# Final Report: North Cave Hills Abandoned Uranium Mines Impact Investigation

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**April 18, 2007**

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# 1.0 Introduction

This final report has been prepared as part of the North Cave Hills Area Abandoned Uranium Mines Impact Investigation conducted under a Joint Venture agreement between the United States Department of Agriculture-Forest Service (Forest Service) and the South Dakota School of Mines and Technology (SDSM&T), and a subcontract with Oglala Lakota College (OLC). Funding for this on-going study has been provided through US-EPA Region 8. This report describes both the field and laboratory methods used to collect data, and results for the evaluation of potential environmental impact of abandoned uranium mining and exploration sites in the North Cave Hills, Harding County, South Dakota. Specifically, this final project report addresses:

- Off-site migration of sediment spoils and associated metals and radionuclides from the North Cave Hills region of USFS administered lands into potentially impacted drainages (sediments and surface waters);
- Sliding, slumping, and sheet erosion of mining spoils and associated metals and radionuclides from USFS administered lands onto adjacent private lands;
- Off-site migration of airborne dust particulates and associated metals and radionuclides by wind erosion of mining spoils from USFS administered lands onto adjacent and regional private lands;
- Potential contamination to the regional ground water supply by introduction of metals and radionuclides into regional aquifers that provide drinking water to local residents and livestock.

# 2.0 Background Information

The North Cave Hills area is part of the Sioux Ranger District, Custer National Forest, Region 1 of the USFS. The complex is located approximately 25 miles north of Buffalo, South Dakota (Harding County Seat) and 150 miles north-northwest of Rapid City, South Dakota. Ludlow, South Dakota, is the closest municipality located 5 miles due east (Fig. 2.1).

## 2.1 Geomorphology

The North Cave Hills rise about 400 feet above the surrounding plains to an altitude of approximately 3,400 feet. They are characterized by steep-sided and generally flat-topped, forested buttes rimmed by 60-150 feet high sandstone cliffs. Below the cliffs, softer sedimentary rocks including shale, siltstone, coal and loosely cemented sandstone form steep, grass-covered slopes. From a geomorphic perspective these slopes contain evidence of geologically rapid retreat. Erosion of the softer sedimentary rocks below the sandstone cliffs promote rockfall from above and ultimate cliff retreat resulting in smaller butte areas through time. Most of the rim slopes and canyons are steep-sided, mantled by rock debris, and contain relatively deep box canyons all of which are indicators of the rapid rates of erosion. There are many locations around the main platform that show naturally occurring small-scale solifluction, sliding, and slumping. The entire platform is tilted by several degrees to the north-northeast and is divided here into three geomorphic units: 1) a highly dissected, more rugged tableland to the north, bounded in the south by Devils Canyon; 2) an adjoining broad, central table bordered to the south by the deeply incised drainage of Schleichart Draw; and 3) a southern table which is dissected into a northern and southern unit by Davis Draw.

## 2.2 Geology

Regional bedrock consists of the Late Cretaceous Pierre Shale, Fox Hills sandstone, and the Hell Creek Formations. Overlying Tertiary rocks include the Ludlow and Tongue River Formations (Table 2.1). Both the Pierre and Fox Hills units outcrop further south, outside of the study area (Fig 2.2).

The oldest rocks in the study area are the Hell Creek Formation clay, carbonaceous shale, siltstone, and sandstone units. The Formation is exposed in a small window along Bull Creek and major drainages at the base of the North Cave Hills. The Cretaceous-Tertiary contact is gradational and poorly exposed. Thus, is has been generally assigned to the lower-most coal unit in the overlying Tertiary rocks.

The lower-most Tertiary Ludlow Formation consist of gray to buff colored and relatively unconsolidated sandstone, siltstone, and clayey sand and silt units that weather yellowish gray. Occasional cross-bedding and ripple marks are evident in the sandy parts and ironstone concretions are ubiquitous throughout. Lignite coal and ligniferous shale units, referred to as 'blackjack', are ubiquitous in the Ludlow. The lower 200 feet of the Formation is designated as 'unnamed coal beds'. Above the lower zone, the major coal units are the Lonesome Pete coal zone, coal bed B, C coal zone, carbonate coal zone, and coal bed D.

The Ludlow-Tongue River Formation contact is sharp and marked by the appearance of the first massive sandstone outcrop. The lower-most sandstone, immediately above the Ludlow Formation, is yellow to brown, cross-bedded, slightly cemented with calcite, and massive having a thickness of 30-100 feet. The unit also forms the principle aquifer in the area. The upper sandstone unit is massive, non-calcareous, loosely consolidated and ranges up to 135 feet thick. A uranium ore zone consisting of impure lignite beds intercalated in siltstone and claystone units occurs about 110-150 above the base of the Formation. These coal units have high uranium concentrations and can be several feet thick. This unit also separates the lower and upper sandstone units.

Weathering and erosion of the above sequence has formed resistant sandstone rim rock capping the North Cave Hills. Tertiary Tongue River Formation rocks form the rim rock and are underlain by shallow slopes comprised of loosely consolidated sand, silt, and clay layers with intercalated coal seams of the Tertiary Ludlow Formation. Strata are relatively flat-lying with a regional dip of 1-2 degrees to the NE, but also display several areas of gentle folding and possibly faulting which control the orientation of local dip directions.

Curtiss (1955) noted "a well-defined right-angle joint pattern, which trends north-south, east-west is conspicuous in the basal Tongue River massive indurated sandstone, particularly in the North Cave Hills. Therefore, joint control may provide excellent permeability channel ways for the downward movement of uranium charged solutions into the Tongue River and Ludlow formations from the overlying White River sediments"*(before White River Formation was stripped away by erosion in the North Cave Hills)*. It is also possible that these same joints, which are evident at the base of many abandoned uranium mines, are conduits for entry of contaminants into underlying sandstone aquifers.

Regionally, broad anticline-syncline pairs oriented in an approximate ~N35°W direction lay to the west and extend into SE Montana. These features are the southeastern-most extension of the Ordovician Cedar Creek Anticline. The Cave Hills region lies about 15 miles to the E-NE of this structure but its presence may impact the dip orientation of the platform areas in the Cave Hills and be partly responsible for the orientation of the surface drainage system that has developed.

The presence of deep-seated fractures on massive sandstone beds at the base of many abandoned uranium mines suggest that deep ground water flow directions could be impacted by these features. Fracture systems are important in flow direction studies in that more volume of water may be conducted through fractures (secondary porosity) than through the primary porosity and be in a different direction than the regional dip of the aquifers themselves. This condition can be exacerbated in densely fractured rock or where the fractures are large. For example, it is known from the Black Hills that fracture flow can be many orders of magnitude greater than incipient porosity flow. Thus, ground water flow patterns can be affected by fracture patterns and density. In addition, the wide range of depths to the Hell Creek aquifer (~150-250+ ft) also suggests that local stratigraphic highs and lows might impact flows immediately around any particular well.

## 2.3 Surface Water Hydrology

The regional drainage pattern is strongly controlled by the regional structural grain, the prominent form being a conjugate set of fractures striking approximately N50-55°W and N10-50°E. Major, broad drainages dissecting the North Cave Hills have their headwaters close to the eastern edge of the tables and flow toward the northwest in the northern part and to the southwest in the southern part, essentially crossing the whole platform. Northern drainages are captured by Crooked Creek, which flows north around the North Cave Hills on their western side and then turns east to ultimately join the North Fork of the Grand River at Haley-Bowman Reservoir in North Dakota. Southern drainages are captured by Campbell Creek flowing toward the southeast along the southwestern side of the North Cave Hills. Campbell Creek flows into Bull Creek which joins the South Fork of the Grand River. The North and the South Forks of the Grand River are the major contributories to Shadehill Reservoir, the major reservoir in northwestern South Dakota. Drainages on the eastern edge of the North Cave Hills only cut back into the tables for relatively short distances of up to about one half of a mile. In the northern and central tables, these easterly drainages are all parts of the headwaters or contributories to Petes Creek which flows north along the eastern side of the Cave Hills and joins Crooked Creek at the northern end of the North Cave Hills. East-flowing drainages of the southern table are part of the headwaters of Big Nasty and Jack Creeks which both join the South Fork of the Grand River. Therefore, all water draining of the North Cave Hills ultimately enters the Shadehill Reservoir.

On the prairie parts surrounding the buttes, channel morphology is more representative of a dry, supply limited system and is consistent with much of the western plains and Rocky Mountains that have been in a period of erosion and incision for approximately the past 140 years.

Climatic shifts between arid and humid since the cessation of glaciation in the Late Pleistocene (~12,000 yrBP) has led to the development of a terrace system along many western stream valleys that represent these changing climates. Humid periods were times of aggradation in stream valleys and arid periods were times of erosion often accompanied by channel deepening. At least four such periods have been identified by terraces surrounding incised stream channels, i.e., each elevated terrace marks a previous valley fill. A return to more arid conditions after the end of the Little Ice Age (ca. 1880) was typified by gully erosion and in the western US, was exacerbated by grazing and sod-busting (Leopold, 1994). Typical western South Dakota prairie channels are narrow and deep and often contain between 1-3 terraces above the current channel. A recent study by Roeser (2004) confirmed a predominant 'F' channel type exists in NW South Dakota. F channels are defined as entrenched systems having high to moderate width/depth ratios and moderate sinuosity (Rosgen, 1996) In addition, it is common that undercut banks fail promoting more stable conditions locally and in time will generate sufficient sediment in the channel to reestablish a stable channel system. Roeser (2004) also evaluated the stage of channel evolution these stream were currently in using Schumm's channel evolution model (CEM) (Schumm et al., 1984). Northwestern South Dakota channels were classified as primarily existing in CEM stage IV, a stabilizing entrenched channel with several channels in CEM stage III (active bank-widening promoted by bank failure). The end-point for these systems is a CEM stage IV, a stable entrenched system with a developed floodplain. Evolution from stage III to stage IV will, by nature of the process, produce additional sediment load to the stream systems until stabilization has been achieved.

Several spring horizons, generally associated with thicker lignite seams, encircle the North Cave Hills on USFS administered land. Two prominent horizons occur just above and below the indurated sandstone cliffs of the Tongue River Formation, and a third just above the base of the grass-covered slopes. Many of these springs are perennial. In addition, several of the springs are developed for stock watering and at least two springs are known to be used for domestic supplies. All watersheds are marked by numerous small stock dams and several larger-sized reservoirs on and off USFS administered land. Smaller dams and reservoirs are generally designed for 100% capture without a spillway or stand-pipe design.

### 2.4 Groundwater Hydrology

Groundwater supplies all of the human and stock watering needs in and around the North Cave Hills groundwater study area, defined as the area within a 5 mile radius outward of the Forest Service boundary (Fig. 2.3). Sources of groundwater include springs, shallow unconfined aquifers, and deep confined aquifers. At the time of this study two ranch homes were being supplied drinking water from a spring source, three homes were supplied by shallow alluvial systems, two consisting of localized aquifers having no lateral extent and one sourced from alluvial materials along an ephemeral stream channel, and the remaining homes were supplied by deep aquifers. Aquifer depth varied from 30 to 55 feet for the unconfined alluvial systems to >100 feet for the confined aquifer systems.

There are no established water distribution systems for human consumption and each household is supplied from a local well or small feed-line system connecting multiple homes on the main ranch from one local supply well. There are at least 2 identified distribution systems that are used for stock watering where a single well supplies more than a single ranch's stock water. All other stock water supplies are from individual wells.

Water sources were characterized as local or regional. Local supplies were classified as water derived from either a spring or a shallow unconfined aquifer and regional supplies were classified as water derived from deeper confined aquifers. Waters feeding the local supplies were derived from either precipitation infiltration on the sandstone bluffs or precipitation filling small and isolated alluvial patches. Springs emerge when downward infiltrating water encounters an impermeable layer exposed in the many canyons that downcut through the bluffs. These type of springs are ubiquitous in the region and occur on Forest Service and private land mostly near the sandstone bluffs. Many of the spring locations are marked on the USGS 7.5 minute quad map series that cover the region. Shallow alluvial aquifers occurred where topographic lows were filled by alluvium above an impermeable shale. Three such systems were identified in the study area; two were isolated accumulations of aquifer material having limited lateral extent (additional wells drilled nearby failed to penetrate any alluvium) and the third occurred in shallow alluvium along an ephemeral channel, the extent of which was undetermined. All three of these wells were between 30 and 55 feet deep and were produced using a jet pump (depth to water <25 feet). Regional supplies were classified as water sources obtained from a deep confined aquifer (>100 feet) that was recharged in zones removed from the North Cave Hills area. The majority of these wells were sourced in the Cretaceous Fox Hills sandstone (Fig. 2.2), a 25-200 foot thick grayish-white to brown marine sandstone unit (Paterson and Kirchner, 1996; Page et al., 1956) that is utilized regionally as a drinking water source. The Fox Hills lies below the Hell Creek formation that is up to 425 feet thick and consists of brown shale and gray sandstone with thin lignites in the upper half and mainly sandy beds in the lower half (Paterson and Kirchner, 1996). Some wells may be developed within the lower Hell Creek and the well depth will be dependent upon local stratigraphy.

Local stratigraphy for depths below the surface to several thousand feet is mostly unknown. All landowners in the study area were surveyed to obtain well information such as total depth, depth to water, producing formation, and production tubing size. However, no landowner possessed a well log that could define the stratigraphy or the exact depths of the producing formation. Partial well information was obtained from various sources and included twelve photocopies of well completion reports from the SD DENR, two records of location and depth data having no stratigraphic information from the SD DENR, and six well records from the USGS National Water Information System (NWIS) that correlate to wells tested in this study. Copies of all these reports are provided within Appendix A2.

Stratigraphic control was established using published geologic maps (Page et al., 1956; Pipiringos et al., 1965) in conjunction with well logs from 55 oil wells drilled throughout the region. Two cross sections were constructed using a subset of the database of 55 wells (Fig. 2.4). Sections A-A' from west to east and B-B' from south to north utilizing 6 and 10 well logs, respectively. All well depths were corrected to the Kelly Bushing elevation (reference elevation during oil drilling and based on sea level as '0' elevation. The resultant probable flow directions and gradients for the confined groundwater system in the Fox Hills Fm are a W-E dip of 38 feet per mile and a S-N dip of 21 feet per mile (Fig. 2.5). The resultant average dip direction is north east at ~30 feet per mile, or ~0.3° and is in agreement with published values of a north east dip of between 10 and 40 feet per mile (Page et al., 1955). Published USGS studies (Pipiringos et al., 1965) also indicate a general northward dip of about 25 feet per mile. Although this is a low slope, it suggests water will flow in a northeasterly direction away from the Cave Hills and toward the center of the Williston Basin.

## 2.5 Regional Climate and Wind Patterns

The climate in the study area is typical intercontinental arid characterized by warm, mostly dry summers and cool dry winters. Typical moisture trends include a bimodal precipitation distribution centered on June and late September and averages ~12" per year. On average, snowfall accumulation is rare and does not contribute significantly to the total precipitation amount. Long-term average high temperatures range from 30°F in January to 85°F in July and August. Agronomically, the region is managed as arid lands.

Long-term climate trends for the North Cave Hills area were obtained from surrounding locations that are part of the RAWS climate achieve maintained at the Western Regional Climate Center housed at the Desert Research Institute (DRI) at University of Nevada, Reno (http://raws.dri.edu). Sites utilized in this study include RAWS sites at Cannonball Creek MT, Hackberry Creek MT, Knowlton MT, Sand Creek ND, and Camp Crook SD (Fig. 2.6). These stations ranged from 40 to ~100 miles from the North Cave Hills. Three of the sites were located to the north or northwest (Sand Creek ND, Cannonball Creek and Knowlton MT) and two sites were located to the south west (Camp Crook SD and Hackberry Creek MT).

Wind roses were constructed for each of the five sites indicating the predominate wind direction in this region is from the northwest (Fig. 2.6). The secondary predominance is from the southeast at three sites (Cannonball and Hackberry Creeks MT and Sand Creek ND) and from the southwest at two sites (Knowlton MT and Camp Crook SD). The least predominant wind direction is out of the northeast. The resultant wind frequency of occurrence for the four primary direction quadrants has the following distribution: 35% from the northwest, 22% from the southwest, 21% from the southeast, 14% from the northeast, and 7% calm (<1.3 mph). Average wind speeds, from highest to lowest, are from the northwest at 10.9 mph, the northeast at 8.6 mph, the southeast at 8.2 mph, and from the southwest at 7.7 mph.

Wind speed and its interaction with dry soil particles are the critical factors that lead to erosion events (Stetler, 2002). Any particular soil or loose material will produce wind-eroded sediment as a function of these two factors. However, in a constant wind speed, wind erosion and dust transport will be controlled by the particle size distribution of the soil mass and the availability of these particles to the wind stream; i.e., the surface should be dry and devoid of surface crust and heavy vegetation. Studies have shown that one soil type will vary with another in respect to the required wind velocity to produce wind-eroded dust (Stetler and Saxton, 1996) and the determination of that particular wind speed is not trivial. Additionally it has been shown that for a natural size distribution of particles (such as a soil), a given wind velocity will entrain particles of many grain sizes (Nickling, 1988). Thus, for natural silt-loam soils, a threshold wind speed of ~10-11 mph will be sufficient to entrain and transport a wide range of the dust- and silt-sized particles (Saxton, 1995), given dry and loose surface conditions. For large regional studies with an absences of detailed entrainment data, such as the current project, it is sufficient to assume a threshold wind velocity based on the wind frequency distribution and soil properties.

Analysis of the wind frequency data, wind roses, and soil particle size distributions, has led to the selection of a conservative threshold wind speed of 13 mph for the North Cave Hills area. Although this value is slightly higher than the threshold wind speeds given above it correlates well to Saxton's data (1995) and also reflects the lower range of a wind speed category used in the Beaufort Scale, which is the basis for the wind frequency data that were used. Based on this analysis, wind speed in excess of the threshold value from all directions occurs 23.2% of the time, or about one day out of every four. On a quadrant basis, above threshold wind speed occurs 60% of the time when the wind is from the northwest (one out of every seven days), 18% of the time when wind is from the southeast 12% of the time when wind is from the northeast, and 10% of the time when wind is from the southwest. It should be noted that even though the northeast quadrant is the least predominant wind direction (14% of the time), it is the third most abundant quadrant in terms of above threshold winds at 12%.

This analysis indicates that above threshold wind speeds are common having a probability of occurrence of one in four. The greatest potential for soil erosion is from winds originating out of the northwest, which also correlates to the quadrant having the highest average wind speeds. Erosion potential under these wind conditions will vary based on antecedent moisture conditions in the soil, vegetative cover, and development of surface crusts, all of which impede grain entrainment processes. However, visual inspection correlates well to the precipitation record and indicates that the greatest potential for wind erosion processes occur between the early spring to late summer-early fall time periods. High winds associated with the changing seasons (winter to spring and summer to fall) also contribute to this time period as being the most active in terms of dust generation. Lastly it should be noted that soil erosion can occur at any time, particularly if mechanical disturbance of the soil surface has occurred.

## 3.0 Historical Mining Activities

Only a few coal claims were located in Harding County prior to 1920. Uranium exploration began in 1954 when the Atomic Energy Commission decided to fly airborne surveys over the Slim Buttes (approximately 20 miles to the east of the Cave Hills). According to Curtiss (1955), "Messrs. Ellis and Fiegen, pilots from Spearfish, were scheduled to fly over the buttes, but a high wind precluded their operations. Instead, they flew over the Cave Hills and recorded high anomalies. As a result, they staked the first claims on August 15, 1954. Since that time, activity in this area has been intense."

Active mining started around 1954. Mine sites are located primarily within an approximately two-mile broad, northwest trending strip crossing the central North Cave Hills ("hot zone"). Mining was permitted under the General Mining Laws and Public Law 357, which required no form of restoration. Most mining and mining prospects are located on USFS administers land, but at least two actively mined sites and several prospects and exploration cuts and digs are situated on private land surrounding the North Cave Hills. These uranium mines are abandoned coal strip mines located on relatively flat areas along the top of the buttes. Mining consisted of the removal of up to 80 feet of overburden to reach the uranium bearing lignite beds ("ore zone”).

Extensive mining activity occurred in the early 1960s in an effort to supply contracts for uranium, but all active mining in the area ceased shortly thereafter in 1964. Documented mine sites, spoils, exploration activities and subsequent erosion of spoils cover almost 1,000 acres (see Table 3.1 and Fig. 3.1). Most of the spoils were pushed over the edges of buttes onto the steep slopes below the rim rocks during mining (Fig. 3.2). Additional spoils have been deposited down-slope by subsequent water and/or wind transport. At these sites, the sandstone cliffs are mostly covered, and the overall slope angles are highly over-steepened. The spoils are also mostly void of vegetation, and their composition is also conducive to water channeling and tunneling. All these conditions contribute to high erosion rates and also make these sites highly prone to sliding and slumping. At two sites, Bluffs B and H, the spoils have slid and/or slumped onto adjacent private land, and subsequent sheet erosion of these deposits formed shallow depositional cones and veneers of sediment down gradient (Fig. 3.3). Uncontrolled, channeled runoff from the spoils locally also caused up to approximately 12 feet deep gully erosion. At several sites highly radioactive material was left exposed on the pit floors or spoils.

