Long-Term Stewardship at a Former Uranium Mill Tailings Site in Riverton, Wyoming – 17090

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ABSTRACT

The US Department of Energy Office of Legacy Management (LM) is responsible for maintaining protective public health and environmental conditions at former uranium mill tailings sites nationwide via long-term stewardship. One of these sites, a former uranium mill near Riverton, Wyoming, is within the boundary of the Wind River Indian Reservation and operated from 1958 to 1963. Tailings and contaminated material associated with mill operations were removed and transported to an offsite disposal cell in 1989. The remedial action was completed under Title I of the Uranium Mill Tailings Radiation Control Act of 1978. Milling operations, which included an unlined tailings impoundment and an unlined evaporation pond, contaminated the shallow groundwater, resulting in a downgradient groundwater plume that discharges to the Little Wind River. A natural flushing compliance strategy was implemented in 1998. This strategy allows contaminants of concern to naturally flush from the groundwater, provided that contaminants flush below US Environmental Protection Agency maximum concentration limits within 100 years. As part of the compliance strategy, LM has implemented a groundwater monitoring program along with institutional controls that include the installation of an alternate water supply, continued sampling of private wells, and restrictions on well drilling and gravel pit construction. LM works closely with local stakeholders and community members to ensure that these institutional controls are in place and maintained.

The Riverton site provides an interesting case study where contaminant remobilization due to river flooding prompted a reevaluation of the conceptual site model to verify if the current compliance strategy would remain protective of human health and the environment. Concentrations of groundwater contaminants, which include sulfate, molybdenum, and uranium, were transiently elevated following flooding of the Little Wind River in 2010 and 2016. These flood events provided the impetus to investigate other aspects of the hydrologic system, including the unsaturated zone, naturally reduced (sulfidic) zones, and evaporite deposits. New site conceptual models, field and laboratory studies, and numerical models are being developed to explain how biogeochemical sediment–water interactions contribute to plume persistence and flood-related increases in groundwater concentrations. Updated human health and ecological risk assessments are progressing to evaluate the risk to human health and the environment based on current site conditions. Groundwater concentrations may

remain above US Environmental Protection Agency maximum concentration limits beyond the 100-year natural flushing regulatory time frame. LM in its capacity as a long-term steward continues to monitor the site to ensure protectiveness is maintained and to determine the feasibility of alternative compliance and remediation strategies.

INTRODUCTION

Riverton, Wyoming, Processing Site

The former Riverton, Wyoming, Processing Site in central Wyoming is on the Wind River Indian Reservation just outside of Riverton, Wyoming (Fig. 1) and about 40 miles west of the Gas Hills uranium mining district. The site is the location of a former uranium and vanadium ore processing mill that operated from 1958 to 1963, which produced 1.4 million cubic meters of tailings. The tailings pile covered about 29 hectares of the 56.7-hectare site. Milling operations, which included the use of an unlined tailings impoundment and an unlined evaporation pond, contaminated the shallow groundwater, resulting in a downgradient groundwater plume that discharges to the Little Wind River. In 1988 and 1989, the US Department of Energy (DOE) removed the mill tailings to the Gas Hills East, Wyoming, Disposal Site (Fig. 1) in the Gas Hills mining area. The tailings pile was excavated to an average depth of 1.2 m below ground surface based on a radium (^{226}Ra) soil standard in Title 40 *Code of Federal Regulations* Part 192.

