CSMRI Creekside Site
Draft
Report on Background

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List of Acronyms

BCWP	Background Calculation Work Plan
CDPHE	Colorado Department of Public Health and Environment
COPCs	compounds of potential concern
CSMRI	Colorado School of Mines Research Institute
mg/kg	milligrams per kilogram
σ	standard deviation
pCi/g	picoCuries per gram
RI/FS	Remedial Investigation/Feasibility Study
RPD	relative percent difference
TCLP	Toxicity Characteristic Leaching Procedure
μ	mean
UCL	upper confidence limit

1. Introduction

The Colorado School of Mines Research Institute (CSMRI) was a complex of buildings that supported the mining industry by evaluating ore samples. The processed ore samples contained concentrations of metals and radioisotopes above background. Some of the processed ore was used as fill in portions of the site. The site was operational from the early 1900s until approximately 1987.

To prepare for the eventual cleanup of the site, consultants have prepared reports detailing their approach to determining background concentrations for metals and radioisotopes at the site. Three such reports have been completed, two by URS in 2000 and 2002, and one by New Horizons in 2004. The geologic complexity of the site makes determining background difficult. Appropriate background levels of compounds of potential concern (COPCs) are critical in that they are used to establish cleanup objectives. If these values are too low, cleanup may include native material, and if too high, cleanup may exclude target material.

This report presents a short site summary, including the geology, contaminants, and history. This report also presents the science behind the three reports, evaluates the validity of the science, and describes our approach for determining background values for the site so that cleanup may proceed. This document concludes with a table of background values that Stoller will use to move this site forward.

2. Site Summary

The CSMRI Creekside site is located along the south bank of Clear Creek in Golden, Colorado (Figure 1). The majority of the site sits on a stream terrace created by Clear Creek. Topography on the terrace is gently sloping toward Clear Creek; however, where the terrace ends, a scarp of approximately 50 feet drops down to the current level of Clear Creek.

2.1 Site Geology

The CSMRI site is located along the front range of the Rocky Mountains adjacent to Clear Creek (Figure 1). The bedrock underlying the site consists of steeply dipping beds of four different formations. These Formations are the Pierre Shale, the Fox Hills Sandstone, the Laramie Formation, and the Arapaho Formation.

A geologic bedrock map of these formations is provided as Figure 2. These formations range from fine-grained shales and coal beds to coarse-grained sandstones and conglomerates. The coal bed within the Laramie Formation was surface mined, with the resulting hole being filled in with a material from an unknown source. Each of these formations has a different chemical composition and can be expected to have different background concentrations of metals and radioisotopes.

The bedrock formations are overlain by four younger surficial deposits in the vicinity of the CSMRI site. These surficial deposits are most impacted by the releases from the CSMRI site, with minor impacts to the underlying bedrock formations. These younger deposits are Louviers Alluvium, Post Piney Creek Alluvium, Colluvium, and artificial fill.

Detailed lithologic descriptions of these units can be found in the Remedial Investigation/ Feasibility Study (RI/FS) (New Horizons 2004). A geologic map showing the extent of these four deposits is presented as Figure 3. Each of these four deposits has different chemical composition and can be expected to have different background concentrations of metals and radioisotopes.

Determining background concentrations for site contaminants should consider the background activity of the four bedrock formations as well as the four surficial deposits. Additionally, blending of different geologic units most likely occurred during the mining of the coal bed and development and demolition of the site buildings, further complicating the geologic picture and background determination.

2.2 Site Contaminants

The COPCs released by CSMRI into the soil included radioisotopes and metals. The radioisotopes include radium, thorium, and uranium, and the metals include arsenic, cadmium, lead, mercury, molybdenum, and vanadium. The metals all generally occur together, and the cadmium, molybdenum, and vanadium were only detected above the Colorado Department of Public Health and Environment (CDPHE) residential standard in less than 2% of the samples collected. Toxicity Characteristic Leaching Procedure (TCLP) results indicate that the affected material is not hazardous waste and may be disposed of in a licensed solid waste facility.

All of these COPCs occur naturally in the bedrock formations and in the surficial deposits that comprise the CSMRI site.

2.3 Site History

The site has been partially remediated. The exact extent to which remedial activities are complete is not known. The buildings have been demolished and removed from the site, and the foundations were mostly demolished and removed from site. An attempt was made to characterize the soil and determine lateral and vertical extent of impacts. Based on this extent determination, the removal of contaminated soil was initiated. During the removal action, estimates of impacted quantities were exceeded and the removal halted.

Material removed from the site was placed in supersacks and staged adjacent to the site. Characterization samples collected from the bagged material for use in determining disposal options indicate that the concentrations of radioisotopes range from less than 1 picoCurie per gram (pCi/g) to almost 50 pCi/g. The geometric mean concentration of Ra-226 is less than 5 pCi/g above background.

The site currently has more than 30 excavations with associated (adjacently located) soil stockpiles and seven excavations from which soil was removed and bagged. The soil is stockpiled in bags for offsite disposal.

3. Summary of Existing Background Reports

Three background studies have been completed that attempt to establish background concentrations for metals and radioisotopes. The following sections summarize the portions of these reports that address background soil concentrations. Background concrete survey

information has been omitted, because that portion of site cleanup is complete. Raw data from each sampling location is listed in all three reports.

3.1 URS 2000 Report

This section provides a summary of URS' initial background characterization report of the CSMRI site (URS 2000).

3.1.1 Location

Thirty grid nodes, each 10 feet apart, were flagged at the base of Mount Zion (southwest of the site). The approximate location of this study is shown on Figure 4.

3.1.2 Sampling Procedure

Background fieldwork included a gamma survey over the entire grid area both at the ground surface and 1 meter above the ground surface. Measurements were made using the following instruments:

- A Ludlum model 19 microR meter calibrated to Cs-137 for external gamma exposure rate measurements;
- A Ludlum model 44-10 NaI scintillation detector calibrated to Ra-226 for detection of low-energy gamma radiation; and
- A Ludlum model 44-9 Geiger-Mueller detector calibrated to Cs-137 for detection of beta and gamma radiation (fixed beta/gamma survey).

Nine soil samples were taken for laboratory analysis from randomly selected grid nodes. At the time of sampling, one rinsate blank and one field duplicate sample were also collected.

3.1.3 Laboratory Analysis

Soil samples were sent to Environmental Chemical Corporation (Denver, CO) where radiological and elemental analyses were performed. Alpha and gamma spectroscopy were used to detect Ra-226, Ra-228, Th-228, Th-230, Th-232, U-234, U-235, and U-238. Chemical methods were used to determine arsenic, cadmium, and lead concentrations.

In its report, URS claims that no significant problems were encountered with quality control methods during analysis of the samples. The following issues were reported.

- Field duplicate results showed that arsenic has a high relative percent difference (RPD), suggesting that arsenic concentrations vary widely over a relatively short distance. A high RPD was also reported for cadmium but was not considered significant since the cadmium concentrations in each sample were very low (less than 1 mg/kg [milligrams per kilogram]).
- Lead was detected in the method blank; therefore, all lead results in the soil samples were subsequently flagged with a data qualifier indicating blank contamination. The contamination was not considered serious, and the data usable since the lead concentration in the blank was a fraction of a percent of the lead concentrations in the soil samples.

3.1.4 Background Calculations

Radioisotopes

In its 2000 report, URS did not calculate background cleanup levels for radiological data and reported only the mean and total propagated error of the data from the soil samples. The field duplicate sample was included in the summary statistics. Averages for the data are shown in Table 1. (The standard deviation of each data set was calculated and is included to better describe each distribution.)