In addition to the mining sites, numerous prospecting pits or contour benches are visible in the field on both USFS administered and private lands and have been mapped and documented in the area (Pioneer, 2005). These mostly obvious, but sometimes also overgrown and sublime features were made by dozers or backhoes to expose outcroppings of fresh rock. One mine site on private land on Flint Butte, located immediately northeast of Ludlow, has been hypothesized as a potential source of molybdenosis in cattle grazing at and in the near vicinity of this site (Stone et al., 1983). Molybdenosis results from the interactions of Cu, Mo, sulfide, and sulfate in the rumen and tissues of ruminants, which make Cu metabolically unavailable (Stone et al, 1983).

## 3.1 Control Structures and Previous Mitigation Activities

In 1987, the USFS installed five sedimentation ponds (constructed using a common standpipe design) on USFS administered land to contain/control runoff and offsite migration of sediments from the Riley Pass Mine, the site with the largest erosion potential. Ponds #1 and #2 were installed on the eastern side of the pass just above the relocated Riley Pass Road in the headwaters of Pete’s Creek. Ponds #3, #4, and #5 were constructed on the western side in Schleichart Draw just below the mine site. Another pond is planned to be constructed for capturing runoff into Pete’s Creek from the spoil piles along the northeastern side of Bluff B. This part of the drainage is presently not contained by any control structure.

A series of other ponds and reservoirs exists further down the Schleichart draw along the western side of the North Cave Hills. According to a chronologic series of aerial photographs, Schleichart Dam Reservoir was constructed in1935 by the Civil Conservation Corps (CCC) (Laurie Walters-Clark, USFS, personal communication) before regional uranium mining operations began. Further downstream within this drainage, the Schleichart Ducks Unlimited Pond was completed in late summer of 1987 as part of a (now abandoned) wildlife habitat improvement project. Just at the USFS boundary of this drainage on land recently acquired by the USFS is Brown Reservoir. This reservoir captures all of Campbell Creek and Davis Draw drainages. Brown Reservoir was most likely constructed before 1958, but after 1938 (probably in the early 1950’s;

J.D. Brown, local rancher, personal communication).

The sedimentation ponds filled up rapidly over the years. Ponds #3, 4, and 5 were cleaned out by the USFS in 1990, and all ponds (#1-5) were cleaned out again in 1997 and 2004. The competence of these ponds was tested during several strong rainfall events. Many stock dams and reservoirs on private land overflowed and were breached during a significant rain event that occurred in 1992 when a highly localized thunderstorm dumped up to 10 inches of rain within approximately three hours along the northeastern side (Randy Feist, local rancher; personal communication) and up to 2-4 inches along the western side of the North Cave Hills (Mert Clarkson, local rancher; personal communication). This event caused localized flooding and breaches/overflow of stock dams and sedimentation ponds on USFS administered land. In a possible response to this event, the culvert at pond #2 had to be replaced and the road reconstructed in 1993. During another event in 1995, the culvert in pond #5 failed and was repaired and the road was reconstructed in 1997. Sedimentation ponds were subsequently cleaned out and repaired after this event (Laurie Walters-Clark, USFS, personal communication). The sediments removed from these ponds were dumped at a designated site within Bluff B. At this time it is not known how these or other significant rainfall events during- and post-mining affected the spread of mine spoils and associated metals and radionuclide loads within the local and regional drainages.

## 3.2 Previous Investigations

Previous investigations were mainly focused on USFS administered land and consisted of surface soil, sediment, and water samples. A comprehensive compendium of all data and conclusions is presented in the USFS-Pioneer Investigations Report (2005). These studies document higher than normal, though widely varying, concentrations of target analytes in background samples of soil, sediment, and water. They also show a wide variance in concentrations of target analytes in mine spoils and in sediments and surface water of drainages impacted by mining. Significant changes in contaminant concentrations are obvious for surface water samples taken at the same site, but in different years (1999 and 2000) during the month of August (Pioneer, 2005).

Concentrations range from below the established average background to 10 times higher for sediment samples in impacted drainages and several 100 times higher for spoil samples at mapped mine sites. Bluffs B and H were identified as the areas of most concern. Bluff B is of concern due to the large amount of disturbance resulting from past mining activity while Bluff H appears to have a higher contaminant level. Pete's Creek and Schleichart Draw were shown to be the two drainages most impacted by the mining activities.

All measured contaminant concentrations in water, except total uranium and $U^{235}$, exceeded 3 times background water downstream from Bluff I (RP-SW-Il through -15). Bluff B (RP-SWB3) and Bluff J (RP-SW-J2 and -J3) were below three times background for total uranium and $U^{235}$. Since only four locations with available surface water flow were sampled, samples RP-SW-I1 through –I5 were collected after a storm event.

Surface water upstream of Schleichart Draw Reservoir (RP-SW-SP6) exceeded 3 times background for arsenic, copper, lead, molybdenum, selenium, thorium, vanadium, $Ra^{226}$, and TSS. Surface water downstream of the Schleichart Draw Reservoir (RP-SW-SP7) exceeded 3 times background for arsenic, copper, lead, molybdenum, vanadium, $Ra^{226}$, and TSS, but at significantly lower concentrations than the upstream sample, indicating the reservoir is removing contaminants from surface water. Surface water below the Ducks Unlimited Pond (RP-SW-SP8) exceeded 3 times background only for molybdenum and $Ra^{226}$, and again, all contaminants were at significantly lower concentrations than the sample collected upstream of the Ducks Unlimited Pond, indicating the pond is also removing constituents from surface water. Re-sampling upstream and downstream of the Ducks Unlimited Pond (RP-SW-SD2 and -SDl, respectively) in 2000 showed only arsenic exceeding background concentrations at both locations. Arsenic, molybdenum and TSS concentrations were higher downstream of this pond than upstream.

Surface water sample data were compared with the EPA's Acute Ambient Water Quality Criteria (AAWQC; EPA, 1996) and the State of South Dakota Surface Water Criteria. The AAWQC only exist for arsenic (360 µg/L), copper (17.7 µg/L), and lead (82 µg/L).The AAWQC for arsenic and lead were exceeded for all the sediment ponds and above the Schleichart Draw Reservoir, but not below. The AAWQC for copper was exceeded for all the sediment ponds above and below the Schleichart Draw Reservoir, but not below the Ducks Unlimited Pond. The AAWQC for copper and lead were exceeded for Sample RP-SW-I1.

Following the collection of each water sample, a sediment sample was collected from the streambed or sediment pond. Arsenic concentrations in sediment downstream from Bluffs D, F, G, and H exceed 3 times local background. Molybdenum concentrations exceeded 3 times background downstream from Bluffs B, C, D, F, G, H, and I. $Ra^{226}$ concentrations in sediment downstream from Bluffs B, C, D, F, and H, and Sediment Pond 2 exceed 3 times local background. $U^{235}$ concentrations exceed 3 times background downstream from Bluffs B, C, D, and F.

The sediment particle size data show a significant reduction in the median grain size (the $D_{50}$ coefficient) occurring at all downstream sample locations relative to the background locations for each of the bluffs, except for Bluffs A, C, E, J, and K, the western sides of Bluffs F and H, the northern side of Bluff I, and the southeastern end of Bluff B. A few of the sediment particle size sample locations show greater amounts of fine-grained materials (less than #200 mesh silt) relative to the background sediment (30% fines).

All of the sediment pond samples (RP-SE-SPI through -SP5) have both significant median grain size reduction and significant fine sediment relative to background, indicating that they are performing their function of removing sediment. Stream sediments downstream from the Schleichart Draw Reservoir have 20% more fines than the upstream sediment (79% versus 59%). Similarly, stream sediments downstream from the Ducks Unlimited Pond have 5% more fines than the upstream sediment (84% versus 79%). This was attributed to the lower ponds removing more of the larger size sediment than the fines.

Field surveys by Pioneer in 1999 and 2000 in the North Cave Hills for gamma radiation show background levels of 10 to 20 µR/hr (microRem/hour) and localized readings of up to 4000 µR/hr in black sediments within the mined areas. The very high average readings of 6,000 to

60,000 and 10,000 to 35,000 counts per minute (CPM) for Bluffs B and H, respectively, and the maximum readings of over 800,000 CPM in some lignite samples in the Portage, 2004 study could not be confirmed. Our own preliminary investigations during two field reconnaissance trips show the following, uncalibrated**,** radiometric readings: background of 40-70 CPM (counts per minute); general mining spoils ranging from background readings to about 300 CPM, with localized coal pieces of 300-700 CPM, and, on the west side of Bluff H, spoils of ochre sandstone rich in brown to yellow colored phosphatic concretions with localized readings of 300-700 CPM; open face cuts of lignites within the mined areas registered at about 600-4000 CPM; one, localized fragment of black-colored sandstone found in the spoils of Bluff B showed a reading of 45,000 CPM. None of the prospecting pits or contour benches surveyed by our preliminary surveys showed readings above background.

## 4.0 Project Objectives

The overall objective for this investigation was to determine whether heavy metal and radionuclide environmental contaminants have been transported from historical mine sites on lands administered by the Forest Service onto private lands. Mechanisms of environmental transport were thought to include:

1. Erosion of spoil sediments through adjacent drainages;
2. Dissolution of hazardous metals within runoff water and groundwater; and
3. Erosion/deposition of small diameter spoils particles by wind transport.

The field sampling objectives were developed to ascertain whether surrounding private lands have been negatively impacted by migrating contaminants from historic mining sites within the watersheds surrounding the North Cave Hills area, and determine whether such contaminants pose a potential health risk to the surrounding population. As a result, the field sampling protocol were developed to:

1. Establish background concentrations and variability for the environmental contaminants (target analytes) addressed within this study;
2. Determine whether present contaminant concentrations exist in surface waters and sediments coming off USFS administered land and whether they can be attributed to impacts stemming from historical uranium mining and exploration;
3. Discriminate whether sources of environmental contaminants found within down-drainage surface waters and sediments on private lands can be attributed to historical mining and exploration operations on USFS administered land, from naturally occurring mineralization, or from other historical mining and exploration activities in the drainage;
4. Determine if heavy metals and radionuclides exist in aquifers used by private parties for domestic and/or stock use in a perimeter of 5 miles around the North Cave Hills area, and establish potential sources and migration pathways if present;
5. Quantify whether wind erosion serves as a potential contaminant migration source from mine spoils on USFS administered land;
6. Determine if down-gradient contamination within ambient air dust may be attributed to mine spoils on USFS administered land.

# 5.0 Field Sampling Strategies

As outlined above, previous site investigations primarily focused on environmental conditions within USFS administered land, and had not addressed potential environmental impacts that may have migrated offsite onto private lands. The sampling strategy developed to discern potentially impacted surface waters was a "watershed" approach. It was assumed that all runoff water and eroded sediments (except for wind erosion) would ultimately end up in the adjacent drainages and subsequently migrate downstream through the drainage networks. Based upon the overall goal of assessing the environmental impacts of historical mining activities on surrounding private lands, the surface water sampling events were divided into two distinct phases, Phase I and Phase II. For the initial Phase I sampling events that occurred during June 2006, target analyte concentrations of all potentially impacted drainages leaving USFS administered land were determined at or near the USFS-administered/private land boundary. Additionally, background concentrations for the target analytes were established for drainages based on sampling locations of drainages assumed to not be impacted by the mining activities. The gathered data were subsequently used to evaluate which drainages were most heavily impacted. Total and dissolved metals concentrations were analyzed for most water samples collected (some Phase I, all Phase II samples) to ascertain the primary phase of potential contaminants mobility (e.g., associated with < 0.45 μm sized sediments or sub-colloidal) within the watershed.

After initial evaluation of the Phase I results, the drainage with the highest environmental concern was selected for Phase II sampling. For this phase, downstream sampling continued to a point where target analyte concentrations were comparable to established background levels. Phase I results indicated that the Pete's Creek drainage appears to be the most heavily impacted, and thus was selected for Phase II sampling.

## 5.1 Target Analytes

Target analytes for metals and radionuclides chosen for this study (Table 5.1) were similar to those used within previous investigations, thus allowing direct comparability of the data (except for Denver, Knight, and Piesold, 1991). Analytical methods and procedures for determination of analyte concentration were also similar to those employed within previous studies with the exception of our study analyzing for both total and dissolved metals concentrations for the surface water samples. In addition, this study analyzed for select anions and other water quality characteristics (Table 5.2) to further characterize contaminant geochemical mobility.

## 5.2 Background Sampling

Previous investigations determined background concentrations for the target analytes in soils in undisturbed areas within the same stratigraphic interval as the mined lignite ("ore zone") and in sediments and surface water in drainages deemed to be not impacted by mining activities. Judging by these data (a compilation of all data and average concentrations are listed in Portage, 2005, Appendices A and B), soil contaminant concentrations vary widely depending on two factors:

1. Sample location within or outside of the "hot zone" crossing the central North Cave Hills; and
2. Soil type, meaning a lignite or non-lignite based sample.

Based on map analysis and an initial field reconnaissance performed in March 2006, three control drainages were initially selected to represent various "background" conditions for the surface water sampling. The number of control drainages used was increased depending on sampling medium (as discussed within individual results sections). Sampling locations for these drainages are all near or at the USFS/private land boundary, and surface water samples were taken at these sites for establishing background. Detailed discussion regarding background sampling locations and results have been provided within the individual results sections.

### 5.3 Surface Water Quality Standards

The Draft Applicable or Relevant and Appropriate Requirements for the Riley Pass-Mine Site, South Dakota Department of Environment and Natural Resources (DENR) Water Quality Standards (DENR 2002 as presented in Pioneer 2002) are shown in Table 5.3. These results were used to compare regional surface water results to DENR water quality standards.

## 6.0 Surface Water Results

Results of the surface water investigations completed during June and July 2006 for the North Cave Hills complex are presented herein. Sampling events for the determination of surface water quality within the North Cave Hills complex were divided into two distinct and separate sampling events:

- Phase I where collection of (available) surface water samples within drainages located at the interface between USFS administered lands and private land occurred. Phase I sampling locations are show in Figure 6.1;
- Phase II where comprehensive sampling of the Pete's Creek drainage and connected sub-drainages occurred. Pete's Creek was considered as most likely impacted by historical mining operations that occurred on both public and private lands. Phase II sampling locations are shown in Figure 6.2.

Previous investigations (Pioneer 2002) had shown that elevated heavy metal and radionuclide concentrations existed within sedimentation ponds #1 and 2 which were constructed to collect sediment-laden runoff from Bluff B. These sedimentation ponds are located near the headwaters of the Pete's Creek drainage.

### 6.1 Establishment of Background Concentrations

Based on map analysis and an initial field reconnaissance performed in March 2006, four control drainages were selected to represent various "background" conditions for surface water sampling. These sampling locations were considered to be outside of the predominant mineralization zones within the North Cave Hills area, and thus best represent non-mining impacted drainages. Sampling locations for these drainages are all near or at the USFS/private land boundary, and surface water samples were taken at these sites for establishing background.

1. NCH SW 21: Smaller northwesterly drainage with an area of approximately 2/3 of one square mile fed by Cox Springs #'s 1 and 2. No mining or exploration activities are documented in this watershed. This drainage represents "pristine" conditions outside of the "hot zone" in the highly dissected northern part and flows into Crooked Creek;
2. NCH SW 24: Uppermost drainage of Campbell Creek draining almost exclusively private land with an area of approximately one square mile. This sample location is situated at the upper end of a stock dam. Any drainages coming off USFS administered land on the southwestern side enter Campbell creek below this point; and
3. NCH SW 26: Icebox Canyon and the drainage immediately to the west fed by Travers Spring #2 which drain part of the "hot zone" on the southwestern side. No mining or exploration activities are documented in this watershed. This site is a relatively large side drainage (approximately one square mile) of Schleichart Draw and Campbell Creek. The sampling location is located at the upper end of a stock dam on State land.
4. NCH SW 31: Spring water from Randy Fiest homested. Sample collected at end of wellhead adjacent to horse corral. Source of water is shallow spring located on USFS administered land.

Sampling locations and results from the four background surface water sampling sites (NCH SW 21, 24, 26, 31) are presented Figure 6.3 and Table 6.1. Background concentrations were established by calculating the mean analyte concentration from the 4 sampling sites and adding 3 standard deviations to the mean concentration. The resulting "background" concentration is considered to statistically represent the regional background concentration for five of the eight analytes measured (arsenic, copper, molybdenum, uranium, and vanadium. The other analytes measured (lead, thorium, and selenium) were found to be consistently below SDSM&T EMES lab analytical detection limit (< 0.005 mg/L), and as a result, a background concentration could not be established.

The established background concentrations for total arsenic, copper, molybdenum, uranium, and vanadium are 0.020, 0.039, 0.040, 0.027, and 0.007 mg/L respectively, suggesting that for a regional basis, naturally elevated concentrations of these metals exist and are likely not attributable to historical mining activities

For the overall assessment of surface water quality within the North Cave Hills complex, total and dissolved metals concentrations were compared to our established regional background concentration for both Phase I and II sampling events. Contaminant concentrations found to exceed the established background (i.e., greater than the mean + 3 standard deviations) were considered to be "greater than background" and thus presumably "impacted" from historical mining operations. Within Table 6.1, analytical results have also been reported as "> background", ">3x background" and the ratio of analyte concentration to background (x background) to describe the level or degree of contaminant concentration relative to background. Results have been classified as "impacted" when the analytical results were greater than established background. The background concentrations for contaminant metals established for surface water in this study are similar to previous studies (Pioneer 2005).

## 6.2 Phase I Results

Initially, through our review of available hydrologic maps and through preliminary field reconnaissance, approximately 26 potential surface water sampling sites were identified along the USFS-administered land/private land boundary. However during the Phase I field sampling events of June 2006, not all of the identified sampling sites had appreciable drainage that would allow the collection of a water sample. As a result, a total of 17 Phase I samples were collected representing 9 sampling locations. Sample locations for Phase I samples are shown in Figure 6.1. Phase I samples were analyzed for water quality parameters outlined within Tables 5.1 and 5.2. In addition, select samples were analyzed for radiochemical parameters (gross alpha, $U^{235}$, $Ra^{226}$) at sampling locations thought to exhibit elevated total uranium concentration based upon total uranium analytical results. $U^{235}$ was chosen to provide comparison between Pioneer 2005 data and results from this study. $U^{238}$ however would be a more appropriate contaminant to determine since typically >95% of total uranium is commonly present as $U^{238}$ in common aqueous-based environmental samples. Future sampling events (i.e., South Cave Hills and Slim Buttes) will analyze for $U^{238}$ instead of $U^{235}$.

The majority of the Phase I metal and radionuclide results were analyzed only for total metal concentrations. The sampling and analysis protocol was modified near the completion of the Phase I sampling to include both total and dissolved metals concentrations, thus allowing a better characterization of contaminant transport within the corresponding water column. For Phase I, dissolved and total metal concentrations are reported only for samples NCH SW 1-5, 2-5, 27-2, and 28-2, with the remaining Phase I results only providing total metal concentration. A summary of the total and dissolved (if measured) metals concentrations from the Phase I study are presented in Table 6.2.

The area with the highest surface water concentrations of arsenic and uranium, the contaminants of greatest concern for this study, were found in the headwaters of the Pete's Creek drainage. The upper reaches of the Pete's Creek drainage is fed from sediment and surface water runoff from Bluff B (Figure 6.4), and samples collected at the discharges of sedimentation ponds #2 (NCH SW 1) and #1 (NCH SW 2) contained the highest average concentrations of total arsenic (0.676 and 0.569 mg/L, respectively) and total uranium (0.135 and 0.080 mg/L, respectively) for the Phase I study. In addition, elevated arsenic and uranium concentrations were found at sampling sites NCH SW 16 (drainage from Bluff H) and NCH SW 18 (drainage from Bluffs F and G). Sites NCH SW 1, 2, and 18 exceeded background concentrations for arsenic (28 to 33x background), copper (2.3 to 4.2x), molybdenum (2.7 to 4.97x), uranium (2.9 to 5.0x), and vanadium (21 to 39x), and thus met the "impacted" criteria of greater than established background (i.e, greater than the mean plus 3 standard deviations for the background sites). Note all surface water vanadium concentrations did not meet external quality control (QC) data assessment criteria, and thus may only be used as estimated concentrations (see Data Validation section). For site NCH SW 16, concentrations exceeded background for arsenic (0.114 mg/L, or 5.6x background) and molybdenum (0.092 mg/L, or 2.3x background), and slightly for uranium (0.029 mg/L, or 1.0x background).

For the remaining Phase I samples, sites NCH SW 27 and 28 reported several contaminant concentrations that exceeded background. Site NCH SW 27, located near the terminus of Schleichart Draw as it crosses the USFS road onto private land (Figure 6.5), exceeded background for copper (0.063 mg/L average, or 1.6x background), uranium (0.097 mg/L, or 3.6x background), and vanadium (0.008 mg/L, or 1.2x background). Further down Campbell Creek near the discharge of an existing stock dam (Figure 6.6), site NCH SW 28 exceeded background for copper (0.067 mg/L average, or 1.8x background), molybdenum (0.049 mg/L, or 1.2x background), and uranium (0.044 mg/L, or 1.6x background). For the remaining Phase I sampling sites, background concentrations were exceeded arsenic at NCH SW 25 (0.028 mg/L average, or 1.4x background), copper at site NCH SW 23 (0.048 mg/L average, or 1.3x background), and vanadium at site NCH SW 25 (0.025 mg/L, or 3.9x background). All other Phase I sampling sites were reported less than background for arsenic, copper, molybdenum, uranium, and vanadium.