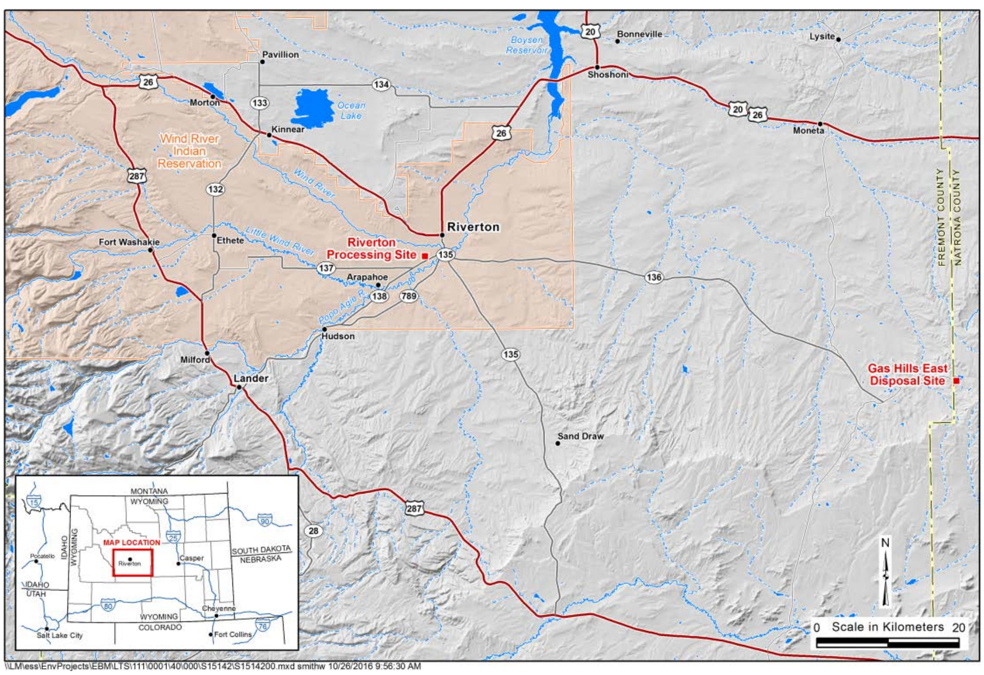

Fig. 1. Riverton Site Location Map.

DOE continued its work onsite in the 1990s with an initial groundwater characterization. In 1998, DOE completed a Site Observational Work Plan that summarized existing characterization data and proposed a site-specific groundwater compliance strategy of natural flushing in conjunction with institutional controls (ICs) and verification monitoring [1]. DOE formally submitted this plan to the US Nuclear Regulatory Commission (NRC) in the Ground Water Compliance Action Plan (GCAP) in 1998 [2]. NRC concurrence was received. The natural flushing compliance strategy requires concentrations of four groundwater contaminants (manganese, molybdenum, sulfate, and uranium) to be below US Environmental Protection Agency maximum concentration limits within a 100-year compliance period. However, the regulatory compliance strategy did not require detailed evaluations of the solid phase in the saturated and unsaturated zone that could influence future groundwater concentrations. ICs for the protection of human health and the environment include prohibiting the use of the groundwater in the shallow alluvial aquifer, along with restrictions on well drilling and gravel pit construction, continued sampling of private wells, and a provision for an alternate drinking water supply system for residents within and near the IC boundary. In 1998, DOE contributed funding for the construction of the alternate drinking water supply system (Fig. 2). In addition, DOE has conducted verification monitoring since 1998 to document site conditions and assess the progress of natural flushing. In 2003, the DOE Office of Legacy Management (LM) was formed, and ongoing long-term surveillance and maintenance (LTS&M) activities at Uranium Mill Tailings Radiation Control Act sites, including the Riverton, Wyoming, Processing Site, were moved under the new organization. Additional details about the Riverton site, along with links to site documents and data, can be found at http://www.lm.doe.gov/riverton/Sites.aspx.