Table 1
URS 2000 Radioisotope Background Concentrations

	Ra-226	Ra-228	Th-228	Th-230	Th-232	U-234	U-235	U-238
μ (pCi/g)	0.94	1.13	0.51	0.47	0.76	0.80	0.14	0.74
σ* (pCi/g)	0.75	0.28	0.20	0.43	0.71	0.70	0.19	0.52
μ + 2σ* (pCi/g)	2.4	1.7	0.91	1.3	2.2	2.2	0.52	1.8

*Calculated by Stoller
σ standard deviation
pCi/g - picoCuries per gram
μ mean

Metals

Data from the field duplicate sample were not included in the summary statistics for the elemental analysis. Four of the samples showed results below the method detection limit for cadmium. For these samples, a value of 0.0015 mg/kg was used to determine the 95% upper confidence limit (UCL). The laboratory data package included in Appendix D of the report indicates that the method detection limit for each of the cadmium samples would be roughly 0.03 mg/kg.

One of the samples was considered an outlier because of its elevated arsenic level and dropped during the statistical analysis for some compounds. The 95% upper confidence limit was calculated for the data with the outlier included but was not calculated when it was dropped. The treatment of this arsenic value was not consistent.

The 95% upper confidence limit is not calculated for lead since the laboratory blank was flagged for lead contamination.

Results of the elemental analysis are summarized in Table 2. (Results for As+ are those calculated without data from sample 19, considered an outlying result.)

Table 2
URS 2000 Metals Background Concentrations

	As	As+	Cd	Pb
μ (mg/kg)	11.62	5.29	0.27	59.61
σ (mg/kg)	19.3	3.81	0.28	43.00
95% UCL (mg/kg)	46.59	NA	0.79	NA
μ + 2σ* (mg/kg)	50	13	0.83	146

*Calculated by Stoller
mg/kg - milligrams per kilogram
NA – not assessed
σ standard deviation
μ mean
UCL – upper confidence level

3.2 URS 2002 Report

In 2002, URS performed a second background characterization report (URS 2002) primarily because radionuclide concentrations found in URS' 2000 report were below regional estimates for naturally occurring radionuclides. Questions were also raised as to whether or not the soil compositions encountered in the previous background study were representative of those at the CSMRI site.

3.2.1 Location

After performing a visual inspection of the CSMRI site and walking over numerous potential background areas, URS representatives chose a sampling area extending from the hillside southwest of the site to the cobbles and sediments of Clear Creek west of the site. This was done in an effort to incorporate a range of desirable locations thought to represent the site. The approximate location of this study is shown on Figure 4.

- Upper hillside areas include soils similar to higher-elevation materials from Table Mountain the Moungier alluvial Fan.
- Intermediate and lower-elevation materials consisted of the Louviers Alluvium and the Post Piney Creek Alluvium.

3.2.2 Sampling Procedure

Background surveying and sampling procedures consisted of the following steps:

- A transect 1 grid unit wide by 63 grid units long was marked and numbered sequentially starting from the top of the hillside (with elevation decreasing along the transect). Each grid unit was 3.3m × 3.3m square.
- Gamma surveys were taken 15 cm from the ground surface over a period of 1 minute per cell using a Ludlum 44-10 detector paired with a Ludlum 2220 scaler/ratemeter.
- A stratified-random sampling design was used to choose 10 of the 63 grids for surface soil sampling. A similar procedure was used to select three subsurface sampling locations from the 10 surface-sampled grids.
- Surface samples: 0 to 6 inches of soil.
- Subsurface samples: 6 to 12 inches of soil.

- In each grid unit selected for surface soil sampling, five surface samples were taken (each about 200g for a total of approximately 1,000g per grid). At the time of sampling, the surface samples from one grid were mixed and split into fractions of roughly 500, 100, and 400 grams.

    - The 500g sample was sent to Acculabs, Inc. (Golden, CO) for radiological analysis using alpha and gamma spectrometry.
    - The 100g sample was analyzed for metals by Acculabs.
    - The 400g sample was sent to URS' Salt Lake City lab for a secondary radiological analysis using gamma spectrometry.

3.2.3 Laboratory Analysis

Acculabs' radiological analysis included alpha spectrometry for Th-228, Th-230, Th-232, U-234, U-235, and U-238; and gamma spectrometry for Ra-226, Ra-228, eTh-228 (Tl-208/0.36), and K-40. Acculabs also analyzed soil samples for arsenic, barium, cadmium, chromium, lead, mercury, molybdenum, selenium, silver, vanadium, and zinc.

URS' Salt Lake City lab performed gamma spectrometry for eU-238 (U-235/0.047), Th-234, Ra-226, Pb-210, Ra-228, eTh-228 (Tl-208/0.36), and K-40. Here the prefix "e" represents an "equivalent" measurement. The fixed natural activity ratio of U-235 to U-238 is 0.047 (assuming no isotopic depletion or enrichment is performed at the site), and the gamma spectrometry measurement of U-235 is considered a good surrogate for determining the activity of U-238. As part of the Thorium series, Th-228 reaches secular equilibrium with Tl-208 after several Ra-224 half-lives. Thus, Th-228 may be measured via Tl-208, which results from the decay of Th-228 36% of the time.

Surface and corresponding subsurface soil samples were compared for significant differences by paired analyses of the difference between means.

- Among the Acculabs radiological measurements, only U-235 showed a significant difference between surface and subsurface samples. In its report, URS claimed that the difference is so slight it is not significant when systematic analytical errors are considered. No significant differences were detected between surface and subsurface samples for the elements measurements. It was also determined there was no significant difference between measurements of U-234 and U-238.

    - In its report, URS averaged surface and subsurface radiological data from Acculabs when determining background levels. Surface sample data were used to represent background elements data.

- Among the URS radiological measurements, surface samples of Pb-210 showed a significant difference from the subsurface samples (surface samples showed higher Pb-210 concentrations). URS speculated that the difference may be attributed to surface deposition of atmospheric Rn-222 decay products. URS accounted for this difference when reporting results by averaging surface and subsurface data for Pb-210. For all other data, URS used surface sample data to represent radionuclide background concentrations.

After surface and corresponding subsurface samples were determined equal, the surface sample results from Acculabs and URS were compared for significant differences. Specifically, Acculabs' U-238 measurements were compared to URS' measurements of U-235 and Th-234, Acculabs' Th-228 measurements were compared to URS' measurements of Tl-208, Acculabs' Ra-226 measurement was compared to URS' measurements of Pb-214 and Bi-214, and Acculabs' Ra-228 measurement was compared to URS' measurement of Ac-228. The comparisons indicated that the URS and Acculabs measurements of Ra-228 concentration are significantly different. However, URS did not pursue this difference because of its secondary importance in characterizing CSMRI contaminants.

3.2.4 Background Calculations – Acculabs Radiological Data

To determine background cleanup levels, it appears that URS combined surface and subsurface data from Acculabs' radiological analysis to compute the mean and standard deviation of the data set. URS then reported a value of $\mu + 2\sigma$ as the background cleanup level. Results are summarized in Table 3.

Table 3
URS 2002 Acculabs Radioisotope Background Concentrations

	U-238	U-235	U-234	Th-230	Ra-226	Th-232	Ra-228	Th-228	eTh-228	K-40
$\mu + 2\sigma$ (pCi/g)	3.6	0.19	3.9	3.1	3.7	4.0	5.5	4.3	5.6	30

σ standard deviation
pCi/g - picoCuries per gram
μ mean

3.2.5 Background Calculation - URS Radiological Data

URS also performed an analysis of radiological constituents, but used gamma spectrometry methods as opposed to alpha spectrometry as was used by Acculabs. As a result, the alpha emitting isotopes of U-235, U-234, Th-230 and Th-232 were not measured by URS. Since no significant differences were found between surface and subsurface samples (excluding Pb-210), surface sample data were used to represent background concentrations and calculate summary statistics. For Pb-210, subsurface data were included in the data set. Again, URS calculated the mean and standard deviation of each data set and reported a value of $\mu + 2\sigma$ as the background cleanup level. Results are summarized in Table 4.

