

## **FLUVIAL PLACEMENT OF RADIOACTIVE CONTAMINANTS: A WELDON SPRING SITE CASE STUDY**

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### **ABSTRACT**

The operation of the Weldon Spring Uranium Feed Materials Plant in St. Charles, MO between 1958 and 1966 resulted in the migration and emplacement of radioactive contaminants into surface water drainage systems. Multiple drainage systems, receiving from a variety of waste discharge points, combined to create unique and unexpected depositional environment. Discovery and investigation of the depositional environments was a significant technical challenge due to the complex nature of sediment movement and emplacement. The objective of this investigation was to show that application of the knowledge of geomorphic processes is an essential element of a complete stream characterization, pursuant to risk analysis and remediation. This paper sets out to describe many of the expected and unexpected findings of the investigations by the Weldon Spring Site Remedial Action Project (WSSRAP) into the placement and rework of contaminated sediments in stream systems. Information from this paper will be useful to other agencies and contractor personnel faced with the challenge of locating and quantifying contaminated sediments in seemingly haphazard fluvial depositional conditions.

### **SITE DESCRIPTION AND HISTORY OF CONTAMINATION**

In 1999, the US Department of Energy (DOE) completed remediation of the contaminated stream channel officially referred to as stream 5300. The investigations which resulted in the eventual cleanup of the stream demonstrated that site related contaminants had been incorporated into the sedimentary system over the course of several decades of waste discharge and sediment rework. The stream, commonly known as the Southeast Drainage, received direct discharge of process waters and stormwater runoff from the southeast portion of the Weldon Spring Site Uranium Feed Materials Plant (WSUFMP) during its period of operation between 1958 and 1966. Following the operating period of the plant, the channel received contaminated storm water runoff of progressively lower contaminant concentrations, from 1966 to present. For this study, the preoperation period was considered the timeframe prior to 1958, before WSUFMP operations began. The post operation period is considered the period from 1967 to the present.

During plant operations, the Southeast Drainage received discharge from the sanitary and process sewers, and overflow from the raffinate pits (the sludge settling ponds in which the majority of the solid impurities generated during the uranium purification process accumulated). Little information is available regarding the nature of the discharge

responsible for the introduction of contaminants into the stream system. It is presumed by the investigator, based on personal historical knowledge of the plant operation, that the discharge occurred in daily pulses, mitigated by the detention factors of the raffinate pits. Historical, Department of Energy reports state that "Process sewers were monitored continuously and effluents were diluted as necessary to ensure compliance with applicable discharge limits." (Ref. 6) Fourteen quarterly, semiannual and annual Off-site Environmental Monitoring Reports from between 1959 and 1965 were reviewed for contaminant source information. Over that period, approximately 1471 samples of the process sewer discharge were collected. Those samples indicated an average uranium concentration of 590 pCi/l uranium and an average "high" uranium concentration of 1010 pCi/l in the waste water. Over that same period, 33 samples were collected at the mouth of the Southeast Drainage at its inlet to the Missouri River. The average uranium concentration was 350 pCi/l and the average "high" concentration over that period was 480 pCi/l. For the samples from the nearby lakes and drainage creeks, the tabulated data from these historical reports specifically noted that "On the average slightly less than half the activity was found in the undissolved solids portion of the sample" (Ref. 9); however that note was absent from the data from the Process Sewer. Based on the processes contributing to the Process Sewer discharge, there is the possibility of a substantial fraction of uranium activity being contributed by a solids portion. No information was available in these or any other historical reports reviewed regarding the concentration of the radium and thorium isotopes in the discharged wastewater, although the concentration of those constituents within the solids (sludge within the pits) is well-characterized and understood. It is a reasonable assumption that the emplacement and current location of contaminants in the drainage has been controlled exclusively by the actions of the discharged wastewater and subsequent, intermittent stormwater runoff events.

Based on the DOE data from the Southeast Drainage, the concentrations of radionuclides in sediments prior to remediation ranged from near background, up to several thousand picocuries per gram for radium and thorium isotopes. The highest levels represented sediments with a significant fraction of waste material, as concluded by comparing the measured concentrations with those in the raffinate pits. Although no historical data on the sludges were available representing original discharges from the process sewers, data from the DOE's Remedial Investigation report provided raffinate pit waste concentrations, as displayed in Table I.