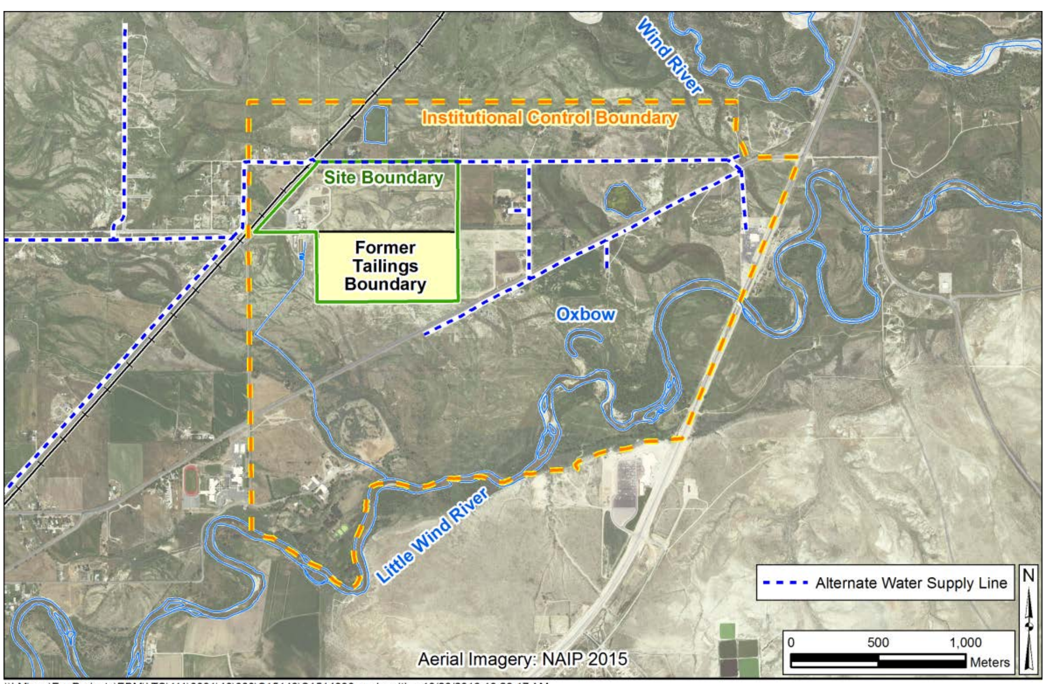

Fig. 2. Riverton, Wyoming, Processing Site with site boundaries, institutional control boundaries, and alternate water supply system.

2010 FLOOD AND NEW DATA COLLECTION

Results of the verification monitoring indicated that natural flushing was generally progressing as expected until June 2010, when significant increases in contaminant concentrations, including uranium (Fig. 3), were measured in several wells downgradient of the site after the area flooded. In response to the unexpected results following the flood, an enhanced characterization of the surficial aquifer was conducted in 2012, which included the installation of 103 boreholes along 9 transects with a direct-push drilling rig, the collection of 103 water samples and 65 soil samples, column tests on the soil samples, and additional groundwater modeling. The 2012 Enhanced Characterization Report [3] presents the results and analyses of this enhanced characterization. Major findings include:

- A better definition of the size and shape of contaminant plumes (Fig. 4 for uranium)
- Verification that leachable uranium was present in the unsaturated zone soils

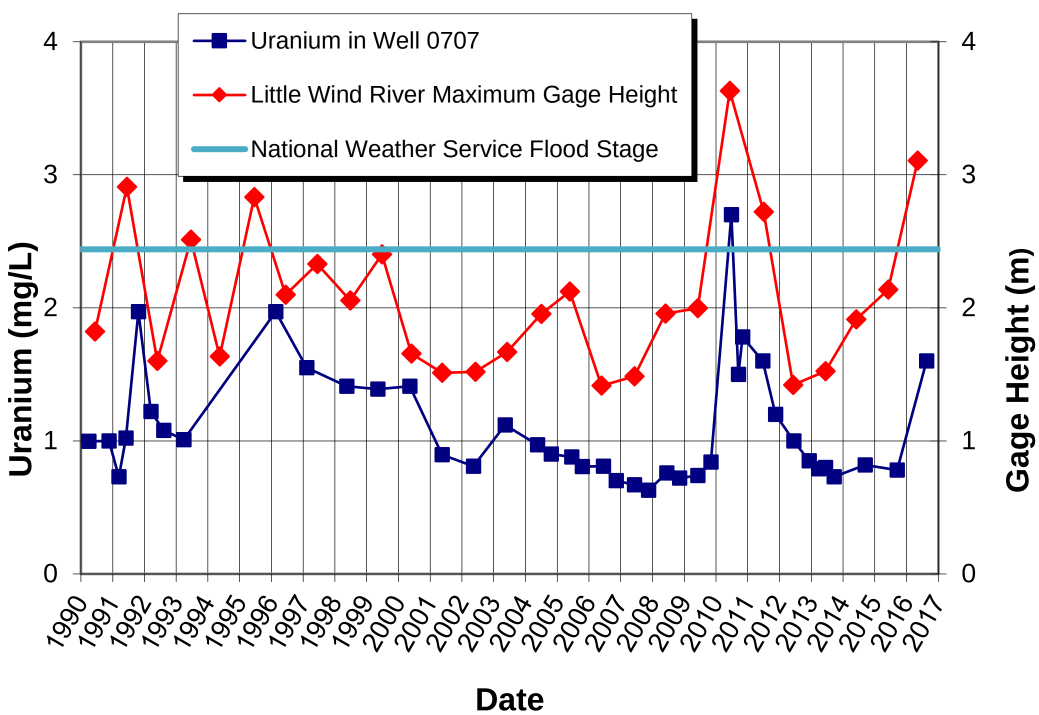

Fig. 3. Hydrograph for the Little Wind River compared with uranium concentrations at well 0707 (see location in Fig. 4).

By 2013, the majority of plume contaminant concentrations had returned to levels near the pre-2010 flood conditions (Fig. 3). However, these concentrations still exceed model predictions for natural flushing [4], and the current data indicate that achievement of natural flushing remediation goals within the 100-year time period is not likely, especially with the high potential for additional floods in the future.