Table 4
URS 2002 URS Lab Radioisotope Background Concentrations

	eU-238	Th-234	Ra-226	Pb-210	Ra-228	eTh-228	K-40
$\mu + 2\sigma$ (pCi/g)	3.4	3.1	4.2	3.8	3.5	3.6	29

σ standard deviation
pCi/g - picoCuries per gram
μ mean

3.2.6 Background Calculations - Acculabs Elemental Data

Since no significant differences were found between surface and subsurface samples, surface sample data were used to represent background concentrations and calculate summary statistics. As recommended in the CDPHE Proposed Soil Remediation Objectives (CDPHE 1997), a value

equal to one-half of the method detection limit was used for cases where the analyte concentration was detected below the method detection limit.

The data were examined for the presence of outliers by using the Dixon Criterion (outlined in NBS Handbook 91). One of the surface samples showed outlying results for barium, chromium, molybdenum, and vanadium. The sample was removed from the distributions for these four elements before summary statistics were computed.

To calculate the 95% upper confidence interval, "t" statistics were used. For those data sets without outlying data points (10 total samples), a t-statistic of 1.833 was used. For data sets with outlying data points removed from the set (nine total samples), a t-statistic of 1.860 was used. Log-normal statistics were used to analyze mercury and silver since the coefficients of variation (standard deviation over the mean) for the raw data exceeded 1. URS then reported a value of $\mu + t\sigma$ as the 95% upper confidence limit background cleanup level. Results are summarized in Table 5.

Table 5
URS 2002 Acculabs Metals Background Concentrations

	As	Ba	Cd	Cr	Pb	Hg	Mo	Se	Ag	V	Zn
95% UCL (mg/kg)	30.4	173	4.2	19.1	310	1.08	11.4	2.5	10.4	28	648
$\mu + 2\sigma$* (pCi/g)	32	178	4.4	19	327	0.73	12	2.5	6.1	29	682

*Calculated by Stoller
mg/kg - milligrams per kilogram
σ standard deviation
pCi/g - picoCuries per gram
μ mean
UCL – upper confidence limit

3.3 New Horizons 2004 Report

New Horizons did not produce a formal background characterization report. Background characterization information was included in the RI/FS (New Horizons 2004).

3.3.1 Location/Sampling Procedure

- As part of the initial site characterization, a gamma survey over the entire site and background sample collection area outside the site boundary were performed. Soil samples were also taken site-wide.
- Four background soil samples were collected outside the site boundary from an area south of the main site entrance.
- In order to generate a sufficiently large background sample set, on-site samples from gamma-surveyed areas that New Horizons determined were at background or below were screened for metals contamination. Eleven samples that did not contain metals concentrations near residential standards were added to the background data set.
- The additional soil samples were representative of the silty/sandy clay soil found on the majority of the site.

3.3.2 Analysis

Surface samples were sent to Paragon Analytic, Inc. (Fort Collins, CO) and analyzed for radiological and metals concentrations.

- Metals analyzed included arsenic, barium, cadmium, chromium, lead, mercury, molybdenum, selenium, silver, vanadium, and zinc.
- Alpha spectroscopy was performed to test for Th-228, Th-230, Th-232, U-234, U-235, and U-238.
- Gamma spectroscopy was performed to test for 40 common isotopes, including Ra-226 and Ra-228. Summary statistics were given only for the radionuclides of concern.

3.3.3 Background Calculations

The background data set for each analyte was checked for normality by plotting histograms. The resulting plots indicated that most of the data were irregularly distributed; therefore, log-normal statistics were used to calculate background concentrations. Background concentrations were determined using "t" statistics. Metals and radioisotopes reported as undetected were assigned values equal to one-half the laboratory detection limit. Laboratory data flagged as "S" (indicating interference from another element) were not included in summary statistics.

Elevated lead levels (at the proposed residential soil standard) were detected in background sample number 4. As a result, background sample 4 was not used in any of the analyses.

3.3.4 Surface Metals

New Horizons presented the 95% UCL for the metal compounds in the RI/FS (New Horizons 2004). Table 6 presents these values.

Table 6
New Horizons Surface Metals

	As	Ba	Cd	Cr	Pb	Hg	Mo	Se	Ag	V	Zn
95% UCL (mg/kg)	13	370	1.5	16	86	0.63	6.1	1.7	0.12	44	250
μ + 2σ* (pCi/g)	12	500	1.6	16	88	0.59	4.1	1.3	0.71	51	277

*Calculated by Stoller
mg/kg - milligrams per kilogram
σ standard deviation
pCi/g - picoCuries per gram
μ mean
UCL - upper confidence limit

3.3.5 Surface Radioisotopes by Alpha Spectroscopy

New Horizons presented the 95% UCL for the radioisotope compounds by alpha spectroscopy in the RI/FS (New Horizons 2004). Table 7 presents these values.

Table 7
New Horizons Surface Radioisotopes by Alpha Spectroscopy

	Th-228	Th-230	Th-232	U-234	U-235	U-238
95% UCL (pCi/g)	2.7	1.7	2.4	1.9	0.098	1.6
μ + 2σ* (pCi/g)	2.8	1.7	2.5	1.8	0.09	1.6

*Calculated by Stoller
σ standard deviation
pCi/g - picoCuries per gram
μ mean
UCL - upper confidence limit

3.3.6 Surface Radioisotopes by Gamma Spectroscopy

New Horizons presented the 95% UCL for surface radioisotope compounds by gamma spectroscopy in the RI/FS (New Horizons 2004). Table 8 presents these values.

Table 8
New Horizons Surface Radioisotopes by Gamma Spectroscopy

	Bi-212	Bi-214	Co-56	K-40	Pb-212	Pb-214	Ra-226	Ra-228	Th-234	Tl-208
95% UCL (pCi/g)	2.7	1.9	0.31	27	2.7	2.3	2.7	2.4	4.1	0.74
μ + 2σ* (pCi/g)	2.8	1.8	0.33	28	2.7	2.2	2.6	2.4	3.9	0.75

*Calculated by Stoller
σ standard deviation
pCi/g - picoCuries per gram
μ mean
UCL - upper confidence limit

4. Assessment of Reports

The following sections assess each of the three background reports for the CSMRI site. Items considered during the assessment include quality of data collected, appropriateness of data analysis, formations sampled, and conclusions.

A general concern with all of the reports is the lack of subsurface sampling and subsurface background determination. In the Proposed Soil Remediation Objectives, CDPHE states that at least one background sample should be taken from each depth that will be sampled at the contaminated site. As described in the Site Summary, seven different geologic units underlie the site. A complete background analysis would include a background evaluation for each geologic unit underlying the site. None of the studies did this.

4.1 URS 2000 Report

Although the majority of the CSMRI site consists of the Louviers Alluvium overlying the Pierre Shale, the location of URS' 2000 background characterization is in a Mounger Alluvial fan area. Material from the Mounger Alluvial fan is located on the southwestern portion of the site but may have been used as fill material for the site. In addition, no subsurface soil sampling was performed.

Page 3-1 of the report mentions that soil samples were mixed at the time of collection. The description of the procedure is ambiguous. URS' Background Calculation Work Plan (BCWP) is referenced for procedural information. The procedure for randomly selecting the nine sites sampled is also supposedly detailed in the BCWP.

An improper use of one-half of the method detection limit in cases where the sample result is below the method detection limit (0.0015 was used when 0.015 should have been used) was noted.

CDPHE also recommends that when more than 15% of the sample results are below detection limits, alternative statistical methods should be used to determine background cleanup levels. This was not done for the cadmium data (where approximately 44% of the samples fell below the method detection limit). However, the Proposed Soil Remediation Objectives do not indicate what the appropriate alternative statistical methods are.

Results from one sample were dropped during the statistical analysis of the arsenic data. Dropping an outlying result is acceptable by CDPHE if a valid statistical method for determining outliers is used. No such method was mentioned in the report. It appears the outlier was identified when the coefficient of variation of the data, with the questionable data point included, was found to be greater than 1. After dropping the outlier from the data set, URS did not re-calculate the background cleanup level (95% upper confidence limit).

Although the method blank was flagged for lead contamination, URS decided the data were usable after an investigation of the method blank data. Lead concentrations were also found to be within range of those determined by Paragon Analytic as part of Environmental Chemical Corporation's quality control program. However, no background cleanup level was calculated for lead.

