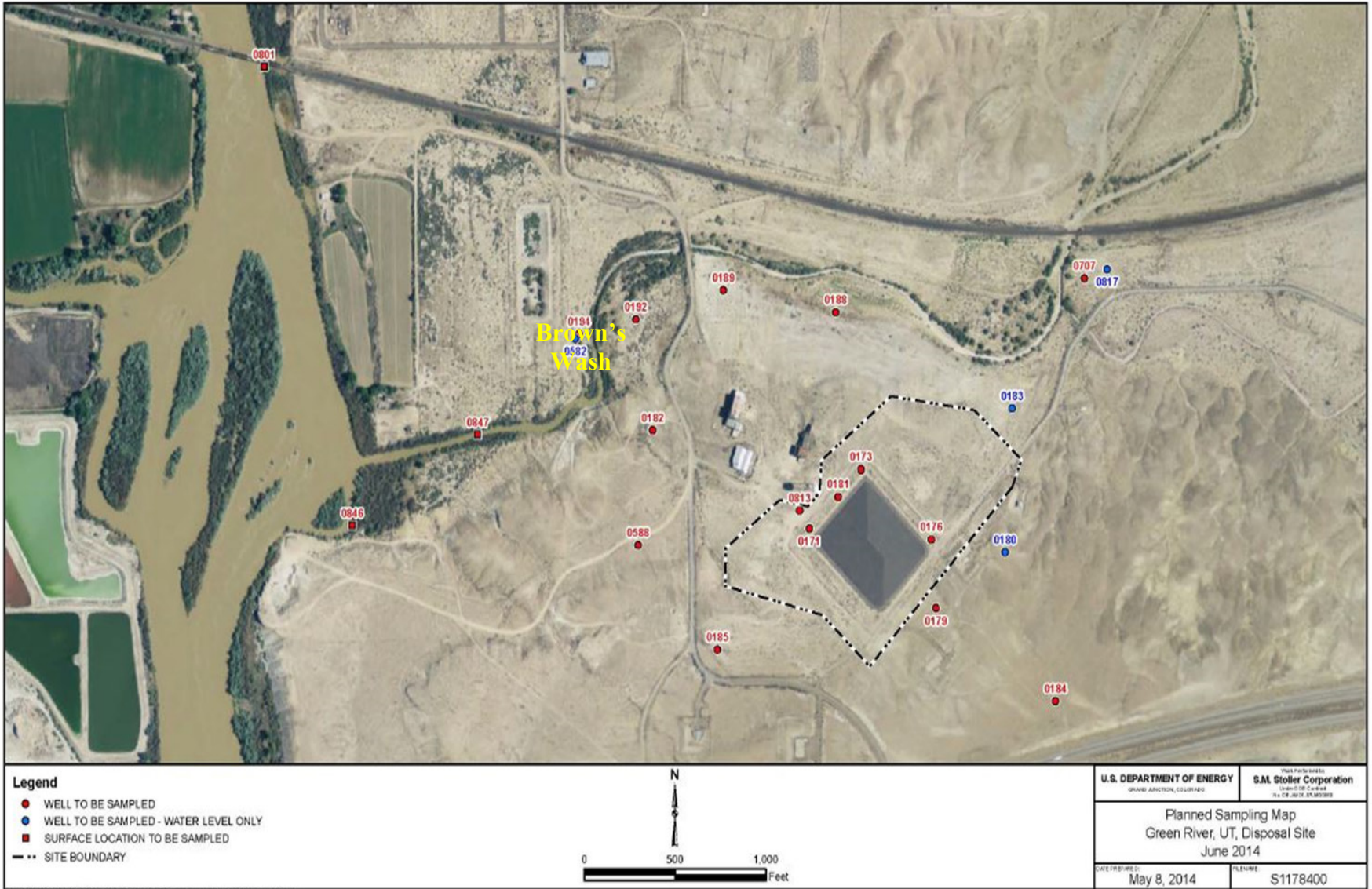


Figure 20. Green River, Utah, June 2014 Sampling Locations



Figure 21. Green River, Utah, Site—Aerial View of Evaporite Deposits in Brown's Wash



*Figure 22. Green River, Utah, Site—Brown's Wash Seep Discharge and Evaporite Deposits Observed During the March 2015 Inspection*