**Table I. Radioactivity in Raffinate Pit Sludge**

Isotope	Maximum Activity in Raffinate Pits 1, 2, or 3 (pCi/g)	Average Activity for Raffinate Pits 1, 2, or 3 (pCi/g)
Radium-226	1700	567
Radium-228	170	85
Thorium-230	34000	23700
Uranium-238	1200	660

The radionuclide concentrations measured within a small number of the Southeast Drainage sediment samples suggested that some original sediment accumulation zones remained in-place, undisturbed since their original deposition during process discharge.

Sediments within the Southeast Drainage were discovered to contain above-background levels of substances considered to be "site related contaminants" during a preliminary investigation in 1984; however, the nature and extent of the contamination was not definitively quantified at that time. The DOE, under the new governance of CERCLA/SARA, found that the necessary regulatory and administrative requirements for determining applicable risk-based cleanup standards and final waste disposition decision had to be completed. Subsequent characterization efforts were conducted over the years between 1987 and 1993 to better define the nature and extent of the contamination within the drainage and arrive at a reasonably-achievable cleanup approach to the contaminated sediment.

### **Geologic Setting of the Study Area**

The Southeast Drainage is located within the Missouri Department of Conservation's Weldon Spring Conservation Area in St. Charles County, Missouri, USA. The area is actively managed for wildlife, contains a variety of terrestrial and aquatic habitats and supports a diverse biota" (Ref 1, pg. 3). Approximately 5% of the drainage basin area is occupied by the WSUFMP property (currently known as the Weldon Spring Site Remedial Action Project or WSSRAP), which served as the source area for the contamination within the Southeast Drainage.

The drainage basin for the Southeast Drainage is an area of 106 ha (262 acres), which drains the northern marginal highlands and valley slopes of the Missouri River, traversing 220 feet of vertical relief over its 1.7 horizontal miles of length to its mouth at the Missouri River. The study area is situated on the extreme southeastern portion of the Dissected Till Plains, a subdivision of the Central Lowlands Plateau Physiographic Province. The uplands consist of 10 to 40 ft. of unconsolidated material, primarily silt and clay matrices, including loess, glacial tills, and gravelly residual soils from the weathering of the limestone bedrock. The study stream dissects a stratigraphic sequence of primarily flat-lying, crystalline to subcrystalline carbonate units with interbedded shales and minor sandstones, within the Mississippian, Devonian, and Ordovician systems.

At its headwaters on the Weldon Spring Site, the SED channel initiates as a series of rivulets on glacial till/loess ridges. The channel gradient ranges from 75 ft./mi. at its lower reach to 220 ft./mi. at its head reach, with an average of approximately 115 ft./mi. over its entire channel length. The channel is incised into colluvial valley materials and the channel width comprises from approximately one fourth to one tenth of the total width of the valley floor. The upper one half of the stream channel base overlies a fairly shallow layer of unconsolidated colluvial material, from approximately 0 to 10 feet based upon the investigator's observations of the exposure of a bedrock channel base in some areas. At approximately elevation 510 ft. MSL the bedrock channel plunges beneath the

valley floor as the stream channel becomes incised into the valley terrace material remaining from Pleistocene fluctuations in the Missouri River elevation (Ref. --).

Four primary springs influence the hydrology of the stream channel, which were identified by this investigator in 1987 as SP-5301 through SP-5304. Springs 5301 and 5302 are primarily wet-weather features, with no perennial flow component other than water discharged under permit from the DOE cleanup operation. These springs represent resurgence of flow lost within the channel at upgradient swallow holes. The lower two springs, 5303 and 5304 represent components of both perennial flow and intra-valley loss, as has been documented by this investigator through work for the DOE/PMC and corroborated by MDNR/DGLS (Ref. 20, 21). Flows in excess of 300 gpm are capable of capture and transport through the subsurface flow system.

The stream channel is appropriately characterized as a meandering channel. Due to its meandering configuration, the stream exhibits the gamut of depositional accumulations typical of a fluvial system, including bed sediments, point bars, overbank deposits, and, what this investigator has termed marginal deposits. Rosgen states in his paper "A Stream Classification System" (Ref. 25).