Calculations of the RPD between the field duplicate and its corresponding soil sample indicate that arsenic concentrations vary widely over a small area. A question then arises as to the validity of removing an "outlying" arsenic result as was done in the statistical analysis.

4.2 URS 2002 Report

Although the majority of the CSMRI site consists of the Louviers Alluvium overlying the Pierre Shale, the location of URS' 2002 background characterization is in an area extending from the Mounger Alluvial fan across the Louviers Alluvium, but mostly in the Post-Piney Creek Alluvium. This study fails to assess the bedrock formations completely.

When gathering surface soil samples, URS gathered five samples from each grid cell and mixed them upon collection. This would seem to "average" the results from one cell initially, possibly affecting the distribution of the data.

In its evaluation of soil sample data, it appears that URS included subsurface sample results when determining the mean and standard deviation of the radiological concentrations found by Acculabs. However, in the analysis of radiological concentrations as found by URS' lab, only surface samples were considered since subsurface samples were found to be not significantly

different from surface samples. This just seems to be an inconsistency, but does not make a significant impact on the final results.

The coefficients of variation for Acculabs' radiological data are all less than one. When the data are checked with normal probability plots, only U-238 shows a somewhat questionable normality.

Using $\mu + 2\sigma$ to determine background cleanup levels for radiological constituents is less conservative than using $\mu + t\sigma$ (as was done in the elements analysis). No explanation is given on why a different technique was used to determine the cleanup level.

In checking the elements data from Acculabs for normality on normal probability plots, it appears that the data for arsenic may not form a normal distribution. Both arsenic and lead have relatively high (0.9) coefficients of variation. The mercury data appear normal (on a normal probability plot) after log-transforming the data, but the silver data appear to have at least one outlying result that may throw off the normality assumption.

Greater than 15% of the data for cadmium, molybdenum, selenium, and silver are below detection limits, yet all were analyzed using normal methods outlined by CDPHE. In cases such as this, CDPHE notes that different statistical approaches should be used for analysis.

4.3 New Horizons 2004 Report

No description is given of how the location of the four background samples outside the site boundary was chosen. From the surficial geological map (Figure 3), it also appears that the area from which the four background samples were taken is an artificial fill area and is thus not representative of the site soils. This area is also an area that has been affected by anthropogenic activities (i.e., it is a previously landscaped area). One of the four background samples collected outside the site boundary was removed from the data set, because it contained elevated levels of lead, supposedly due to the existence of a peat moss contaminant that is known to adsorb metals.

Rather than selecting a background sampling site based on its geological characteristics, New Horizons supplemented background data with samples taken from within the site where gamma readings were low. New Horizons indicated that gamma readings from the areas the supplemental soil samples were taken were below background levels. However, no detail on how these "background levels" were determined is provided and no indication of what formation the samples came from is given.

CDPHE states that at least five samples should be taken to determine background. Even then, non-parametric methods must be used to analyze the data. Preferably, at least nine background samples should be taken.

New Horizons does not go into great detail about how t-statistics were used to determine the background cleanup levels for metals. For the purposes of comparison, the raw data from the background samples were entered into a spreadsheet and a t-statistic of 1.771 (the proper value for a sample with 14 data points) was used to calculate the 95% upper confidence limit.

However, the background cleanup levels determined with this method did not exactly match those presented in Table 4-9 of the RI/FS report.

More than 15% of the data reported for cadmium, silver, U-235, and Co-56 were below method detection limits. In such cases, CDPHE recommends using alternative methods to determine background cleanup levels. This was not done for the New Horizons data. (Most of the radioisotopes detected with gamma spectroscopy were below detection limits. However, 95% confidence levels for these isotopes were not calculated and they were not included in the summary statistics.)

5. Summary of Background Report Analysis.

None of the reports do a thorough job at determining background for the site. The site is geologically complicated and would require a multitude of samples be collected to assess background for each formation present. Additionally, a search of the literature to quantify the range of background concentrations within the seven formations located on site was not completed in any of the three studies.

The URS 2000 study is based on soil that has limited if any relevance to the site. The URS 2002 study comes the closest to sampling the formations of dominant concern and does a good job of evaluating the data. The New Horizons study has many flaws including the fact that samples were selected for inclusion in the background study based solely on having low concentrations of COPCs thereby skewing the results. Table 9 summarizes all the radiological background values from these reports, Table 10 summarizes all the elements background values from these reports, and Table 11 summarizes the strengths and weaknesses of each report.

Table 9
Summary of Radiological Background Values
(all values in units of pCi/g)

μ + 2σ	Bi-212	Bi-214	Co-56	Pb-210	Pb-212	Pb-214	K-40	Ra-226	Ra-228	Tl-208	Th-228	Th-230	Th-232	Th-234	U-234	U-235	U-238
URS 2000	NA	NA	NA	NA	NA	NA	NA	2.4	1.7	NA	0.91	1.3	2.2	NA	2.2	0.52	1.8
URS 2002 (Acculabs)	NA	NA	NA	NA	NA	NA	30	3.7	5.5	NA	4.3, 5.6*	3.1	4.0	NA	3.9	0.19	3.6
URS 2002 (URS)	NA	NA	NA	3.8	NA	NA	29	4.2	3.5	NA	3.6*	NA	NA	3.1	NA	NA	3.4**
New Horizons	2.8	1.8	0.33	NA	2.7	2.2	28	2.6	2.4	0.75	2.8	1.7	2.5	3.9	1.8	0.09	1.6

*eTh-228 = Th-208/0.36
**eU-238 = U-235/0.047
NA – not assessed
σ standard deviation
μ mean

Table 10
Summary of Elements Background Values
(all values in units of mg/kg)

μ + 2σ	As	Ba	Cd	Cr	Pb	Hg	Mo	Se	Ag	V	Zn
URS 2000	50 13*	NA	0.83	NA	146	NA	NA	NA	NA	NA	NA
URS 2002 (Acculabs)	32	178	4.4	19	327	0.73**	12	2.5	6.1**	29	682
New Horizons	12	500	1.6	16	88	0.59	4.1	1.3	0.71	51	277

*Arsenic concentration calculated without suspected outlier.
**Calculated without log-transforming raw data.
NA – not assessed
σ standard deviation
μ mean

Table 11
Comparison of Background Characterization Reports

Document	Strengths	Weaknesses
URS 2000	• Extensive quality control techniques were used in the laboratory analysis. Results are well documented. • Soil collection and analysis included a field duplicate for surface samples. • Soil sampling locations were selected randomly.	• Did not consider all geologic units underlying site (background collection area primarily Mounger Alluvial fan). • No subsurface soil sampling. • Improper use of one-half of the MDL when calculating Cd background cleanup levels. • Normal analysis methods were used in cases where more than 15% of sample results were below MDLs (notably for Cd). • Laboratory method blank was flagged for Pb contamination. Data still determined usable. • An "outlying" value for As was removed from sample results, even though it was shown that As values vary widely across the site. Method used to determine outlying results was not presented.
URS 2002	• Report provides great detail on how sample locations were randomly chosen and methods used to collect samples. • Subsurface samples (6-12") collected in addition to surface samples (0-6"). • Soil collection and analysis included a field duplicate for surface samples. • Laboratory alpha and gamma spectrometry results from two different labs were compared for significant differences. • Surface and subsurface soil samples were compared for significant differences.	• Did not consider all geologic units underlying site (background collection area primarily Post-Piney Creek Shale). • Five samples from each grid cell mixed upon collection. This may have some effect on the overall distribution of the samples. • Some elements data appear to be from non-normal distributions even though coefficients of variation were less than one. Data were evaluated as if from a normally distributed population. • Normal analysis methods were used in cases where more than 15% of sample results were below MDLs (notably for Cd, Mo, Se and Ag).
New Horizons	• Background data distributions were examined. • All background cleanup levels for radionuclides were determined using log-normal statistics, so all data points were included in analysis, and no "outlying" results were discarded (aside from background	• Did not consider all geologic units underlying site (background samples collected in artificial fill area). • No description of how the four off-site background sample locations chosen. • Background sample number 4 was

Table 11
Comparison of Background Characterization Reports

Document	Strengths	Weaknesses
	sample number 4). • Values that are below method detection limits are well marked (with detection limits provided).	preferentially discarded due to elevated levels of Pb (presumably from landscaping activities). • Supplemental "background" samples were taken from site characterization data. Ten samples were chosen from areas of reduced gamma activity (as determined by site characterization gamma survey). • Supplemental "background" samples from on-site were preferentially chosen based on their lack of metals concentrations near residential standards. • Normal analysis methods were used in cases where more than 15% of sample results were below MDLs (notably for Cd, Ag, U-235 and Co-56). • No subsurface background samples collected. • No field duplicates were included with background sample results. • No laboratory quality control measures were mentioned.