## 6.3 Phase II Results

Comprehensive sampling was performed to determine the extent of metal contamination within Pete’s Creek and its tributaries. This Phase II sampling event was performed on June 21 and 22, 2006. Discussions regarding the Phase II sampling results has been divided into two sections:

1. Upper Pete’s Creek: the drainage area between the USFS administered land/private property interface (closest to the abandoned mines) and south of Tufte Road (Figure 6.2, Table 6.3);
2. Lower Pete’s Creek: the drainage area located north of Tufte Road, continuing north to the confluence of Crooked Creek, and further downstream of Crooked Creek east until the stream passes beneath South Dakota State Route 85 (also shown in Figure 6.2, Table 6.3).

Results from the Phase II sampling events have been graphically displayed within the following figures:

1. Extent of contamination within Pete’s Creek and its tributaries relative to established background concentrations for arsenic (Figure 6.7), copper (Figure 6.8), molybdenum (Figure 6.9), uranium (Figure 6.10), and vanadium (Figure 6.11). Sampling sites and color designations based upon stream concentrations relative to background (background, 2x background, 3x background, 6x background, and greater than 6x background) have been included within these figures;
2. Concentration of arsenic (Figure 6.12), copper (Figure 6.13), molybdenum (Figure 6.14), uranium (Figure 6.15), and vanadium (Figure 6.16) plotted as a function of stream distance downstream from Bluff B within Pete’s Creek. In addition, major sub-drainage locations and corresponding contaminant concentrations have been included (e.g., flow from Bluffs F,G, H, I1, and I2 show using blue lines and symbols) . Background (black line) and 3x background (green line) have been designated to show the degree of stream impairment relative to background.

### 6.3.1 Upper Pete's Creek

Within the upper Pete's Creek drainage, site NCH SW 16 was sampled to determine the extent of contamination potentially associated with Bluff H spoils at the USFS administered land/private property interface (Figure 6.17), and these results (discussed in Phase I) showed that significantly elevated concentrations of metal contaminants existed. Sample NCH SW 29 was chosen to assess whether contaminant loading within the upper Pete's Creek could be attributed to localized lignite coal outcroppings commonly found within the upper Pete's Creek drainage and sub-drainages. Sample NCH SW 29 was taken immediately downgradient of a lignite spring discharge (Figure 6.18), and was assumed to presumably not contain contaminants associated with Bluff H spoils and runoff. Results from this lignite spring showed slightly elevated concentrations of copper (0.041 mg/L, or 1.1x background), molybdenum (0.053 mg/L, or 1.3x background), and vanadium (0.011 mg/L, or 1.7x background), and thus contains substantially lower concentrations of metals compared to sites directly influenced by minesite runoff. Further downstream within the upper Pete's Creek drainage, two additional lignite outcroppings were sampled (NCH SW 55, 56) and were found to contain elevated copper (0.120 and 0.126 mg/L, or 3.1 and 3.3x background, respectively) and vanadium (0.042 and 0.039 mg/L, or 6.5 and 6.0x background, respectively). These results suggest that regional lignite outcropping seeps and springs within the upper Pete's Creek drainage do not appear to be a significant source of contaminant loading, with the exception of copper and vanadium. The elevated vanadium concentrations within the natural lignite outcroppings were found at concentrations significantly greater than background, and thus appear to be a natural source of vanadium loading. As discussed earlier, vanadium concentrations did not meet QC data assessment criteria, and thus may only be interpreted as estimates. Neither arsenic nor uranium concentrations exceeding background were found at these lignite outcrop areas.

Within the network of sub-drainages containing runoff from Bluffs F, G, H, I1, I2, sites NCH SW 44 (west fork side drainage; sampled standing water within depressed cow imprints), NCH SW 45 (lower confluence of drainages; standing water), and NCH SW 46 (upper east drainage; cow imprints in sediments) all were found to have contaminant concentrations greater than background. Metal contaminant concentrations exceeded background for arsenic (4.4 to 9.6x background), copper (2.0 to 5.9x background), molybdenum (1.7 to 8.6x background), uranium (2.7 to 11x background), and vanadium (9.4 to 35x background) at these three sites, suggesting that surface runoff and spoil migration from Bluffs F, G, H, I, and I2 have impacted this regional water quality which eventually drains into Pete's Creek. The overall contaminant impact from these sub-drainage may be seen within Figures 6.12 through 6.16 (blue symbols and lines). Overall contaminant concentrations within Pete's Creek did not appreciably increase due to loading from this sub-drainage, however contaminant loading was typically greater than 3x background for arsenic, molybdenum, uranium, and vanadium, while copper was found to be greater than background. Additional surface water sampling is planned for the 2007 field season to confirm metal contaminant concentrations in this area, especially during appreciable flow events since samples collected from standing water may be influenced by metal dissolution from local sediments.

The area that exhibited the greatest degree of contamination was the northern-most sub-drainage from Bluff B. This unnamed tributary flows cross Riley Pass Road/USFS Route 3120 northeast of sedimentation ponds #1 and 2, and historical sediment flows within this tributary have been documented within the Portage (2005) study. Periodic movement of spoils and overburden from this region of Bluff B appear to be a significant source of sedimentation loading within the upper Pete's Creek drainage. For example, during our field sampling events, a very large area (approximately 10 to 20 acres) of historical sediment deposition was observed in the vicinity of sampling site NCH SW 43, up-gradient of the confluence of the northern Bluff B tributary and the main drainage of Pete's Creek. It appears that extensive sediment migration during high flow events from this uncontrolled tributary is responsible for the large degree of sedimentation observed (Figures 6.19, 6.20). Sedimentation appears to occur when surface water velocities, carrying suspended fines and spoil materials from the northern reaches of Bluff B overburden, diminish as the drainage gradient decrease. This relatively slower velocity occurs immediately upstream of the confluence with Pete's Creek. Currently there is no sedimentation pond to collect and minimize uncontrolled surface runoff from northern Bluff B spoils, however conversations with Laurie Walters Clark of the Custer National Forest Sioux Range District confirm that a sedimentation pond will likely be constructed during the 2007 field season. Surface water sampling site NCH SW 43 was located near the head of the large sedimentation zone, approximately 500 m upstream of the Pete's Creek confluence. This sampling site had the highest total metal concentrations observed during the duration of this study. The contaminant concentrations were consistently greater than concentrations observed within Pete's Creek upstream of this tributary (site NCH SW 42), as shown by the lone red circles within Figures 6.12 through 6.16 (at a distance 1.5 km from Bluff B). Contaminant concentrations measured at site NCH SW 43 that were found to be significantly above background include arsenic (1.807 mg/L, or 89x background), copper (0.524 mg/L, or 14x background), uranium (0.638 mg/L, or 23x background), and vanadium (0.473 mg/L, or 73x background). Molybdenum (0.121 mg/L) was found to be only slightly above background (3x). The ratio of dissolved to total metals concentrations for the contaminant ranged from 0.07 for vanadium to 0.23 for uranium, suggesting that the majority of contaminants are associated with the suspended particulate (> 0.45 μm) phase, and subsequently these high contaminant concentrations appear to be heavily influenced by sediment loading. Interestingly, dissolved molybdenum concentrations were significantly greater than its corresponding total molybdenum concentration for this site (NCH SW 43; 8.2x greater), as well as other sampling sites within the upper Pete's Creek drainage (NCH SW 1, 2, 37, 38, 39, 41, 42, 50, 52, 54). None of the other analytes tested were found to consistently show this trend of higher dissolved versus total metal concentrations. Had other samples showed a similar pattern, the probable source of error could be attributed to errors in sampling or digestion. Instead, the high dissolved metals concentrations could be an artifact of sample digestion where filtration (0.45 μm) appears to concentrate or have a "high affinity" for dissolved molydbenium when leached the from suspended sediments. However this speculative explanation has not been supported within the literature. Further review of this phenomena will be undertaken during future sampling events (i.e, South Cave Hills study). The ratio of dissolved to total molybdenum did normalize (less than 1.0) at sampling sites further down Pete's Creek (greater than 13.5 km from Bluff B).

Samples collected further downstream of the sedimentation zone (5.0 km downstream from Bluff B) within Pete's Creek show that attenuation of contaminant concentrations is readily occurring. Sampling sites NCH SW 52, 54, and 57 indicate that contaminant concentrations decrease considerably between stations 1.5 to 5 km as shown within Figures 6.12 through 6.16). For example, total arsenic decreased from 1.052 mg/L (52x background) at site NCH SW 41 to 0.283 mg/L average (14x background) at site NCH SW 57 within this segment of Pete's Creek (3.2 km stream length). The other contaminants showed a similar level of decrease, except for molybdenum. In addition, the ratio of dissolved to total metal concentrations for most contaminants increased significantly within this same reach of Pete's Creek, suggesting that the majority of the contaminant load appears to be associated with dissolved materials. A lower ratio of dissolved to total metals would suggest a higher percentage of metals would be associated with larger, suspended particulates. Thus it appears that the active sedimentation zone (NCH SW 43) is a major sink for the removal of sediment-bound metals. However, the high concentration of dissolved metals down-gradient of the sedimentation zone suggests that metal dissolution (leaching from deposited sediments) is occurring, and thus the deposited "fines" are acting as a major source of metal contaminants found down-stream.

A slight increase or stabilization of contaminant concentrations occurred between sampling sites NCH SW 41 and 54 where sub-drainages from Bluffs F, G, H, I1, I2 flow north into Pete's Creek. While a sample was not collected at this confluence, this sub-drainage appears to be another source of contaminant loading within Pete's Creek. As seen in Figures 6.12 through 6.16, concentrations highlighted with blue diamonds show this sub-drainage is a source of contaminant loading within Pete's Creek, however the loading is not as significant as the contaminant loading from the northern Bluff B sub-drainage (NCH SW 43). Contaminant concentrations down gradient of this confluence (NCH SW 50) show all contaminants exceed 3x background except for copper. Dissolved to total metal concentration ratios ranged from 0.47 for vanadium to 1.05 for copper, confirming again that the metals are either dissolved within the surface waters, or associated with the colloidal fines (< 0.45 μm) and are not easily settled.

Sampling site NCH SW 57 was located immediately downstream of a large outcropping of lignite coal seams within the Pete's Creek drainage (located 5.7 km from Bluff B; Figure 6.21). The lignite outcroppings do not appear to be a source of contaminant loading into Pete's Creek as contaminant concentrations did not increased appreciably when compared to upstream concentrations (i.e, NCH SW 50).

Further downstream within upper Pete's Creek, all metal concentrations (except for molybdenum) increased slightly at sampling site NCH SW 37, located immediately downstream of a sub-drainage flowing from the Flint Hills area (9.1 km downstream from Bluff B). This unnamed drainage consists of overland flow and runoff from the Flint Hills region located south of Tufte Road and both east and west of State Route 85. In addition, overland flow from the Slaba "Flat Top" abandoned uranium minesite (Figure 6.22) located northeast of Ludlow is contained within this watershed. The Flat Top minesite is significant in size (similar to Bluff B) and is located completely on private property. Sampling site NCH SW 36 contained metal concentrations exceeding background for uranium (0.035 mg/L, or 1.3x background), copper (0.175 mg/L, or 4.5x background), and vanadium (0.019 mg/L, or 2.9x background). Additional sampling within the Flints Buttes drainage area, especially within the vicinity of the Flat Top minesite, is planned during the 2007 field season to assess whether this mine is a significant source of contaminant loading into Pete's Creek, in addition to other regional watersheds.

### 6.3.2 Lower Pete's Creek

Further attenuation of contaminant concentrations occurred within lower Pete's Creek drainage north of Tufte Road. At sampling site NCH SW 49, located downstream of a confluence with a drainage from the northern Flint Hills area (north of Tufte Road), concentrations were in excess of 3x background only for arsenic (0.076 mg/L, or 3.7x background) and vanadium (0.020 mg/L, or 3.2x background); all other contaminants were between 1.3 and 2.6x background. The unnamed side tributary (NCH SW 47, 48) was not a source of contaminant loading as all contaminants except arsenic (1.6x background) and vanadium (1.8x background) were less than background.

Crooked Creek prior to the confluence with Pete's Creek (NCH SW 33) had metal concentrations less than 3x background for all contaminants. Arsenic (1.5x background), copper (1.4x background), and vanadium (2.1x background) were slightly greater than background. Downstream of the confluence of Pete's Creek and Crooked Creek (NCH SW 32; 22.9 km downstream from Bluff B), all contaminants were less than 3x background, and only copper (0.085 mg/L, or 2.2x background), molybdenum (0.050 mg/L, or 1.3x background), uranium (0.043 mg/L, or 1.6x background), and vanadium (0.014 mg/L, or 2.2x background) exceeded established background. The source of these contaminants within Crooked Creeks appears to be from Pete's Creek due to the relatively low contaminant concentrations within Crooked Creek above the Pete's Creek confluence (NCH SW 33). At the final sampling location where Crooked Creek flows beneath SD RT 85 (NCH SW 35; Figure 6.23), all contaminant concentrations were less than background except for uranium (0.030 mg/L, or 1.1x background) and vanadium (0.010 mg/L, or 1.5x background). A side tributary draining an area east of SD RT 85 and north of the Flat Top abandoned uranium minesite (northeast of Ludlow; site NCH SW 39) showed only elevated concentration of copper (0.230 mg/L, or 6.0x background); all other contaminants were less than background.

## 7.0 Groundwater Results

A total of 39 groundwater analysis were performed, including duplicate samples, from a total of 34 wells that were selected based on the following criteria:

- Wells that fed a domestic supply;
- Wells that were stock water wells;
- Wells that provided a uniform distribution around the North Cave Hills.

Figure 7.1 shows the well locations and classification based upon domestic or stock water usage. Sampling protocol used was SDSM&T-SOP-FCGW-R02-0506 and is located in the sampling and analysis plan prepared in March 2006. Analysis of the groundwater was the most comprehensive of the sampling performed in this study. Table 7.1 shows the water quality parameters that were analyzed for each sample.

Well coverage around the North Cave Hills was adequate to obtain representative water quality parameters for the region. One potential 'hole' existed in the data and that was the large grazing areas southwest of the North Cave Hills. No wells were present inside this area and the stock tanks were all connected via a distribution system sourced in alluvial gravel along Bull Creek.

The critical parameters for this study were the radionuclides and metals contained in the groundwater. Results from each well were compared to established water quality limits for any parameter using the values in Table 7.2.

Figures 7.3 through 7.10 contain individual metals and radionuclide maps for each metal analyte detected and include gross alpha, $Ra^{226}$, $U^{235}$, and total copper, lead, molybdenum, selenium, and zinc. Total thorium, arsenic, and vanadium were not detected in any of the wells. Table 7-3 contains the complete list of analyte detections from all wells. Using these maps and tables the following general trends were observed.

Twenty six of the thirty four wells tested contained gross alpha emitters. Three wells in the study area exceeded US EPA drinking water MCL for gross alpha (15 pCi/L) and from high to low were 44.4, 29.6, and 19.6 pCi/L. All three of these wells were located to the east and north east of Forest Service administered land. One of the wells was within one mile of the Forest Service boundary and the other two wells were approximately 5 miles to the east of the boundary. The two most contaminated wells were in shallow unconfined aquifers of limited extent. The third was a 400 foot deep well. Most of the wells that contained gross alpha were from deep confined aquifers and the distribution of positive hits around the perimeter of the North Cave Hills suggests that gross alpha is a naturally occurring component in the groundwater system and except for the three wells specified above, does not constitute a water quality problem based on the established MCL.

Uranium was detected in seven wells and ranged from 0.001 to 0.064 mg/L. The MCL is 0.03 mg/L. One well exceeded this value and one well was slightly under the MCL at 0.027 mg/L. Both of these wells were the same wells having the two highest values of gross alpha and are located to the east of the Forest boundary. The other wells containing uranium are located on the eastern and southeastern side of the North Cave Hills and were below the MCL.

Gross alpha and uranium values can be tentatively compared to a 1980 study titled the National Uranium Resources Evaluation (NURE) which tested water wells and soils across the US. These results were given in parts per billion uranium so are not directly comparable to gross alpha (pCi/L) but do correlate to uranium values obtained in the present study. The NURE data indicates trends in distribution of occurrence that appear to be similar to those mapped in this study (Fig. 7.11). Highway 85, Bull Creek, and Ludlow are shown on the NURE map for orientation. High uranium values can be noted to occur near Ludlow, about 5 miles west of Ludlow and about 5 miles north of Ludlow. These areas correlate well to the areas having the highest gross alpha and uranium values detected in this study. In addition, in a general sense the values appear to decrease in the down gradient direction.

USGS NWIS data were obtained for wells within the vicinity of well locations that showed gross alpha exceedences from this study. Table 7.4 shows the comparisons between the USGS and this study. Blank spaces indicate either a no detect or concentration was below detection limits. The N/A marking in the USGS data indicate analytes were not analyzed. Figure 7.12 shows the locations of these wells. Comparison of the data shows there is close agreement in well locations but well depths vary between the two data sets indicating the wells were developed in different strata. Thus, formation data are inconclusive. However, areas that were shown to have high uranium concentrations at the time of the NWIS data correlate to areas of high uranium values from this current study.

The Johnson well sites, NW of the Riley Pass uranium mining areas, have 1 well that both data sets plot on top of each other. The depths do not correlate, however. The NWIS data were collected from a 64 foot deep well and the data from this study were collected from a 400 foot well. Appendix A2 contains a notice of well construction for this site (Elmer Johnson) documenting a 400 foot depth and was drilled in 1973. The NWIS data sheet clearly states a 64 foot well depth indicating a second, and shallower, well exists nearby. Uranium concentrations in both wells are low but the 400 foot well was approximately 1.5 times above the MCL for gross alpha at 19.6 pCi/L. The second Johnson well, shown on figure GW-3 to the west of the USGS well, did not contain uranium but had a gross alpha just under the MCL at 12.4 pCi/L. There are two wells tested that are between the Johnson wells and the Riley Pass mine sites that had measured gross alpha values of 8.4 and 6.2 pCi/L and well depths of 380 (R. Fiest) and 550 (T. Kalisiak) feet, respectively. These data no not allow further speculation as to the reason there are high gross alpha concentrations at a further distance from the abandoned uranium mines than wells closer to the mine sites. All of these wells were reported by the landowners to be completed in the Fox Hills formation.

Two USGS wells at the Welch site near Ludlow are closely located to the existing domestic supply well that is 55 feet deep (see Appendix A2 for a SD water well completion report). The USGS wells are reported to be 50 and 49.2 feet deep and completed in the Ludlow member of the Fort Union formation. The 50 foot well has geochemical data showing a uranium concentration of 0.022 mg/L which correlates well to a value of 0.027 mg/L determined for the 55 foot well which was constructed in 1995 (see Appendix A2 for a SD water well completion report). These two wells are ~100-200 feet apart and were completed in the same shallow alluvial sand.

The Rotenberger site had a total of five wells that were plotted and compared. The three wells from the USGS dataset were 100, 164, and 190 feet deep and the wells from the current study were reported by the landowner to be 60 and 300 feet deep. The 300 foot well was constructed in the past few years and currently is the primary water supply for the ranch. Well results did not contain any uranium and had 3.5 pCi/L gross alpha. Three of the four shallow wells have geochemical data and all contain high uranium concentrations above the MCL of 0.03 mg/L. The 60 foot well also contained 3 times the gross alpha MCL and was measured as 44.4 pCi/L.

All of these data suggest that uranium concentration in groundwater has been present at least since the mid 1970's and has not attenuated.

Three wells contained $Ra^{226}$ in concentrations ranging from 0.5 to 0.7 pCi/L and are all well below the MCL of 5 pCi/L. Two of the wells had concentrations of 0.7 mg/L and were the same wells as ones having the highest gross alpha contents. All of these wells were located to the east-northeast of the Forest boundary.

$U^{235}$ was detected in five wells in concentrations between 0.3 and 1 pCi/L. Four of these wells were located to the east-northeast and one was to the west of the Forest Service boundary. There is no MCL for $U^{235}$ and this radioactivity is grouped with the total gross alpha count.

Three wells had copper detects and all were well below the MCL of 1.3 mg/L. These wells were all located within 1 mile from the Forest Service boundary. Twelve wells contained molybdenum with concentrations ranging from 0.005 to 0.015 mg/L. All but two of these wells were located to the east of Forest Service administered land. Selenium was present in two wells at concentrations of 0.005 and 0.021 mg/L, both of which were below the MCL of 0.05 mg/L. The selenium wells were both located on the eastern side of the North Cave Hills. Two wells contained lead, both at a concentration of 0.02 mg/L which is slightly above the MCL of 0.015 mg/L. These wells were located close to the Forest Service boundary, one to the southeast and one to the northeast.