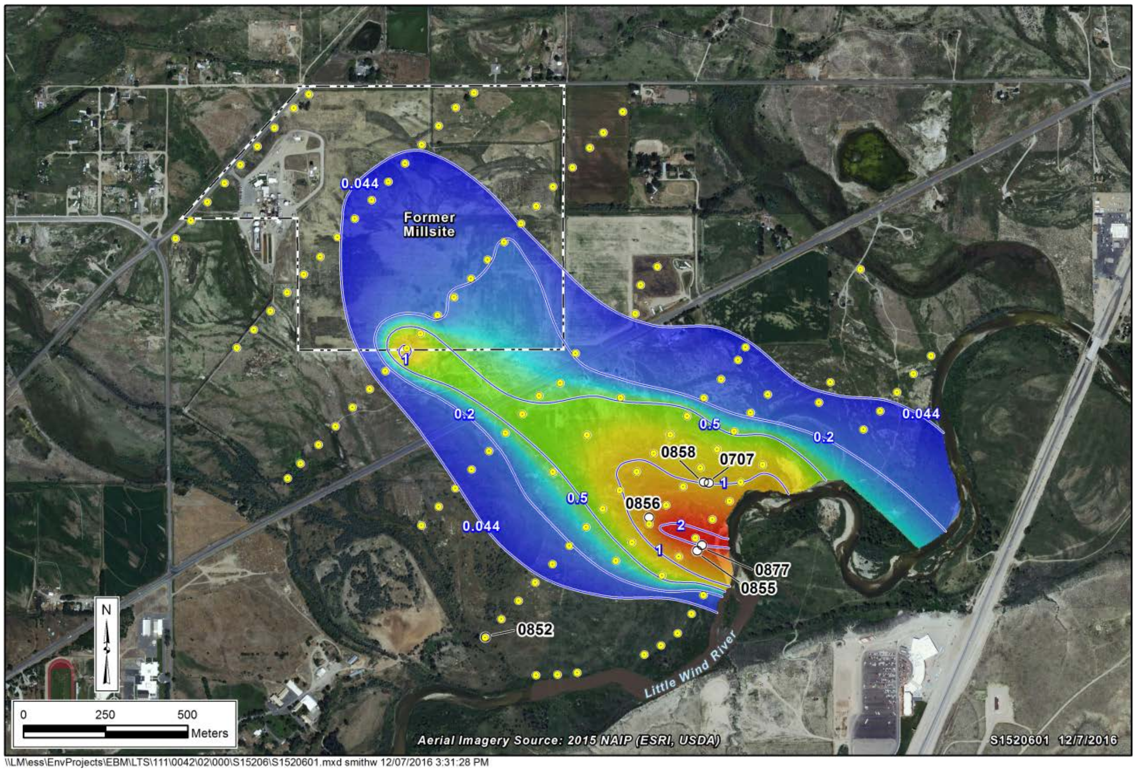

Fig. 4. Uranium plume at the Riverton site based on direct-push drilling locations (yellow dots) in 2012 and 2015 along with key well locations.

NEW CONCEPTUAL MODELS AND 2015 DATA COLLECTION

The flood data from 2010 and additional data collection in 2012 provided information to use in modifying the original conceptual site models that previously did not account for flooding and release of contaminants from the solid phase for the Riverton site [4]. The new information and updated site conceptual models included the recognition of persistent secondary contaminant sources involving sediment–water interactions in the unsaturated and saturated zones that can contribute to plume persistence [4, 5, 6]. On the basis of the 2012 data, the main secondary sources appear to include subsurface evaporite deposits (first hypothesized by Looney et al. [7]), naturally reduced zones (NRZs) with high organic content, and ongoing source zones underneath the former tailings impoundment. These interpretations were based on leaching data from the unsaturated zone, knowledge of plume persistence near the Little Wind River where higher organic content is likely, and ongoing elevated groundwater contaminant concentrations near the former tailings impoundment. However, information collected through 2012 included limited direct solid-phase data and essentially no solid-phase data below the water table.

As part of LM's long-term stewardship, an extensive field effort in 2015 focused on obtaining data to better understand sediment–water interactions at the Riverton site. Key data objectives included identifying inorganic and organic chemistry (including contaminants of concern) to evaluate the influence of secondary solid sources on the groundwater plume. This advanced site investigation [8] used backhoe trenching, sonic drilling, multilevel monitoring wells, direct-push drilling, and temporary well points to collect soil and groundwater samples. Groundwater sampling included the addition of geochemical constituents and isotopes that had not been sampled in the past to better understand postflood conditions and the possibility of previously unrecognized contaminant sources.