6. Proposed Site Background

None of the reports provides both a collection method and analysis above reproach; however, each background characterization study has its merits. Comparing background cleanup levels from the individual reports is difficult, because no two reports applied the same analysis on the raw data to arrive at the reported values (Table 9). By combining the raw sample data from each report, re-applying statistical evaluation, and reviewing background studies from available literature, good estimates for regional background levels can be derived.

Since it appears that methods for determining background cleanup levels vary among the background characterization reports, a suitable first step may be to select an appropriate method for analysis, apply it to the raw data in each report, and compare the results. Characteristics of the method of analysis would include provisions for:

- Checking normality assumptions and dealing with non-normal distributions;
- Handling data sets where more than 15% of the samples are below method detection limits; and
- Handling data sets were fewer than nine background samples are provided.

The method of analysis would correspond to methods outlined in CDPHE's Proposed Soil Remediation Objectives.

Stoller combined usable (reliably collected in an appropriate area) raw data from each of the reports and calculated the corresponding background cleanup levels. This method provides a

larger sample distribution and thus, if the raw data can be considered reliable, provides a less conservative and more accurate estimate of background concentrations.

In addition to an evaluation of available data, a detailed literature search was completed for the seven formations to determine if usable information concerning background concentrations for the site COPCs exists. Both the recalculation of background and the results of the literature search are detailed below.

7. Final Background Analysis

The data from the URS 2000 and URS 2002 reports were combined to determine an estimate of the background levels for the contaminants of concern. Concerns with the methods used to select data representative of background levels in the New Horizons report led to the exclusion of these data from the final background calculation. Methods used to evaluate the data were based on the CDPHE *Proposed Soil Remediation Objectives*, and results for radionuclides and metals are detailed below.

7.1 Radionuclide Data

In the URS 2002 report, each soil sample was analyzed for radionuclide constituents by URS' Salt Lake City Lab and Acculabs in Golden, Colorado. URS analyzed each sample using gamma spectrometry, whereas Acculabs used a combination of alpha and gamma spectrometry methods. These separate measurements were treated as additional samples; therefore, data sets for some nuclides include more data points than others. Since the subsurface data (6 to 12 inches) were shown not to be statistically different from the surface data (0 to 6 inches) in URS' 2002 report, data from each subsurface collection point were included in the analysis. Field duplicates were not included in the final analysis.

Data for each nuclide were graphed on normal-probability plots to determine the shape of the sample distribution. If the nuclide did not appear to follow a normal distribution when plotted on a normal probability plot, the natural log transformation of the data was plotted on a normal probability plot and evaluated. Potential outlying data points were noted, but since Stoller could not make note of apparent anomalies or deviations from standard operating procedures at the time of collection, none of the data were considered for exclusion from the final analysis. URS did not flag any radionuclide data as outlying in either the 2000 or 2002 report.

No radionuclide data were flagged as below method detection limits in either report, but upon closer investigation it was found that in the 2000 report, some radionuclide concentrations did fall below method detection limits. In those cases, URS reported the concentration as the actual value detected, without flagging the data. For the final analysis, the greater of one-half the method detection limit or the originally reported value was used. This occurred for all of the a-228 data and in five other samples for Th-230, Th-232, and U-235.

Colorado's *Proposed Soil Remediation Objectives* states that for samples with fewer than 15% of the values below detection limits, a value of one-half the detection limit should be used. The *Proposed Soil Remediation Objectives* also state that in cases where more than 15% of the results are non-detects, alternative statistical approaches for analysis should be considered. In their *Guidance for Data Quality Assessment, Practical Methods for Data Analysis* document (EPA

2000), the EPA presents several methods for addressing environmental data sets where more than 15% of the values are below method detection limits. For the new background data, a trimmed mean was used to discard values in either tail of data sets where more than 15% of the values fell below MDLs. Twenty-six percent of the Ra-228 was flagged as below method detection limits. A 15% trimmed mean was used to exclude the top and bottom five values of the log-transformed data set from the summary statistics (bringing the total number of Ra-228 samples used to determine background to 25).

Background levels were calculated by taking the mean plus two times the standard deviation ($\mu+2\sigma$) of the data. In cases of log-normally distributed data, the $\mu+2\sigma$ value was found for the transformed data, and the antilog of the result taken to determine the cleanup level. Results are summarized in Table 12. Means and standard deviations are shown for raw data (before transformations to the data were applied) and for log-transformed data, where applicable.

Table 12
Combined URS 2000 and URS 2002 Radioisotope Background Concentrations

	Ra-226[c]		Ra-228[a,b,c]		Th-228		Th-230[a,c]		Th-232[a,c]		U-234[c]	
	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm
μ (pCi/g)	1.9	0.48	2.3	0.74	2.2	NA	1.2	0.01	1.6	0.17	1.6	0.15
σ (pCi/g)	1.0	0.62	1.2	0.33	1.2	NA	0.78	0.70	1.1	0.86	1.1	0.87
μ+2σ (pCi/g)		5.6		4.0	4.7			4.1		6.6		6.6

	U-235[a,c]		U-238		K-40		Pb-210[c]		Th-234[c]	
	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm
μ (pCi/g)	0.12	-2.43	1.6	NA	23	NA	1.8	0.41	1.7	0.43
σ (pCi/g)	0.13	0.81	0.90	NA	2.9	NA	0.99	0.67	0.71	0.45
μ+2σ (pCi/g)		0.44	3.4		29			5.8		3.8

pCi/g - picoCuries per gram
μ mean
σ standard deviation
[a]The larger of ½ the MDL and the value entered in the original table was entered for URS 2000 data below the MDL.
[b]Trimmed mean used to calculate background cleanup levels.
[c]Background levels calculated using log-normal statistics.

7.2 Metals Data

Metals data were analyzed similarly to radionuclide data. In the 2002 URS report, Acculabs evaluated each sample for 11 different elements. Only arsenic, cadmium, and lead were represented in the 2000 report. Since the subsurface data (6 to 12 inches) was shown not to be statistically different from the surface data (0 to 6 inches) in URS' 2002 report, data from each subsurface collection point were included in the final analysis. (In their report, URS only used surface samples to calculate the 95% upper confidence limits for each data set.) Field duplicates were not included in the final analysis.

Data for each element were first plotted on a normal probability plot to determine the shape of the sample distribution. If data did not appear to follow a normal distribution, the natural log transformation of the data was plotted on a normal probability plot and evaluated. Outlying data points flagged in the original reports were flagged in the combined data set. Summary statistics were calculated with and without the flagged outliers included. Other points that appeared to be potential outliers were noted, but since Stoller could not make note of apparent anomalies or deviations from standard operating procedures at the time of collection, only data flagged as outliers in the original reports were considered for exclusion from the final analysis. In the original reports, outliers were flagged in the arsenic, barium, chromium, molybdenum, and vanadium data.