Groundwater sources in the North Cave Hills area contain metals and radionuclides, some of which exceed the US EPA MCL for that species (Table 7.4). Of the wells tested, three contained gross alpha values above the MCL. The landowners of these wells are as follows: William Rotenberger (44.4 pCi/L gross alpha), Mickey Welch (29.6 pCi/L gross alpha), and Merle Johnson (19.6 pCi/L gross alpha). At the time of testing all three of these wells were being used as domestic water sources. Since testing has been completed, one of the wells has been discontinued (W. Rotenberger) and water is being hauled from a nearby deep well. The other two wells are currently being used. One well exceeded the uranium MCL (W. Rotenberger) and two wells exceeded the lead MCL (R. Fiest and J.D. Brown).

Data collected and analyzed during this groundwater study suggest that the metals and radionuclides are components of the groundwater systems within the study area. Further, the distribution of the contaminates suggests these are from natural sources and are ubiquitous in occurrence, particularly gross alpha and zinc. It is indeterminate if the abandoned uranium mines in the North Cave Hills contribute to the metals content of the water. Most likely the chemistry of surface water and local springs are affected by the presence of the mines but the deep aquifers should not be impacted directly. Shale aquicludes above the deep sources protect infiltrating waters from reaching these aquifers, which are recharged away from the local area. The exception to this would be the presence of deep fracture systems allowing local infiltration to reach the water table, i.e., a leaky aquifer. More extensive studies are currently being planned that will be conducted in 2007 to identify if such fractures exist and determine the impact they might have on the deep groundwater system. Composition and pathways of precipitation infiltrated to groundwater is also being investigated with studies to be initiated in spring 2007.

## 8.0 Airborne Particulate Results

Evaluation of airborne contamination to surrounding lands due to entrainment of fine-grained soil particles was analyzed from thirty locations where aerosol dusts were collected using a portable wind tunnel and collection of fine surface materials using a soil scoop plus analysis of ambient atmospheric dust-fall into elevated dust traps at three locations. Wind tunnel locations were selected based on the following criteria:

- Elevations above a drainage channel or stream course to ensure deposition of potentially contaminated dust was by air or was derived by soil forming processes;
- Locations within a 'gridded' network that was accessible and sufficiently distributed in accordance with the prevailing wind directions;
- Locations that had physical indications of the presence of fine-grained surface materials that were derived from either in-situ soil development, wind-blown deposition, or other factors leading to fine-grained materials;
- Locations where surfaces where dry and loose having fine-grained materials available to wind processes and could be either collected from the existing surface or generated through preparation of a standard loose surface.

Ambient atmospheric dust-fall traps were sited based on the following criteria:

- Site locations on the highest accessible elevation locations having a clear, unobstructed wind fetch either toward or away from the North Cave Hills uranium mines;
- Sites that were aligned within the predominant wind direction extending for at least five miles in both the up- and down-wind directions;
- Locations where potential for local disturbances or generation of aerosols were minimal.

In addition, a bulk soil sample was collected at each location a surface dust sample was collected.

Aerosol dusts were collected and analyzed in two phases after initial analysis of phase I sampling indicated the potential for a wind-blown contamination plume to exist in a southeast direction away from the North Cave Hills mine area. Phase II sampling extended the area of coverage to the southeast. Figure 8.1 shows the final sites for both the wind tunnel samples and the ambient atmospheric dust-fall traps.

## 8.1 Bulk Soils Analysis

Soil from each sampling location was collected and sieved using the following mesh sizes: 18, 35, 60, 100, 120, 140, 170, 200, 230, 270, 325, and 400 mesh. These have corresponding diameters of 1000, 500, 250, 149, 125, 105, 88, 74, 62.5, 53, 44, and 37.5 microns, respectively. Particles finer than 37.5 microns were collected in a pan and later analyzed using a laser particle sizer. Appendix A3 contains a summary data sheet for each sampling location that includes the sieve results and a percent-finer-than grain size plot. These data were utilized to gain an understanding of the physical nature of the surface soils in the study area and to evaluate the potential for availability of entrainment and transport of contaminated dust.

Soils in the study area contained fine-grains although variation existed across the study area. There were five sites containing coarse soils, defined as having >40% of the grains larger than 1.0 mm, and were distributed relatively evenly around the North Cave Hills. The ten finest-grained soils, defined as having greater than 10% fine dust (particles smaller than 0.037 mm), were widely and evenly distributed around the North Cave Hills but were further away from the bluffs than the fine-grained soils (see Fig. 8.1 for site locations). This represents a normal sedimentological pattern; coarse-grained materials occur closest to the source area (in this case the sedimentary rock in the North Cave Hills). The patterns also suggests soil genesis was in-situ and was a function of erosion and let-down of the land surface. Low-lying areas closest to the current highlands were the last to be eroded down and, thus, contain the coarsest grains.

The primary focus of this study was entrainment and transport of potentially contaminated dust particles and are defined as grains <0.1 mm (<100 μm) that are available to eolian processes. For all soils, particles <0.1 mm constituted between a high of 52% of the soil (NCH-WTS-34-1) and a low of 12.7% of the soil (NCH-WTS-27-1). Seven out of the thirty sampling locations contained >40% dust particles and nineteen of the thirty sites contained >25% dust particles. Averaging all soils in the study area, 29% of the particles were <0.1 mm in size and theoretically available to dust entrainment and transport.

In general terms, particles having a diameter less than 1 mm (1000 μm) are considered available for aeolian (wind-blown) processes which include transport of particles on the surface (rolling), near the surface (bouncing), and above the surface (elutriation) (Stetler, 2002). For a surface composed of dry, loose material, the exact grain size moving by each of the three sub-processes is most dependent upon the wind speed, roughness of the surface, and percent surface cover. Two important additional factors to the process include antecedent soil moisture (measured in terms of the number of days since the last precipitation event) and the disturbance of the soil either by natural (animal) or artificial (human-induced, i.e. tillage) mechanisms. The former is important in terms of the creation of a surface crust that even though dust exists in the soil, moisture will preferentially orient the grains in a surface-parallel fashion which greatly increases its stability and resistance to wind processes. Such crusts can remain stable for extended times given no disturbances occur on the soil. Thus, grass fields and natural areas with significant grass cover (~>50%) can remain almost totally resistant to wind erosion processes regardless of the wind speed. The later factor is most important in breaking up a surface crust and making the soil susceptible to wind erosion processes. Thus, pastures (from animals) and cropped fields (from tillage) can become highly susceptible to wind erosion processes even if the soil type is identical to a neighboring field that does not experience surface disturbances. Additional complicating factors include the timing of the use as a pasture and the timing of the tillage operations within the yearly precipitation cycle. It is possible, then, to use land as pasture and/or cropped fields and maintain a low potential for wind erosion of the dust. This last scenario may be applicable to the abandoned uranium mine areas as surface crusts would likely form and dissipate annually as a function of precipitation and disturbances. It would be expected for these areas to be susceptible or resistant to erosion at varies times.

The foregoing discussion was necessary to establish a complete picture of the erosion process and understand, at least fundamentally, the role of the critical controlling factors. This is important in two ways in regard to the private lands where samples were collected: 1) potentially contaminated dusts that may have originated from abandoned uranium mine areas would have responded to aeolian processes acting on a surface having a different set of controlling factors than the surfaces tested and sampled in this study; and 2) the potential contamination of private lands from dust originating on abandoned uranium mine lands is being evaluated on the potential for the test site to produce transported contaminated dust. Thus, analytical results may be evaluated in two ways given these conditions: 1) metals contamination from sample sites would be attributed to deposition of dust originating from contaminated abandoned uranium mines; or 2) metals contamination from sample sites would be attributed to natural in-situ soil generating processes and may contain a detectable increase in concentration of specific metals that originated from abandoned uranium mines.

Laser sizing of the particles from the pan (material sieved through the 37.5 μm screen) was performed to further characterize the fine dust particles. Results are contained in Table 8.1. These analyses were based on a machine-set percentile where the percentile value of the measured mass had a particle size greater than the listed size in microns. For example, sample NCH-WTS-23-1, 16% of the dust had a diameter equal to or greater than 43 μm and 95% of the measured mass had a diameter equal to or greater than 11 μm. It is important to note that laser particle measurements are fundamentally different than using a sieve where the former is based on time-of-flight measurements through a volume and are considered 'aerodynamic' diameter. These values can vary significantly from the sieve diameters which are based on the diameter of the 'c' axis of the particle that is able to be physically forced through a square mesh opening. Thus, it is entirely possible that a particle is able to sieve through the 37.5 μm screen and be classified as >50 μm during a laser sizing measurement. More important, in the aeolian process that particle will either be able to be entrained by the wind or it would not, regardless of the sizing technique utilized in lab measurements.

Results of the laser sizing indicate that fine aerosol dusts exist in the soils that were sampled during this study, although in small amounts. Based on the above discussion of aeolian processes and controls it is difficult to make an assessment of the potential sources of the dust. The complication arises from not being able to specifically answer the question if these materials were derived from an upwind source or if the were derived in-situ as part of natural soil processes. Further research would be required to address these questions. However, it is possible to assess the susceptibility of the soils tested to entrainment processes that would liberate the fine dust based on the dust content. Past studies (Stetler and Saxton, 1996; Busacca et al., 1997; Saxton et al., 1998; Saxton et al., 2000) have focused on the particles that are 10 micrometers in aerodynamic diameter or less, the $PM_{10}$ content, as a basis for susceptibility. It has been shown that soils that have about 4% of freely occurring $PM_{10}$ particles are highly susceptible to erosion and liberation of fines (Stetler and Saxton, 1996) and such an abundance of fine particles is a rarity. Comparison of this value to those listed in Table 8.1 show that all but one soil sampled in the North Cave Hills area contain <1% $PM_{10}$ and range between 0.11 and 1.1% with an average of 0.55%. Thus, soils in the study area contain low amounts of aerosol particulates.

## 8.2 Aerosol Dust Results

Field duplicates were collected at a ratio of 1:10 and independent lab duplicates at a ratio of 1:10 yielding a total of 36 analyses. Table 8.2 contains all of the analytical results listed by site number and Figure 8.2 shows a site-composite of analytical results as a bar chart that gives the uranium concentration in mg/kg for each site. Figures 8.3 through 8.10 contain individual metals maps of eight metals including arsenic, copper, molybdenum, lead, selenium, thorium, uranium, and vanadium. In addition, a copper/molybdenum results are presented in Figure 8.11.

Target analytes for this study were focused on uranium and arsenic with lesser emphasis placed on the other metals. The basis for evaluation of increased metals contamination, or impairment, was by establishing a statistical background concentration in soils distributed throughout the sampling area and comparing that value to all sampling locations. Ten background sites were selected based on uranium concentrations and are indicated by bold type in Table 8.2. The statistical background value was computed as 2 times the Standard Deviation of the background concentrations plus the mean of the background sites. For non-detects, the minimum detection limit of the analytical equipment was used and was 1.0 mg/kg for Cu and 0.5 mg/kg for all other metals. The statistical background values are listed in Table 8.2 for each analyte.

Analytical results of the surface dusts indicate the general ubiquity of target analytes in the soils around the North Cave Hills. Uranium was present in all but two samples and arsenic was present in all samples. Vanadium, copper, and thorium were also present in all samples and lead occurred in all but one sample. Molybdenum and selenium had the least occurrences.

Fifteen samples contained uranium concentrations in excess of the calculated background value of 0.74 mg/kg and two of these were duplicate samples at the same location resulting in thirteen locations that were above background concentration. Distribution of these sites extend across the entire sampling area but can be classified into three distinct domains. Eight locations, including the three with the highest uranium concentrations (1.96, 1.66, and 1.6 mg/kg) all occur on a northwest to southeast trend cutting across the center of the North Cave Hills (blue circle on Figure 8.2) and includes the largest abandoned uranium mine areas. The long-axis of this high concentration area also correlates to the predominant wind direction corridor indicating a probable wind influence on the observed distribution. The greatest uranium concentration (1.96 mg/kg) occurs on the west side of the North Cave Hills below and upwind of Bluffs J-K and is upwind of all of the abandoned mine sites. Topographically this area forms a small bowl where swirling winds often entrain coal dust from exposed formations on the side of the hill. This local 'haze' was observed on several trips to the area in the past year. There are two locations north of the North Cave Hills that have uranium concentrations greater than 1.0 and both are in a direction of minimal above threshold wind occurrences (upper red circle on Figure 8.2). However, local topographic influences and the distance between the weather sites analyzed and these locations could account for variations in the indicated wind directions. The last two locations having uranium exceedences occur in the topographic low between the North and South Cave Hills in the Bull Creek drainage (lower red circle on Figure 8.2). Uranium concentrations decrease to below background levels in all areas away from these identified areas.

Arsenic was detected at all sampling locations and five contained concentrations above the calculated background value of 11.93 mg/kg. All exceedence concentrations were located to the east and south of the North Cave Hills. However, concentrations below the background level that were between 9.8 and 11.6 mg/kg are located near to the exceedence locations and appear to form a similar northwest to southeast pattern across the center of the North Cave Hills (Fig. 8.3) as was noted for uranium. There are also two locations in the north that are close in value to the background level and correspond to the high uranium concentrations in the north.

Thirteen locations contained selenium concentrations above the calculated background value of

0.56 mg/kg. A factor to be considered was that 16 samples showed an analytical non-detect and the detection limit of 0.5 mg/kg was substituted for the calculation of the background concentration value. The largest grouping of selenium occurrences were located to the south and southeast of the study area. The sites with the highest concentrations were also located in this area (Fig. 8.7) and were in the general downwind direction of the prevailing wind. One exceedence was located in the north and one was located immediately west of Bluffs J-K.

Molybdenum was detected in all but five samples and six locations contained concentrations above the calculated background value of 1.03 mg/kg. Molybdenum occurrences were widely distributed throughout the study area. All exceedences occurred to the east and southeast of the Riley Pass mine area (Fig. 8.5). Four of these sites appear to be aligned with the prevailing wind direction corridor, similar to the pattern noted for uranium, but two locations (NCH-WT-10-2 and NCH-WT-35-1) fall outside of this corridor, one to the north and one to the south.

Vanadium was detected in all samples and four locations had concentrations above the calculated background value of 22.01 mg/kg. All four exceedence locations were in the extreme southeast portion of the study area (Fig. 8.10) approximately 5 miles south of the observed wind corridor defined by uranium values and do not appear to be aligned with the prevailing wind direction in relation to the Riley Pass mines. Based on mass, vanadium was the highest contributing metal in the soils and averaged 15.9 mg/kg.

Three locations contained copper concentrations above the calculated background value of 12.51 mg/kg and was detected in all samples. All three exceedence locations were in the extreme southeast of the study area (Fig. 8.4) and were the same locations as the three northern-most vanadium exceedences. Vanadium and copper distributions appear very similar in the sense that areas of high and low values are geographically similar. Copper concentrations do not appear to align to the prevailing wind – uranium mines corridor.

One location contained a thorium concentration above the calculated background value of 3.82 mg/kg and was detected in all samples. The exceedence site was located directly north of the North Cave Hills and was not aligned within the prevailing wind – uranium mines corridor (Fig. 8.8).

Lead was detected in all samples but no location contained concentrations above the calculated background value of 14.63 mg/kg (Fig. 8.6). In terms of geographic distribution of the range in concentrations, lead is very similar to both copper and vanadium maps. There are no obvious trends in lead concentration to the prevailing wind direction and uranium mine locations.

Copper/molybdenum ratios were generated for all sites that contained concentrations of both metals (Fig. 8.11). Ratios ranged from 2.80 to 24.96 and averaged 11.32 and only three locations had a ratio <5.0. The three lowest ratios have the following distribution: the lowest (NCH-WT-31-1: 2.8) occurs about seven miles southeast of the Riley Pass mines on the highest elevation site and within the wind – uranium mine corridor; the remaining two sites (ratios of 3.02 and 4.13) occur to the northeast of the Riley Pass mines in the Pete's Creek drainage which contained significant molybdenum concentrations and low Cu/Mo ratios in the surface water system. Although these sampling sites were well above drainage level, it is possible that either wind was a factor or the soils developed from parent materials having an elevated molybdenum concentration and thus, the low Cu/Mo ratios. These analyses show that Cu/Mo ratios are all >2.0 and indicate no potential impairment areas due to high molybdenum concentrations.

Three duplicate lab samples were submitted to an independent laboratory for comparative analysis. The three duplicates samples were obtained from sample numbers NCH-WT-10-2, NCH-WT-20-2, and NCH-WT-30-1. Table 8.3 contains the analytical results for these three samples from both the independent lab and SDSM&T EMES. Figure 8.3 is a graphical display of the data. Appendix A contains individual plots showing a metal-by-metal comparison. The magnitude of the concentrations obtained from the independent lab were almost all higher than those values obtained at the SDSM&T EMES lab. This trend was also observed with lab duplicates from the soil core and sediment samples. Greatest variations occurred for vanadium, thorium, and selenium (SDSM&T EMES results were all less than the minimum detection limit of 0.005 mg/L) with uranium concentrations having the highest agreement. Further discussion regarding data validation and QC has been described within the Data Validation section of this report.

In summary, the analyses indicate the hypothesis for potential airborne dust contamination appears to be partially valid. Uranium concentration distribution show the highest correlation to the abandoned mine sites and the prevailing wind direction forming a northwest to southeast plume. However, the seemingly lack of correlation between uranium and other metals would not support a common wind-derived dust source. Theoretically, wind blowing across a region and entraining and transporting contaminated dust particles would then deposit these particles indiscriminately at some location in the downwind direction. The result would be a nearly uniform chemical signature and the various sampling locations would contain similar metals concentrations. Metals maps show that lead, vanadium, copper, and selenium have the highest concentrations to the southeast of the North Cave Hills. Molybdenum concentrations are highest immediately east of the Riley Pass mines and then to the southeast but are all more northerly of the concentrations for lead, vanadium, copper, and selenium. Uranium concentration are above background both to the northwest and to the southeast (up- and down-wind) of the Riley Pass mines, the only metal having this distribution. Thus, although it appears wind processes could be partially responsible for transporting and depositing dust containing uranium contaminants, the distribution between the other metals are too varied to support this as the primary process.

Absolute values of the metals concentrations in dust at all sampling sites are overall low when compared to those obtained during soil coring. Comparison to concentrations in soils derived from soil coring show that, for example, uranium concentrations average 7.6 times higher than the average concentration from the soil dust samples. Therefore, wind may be a factor in transport and deposition of contaminated particles but the data show the concentration values are low and the identified uranium plume rapidly drops to below background concentrations within the sampling area.

## 8.3 Ambient Dust Results

Three ambient dust collectors were installed across the study area on April 29, 2006, and are shown in Figure 8.1. Ambient dust samples were collected at the following times: August 2, 2006 (all three sites), September 1, 2006 (1 site), October 4, 2006 (all sites), and November 22, 2006 (all sites), yielding a total of three samples at each site and four samples at site NCH-AD-2.

Samples collected on October 4 and November 22 were submitted for analysis but there was insufficient mass to create a duplicate sample per QC requirements. Thus, only analytical results from August 2 and September 1 are included within this report. Table 8.4 contains the analytical data.

Site NCH-AD-1 is the furthest upwind location and is about five miles to the northwest of the abandoned uranium mines and was pre-selected as the background site which would record the composition of dust in the incoming air masses. Site NCH-AD-2 was located about two miles downwind of Bluff B and one-half mile south of Bluff H with the intension of recording a potential local source of contaminated aerosol dusts. Site NCH-AD-3 was located five miles downwind of Bluff H and was located to record the composition of the air masses moving away from potential contamination sites after providing time for aerosol mixing.

Initial sample collection on August 2 indicated bird droppings were problematic, particularly in location NCH-AD-2 which was located near forested lands. Indeed, bird droppings constituted a majority of this sample. Samplers were bird-proofed on September 1 and a wet sample was collected at site NCH-AD-2; the other two sites were dry and the bird-proofing was installed without disturbing the sampler. All subsequent samples were collected from bird-proofed samplers (Fig. 8.12) having an upper spiked ring which eliminated birds from perching on the rim and dropping contributions into the sampler. Sample Number NCH-AD-2-1-ELI was a lab duplicate sent out to an independent lab from the first round of samples.

Data in Table 8.4 are inconclusive in terms of the apparent disparity between the concentration values on the collection dates. However, there is an apparent trend in the concentration values on both collection dates with an observed increase in concentrations between sites NCH-AD-1 and NCH-AD-2 and then decreasing concentrations between sites NCH-AD-2 and NCH-AD-3. All metals except vanadium and thorium show this trend for the August 2, 2006 sample date.

These initial results indicate that air transport of contaminated dusts may be occurring. They would also suggest incoming air masses already contain concentrations of the analytes in question. However, the data do not allow for conclusive statements or conclusions. All samplers were removed for the winter on November 22, 2006 and will be re-deployed in the spring 2007 to collect additional data. In addition, a total of eight ambient samplers will be deployed throughout the region during the next field season.

## 8.4 $PM_{10}$ aerosol Sampling Program

Fine particulate dust less than 10 micrometers aerodynamic diameter ($PM_{10}$) were proposed to be collected at various locations around the North Cave Hills if equipment could be obtained to do the sampling. Instruments required for this work were not obtained (by loan) until September 2006 and after refurbishing motors and cleaning the samplers, significant rains had occurred in the sampling area effectively shutting off the dust production for the winter. This work will be initiated in spring and summer 2007 for both the North and South Cave Hills and Slim Buttes.