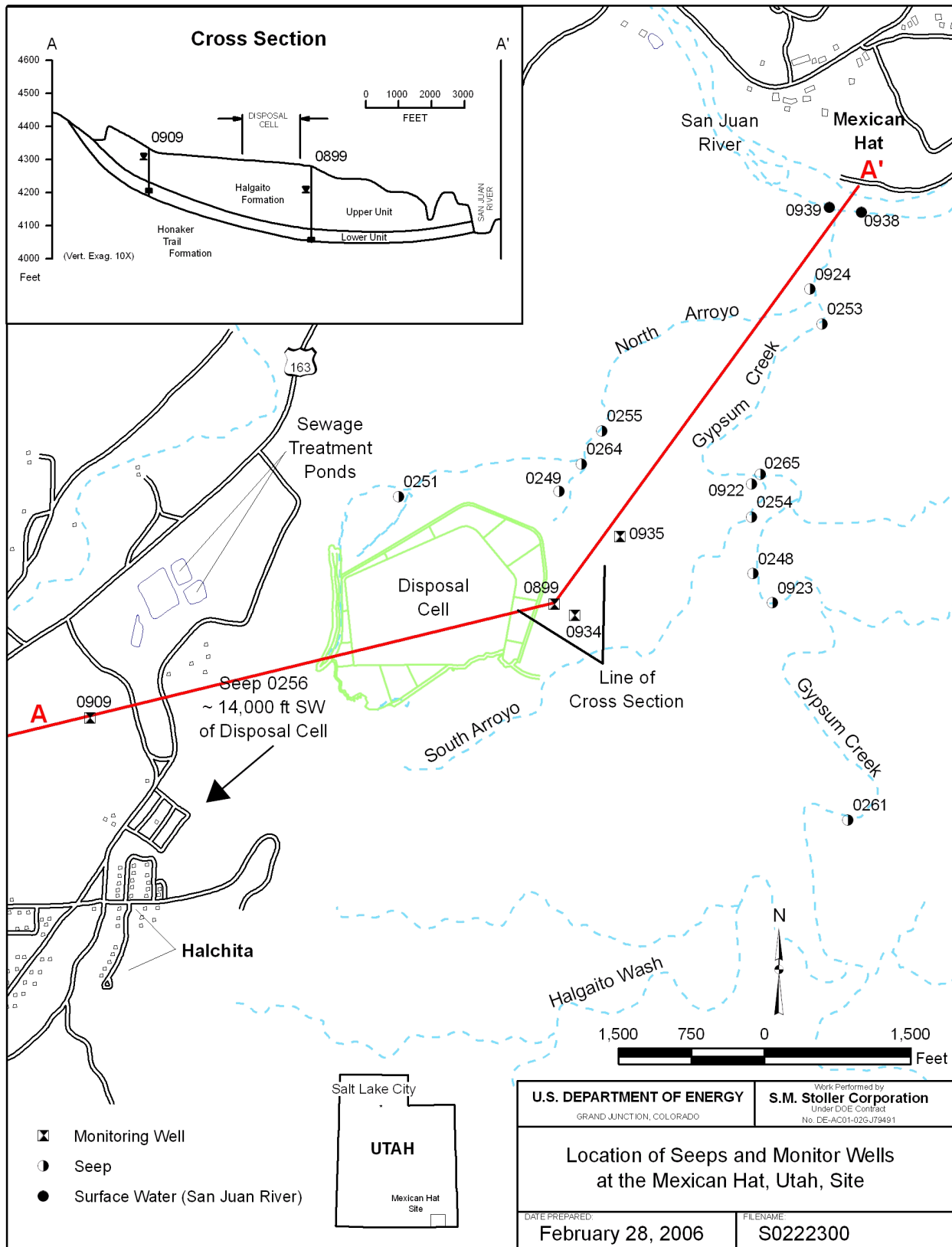
## 11.0 Mexican Hat, Utah, Disposal Site

The Mexican Hat, Utah, Site was identified as having evaporites along the periphery of the site (Table 9), occurring near seeps in the North Arroyo and Gypsum Creek (Figure 23). These seeps were monitored as a best management practice beginning in 1998, in accordance with the Long-Term Surveillance Plan (DOE 2007) and the Ground Water Compliance Action Plan (DOE 1999c).