In their 2002 report, URS used a value equal to one-half the method detection limit in cases where an analyte fell below method detection limits. In the 2000 report, four cadmium values fell below method detection limits, and values of roughly 5% (as opposed to 50%) of the method detection limits were used in their analysis. Those values were corrected in the final background determination by taking one half of the method detection limit (as listed in the laboratory data package) for each sample. Like the radionuclide data, metals data sets where more than 15% of the values were flagged as below method detection limits were analyzed using a trimmed mean. This was done for the cadmium, molybdenum, and silver data sets. All of the selenium data were below the method detection limit.

As shown in Table 13, a value of the mean plus two times the standard deviation ($\mu+2\sigma$) is reported in addition to the 95% UCL for each metal. In cases of log-normally distributed data, those values were found for the transformed data and the antilog of the result was taken to determine the cleanup level. Means and standard deviations are shown for raw data (before transformations to the data were applied) and for log-transformed data, where applicable.

Table 13
Combined URS 2000 and URS 2002 Metals Background Concentrations

	As[a,d]		Cd[c,d]		Pb[d]		Ba[b,d]		Cr[b]		Hg[d]	
	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm
μ (mg/kg)	12	1.9	1.3	-0.30	106	4.2	106	4.6	13	NA	0.23	-1.95
σ (mg/kg)	14	1.0	1.4	0.66	112	0.98	32	0.31	2.6	NA	0.23	1.05
μ+2σ (mg/kg)		51		2.8		478		189	19			1.2
95% UCL (mg/kg)		38		2.4		363		178	18			0.92

	Mo[c]		Se		Ag[c,d]		V[b,d]		Zn	
	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm	Norm	Log-norm
μ (mg/kg)	4.7	NA	2.5	NA	2.2	0.00	19	2.9	350	NA
σ (mg/kg)	3.4	NA	0	NA	2.5	0.92	4.1	0.19	245	NA

μ+2σ (mg/kg)	11		2.5			6.4		27	841	
95% UCL (mg/kg)	11		2.5			5.6		26	787	

mg/kg - milligrams per kilogram
μ mean
σ standard deviation
[a]Outlier flagged in URS 2000 report included in analysis.
[b]Mean, standard deviation and background level calculated without flagged outlying data points.
[c]Background levels calculated with trimmed data set.
[d]Background levels calculated using log-normal statistics.

7.3 Literature Search

An extensive literature search for previous background studies performed along Colorado's Front Range was conducted at the Colorado School of Mines Arthur Lakes Library and at the CDPHE Public Review and Environmental Records office. The data found are predominantly represented by regional background studies performed for the Rocky Flats site and site characterization and background studies performed for the Molycorp, Inc. Louviers site. The literature search uncovered more background information for naturally occurring radionuclides than for the metals of concern at the CSMRI site.

Means for background data found in the literature search were compiled and compared to means calculated in the CSMRI evaluation. In some cases, the means found in the CSMRI evaluation fell within the range of means uncovered in the literature search. Except for molybdenum and vanadium, if the CSMRI mean did not fall within the range of means found in the literature search, the CSMRI mean background value was larger. Tables 14 and 15 summarize data found in the literature search. For comparison, the last row in Tables 14 and 15 shows the means reported in Table 12 for radionuclides and Table 13 for metals, respectively.

Table 14
Rocky Flats and Louviers Site Background Radioisotope Concentrations Compared with CSMRI Concentrations

	Ra-226	Ra-228	Th-228	Th-230	Th-232	U-234	U-235	U-238	Pb-210
Min (pCi/g)	0.63	0.20	0.60	0.10	0.12	0.63	0.01	0.64	0.50
Max (pCi/g)	3.2	1.7	0.90	1.6	2.6	1.13	0.08	2.8	2.6
CSMRI μ (pCi/g)	1.9	2.3	2.2	1.2	1.6	1.6	0.12	1.6	1.8

pCi/g - picoCuries per gram
μ mean

Table 15
Rocky Flats and Louviers Site Background Metals Concentrations
Compared with CSMRI Concentrations

	Pb	Ba	Cr	Mo	V	Zn
Min (pCi/g)	7.0	59	6.0	4.8	22	18
Max (pCi/g)	19	106	19	7.1	28	60
CSMRI μ (pCi/g)	106	106	13	4.7	19	350

mg/kg - milligrams per kilogram
μ mean

The literature search was conducted primarily to estimate whether or not the new CSMRI background values were reasonable for the region. Of most concern are Ra-226 and Ra-228 background values. As shown in Table 14, the mean of the combined URS 2000 and 2002 Ra-226 data falls within the range of background means found during the literature search. However, the calculated Ra-228 mean falls above the maximum value found in the literature search.

Variations in surface geologies, data distributions, depths of samples, number of representative sites, etc. make it difficult to directly compare background values. Relatively large standard deviations in the combined URS data tend to elevate cleanup levels beyond those found in the literature search. As noted in Tables 12 and 13, log-normal statistics were used in some cases to determine the background levels, which also tends to result in larger background levels.

7.4 Conclusions

Three previously reported background studies have been completed for the CSMRI Creek Side Site. Data collected from two of the studies were used to re-evaluate background following guidance from the CDPHE and the EPA. New background concentrations for the Site COPCs were determined and will be used for a reevaluation of risk as well as a re-evaluation of DCGLs. These values are presented in Tables 12 and 13.

8. References

CDPHE 1997. Colorado Department of Public Health and Environment. Proposed Soil Remediation Objectives Policy Document. Prepared by the Hazardous Materials and Waste Management Division, December.

EPA 2000. Guidance for Data Quality Assessment: Practical Methods Data Analysis, document number EPA QA/G9, prepared by the Office of Environmental Information, July 2000.

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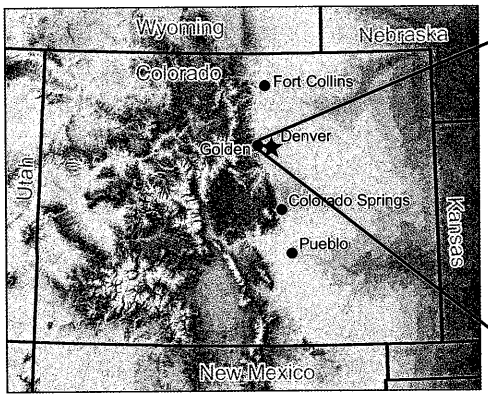
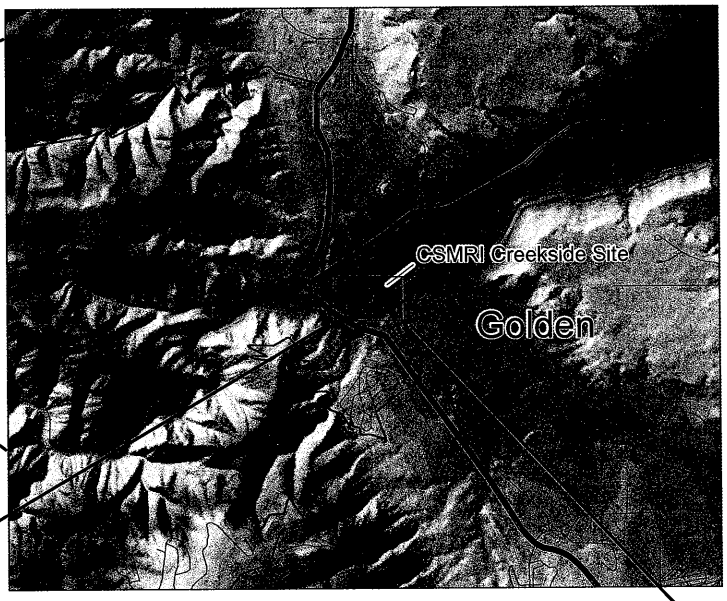
URS 2000. Background Characterization Report, prepared for Colorado School of Mines Environmental Health and Safety, prepared by URS Greiner Woodward Clyde International-Americas, Inc., July 7, 2000.

URS 2002. Colorado School of Mines Research Institute Supplementary Background Characterization draft final report, prepared by URS Corporation, January 28, 2002.