### 8.5 Proof of Concept

Alternate methods of sampling and collecting the dust component of the soil were explored in addition to the use of the wind tunnel. These alternate methods included:

- sieving out and analyzing the finest dust from a bulk soil sample (from one 3-4" deep hole yielding about 150-200 grams of soil) using a 400 mesh sieve (37.5 μm diameter);
- using a stainless steel soil scoop in the field to gently graze the surface and collect the upper-most layer of fines and dust from several different locations within an area of at least 100 $ft^2$.

In addition to these experiments, the stainless steel soil scoop was used to gently graze the surface of a recently run wind tunnel test plot so that evaluation could made on any potential differences in surface composition before and after a wind tunnel run.

Wind tunnel tests were conducted by establishing a standard surface over which to place the working section of the tunnel. A standard surface was prepared by using a standard garden rake to vigorously disturb the surface to a depth of at least 1", deeper if possible. This serves two primary purposes: 1) it creates equal surface conditions at all sites; and 2) it allows dust generation to become a function of the soil properties and not a surface crust, vegetation, or some other factor. A standard surface has been used extensively by the author in previous wind tunnel experiments on the Columbia Plateau (Stetler and Saxton 1996, Saxton et al. 2000).

Once the wind tunnel has been set up on the standard surface, a sampler was placed at the exit of the working section to catch eroded and transported dust. Each test lasted 8 minutes, the first 4 minutes at a wind speed of approximately 35 mph and the last 4 minutes at a wind speed in excess of 40 mph. Previous work has shown that dust generation stagnates after a few minutes (usually much less) of constant wind so increasing the speed provides a second burst of dust from the surface. In the Air Results section earlier in this document was a discussion on percent $PM_{10}$ content in the soil. Table 8.1 shows that soils in the study area contained <1% $PM_{10}$ and most of the soil were half that value. The interpretation is that these soils do not inherently contain a high amount of aerosol dust particles and, thus, dust generation should be expected to be low regardless of even the most favorable surface conditions. Anecdotal evidence from the author while working on the Columbia Plateau is germane to this discussion and is as follows: wind tunnel runs on the Columbia Plateau was conducted on soils that had up to 4% $PM_{10}$ content. During a run, visible dust could be observed exiting the working section of the tunnel almost throughout the duration of the 8 minute run. In situations where the surface became unproductive, dust could be observed to move at each wind speed increase. Mass of the samples collected was generally in the 2-5 gram range. At the North Cave Hills, visible dust was observed during only 1 wind test. At test start-up when the surface goes from '0' to '35' mph wind speed, no dust was observed in the air, save the noted single test. Placing one's hand at the exit of the working section was the only method used to verify particles were moving, i.e., they pelted the hand. Collected soil mass after the 8 minute run was 1 gram maximum and much less on several runs. This indicates that 'blown dust', although a common process visible on windy days, constitutes a minor part of the erosion processes.

Therefore, a field method which yields identical chemical results to wind tunnel samples but is easier to collect a significant mass of fines was the focus of these experiments.

The results shown in Figure 8.13 confirms that there is no difference in chemical analysis between a wind tunnel sample and sampling from the wind tunnel trackway using the soil scoop. These data are also shown with an analysis of the fine dust sieved through a 400 mesh screen from only one hole. There are not significant differences between these three methods. The raw data for this site is shown in Table 8.5. This table shows data from four additional sites where samples were obtained by the wind tunnel, soil scoop, and sieving a bulk soil sample. Each analyte shows a close comparison between concentration values obtained from the various method utilized to collect the dust sample. There are some variations between methods but none are significant and are well within the range of concentrations reported for all test sites in Table 8.3.

It may at first appear surprising that comparable values could be obtained using all four of the methods described. However, this simply indicates that in the local area from which the samples were obtained that the chemical signature was more a function of the soil generation and not due to wind factors. Thus, analyses from a bulk soil sample obtained from a 3" deep hole give almost the same results as from using a wind tunnel over 30 $ft^2$ of prepared surface or from scooping the surface dust from over a 100$ft^2$ area.

Results indicate that either of the above methods is valid. Recommendations are to utilize the wind tunnel in critical and easily accessible locations and use the soil scoop elsewhere

## 9.0 Soil Results

The soil study was performed to determine the overall extent of spoils and soil movement from the North Cave Hills abandoned minesites. Aside from the potential for airborne contamination of soils, soil quality on private land may be affected directly at two general locations where mine spoils from Bluffs B and H have actively encroached the USFS-administered/private land interface. Sediment movement typically occurs by sheet erosion and gullying and/or by slumping and sliding. For this study, three soil cores were taken at each site (Bluffs B and H) in the vicinity of the spoil pile toes to a depth of 5 feet through a veneer of eroded sediments into virgin soil. This depth was deemed to be sufficient after visual field inspection of each core. Two composite samples were taken per core, one above and one below the spoils/soil interface. In addition, surface soil was more extensively sampled on private land below the spoils of Bluff B.

### 9.1 Background Concentration of Target Analytes

Both sites represent a similar geological setting in that they are located to the east and directly below an abandoned mine within the "hot zone". Therefore, concentrations for the target analytes of the lower sampling intervals of all six cores were included in the determination of the background to gain a more significant number of samples, rather than to establish separate backgrounds for each site. A seventh background sample was taken from the lower interval of a sediment core in a shallow drainage to the east of Bluff B which penetrated in-situ formation

(Table 9.1).

The upper limit of the background concentrations was calculated by adding three standard deviations to the mean value of the background samples. The resulting value was then rounded to the next whole number. Multiples of this number were then taken to establish the concentration intervals of 2x, 3x, and greater than 3x background for each analyte. The range of background values for the Copper/Molybdenum Ratio was determined by taking the 95% confidence level around the mean. Also, the value of this ratio decreases as the molybdenum concentration increases. Therefore, 1/2x and 1/3x background values where established by dividing the mean value by 2 and, respectively, 3. Another bracket for this ratio was established for values that are higher than the background range (Table 9.1).

Background concentrations for the target analytes were also established for soils within the “hot zone” on USFS-administered land in the North Cave Hills by the Pioneer (2005) study. Background samples where taken along undisturbed outcrops of the mineralized zone. This zone occurs within a major lignite seam approximately 60-100 feet above the sediments underlying the soil horizons at the base of the bluffs and associated spoil piles. Therefore, the background data cited in the Pioneer (2005) are not representative for this study. Nevertheless, target analyte concentrations were similar to the ones obtained in this study, except for one sample with very high concentrations for all target analytes but thorium (Table 9.2). Selenium values for the Pioneer 1999 sampling event also appear very high when compared to the Portage 2004 sampling run and this study. The approach of the Pioneer (2005) study establishing background by calculating a mean value based on a small population of samples lacking a normal distribution appears questionable.

## 9.2 East-Side Spoils of Bluff B

The mine spoils on the east side of Bluff B are over-steepened and sparsely vegetated. Years of erosion has left these deposits deeply furcated, and in several places the once covered sandstone cliffs are reappearing. Runoff water from the barren expanses of the strip mine above is channeled into a few distinctive lows in the bench line where it is then discharged down slope across the spoils. Several deep gullies have developed at these places in the spoil deposits.

Below the major discharge point on the east side of Bluff B, the high volume of water combined with the abrupt flattening of the slope at the base of the spoil have carved out an up to 5m deep and 3m wide gully into the gently sloping talus deposits and in-situ Ludlow Formation at the base of the table of Bluff B (Figures 9.1 and 9.2). This gully shallows out to about knee-deep at the USFS-administered/private land interface (Figure 9.3), then deepens again to approximately 1.5m on the Gene Feist property and shallows out to near surface depth just before it reaches the fence line at Riley Pass Road (Figure 9.4).

Washover and splay deposits at the lower end of the Gene Feist property either represent an alternate course in the lower reach during bank-full flow or might be evidence of a previous course of the channel before entrenchment. The channel also appears to have been filled just above the fence line with one or more truck loads of gravel to cobble sized mine spoil material either to control erosion or to create a ford in the channel (Figure 9.4). Evidence of Incipient gullying also appears at several other sites on the Gene Feist property (Figure 9.5) and flow channeling can be connected to preferred discharge sites at the base of the spoils. Minor slumping and soil flow also form several sediment lobes at the base of the spoil piles. Wholesale sheet erosion of the spoils also creates silt to sand sized washover fans that cover the gentle slopes at the base of the bluff (Figure 9.6). Two of these lobes extend onto the Gene Feist property.

Four composite samples of soil cores penetrating the washover fans and 19 surface (scoop) samples were collected at the site (Table 9.3). Concentrations of copper, lead, selenium and thorium of all samples fall within the background range; the maximum vanadium concentration just exceeds the upper limit of the background. Therefore, these target analytes are not discussed further.

Most uranium concentrations were found below the background limit of 22 mg/kg, but generally decreased with increasing distance to the base of the mine spoils. Relatively higher concentrations were also associated with washover deposits and channel sediments. Uranium concentrations also reached 2x background concentrations at two sampling sites in the northwestern corner of the soil survey where washover sediments are derived from the northeastern most part of Bluff B. Both sampling locations are located on USFS-administered land (Fig. 9.7)

Arsenic concentrations generally follow the same pattern, but reach 2x background concentration (32-64 mg/kg) at several sampling locations, including some sites on private land. Site #8 at the western limit of the soil survey along Riley Pass Road reached 3x background, but actually represents drainage sediments. The one sample in the northwest corner of the survey associated with the highest uranium concentration also marginally exceeded 3x background (96 mg/kg) for arsenic (Fig. 9.8).

Molybdenum concentrations also display the same trends as the uranium and arsenic data. Only five samples exceeded background and were within the 2x background interval, however two of these barely exceeded the background limit. The second highest molybdenum concentration was associated with the drainage sediments at site #8. Nevertheless, the highest concentration occurred in the northwestern corner and is associated with the high uranium and arsenic values in washover deposits derived from the northeastern part of Bluff B and the associated mine spoils. Therefore, the higher molybdenum concentrations may be linked to sediments derived directly from the mine spoils. These high concentrations also resulted in very low values of the copper/molybdenum ratio in the 1/3x background range (0.25-0.5), further deteriorating the already marginal soil quality in the study area with regard to this parameter (Fig. 9.9).

## 9.3 North-East Side Spoils of Bluff H

A large mass of spoils and in-situ formation slid off at the north side of Bluff H. This landslide can be linked to the severe over-steepening of the slope profile with unconsolidated spoils during the mining operations. The large, rotated mass of the landslide forms a prominent hill below the head scarp and is partially located on private land (Rothenberger property). The entire mass appears to be relatively stable due to the relatively dense cover of shrubs and sod, and, therefore, only sheet erosion occurs at the toe of this mass. Nevertheless, continuous slow movement and soil creep is evident by the zigzagging of the fenceline which had to be re-positioned and repaired in the past (Bill Rothenberger, landowner, personal communication).

The head scarp of the slide forms a crater-like setting, and the water collecting there drains to the east through a well-defined erosional gully. The mouth of this gully is located on USFS-administered land, but a fan of silt to cobble sized washover sediments spreads out over the gently sloping soils at the base of the bluff onto private land.

Three soil cores were taken around the northeastern edge of the slide mass (Figure 9.10). Sample #13 was placed on the washover fan described above; sample #12 represents a hand auger sample taken in the drainage below and is presented in the figures for reference only. Target analyte concentrations are listed in Table 9.4. Similar to the soil survey results found below Bluff B, concentrations of copper, lead, selenium, vanadium and thorium for all soil samples below Bluff H did not exceed the background range. Uranium concentrations also were below the upper limit of the background (Fig. 9.10).

Arsenic and molybdenum concentrations were below the background range (<32 and <15 mg/kg, respectively) for the two samples collected at the front toe of the landslide. Only the sample located on the washover fan deposits had an arsenic concentration within the 2x background range (58.7 mg/kg). Although the molybdenum concentration of this sample was within the background range, the absolute value (12.4 mg/kg) was either double or triple of the other two sample results. This elevated molybdenum value degrades the already marginal values of the copper/molybdenum ratio for the background range (0.75-2) to about ½ of the value for the other two samples (Figs. 9.11 and 9.12). Therefore, the elevated arsenic concentration and marginally degraded copper/molybdenum ratio appear attributed to the mine spoils of Bluff H.

### 9.4 Comparison of Bluff B and H Soil Results to Pioneer (2005) Study

Soil sampling sites on bluffs A, B, C, D, E, F, G, H, and I1 and I2 of the Pioneer (2005) study where re-plotted over the base map used in this study, and the associated analytical data for uranium, arsenic, molybdenum and the copper/molybdenum ratio were re-contoured according to the background range established for this study. A second set of maps shows these values for Bluffs J – L and the background samples used collected for the Pioneer (2005) study (Figs. 9.13 - 9.20).

These maps show that the very high concentration for these elements are limited to a narrow band within the hot zone and are associated with the lignites exposed in the highwalls of the mining operations or in the spoils of bluffs A, B, C, D, F, and H. Background sample RP-SS-X, with anomalously high target analyte concentrations, might represent the pre-mining soil concentration of target analytes within the hot zone, but these high concentrations must have been limited to a narrow and laterally limited band along the outcrop of the uraniferous lignite. Due to the extensive mining operations, background concentrations of soils within the hot zone cannot be accurately determined. Nevertheless, the mining operations exposed these deposits and made them vulnerable to accelerated erosion. Uraniferous lignite and other sediments with high target analyte concentrations are also mixed in with the mine spoils. Target analyte concentrations in these samples are all above the 3x background range established for this study. Mixed-in mine spoils at the bluffs listed above are an order of magnitude higher, and lignite samples are even up to two orders of magnitudes higher than the sample concentrations observed in the soil surveys of this study.

All other background samples show uranium, arsenic and molybdenum concentration that are either within the background or the 2x background ranges established for this study. Mine spoils composed of pure overburden sediments show target analyte concentrations within the same range, even when they are located within the hot zone. Soil samples taken of the mine spoils of Bluffs J, K and L on the western side of the North Cave Hills all exhibit concentrations within the same range. Only the two lignite samples at Bluffs J and K are above 3x background for the target analytes.

The copper/molybdenum ratios of the background samples fall within or around the background range of this study. Many of the uncontaminated overburden sediments at the mine sites show even much higher values indicating favorable soil conditions with regard to this parameter (Figs. 9.19 and 9.20). Nevertheless, lignite and mixed spoils samples display very low values of this ratio well below the 1/3 background range. The low values are not due to lower copper, but to the very high molybdenum concentrations in these samples (Figs. 9.17 and 9.18).

These observations confirm that the lignites exposed in the highwalls of the abandoned mine sites and the associated spoils are a significant source of contaminated sediments covering the soils at the base of sites located along the eastern side of the North Cave Hills. On the western side, Bluffs J, K1 and K2 Bluff constitute only minor sources of contaminated sediments, and Bluff L does not appear to be a source for contaminated sediments. This signifies that bluffs containing contaminated sediments are also source areas for the migration of contaminated sediments within the local drainages.

## 10.0 Sediment Results

Map analysis according to the watershed approach described above led to the identification of 14 drainages that leave USFS-administered land and are potentially impacted by sediment transport from the mapped mine sites. Additionally, 4 drainages not impacted by mining and/or exploration activities were selected to represent various background conditions. A fifth drainage with extensive exploration, but no mining activities in its watershed was added to represent background conditions after checking the field and analytical data.

During phase I, sediment cores were taken in 12 of these drainages at or near the USFS-administered/private land interface to the depth of in-situ formation or to a maximum depth of 20 feet. Several holes did not reach in situ formation due to refusal (penetration limit of the direct–push probing equipment) due to hard underground. Two sites were limited to one-foot deep hand-auger samples because the track-mounted probe (Geoprobe™ DT6610) could not access the sites. The location of several sites originally surveyed late in 2005 for the SAP also had to be shifted up- or downstream away from the USFS-administered/private land boundary in several drainages due to the unusually wet conditions in late spring and early summer of 2006. Stock dams and ponds were filled to near maximum capacity and access was only possible in the uppermost reaches. Extensive marshes also had developed in some reaches and three sites in the upper Pete's Creek drainage selected for Geoprobe coring could only be sampled with the hand auger.

The Pete's Creek Drainage was sampled more extensively downstream beyond the USFS-administered/private land interface during phase II. Eight additional sediment cores and 25 hand-auger samples were collected. Results of both phases will be discussed in whole within the context of each drainage.

A stratigraphic relationship between the sediments of the various drainages could not be established. The transition from drainage sediment to weathered in-situ formation in the cores was based on the presence of lag deposits like gravel or coarse sand within the section that indicate the base of the channel. In some cores, a paleosol horizon was chosen to represent the transition zone. Nevertheless, this transition could not be determined in several cores because a clear lag deposit or paleosol horizon was missing, and the underlying in-situ sediments of the Ludlow or Hell Creek Formations were similar in grain size and appearance to the drainage sediments (see Table 10.1).

After retrieval of the core, the plastic sleeve was cut open, described in a core log, and the sediments were field-screened for the target analytes with a hand-held X-ray fluorescence spectrometer (XRF) by taking readings of each interval described in the core log or, at a minimum, at 1 ft intervals. Composite samples were then taken with a stainless steel lab spoon by removing a groove of equal dimensions along the side of the cut core sleeve. The length of each sampling interval was based on the XRF readings and stratigraphic observations such as grain size and color changes.

Hand Auger samples with a 0.5 inch diameter were sampled across their entire length unless except when a stratigraphic change was discernible. Field screening and analysis with the hand-held XRF unit was not possible due to the interference of the steel tube of the auger.

## 10.1 Background Concentration of Target Analytes

The following 5 drainages were selected to determine the background concentrations of the target analytes in drainage sediments on private land as they move off USFS-administered land in the North Cave Hills (Figure 10.1):

1. #20: Very small watershed (under 10 acres) along the eastern side without any documented mining or exploration activities, about one mile north of Bluff A. This drainage is potentially spring-fed and represents "pristine" conditions of one of the short easterly drainages and flows into Pete's Creek to the east;
2. #21: Smaller northwesterly drainage with an area of approximately 2/3 of one square mile fed by Cox Springs #'s 1 and 2. No mining or exploration activities are documented in this watershed. This drainage represents "pristine" conditions outside of the "hot zone" in the highly dissected northern part and flows to the west into

Crooked Creek;

3. #24: Uppermost drainage of Campbell Creek draining almost exclusively private land with an area of approximately one square mile. This sample location is situated at the upper end of a stock dam. Any drainages coming off USFS administered land on the southwestern side enter Campbell creek below this point; this drainage represents "pristine" conditions on private land;

4. #26: Icebox Canyon and the drainage immediately to the west fed by Travers Spring #2 represent "pristine" conditions within the "hot zone" on the southwestern side. No mining or exploration activities are documented in this watershed. This is a relatively large side drainage (approximately one square mile) of Schleichart Draw and Campbell Creek. The sampling site is located at the upper end of a stock dam on State land;

5. #29: Very small (under 5 acres) ephemeral drainage with extensive exploration activity in its watershed; east of Bluff H, but not impacted by mining and just northeast of the "hot zone". Sampling site is located at the USFS-administered/private land interface.

Shortened versions of the core logs for these sites are presented in Table 10.1. Cores were taken in 5' long plastic sleeves, and, if part of the core was not recovered, the first described interval of each core section in the core log was adjusted to the top of this section (e.g. to 0' for the first section, to 5' for the second, etc.). The bottom of the channel sediments in core log of site #21 might have been picked at 13' or 16.5', but was not determined due to the lack of a clear boundary. Background concentrations for cores with more than one sampled interval were established by first weighting the concentrations according to the length of each interval with Equation 10.1 below:

$$\text{Total Concentration} = \left(\frac{IL_1}{IL_T} * C_1\right) + \left(\frac{IL_1}{IL_T} * C_2\right) + \bullet\bullet\bullet + \left(\frac{IL_n}{IL_T} * C_n\right) \quad \text{[Equation 10.1]}$$

Where:

$IL_1$ = interval length of sampling interval 1 [ft]

$IL_T$ = total length of core [ft]

$C_1$ = analyte concentration of sampling interval 1 [mg/kg]

The mean of the total concentrations was then calculated, and the background concentrations for each target analyte were established by the procedures described within the Soil Results section below (Table 10.2). Sediment samples representing in-situ formation were not included within these calculations, and the analytical results for these intervals are shown here for completeness only. Nevertheless, inclusion of these intervals into the background calculations would either elevate or decrease the upper limit of the background only slightly. Even the relatively high uranium and molybdenum concentrations of the coal seam sampled at the bottom of site #24 increased the background limit from 3 to 4mg/kg and from 5 to 6 mg/kg, respectively, after adjusting to a whole number (due to the short interval length and, therefore, small contribution to the concentration over the whole length of the core). To account for the possibility that these in-situ sediments contribute to the background concentration, the upper limit for uranium was raised to 4 mg/kg and for molybdenum to 6 mg/kg.

The calculated background concentrations are representative for the entire channel depth of the channel, and thus provide a historical of channel sediments. As a result, the background limits are appropriate for the evaluation of historical releases of contaminated sediments into the impacted drainages.