This sampling was performed to achieve the following:

- Better define the contaminant plumes
- Verify the occurrence of persistent secondary contaminant sources
- Better understand the reason for the contaminant increases after the 2010 flood
- Assess contaminant plume stagnation near the Little Wind River

Soil data from trenches and sonic drilling confirmed a general sequence of silt (approximately 0 to 1–1.5 m in depth) underlain by unsaturated and saturated sand and gravel (approximately 1–1.5 to 5 m in depth), which is underlain by a silty/fine sand bedrock (Wind River Formation) that forms a semiconfining layer below the sand and gravel. The geochemical data indicate:

- Elevated concentrations of several constituents in the silt zone, including chloride (Fig. 5), likely due to the formation of evaporites that occur over the contaminant plume and outside of the contaminant plume due to high evapotranspiration rates across the site
- Uranium appears to be concentrated in the silt over the groundwater contaminant plume (Fig. 6) and in NRZs (Fig. 7) found near and below the water table close to the Little Wind River
- In the former tailings impoundment area, a thin unsaturated zone with native silts/clays (nonfill material) and the underlying saturated sand and gravel deposits have slightly higher uranium and sulfate concentrations relative to background

The elevated uranium near the former tailings impoundment provides a continuing source for the uranium plume that was not considered in earlier natural flushing models. Uranium released from the silt layer during flooding may add uranium to the groundwater plume near the Little Wind River. NRZs may act as a uranium source and/or sink depending on geochemical conditions. These mechanisms provide a possible explanation for plume persistence and elevated contaminant concentrations after flooding events.

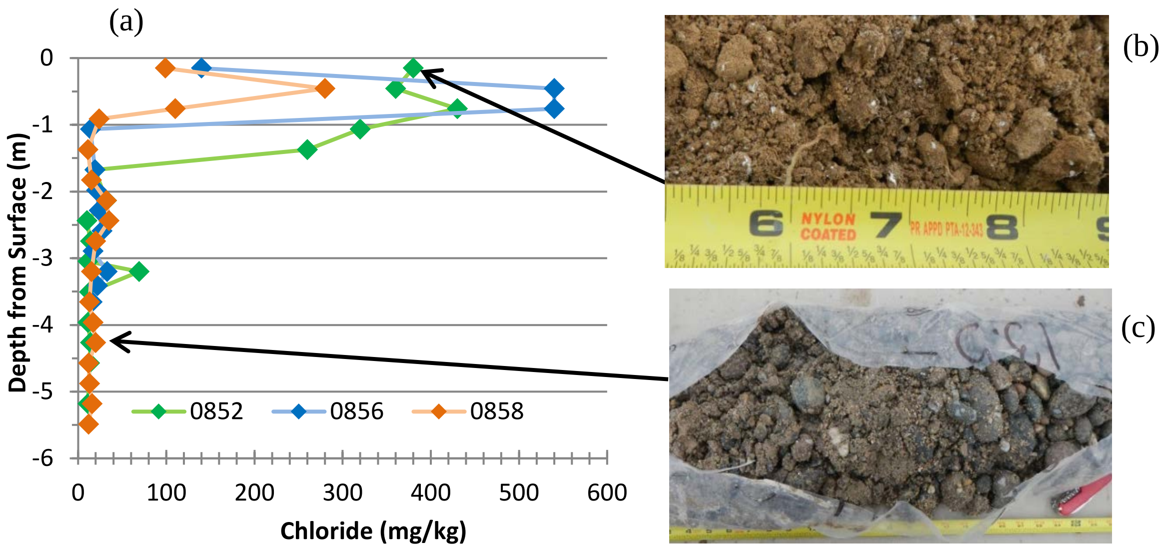

Fig. 5. Solid-phase chloride concentrations with depth (a). Borehole 0852 is outside of the uranium plume, and boreholes 0856 and 0858 are within the uranium plume (see locations in Fig. 4). Photographs of silt with white evaporite flecks (b) and underlying sand and gravel (c) in borehole 0852 at the depths indicated by the arrows.