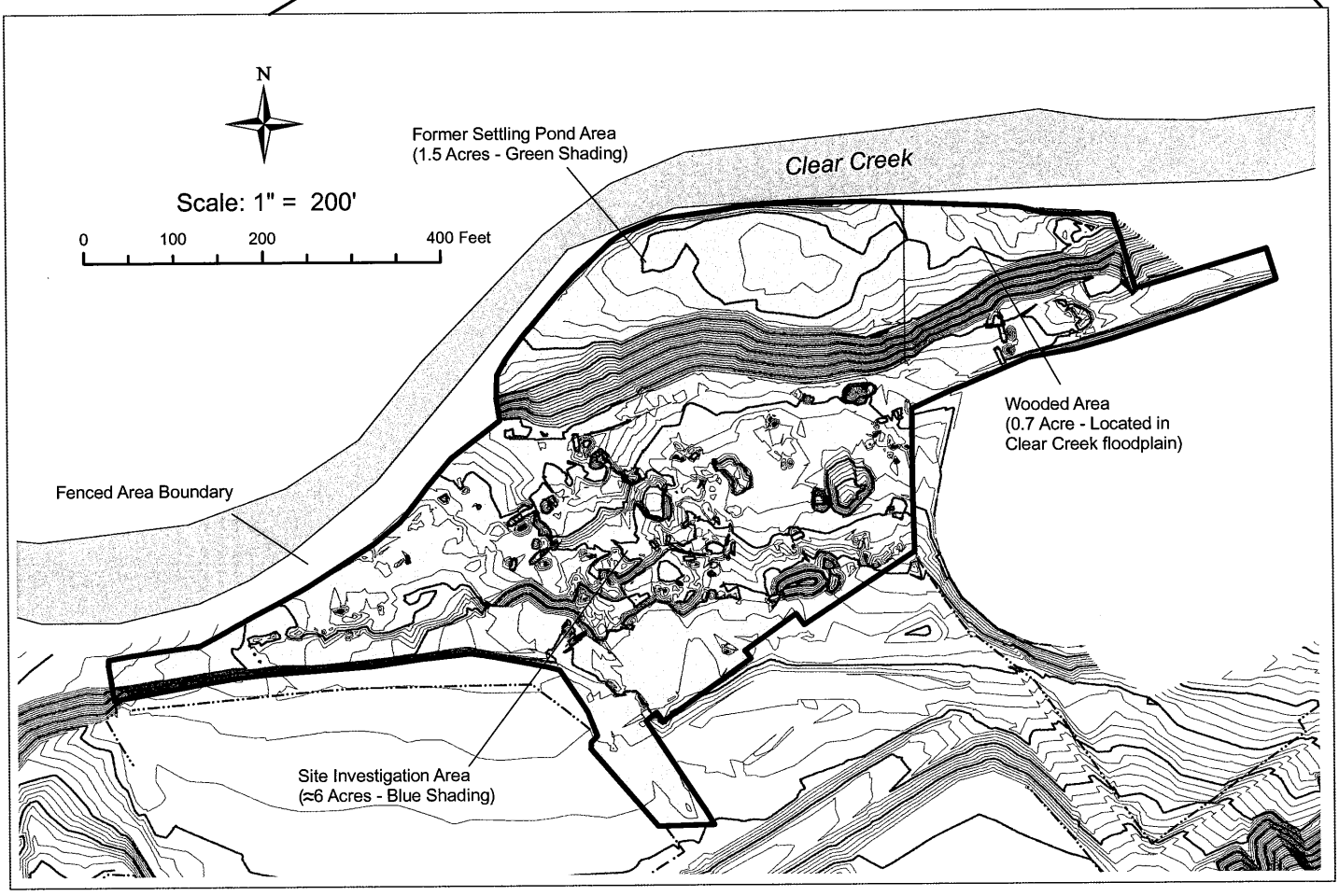


Figure 1

CSMRI
Site Location Map

Explanation

- CSMRI Creekside Site
- Fences
- Topography (1 ft Intervals)
- Topography (5 ft Intervals)

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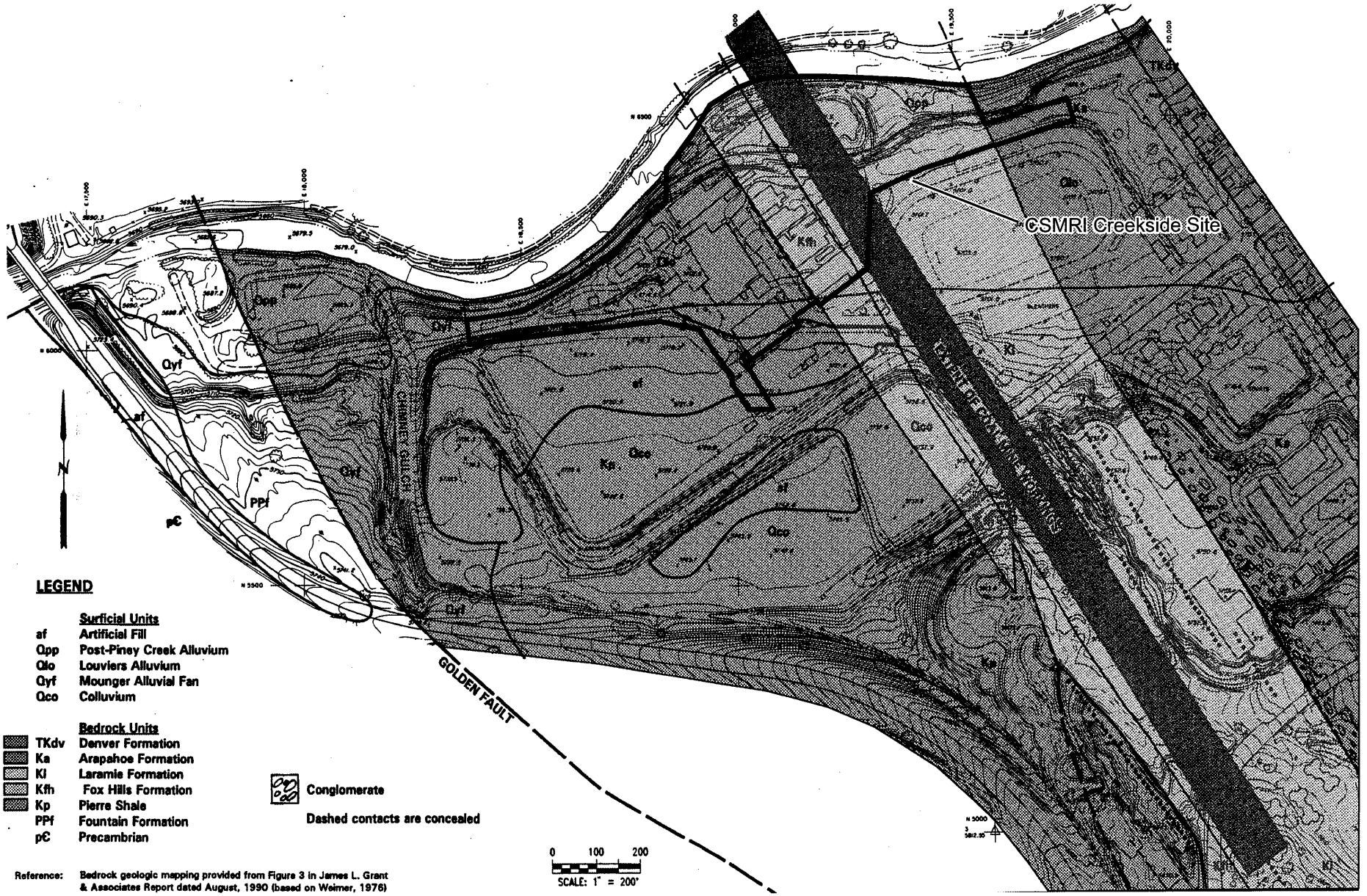