Background concentrations for the target analytes were also established for drainage sediments within the "hot zone" on USFS-administered land in the North Cave Hills by the Pioneer (2005) study (Table 10.3). Surface samples were collected in August 1999 in drainages undisturbed by mining activities. Each of these samples was paired with a soil sample that is located higher up in the same watershed. The background data (mean concentrations) cited in the Pioneer (2005) cannot be compared directly to the values established for this study due to the different sampling area and sampling strategy. Nevertheless, target analyte concentrations are similar to the values established for this study, with the exception of uranium (approximately 2x higher) and selenium (7x higher) when compared to background established for this study. Selenium values for the Pioneer 1999 sampling events within the drainage sediments also appear very high compared to both the Portage 2004 sampling results and this study.

A key finding from the Pioneer (2005) study was the rapid decrease in the uranium, arsenic, and molybdenum concentrations from soil sample RP-SS-X1 (Table 9.2) to the sediment sample RP-SE-XI (Table 10.3) collected within the drainage just below. The soil sample likely represents the only true "pristine" background conditions within the highly mineralized "hot zone". Nevertheless, just a few hundred meters down-gradient, the uranium and arsenic concentrations were diminished by over an order of magnitude and the molybdenum concentration by over two orders of magnitude. This shows that the sediment contributions to the drainage from this relatively narrow outcropping is not very high, and that the mixing and dilution with sediments derived from the un-mineralized section appears very effective in lowering contaminant concentrations in this natural setting undisturbed by any mining activities.

## 10.2 Contaminant Concentrations in Sediments

Analytical results for drainage sediments other than the background samples are presented in Table 10.4, including sampling intervals with in-situ formation. Statistical values for these samples are shown in Table 10.5. Core logs for the sites with Geoprobe cores can be found Appendix D. Concentrations for uranium, arsenic, and molybdenum, the three elements of most concern, and the copper/molybdenum ratio are also presented graphically within Figures 10.1 through 10.33. Analytical results for the other five target analyte are only presented in the Tables 10.4 and 10.5 and discussed below.

Concentrations for the upper background limits were only exceeded minimally in one sample for copper by less than 1 mg/kg and in two samples for lead by less than 2 mg/kg. Vanadium concentrations were 2x background in four drainage samples; the higher vanadium concentrations were associated with relatively high arsenic concentrations in these samples. One in-situ sample of a coal seam also was within the 2x background range for vanadium, but was associated with relatively high uranium and low arsenic concentrations. Table 10.5 also shows that the minimum, maximum, and average concentrations for these three elements were essentially the same for the drainage and the in-situ formation samples with regard to these three elements.

Selenium background concentrations exceeded the background in seven drainage samples in the upper Pete's Creek drainage. Nevertheless, only two of these samples exceeded the background by more than 2x. Both samples represent coarse grained sediments at the base of the channel at site #1 below sediment pond #2 and displayed very high selenium concentrations of 4x and 8x background, respectively. Selenium concentrations also exceed the background in five in-situ formation samples. Three of these samples were from the cores of sites #1 and #2, but the concentrations were only 2x and 3x background in the in-situ formation when compared to 5x and 8x higher values for the drainage sediments at the same location. Higher selenium concentrations of 2x and 4x background were also found in in-situ formation at site #25 in a side drainage of Campbell creek. The range and average of the concentration values (Table 10.5) also shows that concentrations for in-situ formation and drainage sediments were essentially the same except for the upper Pete's Creek drainage, especially at site #1.

Thorium concentrations only slightly exceed the background limit in three drainage samples and were associated with relatively high uranium concentrations. Nevertheless, high uranium concentrations are not necessarily associated with high thorium concentrations within all samples. Concentrations were 2x background level in samples representing in-situ formation, but only two of the three samples were associated with relatively high uranium concentrations. All samples with higher thorium concentrations originated from the upper Pete's Creek drainage.

Uranium, arsenic, and molybdenum concentrations of drainage sediment samples were much higher when compared to the in-situ formation samples (Table 10.5). With the exception of uranium, the average concentrations of the drainage sediment samples were twice as high. Therefore, these three elements were the target analytes of major concern. Copper/molybdenum (Cu/Mo) ratios are also presented because deteriorating values were a direct result of the high molybdenum concentrations; with a few exceptions, copper concentrations were relatively uniform throughout the study area. Concentrations of these elements and the Cu/Mo ratio are shown as bar graphs (Figs. 10.2, 10.4, 10.6, 10.8) plotted on a series of maps for all sediment samples including samples of the underlying in-situ formation. The upper Pete's Creek drainage was presented in a series of inset maps (Figs. 10.3, 10.5, 10.7, 10.9) because of the higher sample density in this area. Another series of maps at the end of this section (Figs. 10.14 through 10.17 and 10.22 through 10.25) is based on only the top intervals at each sampling location only and presents each sampled stream segment according to a color-code based on the concentration value. The upper Pete's Creek Drainage and Schleichart Draw are discussed in two separate sections.

### 10.2.1 Uranium Concentrations

Drainages potentially impacted by mining activities generally had uranium concentrations within the background limits at the USFS-administered/private land interface (Fig. 10.1). Background limits were exceeded only minimally by 0.1 mg/kg in Schleichart Draw and 0.4 mg/kg in the drainage below bluffs K1 and K2 (below confluence of Devils and Sawmill Canyons). Uranium concentrations also varied between background and 2x background. These variations may be attributed to either the scouring and random redistribution of more contaminated sediments within the stream channel or to sediment contributions from coal seam outcrops that may contain low-level uranium concentrations in the lower Pete's and Crooked Creek drainages.

Sediment samples of in-situ formation also were within the background range, except at sites #24 with >5x background (this interval was left out mistakenly on the maps, but is listed in Table 10.4) and #25 with >3x background (Fig. 10.2). Both intervals consisted of an in-situ coal seam at the bottom of the borehole.

The upper Pete's Creek drainage displayed the highest uranium concentrations (Fig. 10.3). Sediment samples with in-situ formation were in the upper or 2x background range and reach >3x and >4x background at sites #2 and #17, respectively, where the core penetrated a coal seam at the bottom of the borehole. Drainage sediments in the side drainages also exhibited concentrations in the upper or 2x background range except for the drainages connected to the mine spoils of Bluff B and Bluff H. The highest uranium concentrations occurred in the drainages below sedimentation ponds 1 and 2, the drainage connected to the gully below the northeast spoils of Bluff B, and, to a lesser degree, the drainages below the east and west sides of Bluff H.

### 10.2.2 Arsenic Concentrations

Sediment samples consisting of in-situ formation generally exhibited arsenic concentrations within the background range except for site #22 below the confluence of Devils and Sawmill Canyons where the concentration was 2x background (Fig. 10.4). Arsenic concentrations from in-situ formation samples in the upper Pete's Creek drainage were also within the background or 2x background range, even within the coal seams that contained elevated uranium concentrations (Fig. 10.5).

Arsenic concentrations of drainage sediments generally were within the background limits at the USFS-administered/private land interface except for site #23 below Bluff J with a concentration of 2 x background (Fig. 10.4) and in the upper Pete's Creek drainage (Fig. 10.5). This drainage showed the highest concentrations, and the highest arsenic concentrations of up to 5x background occurred in coarse mine spoils at the base of the channel below sedimentation pond 2. The highest uranium concentrations at this site were in finer-grained sediments at the top of the core. The higher concentrations of the lower intervals of the channel sediments at sites #34 and #35 downstream of pond 2 may be related to historical release of coarser-grained mine spoils from Bluff B. Other drainage sediments containing up to 3x background concentrations occurred in the side drainage linked to the gully below the east side of Bluff B and in the side drainage to the east of Bluff H.

Arsenic concentrations varied in the lower Pete's Creek and Crooked Creek drainages between the background and 2x background (Fig. 10.4). Site #31 is located at the lower end of a side drainage of Pete's Creek and connects to the west side of an abandoned uranium mine on private land near the town of Ludlow (Flat Top mine). Sediments at the base of the channel exhibited arsenic and molybdenum concentrations of 2x background which could indicate historic releases of contaminated sediments from the Flat Top mine on private property (Figs. 10.4 and 10.6). Nevertheless, the uranium concentration was within the background limit, and the sediment flux in this drainage is well checked by a series of large stock dams. It is more likely that the varying arsenic concentrations at this site and in the lower Pete's Creek and Crooked Creek drainages are due to the same reasons as for the varying uranium concentrations. Furthermore, crop farming increases in the lower part of these drainages, and contributions from non-point sources of arsenic related to the use of arsenic-containing pesticides could also be possible.

### 10.2.3 Molybdenum Concentrations

Molybdenum concentrations in sediment samples representing in-situ formation did not exceed the background limits except at site #22 with a concentration of 2x background (Fig. 10.6) and in the upper Pete's Creek drainage where concentrations varied from background to 2x background and to 3x background in the coal seam at site #2 (Fig. 10.7).

Drainage sediments had molybdenum concentrations in the background range except at site #22 (Fig. 10.6) with a 2x background concentration (this site also had arsenic in the 2x background range) and in the upper Pete's Creek drainage. The highest concentrations of up to 16x background occurred below sedimentation pond 2, >3x background in the drainage linked to the gully below Bluff B, and as high as 8x and 3x, respectively in the drainages flowing north from Bluff H. Molybdenum concentrations in the lower Pete's Creek and Crooked Creek drainages also varied between background and 2x background values for the same reasons inferred above for uranium and arsenic.

### 10.2.4 Copper/Molybdenum Ratio

Copper/molybdenum ratios deteriorated to below background values (lower values signify greater impairment) where the molybdenum concentrations were relatively high. This occurred at sites #22 and #23 where ratios of <1/3x or 1/2x background occurred (Fig. 10.8). Several sediment samples of sites from the lower Pete's Creek and Crooked Creek drainages also had values of 1/2x and 1/3x background with high molybdenum concentrations controlling the ration. Nevertheless, the lowest copper/molybdenum ratios were associated with the more highly contaminated sediments released from Bluff B and H in the upper Pete's Creek drainage (Fig. 10.9).

## 10.3 Sediment Contaminant Concentration and Source Distance

To determine the distance of the sampling sites to the potential sources of contaminated sediments, the affected drainages were digitized manually to the lowest possible stream order and highest accuracy recognizable on the digital aerial ortho-photos available for the study area. These calculated stream lengths were determined to be up to two times the thalweg length when compared to the hydrographic layer for the ortho-photos available from the USGS. The distance of each sampling site to its potential source areas (bluffs) was then plotted against the uranium, arsenic, and molybdenum concentrations and the copper/molybdenum ratio of the top interval of each sediment core or the hand auger samples. Distances for each sample to its potential sources are shown in Appendix A4. A particular sampling site might plot several times within the same graph at the same concentrations, but at different distances depending on the number of potential sources.

Figures 10.10 to 10.13 compare drainage sediment samples within the Pete's Creek to those within the Crooked Creek drainages. These graphs show that the potential sources within the upper Crooked Creek drainage (Bluffs J and K1 and K2) have uranium and molybdenum concentrations at or slightly above background and arsenic concentrations at or below 2x background. These low concentrations remain essentially unchanged within the lower part of the drainage at and below the confluence with Pete's Creek about 30 km downstream from the source area. Copper/molybdenum ratios behave slightly different where the ratios improve from very low in the source area to very high values in the downstream reaches.

Concentrations for these three contaminants in the Pete's Creek drainage show the highest values of all samples in the source area (Bluffs A-I), then drop to background values about 1 km downstream, but increase rapidly again over a short distance. Nevertheless, concentrations reduce again to background values 5 km downstream and remain at or slightly above background values to the confluence with Crooked Creek about 13 km downstream from the source area. Copper/molybdenum ratios behave similarly improving from generally very low values at the source area to relatively higher, but still considered low values in the downstream reaches. This clearly shows that only the bluffs in the upper Pete's Creek drainage contribute contaminant concentrations above background values to this drainage system.

The concentration ranges for each stream segment is also shown in a series of maps. These maps also display the drainage sampling sites and concentrations of the Pioneer (2005) study; concentrations also were re-categorized according to the background limits established for this study. The site numbers for this study contain numbers only on these maps, whereas the site numbers for the Pioneer (2005) study are designated by letters and numbers on these maps. Some caution applies, though, when comparing the Pioneer (2005) data to the data obtained for this study. Only scoop samples of surface sediments were taken during the 1999 and 2004 sampling runs in the Pioneer (2005) study, and sampling occurred under relatively wet conditions for this study in 2006.

These maps not only reconfirm the source areas determined in the previous figures in a more visual fashion, but also extend the drainages onto USFS-administered land by inclusion of the Pioneer (2005) data. Drainages in the upper Crooked Creek drainage on USFS-administered land close to the source areas of Bluffs J and K1+2 showed uranium, arsenic, and molybdenum concentrations at background or 2x background values (Figs. 10.14 through 10.16). These values remained essentially the same on the adjacent private land. Only the copper/molybdenum ratio deteriorated to <1/3x background on private land below Bluff J due to the relatively higher molybdenum concentrations (Fig. 10.17). The contaminant concentrations also remained low in the downstream reaches.

Side drainages on USFS-administered land within the upper Pete's Creek watershed showed very high uranium concentrations in drainage sediments below every source area (Bluffs A-I). These very high concentrations were mostly limited to Bluffs C-H for arsenic and molybdenum. The contaminant concentrations rapidly diminished to background or 2x background values at the USFS-administered/private land interface in most side drainages. Contaminant concentrations on private land only remained elevated within side drainages connected to Bluffs B and H, but rapidly diminished to or close to background values within the main drainage of Pete's Creek.

Potential source areas in the upper Campbell Creek drainage were limited to Bluff L. Side drainages on USFS-administered land displayed contaminant concentrations and copper/molybdenum concentrations at background or 2x background and displayed background values only at the USFS-administered land/private land interface. Schleichart Draw will be discussed in a separate section.

### 10.4 Contaminant Concentrations in the Pete's Creek Drainage

This section discusses the various source areas (bluffs) and their potential contribution of contaminant sediments to the Pete's Creek drainage in more detail. Figure 10.18 shows that the highest uranium concentrations occured below sedimentations pond 1 and 2 and at a site in a drainage approximately 2 km below Bluffs H and I1+2. Neither of these bluffs showed high uranium concentrations upstream at the USFS-administered land/private land interface. Uranium concentrations subsequently fall off rapidly in the main Pete's Creek drainage below ponds 1 and 2 to background values just before the confluence with the side drainage connecting to the gully below the east side spoils of Bluff B. Uranium concentrations in this side drainage were initially at 3x background at the USFS-administered land/private land interface, and then reduced to background or slightly above background values before the confluence with the main Pete's Creek channel. Uranium concentrations increased again after the confluence.

The rapid decrease below ponds 1 and 2 is most likely due to the extensive marsh which developed in the drainages below ponds 1 and 2 under the wet conditions observed during the spring and summer 2006. This marsh most likely filters out (or adsorbs) the highly-contaminated sediments that pass through the sedimentation ponds. In contrast, the gully and the adjoining drainage below the west side spoils of Bluff B is mostly down-cutting, and very few, coarser-grained sediments remain in the channel. Nevertheless, a tremendous amount of sediments is passing through this channel at higher discharges, which are subsequently deposited into the main channel of Pete's Creek. These sediments have filled up the main drainage to such a degree, that backflow sediments consisting primarily of mine spoils are deposited upstream in the main channel during high flows. It is highly likely that this gully will eventually develop into the main channel in the future due to the retaining action of the two sedimentation ponds in the old channel. Therefore, it is not surprising that the concentrations increase again at this location within Pete's Creek.

Arsenic and molybdenum concentrations and the copper/molybdenum ratio behave in a similar manner (Figs 10.19 through 10.21). Of interest, arsenic did not have the highest concentrations below Bluff H and I1+2 or below ponds 1 and 2, but instead within the side drainage connecting to the gully on the east side of Bluff B. Nevertheless, when drainage sediments at lower core intervals are considered, the highest arsenic concentrations still occurred below ponds 1 and 2.

Sampling sites in side drainages joining Pete's Creek in its lower reaches with no identified source were arbitrarily set at a distance of 0.5 km. None of these drainages exhibited contaminant concentrations above background, and the copper/molybdenum ratios were also relatively high.

A series of maps of the upper Pete's Creek drainage also confirms these results (Figs. 10.22 through 10.25).

### 10.5 Contaminant Concentrations in Schleichart Draw

Schleichart Draw drains the western part of the central North Cave Hills and its upper reaches connect to the west side of the Bluff B spoils and to Bluff C. Schleichart Draw leaves USFS-administered land in its lowermost reach and then joins Campbell Creek which reenters USFS-administered land again about 1 km below the confluence.

The figures presented within this section include results from the 1999 sediment sampling by Pioneer (2005) within the upper reaches of Schleichart Draw and from this study containing the lower reach of Schleichart Draw. It is important to reiterate that the two data sets represent two different points in time (summers of 1999 and 2006). Samples collected during this study consist of core and hand auger samples and, therefore, represent drainage sediments accumulated over a certain span of time, rather than the scoop samples of the Pioneer (2005) study which likely only characterize the time span between two major flooding events.

Copper, lead, and vanadium concentrations for Schleichart Draw sediment samples on USFS–administered land collected during the Pioneer (2005) study ranged from above background to below 2x background values established for this study and showed no trend (neither increased or decreased concentration) with distance from the source bluffs. For this study, contaminant concentrations within the lower Schleichart Draw drainage on private land all were below background for these three contaminants (Table 10.4).

Selenium concentrations in the Pioneer (2005) study did not show a definitive trend, but did have exceptionally high concentrations ranging from >12x to 30x background. As stated previously, the high selenium concentrations reported contradict all other data sets cited in the Pioneer (2005) or within this study, and thus appear to be due to analytical error. Selenium concentrations for the two sampling locations of this study in lower Schleichart Draw all were below or slightly above background (Table 10.4).

Uranium concentrations ranged from >5x to 15x background and decreased with distance from the source in upper Schleichart Draw (Fig. 10.26). Concentrations markedly increased below Pond 3 and below Pond 5 (Figs. 10.26 and 10.30). This increase may be attributed to inconsistencies with sampling locations (such sampling pond inflow versus outflow) for the ponds or reservoirs, or from breaching and subsequent overflow of the ponds or reservoirs during flood events. The increase measured below Pond 5 may have also been caused by sediment loading from unchecked side drainages connecting to Bluffs C, E, and I1. Samples collected during this study were just above background at the USFS-administered land/private land interface (Sample #27), and below background below the Brown Reservoir (Sample #30; Figs 10.26 and 10.30; Table 10.4) within Schleichart Draw.

Arsenic concentrations within the upper Schleichart Draw ranged from slightly above background to below background, and generally decreased with distance from source (Fig. 10.27). Arsenic concentration increased below Pond 3, however arsenic did not increase below Pond 5 as did uranium (Figs. 10.26). For samples collected below the USFS administered land/private land interface in lower Schleichart Draw, arsenic concentrations increased, however they were all below background concentrations (Figs. 10.27 and 10.31). The slight increase in arsenic observed may be attributed to localized lignite particles collected within the sample below Brown Reservoir (Sample #30).

Molybdenum concentrations within upper Schleichart Draw all were below background, and slightly increased with distance from source (Figs.10.28 and 10.32). Molybdenum concentrations below the USFS administered land/private land interface were below background, and increased slightly with distance from the source.

Copper/molybdenum ratios were favorable in the upper Schleichart Draw with values of over 5, but decreased to below 3 as a result of increased molybdenum concentrations (Figs.10.29 and 10.33). All values were above background (favorable) within the upper Schleichart Draw. Copper/molybdenum ratios in lower Schleichart Draw continued to deteriorate to below background (unfavorable) below Brown Reservoir due to the relative increased molybdenum concentrations compared to copper.

## 10.6 Sedimentation Pond Failure

Sedimentation Ponds #1 and 2 are located east of Riley Pass below the spoil piles of Bluff B. The two ponds are part of a series of 5 sedimentation ponds constructed in 1987 to control runoff from Bluff B spoil piles in the upper Pete's Creek and Schleichart Draw drainages. Contaminant concentrations of the sediments and the surface water contained within in the two ponds were found to be many times higher than background concentrations for both the Pioneer 2005 and this study.

Two major problems related to the operational design of the two ponds were observed during the surface water and sediment sampling events of 2006:

1. During low flow conditions following a major discharge event (e.g., sediment pond water not visibly overflowing into the standpipe), there was viable discharge from both the standpipe outflow and the earthen material surrounding the standpipe. Water appears to be channeling or flowing around the horizontal standpipe located at the base of the pond, and infiltrating into the standpipe from rusted or otherwise defective sections of the pipe. Water was visibly entering the standpipe through holes where rivets were missing (Figs. 10.34 and 10.35). As a result, water levels within the ponds had adjusted to a level below overflow elevation, decreasing the overall detention time within the pond. (Fig. 10.36).

If the rivets were replaced within the standpipe, the pond water elevation would rise and would subsequently increase the pore water pressure surrounding the standpipe. These conditions would likely result in increased discharge from the soil surrounding the standpipe, and could potentially undermine the earthen retaining structure and the road crossing above.