"Stream morphology and related channel pattern are directly influenced by eight major variables including width, depth, velocity, discharge, slope, roughness of channel materials, sediment load and sediment size. A change in any one of these variables sets up a series of concurrent changes in the others, resulting in altered channel patterns. Since stream morphology is a result of an integrative process of mutually adjusting variables, those most directly measurable have been incorporated into the delineative criteria for stream types."

The Southeast Drainage may be classified, according to the Rosgen classification system as fitting generally into the "C" Stream Type category with reaches fitting other category classifications at the upper and lower ends of the drainage. The majority of the stream has fit the general description of "low gradient, meandering, point-bars, riffle/pool [stream flow], alluvial channels with broad, well-defined floodplains." The entrenchment ratio is greater than 2.2, the width/depth ratio varies from 3 to 7, the sinuosity ranges from 1.1 to 1.5 and the slope is less than 0.02 overall.

Some depth-dimensional data were collected. These data, reviewed and analyzed collectively in context of their original 3 dimensional locations and relative concentration, provide the initial evidence that at present, the stream channel does not exhibit continuous or consistent contamination levels from its source to its mouth at the Missouri River. Instead, what the data indicate is the occurrence of frequent, isolated pockets of contaminated sediment, primarily on the margins of the channel, but to some extent outside the channel boundaries and across the valley floor. These data and the information available from the DOE regarding their locations and depths were used by this investigator to evaluate the causes and relationships of contaminant occurrence in the Southeast Drainage.

## REVIEW OF STUDY AREA

The DOE collected data on radionuclide concentrations in the Southeast Drainage stream sediment materials based upon a number of different strategies. Most were governed by the apparent radioactivity levels as measured with a field radioactivity instrument (Ludlum Model 44-9). The majority of the sample data were collected from sampling locations which were determined by the occurrence of radiation levels at the ground surface. The criteria for choosing sampling points were:

- 1) field located points based on a pre-defined spacing interval, or
- 2) that the apparent activity of the surface sediments was greater than or equal to 1.5 times the background meter reading.

Sample locations were not selected or biased based upon geologic conditions or other physical parameters. As a result, the available data set is representative of areas whose surface radioactivity expression exceeded the minimum screening criteria. Based on these criteria and the multiple characterization efforts, a large database was created representing Southeast Drainage contamination.

It was necessary to isolate the data set into potential target populations for analysis. In order to best determine whether some systematic approach to stream characterization was feasible, this would mean that various types of sediment deposits would have to be identified and distinguished. To accomplish this, fluvial dynamics of the study stream were analyzed and separate target populations were identified to facilitate some interpopulation comparison. A systematic review of the physical characteristics of the stream valley and the incised stream channel was performed. This review involved the following steps:

Step 1. Review the physical characteristics of valley system and its geomorphic aspects, including topographic setting, hydrology, base level controls (short-term and long-term), sediment materials, and historical channel alignment, to provide an understanding of the system dynamics.

Step 2. Segregate the sediment deposits into separate study populations (hereafter referred to as "categories") based upon some distinguishing hydraulic/geomorphic control factors. This was done by mapping the drainage and categorizing the stream deposits.

Step 3. Assemble the contaminant occurrence data and partition the data into population categories.

Step 4. Evaluate the contaminant data using statistical techniques to determine association with geomorphic occurrence, based on specific categorization of those physical factors.

Steps 1 through 3 were considered necessary to identify, quantify and isolate the contaminant occurrence conditions, to allow for the statistical analyses of Step 4. Prior to performing the field mapping, it was anticipated that subtle differences in physical characteristics of the stream would play a significant role in the investigation. The following text describes all the elements included in Steps 1 through 3, which set the groundwork for understanding the study system..

### **Review of the Geomorphology of the Southeast Drainage.**

The Southeast Drainage has been a topic of general study for the DOE and its contractors since at least 1984. This investigator has been personally interested and focused on its hydrology since 1988. The elements of the geomorphology of this drainage relevant for consideration in this study are 1) flow periodicity and quantity, 2) karst influence on surface flow expression, 3) channel geometry relative to sediment accumulation zones, 4) historical changes in channel alignment, and 5) sediment grain size and mineralogy.

### **Flow Periodicity and Quantity.**

Flow periodicity and quantity is significant to this investigation since stream flow provides the energy and the medium for sediment and contaminant movement. There are two separate sources for flow in the Southeast drainage. Those sources are 1) man-made (or anthropogenic) sources such as process discharges, and 2) natural runoff.