Figure 2

CSMRI
Bedrock Geologic Map

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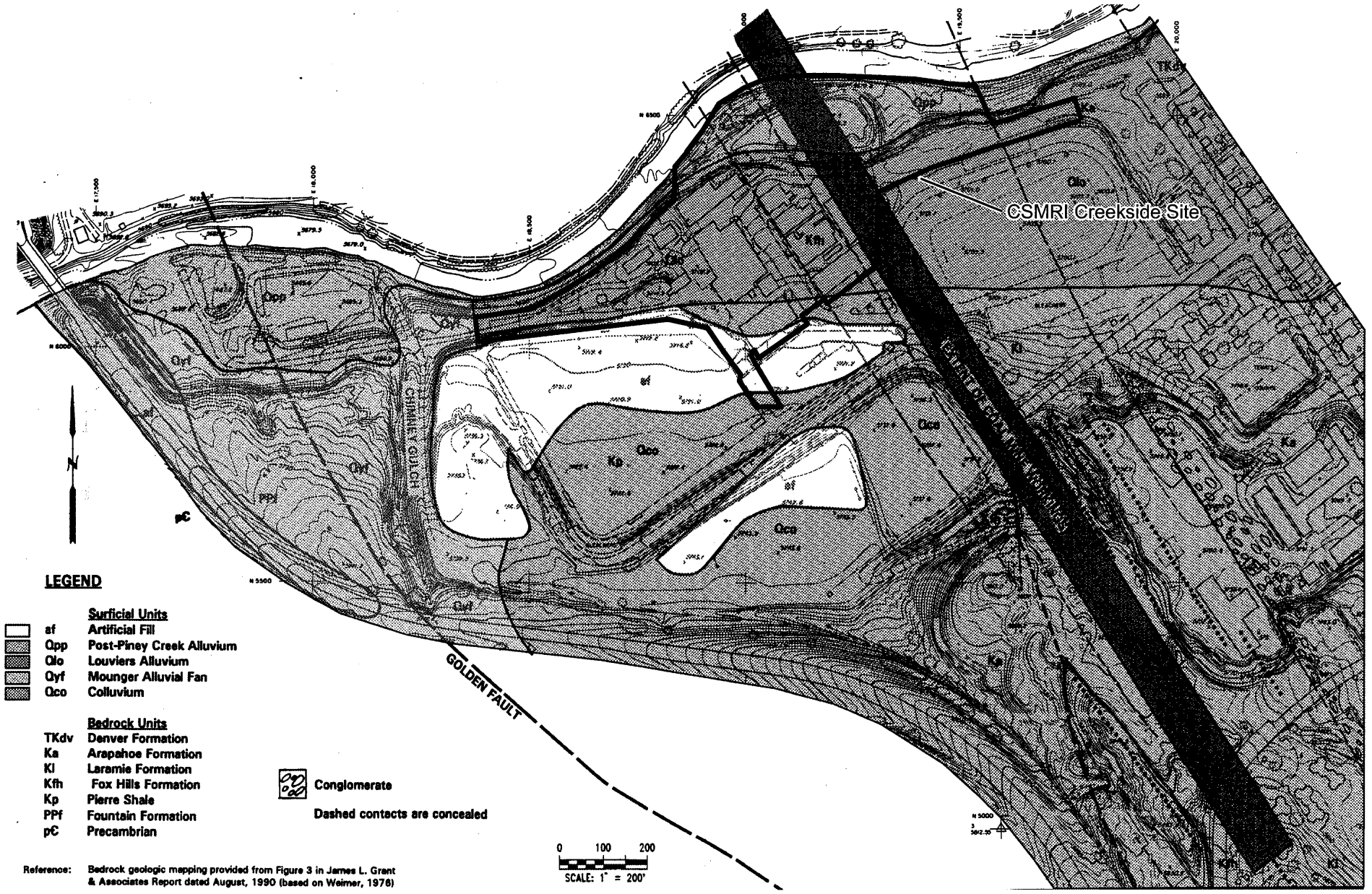

Figure 3

CSMRI
Surface Geologic Map

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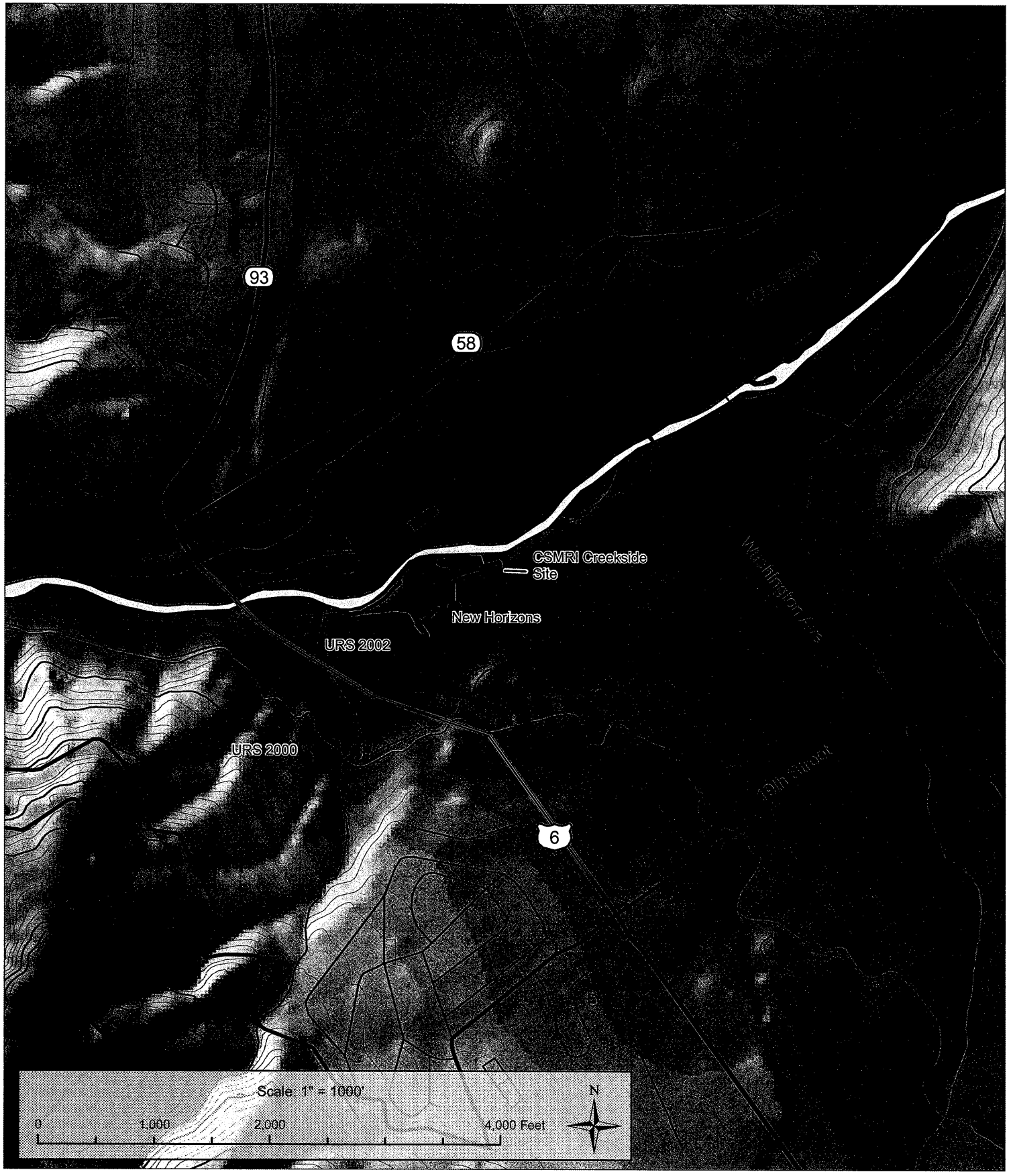

Figure 4

Locations of Previous Background Studies

Explanation

- Background Sampling Location
- CSMRI Creekside Site
- Divided Highways
- Major Roads
- Side Roads
- Hydrography
- Topography (40 ft Intervals)
- Topography (200 ft Intervals)

CSMRI

Stoller

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