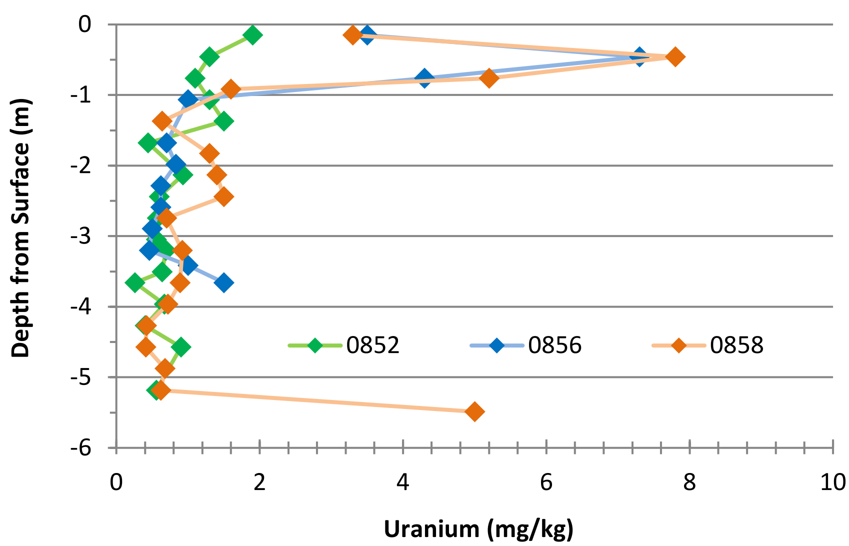

Fig. 6. Solid-phase uranium concentrations with depth. Borehole 0852 is outside of the uranium plume, and boreholes 0856 and 0858 are within the uranium plume (see locations in Fig. 4).

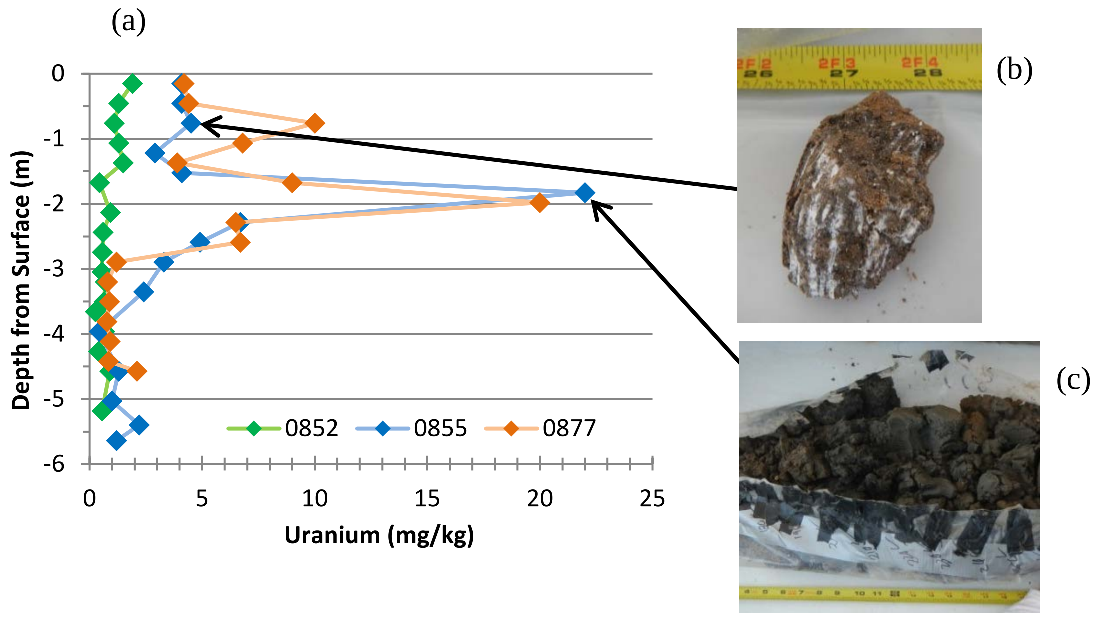

Fig. 7. Solid-phase uranium concentrations with depth (a). Borehole 0852 is outside of the uranium plume, and boreholes 0855 and 0877 are within the uranium plume (see locations in Fig. 4). Photographs of evaporites (b) and NRZ (c) in borehole 0855 at the depths indicated by the arrows.

MAY 2016 FLOOD

On May 8, 2016, a large upstream rain event caused flooding of the Little Wind River (Fig. 8) up to the locations of new wells 0852, 0856, and 0858 (Fig. 4). These wells were installed in 2015 as multilevel installations. Uranium and chloride concentrations increased in all wells that were in the flooded zone, but the uranium increase in well 0852 (outside of the main uranium plume) was much less than that in wells 0856 and 0858 within the uranium plume. Multilevel data in well 0858 confirmed an initial increase in chloride and uranium (Figs. 9 and 10) immediately after the May 2016 flood, with a delayed increase in uranium and chloride at depth. As of October 2016, the uranium and chloride concentrations in well 0858 appear to be relatively consistent with depth and have leveled off at concentrations that are higher than pre-May 2016 flood concentrations. These data confirm the release of contaminants from the silt layer during flood conditions, because elevated concentrations of contaminants in the underlying sand and gravel were not indicated in the 2015 solid-phase data. Overall, it appears likely that the NRZs can remove uranium from the groundwater when plume concentrations are high but can slowly release uranium to the groundwater as natural flushing progresses, leading to long-term plume persistence issues. The influence of the NRZs in controlling the groundwater uranium concentrations is an ongoing evaluation in collaboration with researchers from the SLAC National Accelerator Laboratory.