The anthropogenic sources have varied through the years,

- starting with the discharge of waste water (predating WSUFMP operations) from the Weldon Spring Ordnance Works operations during the 1940s,
- then becoming discharge from the WSUFMP operations (during which the contaminants of concern in this study were introduced),
- then transitioning to only leakage from deteriorated potable water lines,
- then, upon initiation of the remediation project, discharge from the state permitted water treatment plant facility.

These process discharge waters have varied in quantity, but all acted to maintain a continuous base flow to parts or all of the stream throughout that historical period. The WSUFMP discharged to the Southeast Drainage at a certain rate, with some probably variable mix of solid and dissolved contamination. The Southeast Drainage possesses a natural base flow which is seasonally variable, but is primarily considered wet-weather flow in the upper one-half of its length. Beginning at Spring SP-5303, perennial base flow of between 5 and 20 gpm is common. These flow conditions, during the periods between rainstorm events, provide for only intra-gravel and shallow pool and riffle flow. Therefore, the wastewaters introduced to this drainage provided from between 100 percent (in the upper reach) and approximately 50% of the streamflow during non-storm

discharge periods. During these periods of discharge to low flow conditions, the investigator speculates that a sort of equilibrium was established between the suspended solids materials and the channel materials, which at that flow rate, would be the base load material within the pool/riffle sequences.

The base flow conditions from groundwater discharges from springs are assumed to have remained relatively constant over the period of influence of contaminant placement. The primary controls on such flow would include precipitation and infiltration sources, karst conditions of the source aquifer, hydraulic gradient, etc, and these conditions are not expected to have changed over this four-decade period. Certainly, they acted in concert with the process water discharges from the plant to provide continuous reintroduction of contaminants into and along the drainage, emplacing contaminated solids into the stream channel base and pools, availing them for rework into the more permanent sedimentary record of the channel deposits.

### **Karst Influence on Surface Flow Expression.**

The karst characteristics of the system had been well identified, in previous studies on the Southeast Drainage performed by this and other investigators. In 1990, this investigator conducted sequential flow studies within the drainage for the DOE to determine the influence of contaminated sediments on clean discharge water. Other information resulting from this study are significant in understanding the relative movement of contaminants through the system during and after plant operation and are discussed in Ref 22. The methods employed in the 1990 Flow Studies were as follows:

“The overall purpose of the studies were to determine whether contaminants in the drainage sediments might have an unacceptable influence on the uranium concentration of the clean discharge water resulting from DOE’s proposed water treatment operations. Since at the time, the discharge rate was not defined, three separate flow events were initiated based on potential discharge rates. These rates were 100, 200 and 300 gallons/minute. Continuous sampling devices were deployed to collect water samples over at least a 24 hour period after passage of flow through each segment. Samples were collected at the wetting front and at fixed points throughout the 1.7 mile channel. Also noted by the investigator were the loss points within the drainage, where surface flow was lost to karst flow. Since the resurgence points were well understood and identified by the investigator previously, sampling points were established there as well. What is significant to this investigation is the correlation of the relative position of water loss zones to flow rate. It was determined that the entire streamflow at the 100 gpm rate was captured by the karst system and travelled subsurface to the sequence of springs within the drainage. At the 200 gpm rate, the entire flow was again captured, however the loss points extended further down stream before total capture was achieved. Finally, at the 300 gpm rate, some continuous surface flow was achieved.”

The significance of this information is that, depending on the rate of the process discharge during WSUFMP operation, the sections of the stream between the loss points and the springs may not have received continuous reintroduction of solids from the discharged waste water. This could have influenced the availability of contaminants in the stream channel along those stream reaches, creating an inconsistent source for rework during storm discharge events. This information was considered during the investigation. No obvious evidence of this characteristic was observed in the data sets, however it was determined that to pursue this characteristic through statistical testing of the data was outside the scope of this investigation.

### **Geometry of the Stream Channel.**

Sediment accumulation zones are related to the flow characteristics of the proximal channel, and flow characteristics are a function of geometry of that channel segment. The investigator utilized existing topographic maps of the drainage to facilitate mapping the stream channel segments and categorizing the resulting sediment accumulation zones. Since correlation of deposit categories with analytical data was only possible where DOE had collected analytical data, only those sections of the drainage were mapped.