2. Runoff water from the spoil piles after rainfalls was heavily laden with sediments before entering the sedimentation ponds, and sand- and silt-sized sediments (consisting mainly of quartz) appeared to readily settle out within the ponds. However, clay-sized particles mostly remained suspended within the water and were not retained by the sedimentation ponds. The very visible and pronounced dispersion of the clay particles in the water flowing from the ponds (Fig. 10.37) was likely due to the relatively high sodium and/or potassium concentrations of the eroding soils and mine spoils (see Pioneer 2005 results). Sediment cores collected at sampling sites #1 and 2 below the two sedimentation ponds showed evidence of sand sized lignite particles enriched with silt and clay, suggesting that less dense lignite particles may float through the ponds and settle out in the marshy areas below the ponds.

## 11.0 Data Validation

This section describes the quality assurance for the analytical results presented within this study. The analytical results presented were collected and analyzed based upon four general data levels established at the beginning of the project. The data levels were distinguished by the types of technology available, documentation, and degree of sophistication.

- **Level IV (Litigation Quality):** Laboratory analysis characterized by rigorous QC/QA protocols and documentation providing qualitative and quantitative analytical data. For this study, all Level IV analyses were performed by Energy Laboratories Inc. (ELI), a National Environmental Laboratory Accreditation Conference (NELAC) certified laboratory using standard EPA methods;
- **Level III (Investigative Quality):** - Laboratory analysis following published EPA methods by an academic laboratory facility [SDSM&T Environmental Mining Experiment Station (EMES) laboratory] that is not certified by NELAC or other organizations. A minimum of 10% of the total number of samples collected were analyzed as duplicate samples by ELI for validation of all Level III data. Level III data represent the majority of the data presented within this study;
- **Level II (Portable Instruments of Investigative Quality):** Field measurements using portable analytical instrumentation including documentation of instrumentation standards and calibrations within field notes;
- **Level I (Screening Quality):** Field screening using portable instrumentation that provided real-time data to assist in the optimization of sampling and for on-site health and safety evaluations.

A summary of the target analytes, analytical methods, data levels, sample media, and data use is presented in Table 11.1. In general, target analytes and analytical methods used for sample analysis for this study were similar to those targeted in previous site investigations within the North Cave Hills (Denver Knight Piesold, 1991; Pioneer 2002, 2005). Additional analysis performed within the context of this study included: nitrate/nitrate, sulfate, and phosphate within select surface water samples allowing better under standing of surface water chemistry as related to contaminant fate and transport; and a comprehensive groundwater analysis of domestic and stock wells that had not been previously studied in the North Cave Hills region. A comprehensive list of analytical analysis parameters for the groundwater study is presented in Table 7.1.

## 11.1 Sampling Procedures

Samples were collected and analyzed in accordance to the Sampling and Analysis Plan (SAP; SDSM&T, 2006) and Standard Operating Procedures (SOP; SDSM&T, 2006) developed for this project. The SAP procedures were developed in accordance with EPA accepted protocols. Provided below is discussion regarding project sampling procedures.

### 11.1.1 Sample Index

Several surface water and sediment and soil sampling locations initially listed in the SAP were based on topographic maps, and several sites were subsequently moved based upon local field conditions encountered. Missing sample numbers within the surface water sample sequence were due to the absence of flowing water within the drainage during sampling.

Sample IDs for groundwater (GW) samples were changed in accordance with SAP naming protocol. The original IDs appear on the ELI analytical reports provided in Appendix B2. New and corresponding old sample IDs are shown in Appendix A2.

Aerosol dust samples were collected using a portable wind tunnel (WT) and/or a soil scoop at each sampling site listed in this report. Sample numbers listed and discussed within this report are only a portion of the total samples collected. Additional samples were collected as part of a separate, on-going study comparing grain size and metals concentrations, and these results have not been included within this report.

Sediment sample ID NCH-SE-37-0/1 was reassigned to NCH-SE-9-0/1 due to a recording error; this error was not corrected on the sample jar ID or the chain-of–custody form. The change was documented in the field book and within the spreadsheet provided in Appendix B4.

Sediment sample ID NCH-SE-62-0/0.3 was mis-interpreted as NCH-SE-52-3 by ELI. The error was corrected on the copy of the original ELI reports provided in Appendix B2.

### 11.1.2 Field Books

A copy of the field notes for each investigation phase (i.e., surface water, groundwater, air particulates, and sediments and soils) is provided in Appendix C. The field books appear complete, and all data, observations, field equipment calibrations, standard certificates, and sample IDs appear to be recorded.

### 11.1.3 Core Logs

Core logs were checked for completeness and accuracy. Logs are only available for sediment and soil sampling sites where cores were collected using either the Geoprobe equipment or the hand auger sample. Logs appear complete and are provided in Appendix D. Errors found within the original core logs were correctly transcribed within the spreadsheet logs (indicated by red font). Spelling errors were also corrected in the transcription.

### 11.1.4 Safety Meeting Forms

Safety meetings were held with the drilling crew for each field day that included sampling activities with the Geoprobe equipment according to the Health and Safety Plan (HSP; SDSM&T, 2006). Each member of the crew acknowledged to have read and understood the HSP. All forms are present and complete, and are provided in Appendix E.

### 11.1.5 Sampling Location Coordinates

Coordinates for all sampling locations were confirmed by visually plotting their location on maps provided within this report. All sampling locations appear to be correct. Coordinates were recorded in Universal Transverse Mercator (UTM) or Latitude/Longitude formats in the field. The data are listed in the originally recorded formats in Appendix F.

Sediment to source distances provided in Appendix A4 were measured using Geographical Information System (GIS) base maps developed for this report. The distances were checked visually on these maps and appear to be complete and correct.

### 11.1.6 Sampling Completeness

Surface water samples were collected at 43 (75%) of a total of 57 locations specified in the SAP; all samples were analyzed for total metal concentrations. Only 32 (56%) were analyzed for dissolved metals. All groundwater, air particulate (wind tunnel) and sediment and soil sampling locations specified in the SAP were sampled.

### 11.1.7 Field Duplicates

For surface waters samples collected, three (3) field duplicates out of a total of 47 samples were collected at the required frequency of 1 sample per every 20 samples as specified in the SAP. Groundwater sampling also complied with the required frequency with 2 field duplicates out of a total of 37 water well samples.

Another set of samples for surface water, air particulates (wind tunnel), and sediments and soils was collected in the field and sent to ELI at a minimum frequency of 1 in 10 samples (10%) for external QC specified within the SAP. Three (3) of a total of 32 (9%) samples analyzed for surface water dissolved metals were sent to ELI; this number is only slightly below the required minimum and was accepted for data validation purposes. For surface water total metals, 13 of 47 (28%) samples were analyzed by ELI.

Sediment and soil samples were dried and pulverized at the SDSM&T EMES lab and then split in four equal parts. Each aliquot was then stored in a relabeled sample jar. Jar 1 was analyzed for every sample; jar 2 was used for lab duplicate samples at the required sample frequency (1 lab duplicate per digestion batch); jar 4 served as a back-up sample. Jar 3 was sent to ELI for external QC analysis as needed.

Wind tunnel (WT) samples consisted soil materials and followed a similar protocol as the SE (sediment) samples. Three (3) of a total of 35 (9%) were analyzed by ELI; this number is below the required minimum, but was accepted for data validation.

For the overall project, a total of 30 of 128 samples (23%) were analyzed by ELI for external QC.

### 11.1.8 Equipment Rinsate Blanks

An equipment rinsate blank consisted of de-ionized water poured through decontaminated field equipment, if non-disposable equipment was used. Equipment rinsate blanks were prepared at a minimum frequency of 1 per 20 sampling sites on sampling equipment that was used and decontaminated for reuse (see Appendix B4). Equipment rinsate blanks were used to assess representativeness of samples collected by that specific equipment. Overall, 3 rinsate samples were collected and analyzed for 31 coring sites, and 3 additional rinsate samples were collected and analyzed for 31 hand auger sites, meeting the required frequency specified within the SAP.

No contaminants were detected in a rinsate sample of the stainless steel spatula that was used for collecting sample from the collected cores.

Uranium, lead, selenium, vanadium, and thorium were not detected in any of the rinsate samples. However, 5 of the 7 samples contained arsenic ranging from 0.00775 to 0.01516 mg/L, exceeding the detection limit by 1.5 to 3x. These values were most likely due to errors associated with arsenic correction factors applied for SDSM&T EMES analysis (see Level III discussion below). A molybdenum concentration at the detection limit was reported for NCH-RI-1. Much higher values of molybdenum of 0.0873 mg/kg (18x detection limit) and copper of 0.05265 mg/kg (10x detection limit) were reported for NCH-37-1. This rinsate sample was collected from the Geoprobe coring assembly without the plastic sleeve that collects the soil core, and it is highly probable that the high concentrations reported were caused by remnant acid wash solution found within the metal casing. Samples typically do not contact the metal casing under normal procedures, but instead are collected and protected within a plastic sleeve. Thus this rinsate sample likely does not accurately represent a pathway for sample contamination during normal operating procedures.

A comparison of arsenic, molybdenum, and copper results immediately preceding, and following a rinsate sample is provided in Table 11.2. By comparing the sediment and associated rinsate results, arsenic, molybdenum and copper concentrations were not appreciably higher in cases where the rinsates showed detectable levels. The field QC assessment for rinsate samples suggest that the decontamination procedures may have been marginally completed for one sample. The low levels reported for the three contaminants found within the rinsate blanks were deemed to be insignificant and would not affect sediment and soil results reported. From a mass balance perspective, the contaminant masses found within the sediments were typically several orders of magnitude greater than concentrations reported from the rinsate samples collected.

Soil samples NCH-SE-63-0 to NCH-SE-81-0 represent soil surface samples collected using disposable plastic scoops that are manufactured specifically for environmental sampling. Therefore, no rinsate blank samples were collected.

### 11.1.9 Field Blanks

Field blanks were prepared by pouring de-ionized water into the appropriate sample containers and adding any required preservative chemicals. A field blank was prepared at a minimum frequency of 1 per 20 samples for the water media only because contamination introduced by improper field activities may be more easily detected in a water matrix. Field blanks provide a measure of potential errors that can be introduced from sources other than the sample, and were used to assess representativeness.

### 11.1.10 Sample Custody

All groundwater and a several surface water samples were hand delivered directly from the field to ELI. The remaining surface water samples and all sediment, soil, and air particulate samples were delivered directly to SDSM&T EMES lab from the field. After processing, duplicates of solid samples were then sent from the SDSM&T EMES lab to ELI. Several water samples were initially refrigerated and stored at SDSM&T EMES, and then delivered to ELI. Samples collected for analysis are listed in the field notes (see Appendix C) and the chain-of-custody (COC) forms (see Appendix E). The COC forms were checked and appear to be complete.

### 11.1.11 Sampling Holding Times

All samples were analyzed within the 6 months maximum holding time specified within EPA Method 200.8 for the target analytes. Several surface water sample volumes were insufficient for the completion of the dissolved metals analysis, and several dissolved metals samples were stored for approximately 5 months without acid preservation (see appendix B1). ELI analysis of surface and groundwater samples were analyzed within the holding times specified by the specific analytical methods employed.

## 11.2 Level IV (Litigation Quality) Data Validation

All groundwater (GW) samples were submitted to and analyzed by ELI, a NELAC certified lab located in Rapid City, South Dakota. All analysis followed EPA protocol and yielded Level IV (Litigation Quality) data. All QC samples passed the internal QC limits criteria established by ELI, and all data passed ELI QC assessment. Results of all Level IV data are shown in Appendices A1, A2, B1 and B2. It should be noted that assigned GW sample IDs were changed after analysis by ELI; thus "New" and "Old" sample IDs have been provided in Appendix A2.

External QC duplicate samples (surface water, air particulates, and sediment and soils) as part of SDSM&T Level III data analysis were also submitted to and analyzed by ELI during this study. These results are also classified as Level IV data.

## 11.3 Level III (Investigative Quality) Data Validation

This section discusses the data validation methodology for all Level III (Investigative Quality) samples analyzed by SDSM&T's EMES lab during November and December 2006. Level III analyses includes surface water (total and dissolved metals), air particulate, and sediment/soil results. The discussion below is organized based upon sample medium classification and internal (SDSM&T EMES lab analysis) and external (comparison between SDSM&T EMES and ELI analytical results) data assessment.

### 11.3.1 Data Qualifiers

A list of data qualifiers, or "flags" used to qualify all Level III data within this study are presented in Table 11.3. Discussion regarding the various data qualifiers used to describe the integrity of the data has included within the data validation sections below.

### 11.3.2 SDSM&T EMES Lab Metal Analysis Quality Assurance

The EPA Method 200.8 digestion procedure for analysis of metals using Inductively Coupled Mass Spectrometry (ICP-MS) was followed to the best of the ability of the SDSM&T EMES laboratory staff for all sample preparation. Logs were kept for all phases of the sample preparation and analysis and will be archived at SDSM&T EMES lab.

The following quality assurance procedures were employed by the SDSM&T EMES lab:

- The Agilent ICP-MS was tuned to optimum performance using a certified tuning solution and the Agilent auto-tune software prior to the start of analyses. The tuning process was repeated whenever instrument maintenance was performed;
- Certified reference standards were used to calibrate and verify the analyses;
- An initial calibration was performed for each batch of samples (containing no more than 25 samples) using at least three data points for each element. Correlation coefficients for all initial calibrations were required to be ≥ 0.99. Printouts of the calibration curves for each element were stored with the original instrument analysis printouts and hardcopies have been archived at the SDSM&T EMES lab;
- Immediately after the initial calibration, an initial calibration verification sample (ICV) and initial calibration blank (ICB) were analyzed. If the ICV or ICB failed to meet QC

standards, the calibration was repeated;

- Continuing calibration verification (CCV) and continuing calibration blank (CCB) samples were analyzed for each 10 samples. If the CCV or CCB failed to meet QC standards, the calibration and analysis of the affected samples were repeated;
- A second source check sample was analyzed immediately following the initial calibration verification and initial calibration blank samples to confirm the accuracy of the initial calibration;
- One duplicate sample, one spiked duplicate sample, one laboratory blank sample, and one spiked laboratory blank sample were analyzed for each batch of samples. If any of these failed to meet QC standards, the data was rejected or flagged at the discretion of the project QA manager;
- To determine the realistic detection limits (i.e., reporting limits), the SDSM&T EMES personnel created a calibration curve using standard solutions at 1 ppb (µg/L), 5 ppb, and 10 ppb, then analyzed the 1 ppb and 5 ppb solutions as samples. Using this data, the lab determined the point at which the analyte signal could be accurately separated from the background signal (noise);
- Acceptable recovery for all spike samples was ± 30% for all samples (water and soil). Any spikes with recoveries outside this range were considered to have failed QC;
- Acceptable variation between duplicate samples was ± 30% for all samples (water and soil). Any duplicates with variation outside this range were considered to have failed QC;
- All data, including data from analyses with failed quality assurance samples were evaluated by the project quality assurance manager and either accepted, accepted with qualifications, or rejected at his discretion;
- In recording the data, all quality assurance failures were noted and identified. The notation "QAF" (Quality Assurance Failure) was assigned to the data for each sample affected by the quality assurance failure. In addition, the failed QA sample was identified. For example, any sample for which the continuing calibration verification fell outside the acceptable range was marked, "QAF - CCV". If the CCV and CCB were outside acceptable limits, the notation "QAF – CCV, CCB" was used.

The argon supply gas used during normal ICP-MS operations forms argon chloride ions within the ICP-MS plasma chamber. These ions are known to interfere with the quantification of arsenic and selenium. ELI corrects for these interferences per correction factors/equations listed within EPA 200.8 methods. The SDSM&T EMES lab only corrected for arsenic concentrations by subtracting the arsenic concentration in the lab blank from the arsenic sample concentrations found within the same digestion batch. Nevertheless, the arsenic concentrations in several lab blanks were found to be below the detection limits, and thus no correction was applied to these samples. The correction factors resulted in negative arsenic concentrations for several samples containing low arsenic concentrations. In addition, several digestion batches met QC criteria for uncorrected data, however corrected data did not meet QC criteria. As a result, all Level III arsenic concentrations reported were qualified with a "CF"-flag due to inherent errors associated with the correction factors applied. The correction factor used for arsenic and the lack of correction for selenium concentrations help explain the occurrence of QC failures for low arsenic and selenium concentrations within this study.

The detection limits in water and soil matrices reported by SDSM&T EMES and ELI for all Level III data is presented in Table 11.4. ELI reporting limits varied between analytes due to matrix interferences. SDSM&T EMES detection limits were generally higher than ELI detection limits, with the exception of copper and lead in water medium. SDSM&T EMES detection limits were up to 20x higher than ELI for vanadium and thorium. These inter-lab detection limit differences may account for many "not-detected" (ND) metal concentrations reported by SDSM&T EMES when compared to ELI, and vice versa. As a result, metal concentrations that were reported close their corresponding detection limit could not be used for external quality control purposes (e.g., inter-lab data comparison).

Inter-lab data comparisons were performed as part of the external data quality control (QC) process. The failure criteria for inter-lab external QC comparisons were set to the following limits (Table 11.5):

- Error between two corresponding QC samples did not exceed ±30%. These were the same limit criteria established internal QC lab and field duplicate analysis;
- The square of the regression coefficient ($R^2$) was < 0.9000 for the regression analysis;
- The y-intercept of the trendline was 2x higher or lower that the highest detection limits of the eight analytes in water or soil;
- The slope of the trendline was not lower than 0.8 (signifying unacceptable low bias) or higher than 1.2 (signifying unacceptable high bias).

### 11.3.3 Surface Water Data Validation

All QC data and figures for surface water samples discussed below are provided within Appendix B1 materials.

#### 11.3.3.1 Dissolved Metals Internal QC Assessment

Spike Sample Recovery QC:

- All target analytes passed internal QC assessment, however a spike recovery sample was missing for the analytical run performed on 12/11/2006 (undigested samples).

Lab Duplicate QC:

- All target analytes passed internal QC criteria.

Blank Spike Recovery QC:

- Arsenic and selenium exceeded QC limits by +4% and +3%, respectively, for the digested samples. These differences suggest minor problems with the recovery of these analytes for the digested samples analyzed on 11/30/2006, however the QC failures were only slightly greater than the QC limits (i.e., nearly insignificant);
- Thorium and lead exceeded QC limits by +12% and +15%, respectively, for the digested

samples. These differences suggest problems associated with the digested samples analyzed on 11/30/2006;
- A blank spike sample was missing for the analytical batch performed 12/11/2006 (undigested samples).

Lab Blanks QC:

- All target analytes passed internal QC criteria.

Field Duplicate QC:

- Two out of three lab duplicates passed internal QC criteria;
- The sample not passing QC was NCH-SW-57-2 (field duplicate). The sample remained un-acidified after collection for 5 months, and was ultimately compared to NCH-SW-57-1, a sample which was acidified immediately after collection. The comparison resulted in a pronounced low bias for this duplicate sample. True analytical concentrations for sample NCH-SW-57-2 may be approximately 20% higher than reported for U; 30% higher for Mo; 50% higher for As and Cu; and 100% higher for V due to the extended non-acidified holding time of the duplicate sample. Se, Pb and Th percentages were not estimated, but would likely exhibit low bias. This sample was labeled "Sample not acidified for 4-5 months" within spreadsheets found within Appendix B1.

Field Blank QC:

- All target analytes passed internal QC criteria .

### 11.3.3.2 Dissolved Metals External QC Assessment

The error and the regression analysis for the dissolved metals external QC sample pairs (SDSMT EMES and ELI) is provided in Table 11.6. The following data quality assessments were made:

- Uranium and arsenic passed external QC criteria;
- Molybdenum exceeded the external QC criteria for the y-intercept and the slope, and 1 out of 3 samples failed the external QC limits ±30% by +10%. The slope and the high error associated with the highest concentration indicated a positive bias and molybdenum concentrations were qualified with a "J+" flag, and thus the values may only be used for estimating purposes;
- Copper regression analysis was not possible due to the "not-detect" concentrations reported by ELI. SDSM& EMES results were an order of magnitude higher than the reported detection limit. This indicates a high bias and, as a result, the data were qualified with an "R"-flag signifying the data was rejected;
- Lead exceeded (slightly) the external QC criteria for $R^2$, and 4 of 30 samples (13%) exceeded the error limits of ±30% by up to -3.3%. Lead passed external QC criteria despite an overall slightly negative bias;
- Selenium, vanadium and thorium had many "non-detect" concentrations, and thus could

not be used for external QC. Results for these analytes thus may be only used as estimates and were qualified by a "J"-flag.

As an overall assessment, the dissolved metal concentrations should only be used as estimates for the analyte concentrations due to due to frequent internal and external QC failures.

#### 11.3.3.3 Total Metals Internal QC Assessment

Spike Sample Recovery QC:

- All target analytes passed internal QC criteria.

Lab Duplicate QC:

- Arsenic failed the internal QC limits by an additional -27% for the 1st digestion, which could be attributed to either a problem with the analytical methods or error associated with the correction factor used for arsenic;
- All other target analytes passed internal QC criteria.