Scattered, shallow, ephemeral, perched groundwater beneath the Mexican Hat disposal cell is contaminated as a result of uranium processing and remediation activities that occurred onsite, along with naturally occurring uranium in the area. This contaminated perched ground water intermittently seeps out at several locations along North Arroyo and Gypsum Creek downgradient from the site. Evaporite deposits have been observed along these seeps (mainly at seep 0248), as seen in Figure 24 and Figure 25. In the *Resolution of Seep and Ground Water Monitoring at the Mexican Hat, Utah, UMTRCA Title I Disposal Site* (DOE 2006b), a comparison of sample results from upgradient and background seeps appears to indicate that site-related contamination, primarily uranium and nitrate, is present within seeps downgradient of the site. However, because of their remote location and limited water flow, a risk assessment concluded that the seeps present no significant human health or ecological risk. The evaporite deposits associated with the seeps have not been sampled, and the elevated concentrations of uranium and observed evaporites at seep 0248 would make this location useful for collecting and analyzing an evaporite sample.

Table 9. Mexican Hat, Utah, Questionnaire Results

<b>Site Name:</b> Mexican Hat, Utah	
<b>Evaporite Deposits Onsite?</b>	<b>Yes</b>
<b>Specific Location Information</b> Evaporite deposits are present within Gypsum Creek, mainly near seep 0248, and have been investigated in the past.	
<b>Seasonal/Compliance Concerns</b> The site is inspected once per year, usually in May, during which the deposits are observed. The Mexican Hat site has a low amount of precipitation throughout the year. No compliance concerns because an ecological assessment determined no risk present.	
<b>Land Use/Land Cover Changes</b> No changes since surface remediation was completed in 1995.	
<b>Relevant Reports or Documents</b> The <i>Resolution of Seep and Ground Water Monitoring at the Mexican Hat, Utah, UMTRCA Title I Disposal Site</i> (DOE 2006b) discusses the reasons for discontinuing monitoring of eight locations as a best management practice in 2006.	



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Figure 23. Mexican Hat, Utah, Previous Seep Monitoring Locations



*Figure 24. Mexican Hat, Utah, 2006 Photos of Formation of Evaporite Deposits Along Seep 0248*



*Figure 25. Mexican Hat, Utah, Top Left: September 2015 Close-up View of Seep 0248 During Water Sampling Event  
Other Photos from 2015 annual inspection of seep 0248.*

## 12.0 Summary

Surficial evaporite deposits can form at LM sites in arid environments where water evaporation rates are high and water occurs at or near the surface. In addition, subsurface evaporites may form in arid environments where the water table is close to the surface, especially in areas with fluctuating groundwater levels near rivers. Overall, the conditions that favor formation of surficial and subsurface evaporite deposits at LM sites include (1) exposed surface water bodies, (2) groundwater discharge points, usually seeps, and (3) shallow groundwater. Nine LM sites have identified evaporite deposits, 17 sites have no identified evaporite deposits, and 3 sites do not have any information on evaporites (Table 10). Quantitative data on constituent concentrations and mineralogy for sites with identified evaporites are relatively limited, with 6 sites having quantitative data on uranium concentrations and 3 sites with direct mineralogic information (Table 10). Mineralogical information tends to indicate the formation of sodium sulfate salts, except for deposits at the Monument Valley site. The evaporites at Monument Valley are atypical because of the likely precipitation of uranium/vanadium minerals (although no mineralogical analyses are available) at the surface due to concentrations of uranium and vanadium up to 1,500 mg/kg and 1,300 mg/kg, respectively, in the surficial soils beneath a former evaporation pond. The maximum concentration of uranium in evaporites that are likely related to sodium sulfate salts (not including the Monument Valley samples) was 76 mg/kg. For the 6 LM sites with measured uranium concentrations, uranium measured in the evaporite samples are elevated compared to available background concentrations that were always less than average crustal abundance (1.8-2.7 mg/kg). Subsurface evaporites have only been positively identified and measured at the Riverton site, where uranium concentrations were up to 10 mg/kg.

These results indicate that evaporites occurring at the surface and the subsurface can concentrate and store uranium that may be available for later release. Subsequent release may occur under future changes in groundwater conditions (higher water table) and during extreme precipitation events that allow evaporite dissolution.