### **Mapping the Drainage.**

Utilizing an enlarged scale topographic map, generated by the Department of Energy under the Southeast Drainage remedial design, the investigator assigned sediment accumulation zones to one of the four categories listed above and determined to which category each of the sample data points were derived. This effort required traversing the 1.7 mile drainage, locating each previously collected sample point and assigning it a label of 1 through 4 for the appropriate sediment category

## **CONCLUSIONS OF THE STUDY AND SIGNIFICANT OBSERVATIONS**

Significant observations made during this study are highlighted below.

### **Explanation for the Occurrence of Contamination Within Accretion Deposits.**

The objective of this investigation was to show that application of the knowledge of geomorphic processes is an essential element of a complete stream characterization, pursuant to risk analysis and remediation. Information on the physical proximity, geometry, and concentration of known-contaminated sediment zones, when reflected against the typical geomorphic processes involved in a fluvial system, would provide for plausible explanation for the current distribution and occurrence of contamination in the drainage.

Based on the nature of the active accretion deposits' progressive growth and stabilization, it was anticipated at the outset of this study that the radionuclide concentrations within these study deposits would represent a gradational decline in correlation with relative age



of the progressing edge of the deposit. Data collected throughout the DOE investigations suggest that sediments with concentrations on the order of thousands of pCi/g were deposited in various settings within the stream environment. It was hypothesized that the history of contaminant movement down channel would be recorded in the progressive sequence of the study deposit. Some limited sampling performed during the course of this investigation did represent this gradational-decline pattern, although the magnitude of the range of concentrations was less than expected.

More dramatic evidence of this pattern, however, was seen during remediation (removal) of the drainage sediments by the DOE in 1998. During the data collection and scoping of the remedial effort, an accretion deposit of approximate dimensions 10 meters by 18 meters was field surveyed with a radiation instrument, showing no indication of contamination at or near surface. Only one edge of the deposit was sampled for quantitative analytical data by DOE sampling crews, based on indications from walkover surveys. This sampling yielded data which did not exceed the threshold for remediation. Under the DOE's remediation design, this deposit was identified as having to be partially excavated to allow for effective traffic flow of remediation equipment further up-valley. Later, upon excavating the edge of the deposit during DOE's site preparation efforts, sufficiently high contamination levels were detected within the core of the deposit to trigger a decision to include this deposit in the remediation. This event provides additional evidence that progressive growth of deposits, both laterally and vertically, can place progressively lower concentration (reworked) materials adjacent to and above earlier, more contaminated deposits, making characterization design more dependent on understanding the potential factors which emplaced the sediments over time, and accommodating such factors in the sampling approach. It appears, from observations made during the investigation, that the growth of a point bar deposit and its stratigraphic components occur in a methodical manner. As the cutbank progresses, and the inside meander band (point bar) progresses in turn, the top fines layer thickens with distance from the main channel toward the inside channel bank, suggesting a greater dependence on water elevation for deposition of those fines than on the temporal progression of the sequence laterally

It is also important to recognize that accretion deposits can be partially or completely scoured during sufficiently aggressive runoff events and subsequently redeposited with new material, such that continuous, progressive growth cannot be assumed regarding any subject sediment deposit.

### **Suspended Terrace Deposits**

Most contaminated sediment occurrences fit a standard model for emplacement which allows their physical location to be explained or predicted on the basis of the simple stream mechanics. This study encountered some depositional occurrences that did not fit the standard model, and have been explained as a function of transient impediments to flow along stream segments that were otherwise apparently stable during the operational period of the plant. Perched at the top edge of the incised channel was a thin "vener" of relatively high concentration levels of radium-226, detected by a field meter but

otherwise visually indistinguishable as a stream-affected deposit. Sample data placed it as one of the five highest concentration deposits in the drainage. Contamination levels in sediment of this magnitude would necessarily have been comprised of substantial contribution by raffinate material. Based strictly on a rough, mass-balance model, it is unlikely that such high concentrations could have been rendered as deposited during a high discharge streamflow event. However, the physical position of this “vener” deposit relative to the channel base elevation would have required a full-channel flow condition, which based on channel cross section and gradient, would have to have approximated 500 cfs. The standard emplacement model for accretion deposits cannot account for this concentration at this physical position on the channel wall. An alternate model had to be derived for this sediment placement. A reasonable depositional scenario for this contaminant occurrence is as follows:

It is common for trees to become undercut and fall across the stream channel, which subsequently collect debris and create an obstruction to flow. These transient impediments serve to raise the base level in this immediate vicinity and cause the channel upstream of the temporary dam to fill with sediment materials during normal and stormwater discharge events, temporarily raising the channel floor upstream as well. At any time, an observer can walk the Southeast Drainage and find such a condition in some stage of development or deterioration. At base flow conditions during the plant operation, such a natural dam structure at this location could have allowed for the emplacement of high concentration sediments in the pool upstream of the dam at an elevation relatively high on the channel wall. Upon breaching of the structure, the accumulated materials are typically scoured as the channel regains its equilibrium base level. The materials become progressively removed through direct scour and on the channel edges through undercut, sloughing and subsequent scour. Under this type of transient depositional scenario, the stream may very possibly leave such a thin deposit of a contaminated sediment remnant, high on the channel wall, out of reach of the scour effects of stormwater events.

### **Explanation of the Highest Contamination in Marginal Deposits.**

It was expected that the analytical data would illustrate a trend where the highest concentrations occurred in the accretion deposits, based on the premise that historically high concentrations are captured within the core of the deposit and were shielded from rework. Instead, the data showed that the category “Marginal Deposits” had the highest median and average concentrations, and the highest peak values.

This pattern in the marginal deposit data set suggests a phenomenon worthy of review. The six highest concentration data points in this category may represent concentrations that constitute original baseflow deposition of waste materials during plant operation. These deposits would have survived rework and remained intact to the present. This is contrasted with the mechanism required for emplacement into the accretion deposits or any of the other categories of deposits in this study (including, it appears, the bulk of the marginal deposit materials) which would have required rework for emplacement out of the channel thalweg and onto their present elevated position relative to the channel base.

## CONCLUSIONS AND RECOMMENDATIONS

The observations noted during the course of this investigation and the resulting conclusions suggest several significant considerations that impact the successful incorporation of geomorphic processes into the design of subsurface sampling programs in contaminated fluvial sediments. Some reasonable constraints can be placed on the process of predicting potential contaminant locations. Targeting sediment accumulation zones with the potential for highest concentrations is certainly one valid step in the process. What must be recognized is that the dynamics of stream flow allow for the continuum of sediment structures to be created and recreated, and that contaminant location is dependent on multiple variables, including the conditions of introduction of the contaminant into the stream.

### Conceptual Model of the System

An investigator must understand the milieu of the streamflow dynamics and conceptually model the various potential emplacement scenarios in order to effectively scope an investigation for contaminant presence and dimension. Contaminated sediments presently occur wherever materials have been transported during any single discharge event in the post-introduction period, and that have not been re-exhumed and transported by subsequent events. This means that along the entire channel length, all of the isolated and temporary impediments to flow that resulted in channel deposits, all temporary diversions to channel flow which created sediment splays over the valley terrace, are accountable for the potential present-day randomness of the occurrence. The following recommendations must also be considered:

1. Contaminant accumulation zones cannot be effectively predicted from a plan view map, without going to the subject stream for observations.
2. The occurrence of contaminants can exceed reasonable qualitative modeling of the system.
3. As sediment deposits “grow” during the post operational period, the rework of contaminated sediments and the dilution affected by that rework becomes recorded in the sedimentary record.
4. The highest contaminant levels within a given sediment deposit will be found in the oldest residual mid- or post-operation core of that deposit.
5. It must be realized that not every deposit has a pre- or mid-operation history, such that accumulations of the highest levels measured elsewhere within the drainage may not be present within all sediment accumulations.
6. Zones of accumulation are to a large extent transient. Previous accumulation zones may have been entirely or partially remobilized by subsequent flow events. When entirely removed, no evidence of the former contaminant accumulation zone remains. Partial removal results in lobes of contamination which exhibit longitudinal expression along the channel wall. In this investigation, these remnant lobes were found to be isolated, discontinuous and not visually distinctive without the aid of effective field instrumentation or analytical data.

All these factors must be blended into a logical and efficient approach to locating the contaminants of concern in the stream environment. It must be accepted that the best that will be accomplished, when normal economic factors weigh into the scoping process, is that some contamination will be overlooked. Utilizing an approach that considers geomorphic factors will deliver the most complete and cost effective data set.

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