Blank Spike Recovery QC:

- Uranium exceeded the internal QC limits by +8% for the 1st and by +1% for the 2nd digestion. This could indicate a problem associated with analytical methods for 2 of 3 sample digestion batches, however the overall low percentage errors were deemed acceptable and thus passed internal QC criteria;
- Arsenic exceeded the internal QC limits by and additional +1% in the 2nd digestion, however this overall low error was deemed acceptable and thus passed internal QC criteria;
- Lead exceeded the internal QC limits by +11% in the 1st and by +2% in the 2nd digestion. This could indicate a problem associated with analytical methods for 2 of 3 sample digestion batches, however the overall low percentage errors were deemed acceptable and thus passed internal QC criteria;
- Thorium exceeded the internal QC limits by an additional +11% in the 1st digestion, however this overall low error was deemed acceptable and thus passed internal QC criteria.

As a result, all Blank Spike samples passed internal QC assessment.

Lab Blanks QC:

- All target analytes passed internal QC criteria.

Field Duplicate QC:

- All target analytes passed internal QC criteria.

Field Blank QC:

- One of two field blank samples [NCH-SW-21-2 (Blank)] contained a total thorium concentration at 1.5x the detection limit. This result could be classified as a false positive, however the concentration reported is very close to the detection limit. The elevated or residual thorium concentration was likely due to thorium carry-over from the 1st sample digestion and likely represented an artifact. Therefore, the field blanks passed internal QC criteria.

### 11.3.3.4 Total Metals External QC Assessment

The error and the regression analysis for the total metals external QC sample pairs (SDSMT EMES and ELI) is provided in Table 11.7. Based upon these results, the following data quality assessments were made:

- Uranium passed the external QC limits for $R^2$ and slope. Two (2) of 13 samples were "non-detect" and were not be used for regression analysis. Four (4) of 11 samples (36%) exceeded the error limits of ±30% by additional percentages ranging from -2.5% to +24% with an average error of -3.9%. As a result, uranium was considered passing external QC criteria;.
- Arsenic passed the external QC limits for $R^2$ and slope, and only slightly exceeded the y-intercept limit. Two samples were "non-detect" and were not used for regression analysis. Six (6) of 13 samples (46%) exceed the error limits ±30% by additional percentages ranging from only -7.9% to +52% with an average error of -3.9%. As a result, arsenic was considered passing external QC criteria;
- Molybdenum failed the external QC limits for $R^2$ and y-intercept criteria. Seven (7) of 13 samples were "non-detect" and were not used for regression analysis. Five (5) of 11 samples (45%) exceed the error limits of ±30% by additional percentages ranging from -26% to +26% with an average error of 7.7%. As a result, molybdenum did not pass external QC criteria and concentrations were qualified with a "J" flag. The molybdenum results reported should only be used as estimated concentrations;
- Copper failed the external QC limits for slope and y-intercept. Seven (7) of 13 samples were "non-detect" and were not used for regression analysis. SDSM&T EMES reported copper concentrations were 10x higher than the detection limit for 4 of the seven 7 "non-detect" samples analyzed by ELI. Five (5) of 6 samples (83%) exceed the error limits of ±30% by additional percentages ranging from +41% to +164% with an average error of 94.5%. As a result, copper did not pass external QC criteria and concentrations were qualified with a "J" flag. The copper results reported should only be used as estimated concentrations;
- Lead passed the external QC limits for and the $R^2$ and slope, but exceeded the intercept limits. Seven (7) of 13 samples were "non-detect" and were not used for regression analysis. Two (2) of 5 samples (40%) exceed the error limits of ±30% by additional percentages ranging from +36% to +49% with an average error of +17%. As a result, lead did not pass external QC criteria and concentrations were qualified with a "J" flag. The

lead results reported should only be used as estimated concentrations;

- Selenium passed external QC limits for $R^2$ and slope. Nine (9) of 13 samples were "non-detects and were not used for regression analysis. Two (2) of 4 samples (50%) exceed the error limits of ±30% by additional percentages ranging from +6% to +22% with an average error of 28.4%. Also, the highest errors occurred at high concentrations. As a result, selenium did not pass external QC criteria and concentrations were qualified with a "J" flag. The selenium results reported should only be used as estimated concentrations and may be biased high;
- Vanadium failed the external QC criteria for $R^2$ and slope (negative slope). Three (3) of 4 samples (75%) exceeded the error limits of ±30% by an additional percentage ranging from -20% to +143% with an average error of +71%. Nine (9) of 13 samples were "non-detect" and were not used for regression analysis. The vanadium results were rejected due to failure meeting external QC assessment, and were qualified with an "R" flag;
- Thorium failed the external QC criteria for $R^2$ and slope. Four (4) of 5 samples (80%) exceeded the error limits of ±30% by an additional percentage ranging from -7% to +100% with an average error of +42%. Seven (7) of 13 samples were "non-detect" and were not used for regression analysis. The thorium results were rejected due to failure meeting external QC assessment, and were qualified with an "R" flag.

As an overall assessment, uranium and arsenic results passed both internal and external QC criteria despite minor QC failures. Molybdenum and lead results may only be used as estimated quantities or approximations. Copper and selenium may also only be used as estimated quantities, however the results may be biased high. Vanadium and thorium results failed the QC criteria and were rejected, and thus may have limited value.

### 11.3.4 Air Particulate Data Validation

All QC data and charts for air particulate samples discussed below are provided in Appendix B3 materials. Only evaluation of wind tunnel (WT) samples has been presented.

#### 11.3.4.1 Wind Tunnel Internal QC Assessment

Spike Sample Recovery QC:

- Only copper exceeded internal QC limits by only +1% in the 1st digestion. The small margin of the QC failure in 1 of 2 batches was deemed acceptable.

Lab Duplicate QC:

- All target analytes passed the internal QC criteria.

Blank Spike Recovery QC:

- Only copper exceeded internal QC limits by only +1% in the 1st digestion. The small margin of the QC failure in 1 of 2 batches was deemed acceptable.

Lab Blanks QC:

- All target analytes passed the internal QC criteria..

### 11.3.4.2 Wind Tunnel External QC Assessment

The error and the regression analysis for the wind tunnel external QC sample pairs (SDSMT EMES and ELI) is provided in Table 11.8. Based upon these results, the following data quality assessments were made:

- In general, two factors hindered an accurate assessment of external QC wind tunnel samples:

    1. Concentrations were generally low and varied little amongst sample population. As a result, small differences between concentrations within sample pairs led to relatively large errors and failure of $R^2$ and slope criteria;
    2. The small number of samples (3);

- Uranium failed the external QC limits for $R^2$, and 1 of 3 samples (33%) exceeded the error limits of $\pm$30% by an additional -2%. All error values were negative with an average error of -21%. As a result, uranium results were qualified with a "J-"flag, and the uranium results reported may subsequently be used only as estimated concentrations, and may be biased low;
- Arsenic failed the external QC limits for the trendline, and 1 of 3 samples (33%) exceeded the error limits of $\pm$30% by an additional -35%. All error values were negative with an average error of -25%. As a result, arsenic results were qualified with a "J-"flag, and the arsenic results reported may subsequently be used only as estimated concentrations, and may be biased low;
- Molybdenum failed the external QC limits for slope, and 1 of 3 samples (33%) exceeded the error limits of $\pm$30% by an additional -35%. All error values were negative with an average error of -38%. As a result, molybdenum results were qualified with a "J-"flag, and the molybdenum results reported may subsequently be used only as estimated concentrations, and may be biased low;
- Copper failed the external QC limits for $R^2$ and the y-intercept, and 3 of 3 samples (100%) exceeded the error limits of $\pm$30% by an additional -4% to -18%. All error values were negative with an average error of -39%. As a result, copper results were qualified with a "J-"flag, and the copper results reported may subsequently be used only as estimated concentrations, and may be biased low;
- Lead slightly failed the external QC limits for slope, and all errors were within the limits of $\pm$30%. As a result, lead passed external QC criteria;
- Selenium concentrations were reported as near or at analytical detection limit. SDSM&T EMES result were "not-detects" for all 3 samples, whereas ELI results were up to 3x the SDSM&T EMES detection limit. Therefore, error and regression analysis was not possible. Selenium concentrations were qualified with a "J-"flag, and selenium results

reported may subsequently be used only as estimated concentrations, and may be biased low and may yield false negatives;

- Vanadium failed the external QC limits for $R^2$, and 3 of 3 samples (100%) exceeded the error limits of ±30% by an additional -18% to -36%. All error values were negative with an average error of -54%. As a result, vanadium results were qualified with a "J-"flag, and the vanadium results reported may subsequently be used only as estimated concentrations, and may be biased low.
- Thorium failed the external QC limits for the slope, and 3 of 3 samples (100%) exceeded the error limits of ±30% by an additional -23% to -29%. All error values were negative with an average error of -57%. As a result, thorium results were qualified with a "J-"flag, and the thorium results reported may subsequently be used only as estimated concentrations, and may be biased low.

As an overall assessment of the wind tunnel data, all metals displayed a negative or low bias. All metals but lead failed external QC criteria and were qualified with a "J-"flag. Thus, these results should only be used as estimates.

### 11.3.5 Sediment and Soil Data Validation

All QC data and charts for sediment and soil samples discussed below are provided in Appendix B4 materials.

#### 11.3.5.1 Sediment and Soil Internal QC Assessment

Lab Blanks QC:

- Lab blanks in the 1st to the 5th digestion reported vanadium concentration below the detection limit. The samples passed internal QC criteria;
- The lab blank of the 6th digestion showed a residual selenium concentration at 1.5x the detection limit. As a result, the selenium concentrations in this digestion batch were only thought to affect concentrations close to the detection limit, and the sample passed internal QC criteria;

Sample and Blank Spike Recoveries QC:

- Arsenic, copper, selenium, thorium, and vanadium exceeded QC limits by additional percentages of -1% to -5% in one to two digestions. n the in one or two digestions only. This could indicate a problem associated with analytical methods for the sample digestion batches, however the overall low percentage errors were deemed acceptable and thus passed internal QC criteria;.
- Thorium exceeded the external QC limits by an additional percentage of -8% in the 8th digestion. This could indicate a problem associated with analytical methods for this sample digestion batch, however the overall low percentage errors were deemed acceptable and thus passed internal QC criteria;

Lab Duplicate QC:

- Thorium failed external QC limits by an additional -4% in the 4th digestion. This indicates a low bias for the concentrations, but this failure is relatively small for only one out of 8 digestion batches, and these samples were deemed to pass internal QC criteria;

#### 11.3.5.2 Sediment and Soil External QC Assessment

The error and the regression analysis for the sediment and soil external QC sample pairs (SDSM&T EMES and ELI) is provided in Table 11.9. Based upon these results, the following data quality assessments were made:

- Uranium passed the external QC criteria;.
- Arsenic (slightly) failed the external QC limits for $R^2$, and only 3 out of 30 samples (10%) exceeded the error limit of ±30% by an additional +0.5% and -4.2%, respectively. As a result, arsenic passed the external QC criteria;
- Molybdenum (slightly) failed the external QC limits for the y-intercept, and only 4 out of 30 samples (13%) exceeded the error limit of ±30% by an additional percentage ranging from -1.2% to +3.9%. As a result, molybdenum passed the external QC criteria;
- Copper (slightly) failed the external QC limits for $R^2$, and only 5 out of 30 samples (17%) exceeded the error limit of ±30% by and additional percentage of up to -6.3%. As a result, copper passed the external QC criteria despite an overall slight negative bias;
- Lead (slightly) failed the external QC criteria for $R^2$, and only 4 out of 30 samples (13%) exceeded the error limits of ±30% by an additional percentage of up to -3.3%. As a result, lead passed the external QC criteria despite an overall slight negative bias;
- Selenium concentrations were generally low and slightly above the reported detection limit. Therefore, only small differences in concentrations resulted in a large error between the QC sample pairs. Selenium passes the external QC criteria for the regression analysis, but 7 out of 30 samples (23%) exceed the error limits of ±30% by an additional percentage ranging from -25.2% to +53.6%. The large errors were generally positive and were associated with very low concentrations slightly above the detection limits. As a result, selenium passed the external QC criteria;
- Vanadium failed the external QC criteria for $R^2$ and slope, 22 out of 30 samples (77%) exceeded the error limits of ±30% by an additional percentage ranging from -6.2% to -58.6%. Vanadium displayed a strong negative bias, and as a result, vanadium did not pass external QC criteria. Vanadium concentrations were qualified with a “J-“ flag, and the values may only be used as estimates;
- Thorium failed the QC criteria for $R^2$ and slope, and 16 out of 30 samples (77%) exceeded the error limits of ±30% by an additional percentage of up to -58.6%. The largest errors were associated with very low concentrations close to the detection limit. Thorium displayed a strong negative bias and, as a result, thorium did not pass external QC criteria. Thorium concentrations were qualified with a “J-“flag and the values may only be used as estimates.

As an overall assessment of the sediment and soil data, all metals but selenium and molybdenum displayed a more or less pronounced negative bias. Despite minor internal and external QC failures, arsenic, molybdenum, copper, lead, and selenium passed the overall QC evaluation. Only vanadium and thorium failed overall QC evaluation; these data display a pronounced negative bias and can only be used as estimates.

### 11.4 Level II (Portable Instruments of Investigative Quality) Data Validation

Data validation of field data using portable instrumentation (i.e., pH meter and ORP meter) was not possible due to limited statistical control limitations associated with these measurements. Professional judgment was used to assess the field QC for purposes of this study. Calibration standard labels were documented within the field notes (Appendix C1). A summary of the field measurements is provided in Appendix A1 and is deemed correct and complete.

### 11.5 Level I (Screening Quality) Data Validation

This level is characterized by the use of portable instruments that provided real-time data to assist with optimizing field sampling, and for on-site health and safety evaluations. A hand-held scintillometer was used for sediment and soil radiation measurements. The instrument performs an internal calibration check every time it is turned on, and only functions if the calibration check passed the internal standard. A partial log of scintillometer field measurements has been provided in the field notes in appendix C4 and appears correct and complete. The second set of scintillometer logs was recorded by the drilling crew in a separate field book, however copes of these notes have not been provided within the Appendix. None of the radiation measurements recorded in the field notes were higher than the level of concern specified in the Health and Safety Plan.

Sediment and soil samples were also screened in the field using a hand-held X-Ray fluorescence spectrometer (XRF) for all target analytes except thorium. The XRF requires calibration each time it is turned on or if the instrument internally detects a change in calibration. Measurements and calibrations are provided in Appendix B4 and appear to be complete. Note several measurements do not have the correct date and/or time stamp due to errors associated with instrument settings.

## 12.0 Conclusions and Recommendations

The primary objective if this study was to determine the extent of heavy metal and radionuclide contamination found on private property that may be attributed to historical mining operations within the North Cave Hills complex. Of the eight target analytes, only uranium, arsenic, and molybdenum concentrations were found to be above the established background within surface water, drainage sediment, and soil samples collected on private property; vanadium and copper concentrations were reported above established background only within select surface water samples.

Contaminant concentration levels within the Crooked Creek and Campbell Creek drainages within the northern North Cave Hills complex generally were at background or 2x background levels at the USFS-administered/private land interfaces, and contaminant concentrations did not decrease at distances further downstream. For the Schleichart Draw drainage flowing from the southern portion of the North Cave Hills complex into Campbell Creek, uranium concentrations within the surface water was above 3x background, and decreased to less than 2x background within Campbell Creek below the Brown Reservoir.

Results from this study show the highest contaminant concentrations (greater than 3x background) were generally limited to the upper Pete's Creek drainage. Several sources of contaminant loading within the Pete's Creek drainage have been identified, and include:

1. Large volumes of runoff water and spoilage sediments channeling through an un-named tributary of Pete's Creek below the northern reaches of Bluff B. This channeling has resulted in extensive sedimentation of mine spoils within the main channel of Pete's Creek. This un-named tributary appears to be the largest source of contaminant loading in surface water and drainage sediments within the entire Pete's Creek watershed with contaminant concentrations exceeded 3x background;
2. Operational failure of Sedimentation Ponds #1 and 2 below Bluff B resulting in discharging surface water and sediments containing contaminant concentrations greater than 3x background;
3. Surface water runoff and drainage sediments from Bluffs F, G, H, I1, and I2 yielding contaminant concentrations greater than 3x background for most contaminants analyzed;
4. Surface water runoff and drainage sediments from a tributary draining the Flint Hills area south of Tufte Road. The Flint Hills area includes potential runoff from the Flat Top minesite located northeast of Ludlow on private property. Contaminant concentrations of surface water and sediments within this tributary were generally below 2x background, and thus this drainage does not appear to be a significant source of contaminant loading within the Pete's Creek drainage.

Contaminant concentrations for surface water in Pete's Creek were less than 3x background approximately 15-20 km downstream from the source areas, while drainage sediments were at background approximately 5-10 km downstream from the source areas. These results imply that natural contaminant attenuation is actively occurring within the entire reach of Pete's Creek.

Mine spoils have migrated from Bluffs B and H onto private land through slumping and sliding movement actions (area north of Bluff B and northeast of Bluff H), and through sheet erosion and development of washover fans (area northeast of Bluff B). Contaminant concentrations of these sediments on private land were generally at or below background concentrations. However, arsenic and molybdenum concentrations near Bluff B were 2x background, and were 2x and 3x background, respectively, near Bluff H. Contaminant concentrations of sediments collected on USFS-administered lands were generally much higher, and thus continued migration of mine spoils may result in increased sediment contaminant concentrations on private land in the future.

Other findings and recommendations as a result of this study include:

1. Evidence of arsenic and uranium mobility and attenuation within the Pete's Creek

watershed varied considerably. Arsenic attenuation readily occurred within the upper reaches of Pete's Creek, and was likely attributable to the highly oxidative (positive oxidation/reduction potential suggesting oxygen rich) conditions observed. These geochemical conditions promote the formation of insoluble and likely less mobile arsenate [As(V)] species as compared to the more soluble and highly mobile arsenite [As(III)] species common under reducing conditions. Conversely, oxidative conditions typically result in the preferential formation of mobile uranyl [U(VI)] species versus immobile uraninite [U(IV)] species. These complex (bio)geochemical relationships as related to contaminant fate and transport are currently being investigated through graduate student research at SDSM&T;

2. Sedimentation ponds #1 and 2 are currently not effective in capturing surface water and sediment loading from Bluff B spoils. The relatively low dissolved metal concentrations (such as arsenic and uranium) compared to their corresponding total metal concentrations and contaminant concentrations found within the drainage sediments collected immediately downstream of the ponds suggest that a significant mass of sediment (at size fraction <0.45 μm) is effectively passing through these engineered structures. High alkali metal concentrations found within the runoff water entering the ponds appears to disperse suspended clay particles and prevents these particles from settling out within the pond. Suspended coal particles also appear to float through the structure without being removed. In addition, sediment pond water appears to be channeling around the outflow standpipes. These structures appear to be engineered to retain only the coarse fraction of the sediment load and, thus the fine sediment fraction appears to pass through the ponds through the pond outflow. The fine sediment fraction and the coal particles likely contribute to the greatest percentage of down-gradient contaminant loading compared to the coarser silt to cobble sized siliciclastic sediments. Consequently, the sedimentation ponds appear ineffective at reducing or controlling contaminant loading into the upper Pete's Creek watershed. A significantly re-vamped approach to mitigate the environmental effects from Bluff B surface water runoff, such as the use of constructive wetlands for enhanced contaminant remove, is recommended. Studies investigating the relationship between grain size and contaminant concentrations are currently ongoing at SDSM&T as part of graduate student research, and these research findings would be beneficial for the re-design of the sedimentation ponds;
3. The design of the proposed sedimentation pond to be located below the northeastern spoils of Bluff B should be sized to provide sufficient detention time for sediment settling (i.e., removal) under high flow conditions. This design should also include mechanism(s) to retaining the fine sediment fraction lignite particles. The design should also account for the expected runoff water geochemistry for the maximization of contaminant removal. The use of constructed wetlands, as recommended for Ponds #1 and 2 above, should also be considered;
4. Numerous exposed lignite outcroppings are found within the drainages and sub-drainages of the North Cave Hills. These lignite seams are stratigraphically lower (i.e., appear to contain less uranium) than the uraniferous lignite mined in the area, and thus do not appear to be a significant source of contaminant loading within the drainages;
5. The relatively high molybdenum concentrations associated with the mine spoils, as compared to copper concentrations, appears to cause the pronounced deterioration of the copper molybdenum ratios within the North Cave Hills. Thus molybdenum affects the

overall quality of the surface water, soils, and drainage sediments.

Results from the groundwater study suggest that the metals and radionuclides are natural components of the groundwater systems within area surrounding the North Cave Hills region. Further, the distribution of contaminates found within collected samples suggest they are from natural sources and are ubiquitous in occurrence, particularly with respect to gross alpha and zinc. At this time, it is indeterminate whether the abandoned uranium mines in the North Cave Hills contribute to the metals content of the water without more extensive studies.

Trace amounts of aerosol sized dust were found to exist within the soils surrounding the North Cave Hills. Soil particle laser sizing results suggest the North Cave Hills contain <1% $PM_{10}$ and range between 0.11 and 1.1% with an average of 0.55%. Thus, soils in the study area contain low amounts of aerosol particulates and appears to be less susceptible to air entrainment.

Uranium airborne dust contaminant results show the highest correlation to the abandoned mine sites and the prevailing wind direction forming a northwest to southeast plume for the North Cave Hills region. However, the uranium distribution does not correlate with the other metal contaminants, and thus airborne contaminant transport appears only partially responsible for dust contaminant transport and deposition for the North Cave Hills region.

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