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## 13.0 Recommendations

Priority LM sites for future evaporite work should focus on sites with specific time frames for natural flushing or sites with active remediation (Table 10). However, some sites with persistent evaporites have been recommended for additional sampling to allow for better understanding of site processes (see comments in Table 10). Since evaporite formation and storage of contaminants was not considered in the conceptual models for LM sites, the consideration of contaminant storage and later release should be evaluated. Such consideration and a revised conceptual model is current underway for the Riverton site.

A stepwise approach to evaporite evaluations is as follows:

1. Identify whether evaporites are present in the surface or subsurface.
2. Collect and analyze evaporite samples for contaminants of concern (COCs).
3. Evaluate the potential for COC release into the groundwater from dissolution of existing evaporites. This should include an evaluation of the potential for changing site conditions (water table fluctuations) and extreme precipitation events, along with possible COC solubility and transport controls.

This study addressed points 1 and 2 using available data. A new PeSCS TTP can add sites with no information (Maybell, Naturita, and Slick Rock, Colorado with a priority on Naturita and Slick Rock due to compliance strategies—see Table 10) and add quantitative information on COCs in evaporites (point 2) for sites with identified evaporites that currently lack quantitative data (Bluewater, Grand Junction, and Mexican Hat—see Table 10). The addition of evaluating subsurface evaporites at LM sites can be performed on a site-by-site basis. Mineralogical information on evaporites may also be useful and can be addressed the PeSCS TTP. In addition, sites without any identified evaporite deposit have been rated in Table 10 for no further evaluation (level 4) or for some further consideration based on site conditions (level 3). Sites that do not have specific time frames for natural flushing or active remediation may need an evaluation of COC concentrations for due diligence in the evaluation of human health and environmental exposure risks, if those evaluations have not been completed already.

Point 3 will be addressed in more detail in the new PeSCS TTP. This TTP will propose approaches to evaluating long-term COC storage and release in relation to plume persistence and ongoing evaluations of compliance strategies.

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Table 10. Summary of Sites Evaluated and Quantitative Data Analysis

Site	Compliance	Evaporites Indicated	Quantitative Evaporite Analysis	Maximum Uranium (mg/kg)	Maximum Vanadium (mg/kg)	Mineralogy	Further Evaluation Recommendations	Comments
<b>Sites With No Information</b>								
Maybell, Colorado, Disposal Site	No further action with supplemental standards	Unknown	No	–	–	–	3	Rated as evaluation status 3 due to compliance strategy. Recommend visual check for evaporites during dry periods.
Naturita, Colorado, Processing Site	100 year natural flushing with ACLs	Unknown	No	–	–	–	1	Dry climate with nearby river, evaporite formation is likely.
Slick Rock, Colorado, Processing Site	100 year natural flushing with ACLs	Unknown	No	–	–	–	1	–
<b>Identified evaporites</b>								
Bluewater, New Mexico, Disposal Site	ACLs with no ongoing remediation	Yes	No	–	–	Unknown	2	White precipitates on top of disposal cell, after ponded water evaporates.
Grand Junction, Colorado, Site	Natural flushing	Yes	No	–	–	Unknown	3	Visible white evaporites on satellite imagery. Rated as evaluation status 3 due to compliance strategy of natural flushing with no time period. Include additional sampling in PeSCS TTP to better understand the system.
Grand Junction, Colorado, Processing Site	No further action with supplemental standards	Yes	Yes	45.2	–	Sodium sulfates	3	High U sample was collected in the subsurface in footprint of former tailings pile (may be a precipitated uranium mineral), rated as evaluation status 3 due to compliance strategy. Include additional sampling in PeSCS TTP to better understand the system.
Green River, Utah, Disposal Site	No further action with supplemental standards or ACLs (not approved yet)	Yes	No	27.7	15	Unknown	3	Evaluation status of 3 due to compliance strategy. Include additional sampling in PeSCS TTP to better understand the system.
Mexican Hat, Utah, Disposal Site	No further action	Yes	No	–	–	Unknown	3	Rated as evaluation status 3 due to compliance strategy. Recommend analyzing evaporite at seep 0248 to better understand the system.
Monument Valley, Arizona, Processing Site	None yet, GCAP being prepared	Yes	Yes	1,500	2,670	No direct analyses, likely are U/V precipitates	3	Stained soils with yellow and green coloration, high in U and V concentrations, elsewhere U < 10 mg/kg in general.
Rifle, Colorado, Old and New Processing Sites	100 year natural flushing with ACLs	Yes	Yes	64.7	614	Unknown	2	High U sample was collected in the subsurface underneath a former evaporation pond (may be a precipitated uranium/vanadium mineral). Rated as evaluation status 2 in order to get a true evaporite sample.
Riverton, Wyoming, Processing Site	100 year natural flushing	Yes	Yes	73	<10	Sodium sulfates	3	May need better background samples.
Shiprock, New Mexico, Disposal Site	Active remediation, supplemental standards, and natural flushing	Yes	Yes	76	–	Sodium sulfates	3	White, typical sodium sulfate evaporites. Recommend further consideration of subsurface evaporites contributing to plume persistence issues.
<b>No identified evaporites</b>								
Ambrosia Lake, New Mexico, Disposal Site	No further action with supplemental standards	No	No	–	–	–	4	Dry climate, but no groundwater discharge zones, 4 rating based on compliance strategy.
Burrell, Pennsylvania	Sample groundwater every 5 years to verify disposal cell performance	No	No	–	–	–	4	Wet climate.