Fig. 8. View of May 2016 flood with well 0858 in the middle of the photo.

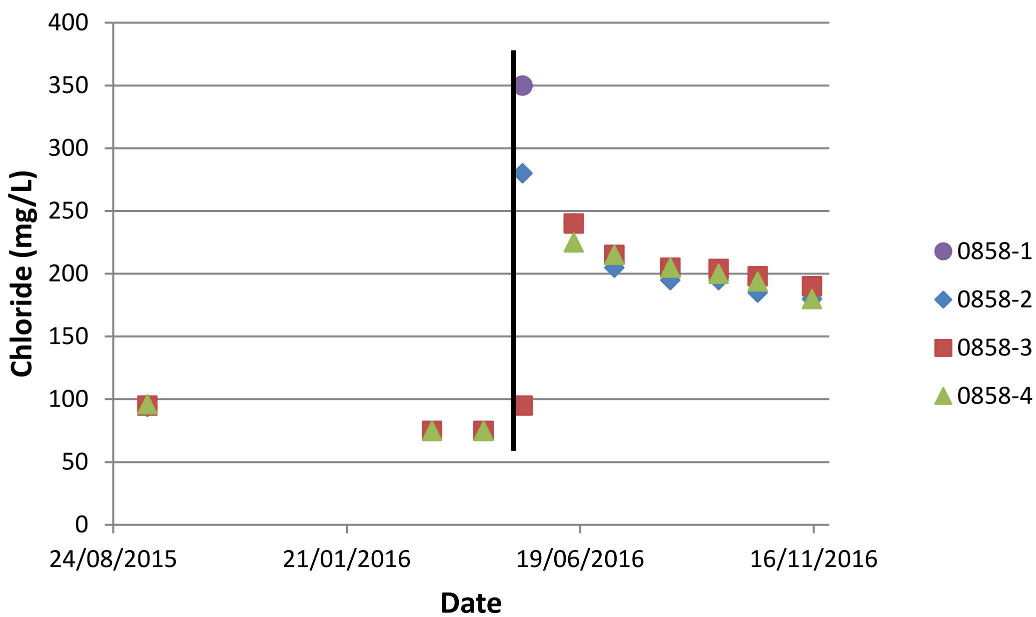

Fig. 9. Chloride concentrations in multilevel well 0858 (location shown in Fig. 4). Vertical line indicates May 8, 2016, flood event. Sample depths are 0.91–1.07 m for 0858-1, 2.29–2.44 m for 0858-2, 3.81–3.96 m for 0858-3, and 5.09–5.40 m for 0858-4. Note that the upper sampling port 0858-1 only had water for two postflood sampling events; the second chloride value was the same as the chloride value for 0858-3.