Table 10 (continued). Summary of Sites Evaluated and Quantitative Data Analysis

Site	Compliance	Evaporites Indicated	Quantitative Evaporite Analysis	Maximum Uranium (mg/kg)	Maximum Vanadium (mg/kg)	Mineralogy	Further Evaluation Recommendations	Comments
Canonsburg, Pennsylvania	No remediation; ACL for uranium, groundwater monitoring, institutional controls	No	No	–	–	–	4	Wet climate.
Durango, Colorado, Processing Site	100 year natural flushing (tailings area) and no further action with supplemental standards (raffinate ponds)	No	No	–	–	–	3	Dry climate, groundwater discharge into nearby river, could have evaporites during drought periods. Add to PeSCS TTP evaluation during dry periods.
Edgemont, South Dakota, Disposal Site	No further action	No	No	–	–	–	3	Dry climate, but no direct groundwater discharge zones, may need to consider evaporation in nearby wetlands.
Falls City, Texas, Disposal Site	No further action with supplemental standards	No	No	–	–	–	4	Drier climate, but no groundwater discharge zones, 4 rating based on compliance strategy.
Gunnison, Colorado, Disposal and Processing Sites	Natural flushing, monitoring, institutional controls	No	No	–	–	–	3	Shallow groundwater with potential for seasonal evaporite formation.
L-Bar, New Mexico, Disposal Site	ACLs and continued monitoring	No	No	–	–	–	3	Dry climate, but no groundwater discharge zones, 3 rating based on compliance strategy.
Lakeview, Oregon	No remediation, no monitoring except for sulfate and manganese	No	No	–	–	–	4	–
Lowman, Idaho, Disposal Site	No groundwater contamination	No	No	–	–	–	4	Mechanical milling process.
Maybell West, Colorado, Disposal Site	No groundwater contamination	No	No	–	–	–	4	–
Monticello, Utah, Disposal and Processing Sites	Active remediation	No	No	–	–	–	3	Potential for seasonal subsurface evaporite formation.
Salt Lake City, Utah, Processing Site	No further action with supplemental standards	No	No	–	–	–	3	Dry climate, perennial stream nearby, evaporites possible in extreme drought conditions.
Shirley Basin South, Wyoming, Disposal Site	ACLs and continued monitoring	No	No	–	–	–	3	Dry climate, but no groundwater discharge zones, 3 rating based on compliance strategy.
Sherwood, Washington, Disposal Site	No groundwater contamination	No	No	–	–	–	4	Wet climate, limited opportunity for evaporite formation.
Spook, Wyoming	No remediation, supplemental standards	No	No	–	–	–	4	–
Tuba City, Arizona, Disposal Site	Was active remediation, current strategy undecided after recent plant shutdown	No	No	–	–	–	3	Dry climate and areas with shallower groundwater. Potential for subsurface evaporite formation.

**Notes:**

Further evaluation criteria:

- 1 = Need to evaluate if evaporites exist and sample for COCs if evaporites exist
- 2 = Need quantitative analyses
- 3 = Consider additional evaluation based on comments
- 4 = Nothing additional required
- = No data available

**Abbreviations:**

ACL = alternate concentration limit

GCAP = Groundwater Compliance Action Plan

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