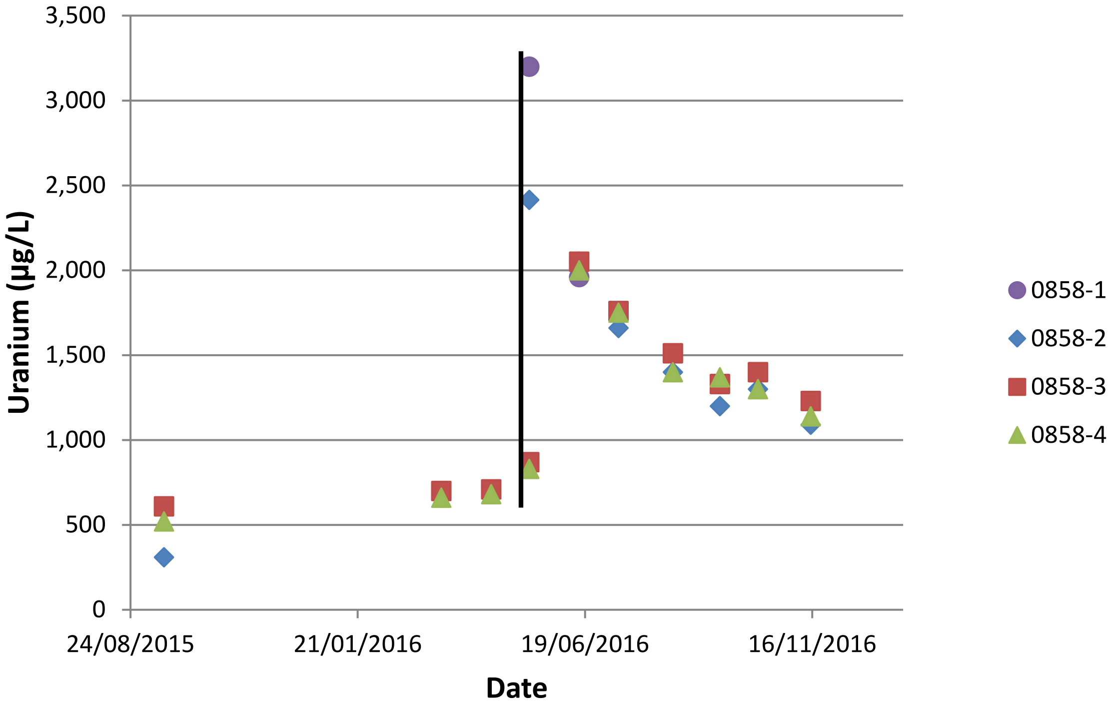

Fig. 10. Uranium concentrations in multilevel well 0858 (location shown in Fig. 4). Vertical line indicates May 8, 2016, flood event. Sample depths are 0.91–1.07 m for 0858-1, 2.29–2.44 m for 0858-2, 3.81–3.96 m for 0858-3, and 5.09–5.40 m for 0858-4. Note that the upper sampling port 0858-1 only had water for two postflood sampling events; the second uranium value was very similar to the value in 0858-2 and 0858-3.

ONGOING LM LONG-TERM STEWARDSHIP

The Riverton site conceptual model has evolved over time as new data have become available. Thus, ongoing LTS&M activities at the Riverton, Wyoming, Processing Site are needed to maintain effective ICs, to further evaluate current compliance strategies, and to determine the feasibility of alternative compliance and remediation strategies. The following LTS&M activities are planned:

- Continue to support the Wind River Tribes for independent oversight
- Continue to evaluate and share the extensive data and interpretations collected to date
- Use additional field work, lab work, and numerical modeling to refine conceptual models and to create snapshots of groundwater plume data
- Conduct soil sampling using trenching, sonic drilling, and the collection of river sediments
- Continue multilevel well sampling on a regular basis to determine the ongoing impact of the May 2016 flood and as an indication of any future seasonal trends
- Conduct annual sampling at groundwater and surface water monitoring locations

- Continue collaborations with DOE's National Laboratories, the US Geological Survey, and universities to optimize successful collection of data and develop a path forward
- Revise human health and ecological risk assessments

In addition, LM hopes to apply the lessons learned from LTS&M activities at the Riverton site to other similar LM sites.

SUMMARY AND CONCLUSIONS

Although LM removed uranium mill tailings at the former Riverton, Wyoming, Processing Site, groundwater contamination persists because of secondary contaminant sources in solid-phase soil in the unsaturated zone and saturated zone aquifer sediments. These secondary sources were neither known nor incorporated into original site conceptual and groundwater models that predicted groundwater would naturally flush within the 100-year regulatory compliance period.

Additional data collection in 2012 included the installation of boreholes along nine transects with a direct-push drilling rig, collection of new water and soil samples, column tests on the soil samples, and additional groundwater modeling. Further, advanced site investigations were performed in 2015. These additional investigations were designed to better understand sediment–water interactions, including vertical variation of groundwater quality, and to identify additional and ongoing contaminant sources.

Periodic flooding of the Little Wind River appears to liberate secondary sources from unsaturated zone silty evaporitic sediments and contributes to biogeochemical changes in NRZs. Multilevel groundwater monitoring after a 2016 flood confirms the release of contaminants from the silt layer during flood conditions. NRZs can remove and slowly release uranium depending upon contaminant concentrations and geochemical conditions. The influence of flood conditions on NRZs is still being evaluated.

At the Riverton site, the long-term stewardship activities that have been conducted, and those being planned, are committed to ensuring the protection of human health and the environment now and in the future. Ongoing LTS&M activities at the Riverton site demonstrate the need to maintain effective ICs, continually evaluate current compliance strategies, and to determine the feasibility of alternative compliance and remediation strategies. Positive and active collaboration by all stakeholders is a key to the success of the long-term stewardship of the Riverton site. In addition, LM hopes to apply the lessons learned from LTS&M activities at the Riverton site to other similar LM sites.

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